Potential Impact Assessment of Climate-related Hazards on Urban Public Health Services: Interaction of Changing Climate-related Hazards and Urban Development in the Future, Khon Kaen City, Thailand

By

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Declaration of authorship

I confirm that this thesis presented for the degree of Doctor of Engineering has

- been composed entirely by myself,
- been solely the result of my own work,
- not been submitted for any other degree or professional qualification.

Wiriya Puntub
Dortmund, November 2021

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Abstract

Recognition of the impact of climate change and development change on the local public health services is growing. To deal with the future changes, public health care demands to shift their planning and operation paradigms, on the one hand, from reactive, responsive and short-term planning to proactive, future-oriented and long-term planning. On the other hand, from too narrow in sectoral and facility-based focus - to linking city-wide spatial planning and network operation perspective. Unfortunately, the existing attempts in health sectors are still inadequate to obtain these necessities.

This research offers a collaborative future-oriented scenarios planning framework tailored for the local public health service in Khon Kaen city, so-called Health Integrative Climate Resilience and Adaptation Future (HICRAF). HICRAF framework is outlined based on the collaborative scenario planning approach, intermixed explorative and normative scenario approaches and composite indicators technique. The HICRAF framework draws into 4 phases, 1) create shared understanding, 2) define the bandwidth of possible climate trajectories and urban development scenarios, 3) set target(s) and a desirable future, and assess the potential impact on local public health service in both plausible and desirable scenarios, 4) layout implementation roadmap with backcasting how the targets could be realized in a given time horizon. Each step involved multiple planning instruments and a wide range of stakeholders' participation. The genesis and application of HICRAF in Khon Kaen city reveal the following key findings and lessons learned.

The potential impact assessment of the scenarios showed that the local public health service could minimize the potential impact from *medium* (Trend scenario) to *low* (Desirable scenario) level by 2037. However, implementation of the Desirable scenario still does not meet the higher tier of potential impact minimization target preferred by the local stakeholders. Suppose the local public health care would like to reach their ultimate goal of minimizing the potential impact level to a *very low* level. In that case, besides ensuring the successfulness of city-wide measures, the least preferred public health sectoral measures are required, such as spatial-based service planning, assignment of alternate care sites, and reformation of healthcare personnel management and procurement policies.

Application of HICRAF in Khon Kaen city demonstrates opportunities to revitalize climate-risk/potential impact assessment practice beyond the place-based concept by cross-pollinating spatial-network operationalization considering both city-wide and sector-specific contexts at a local level. The collaborative scenario planning framework not only bridges the gaps between

global climate trajectories to local climate change adaptation scenarios but also conserves the diversity of multi-stakeholders inputs, obtains informal political buy-in, and ensures co-production among multiple stakeholders. Nevertheless, the application of HICRAF in the study area exhibits two potential dilemmas in the process quality of the collaborative scenario planning, 1) the issues of intergeneration inclusiveness and legitimacy attainment in the participatory process, and 2) complexity in reflecting reality and spatio-temporal fluidity of possible futures. From the composite indicator point of view, HICRAF is simple enough for the local public health facility manager or staff to minister this self-assessment. However, direct input data from individual public health care units may partially capture the exposure and vulnerability components of the composite indicators; therefore, firm cooperation among spatial planning, disaster risk management, and public health care is a pre-requisite to contextualize the future scenarios, especially in the aspect of city-wide hazards and exposure of health population, and dependent critical infrastructures.

This study also found that the outcome of potential impact assessment from the composite indicator operationalization based on the climate risk concept of the IPCC Fifth Assessment Report (AR5) may obscure the visibility of the local public health efforts on climate resilience. Despite the public health care actors making an immense effort to change and transform their working systems or operations, the outcomes in mitigating the potential impact may be so little if there is no change in city-level hazard mitigation and exposure avoidance. However, this drawback spotlights the need for integration and collaboration across sectors and urban domains.

The application of HICRAF in the case study area also reveals that instead of solely relying on the place-based concept, integrating a network-based perspective in climate risk/vulnerability assessment help capture the reality of sectoral operation under changing urban development climate-related hazards in the future. Thus, the co-existing paradox between the place-based and network-based concepts should be investigated further in climate risk/vulnerability assessment studies.

In terms of policy implication, this research fills the gaps in the existing WHO guidelines and the Thai's Health National Adaptation Plan (HNAP) in addressing integrated climate resilience planning for public health services. Furthermore, from the spatial planning point of view, this study calls for collaborative planning among local development domains at the district level in order to align all development agendas and interests of different scales, sectors, social groups, and generations to ensure robust decision-making and climate-resilient future.

Table of Content

List of Tables and Boxes

List of Figures

List of Abbreviation

AH	Area Health
B.E.	Buddhist Era
BaU	Business as Usual
CBD	Centeral Business District
CCMC	Climate Change Management Coordination Division
CH_4	Methane
CHP	Combined heat and power
CHV	Community Health Volunteers
CO_2	Carbon Dioxide
CODI	Community Organizations Development Institute
COVID-19	Coronavirus disease 2019
CSO	Civil Society Organizations
CUP	Contracting Unit of Primary care
DPT	Department of Public Works and Town & Country Planning
DDPM	Department of Disaster Prevention and Mitigation
DHO	District Public Health Office
DOH	Department of Health
DRM	Disaster risk management
DRR	Disaster risk reduction
E	Exposure
EC-EARTH	European Community Earth-System Model
EIA	Environmental Impact Assessment
EU	European Union
GCF	Green Climate Fund
GHG	Green House Gas
GMS	Great Mekong Sub-region
GPP	Gross Provincial Product
H	Hazard
HICRAF	Health Integrative Climate Resilience and Adaptation Future
HII	Hydro – Informatics Institute of Thailand
HNAP	Health National Adaptation Plan

HPC 7	Health Promotion Center 7 Khon Kaen
IPCC	Intergovernmental Panel on Climate Change
ICT	Information and Communications Technology
IT	Information Technology
KKCFF	Khon Kaen Community for the Future Foundation
KKDPM	Khon Kaen Disaster Prevention and Mitigation Office
KKDPT	Khon Kaen Public Works and Town & Country Planning Office
KKGO	Khon Kaen Governor's Office
KKH	Khon Kaen Hospital
KKH 2	Khon Kaen Hospital 2
KKLRO	Khon Kaen Land Readjustment Office
KMO	Kaiser-Meyer-Olkin
KKNRE	Khon Kaen Office of Natural Resource and. Environment
KKOAP	Khon Kaen Office of Agricultural Promotion
KKOTS	Khon Kaen Office of Tourism and Sports
KKPHO	Khon Kaen Provincial Public Health Office
KPI	Key performance indicator
KKPSO	Khon Kaen Provincial Statistic Office
KKSDW	Khon Kaen Office of Social Development and Welfare
KKTS	Khon Kaen Transit System Co.,LTD.
KKTT	Khon Kaen City Development (KKTT) Co., LTD
KKU	Khon Kaen University
LDR	Labor, delivery, and recovery room
LGA	Local Government Administration
LID	Low Impact Development
LRT	Light Rail Transit
M&E	Monitoring and Evaluation
MICE	Meetings, Incentives, Conferencing, Exhibitions
MoNRE	Ministry of Natural Resources and Environment
MoPH	Ministry of Public Health
MoT	Ministry of Transport
MSL	Mean Sea Level
MW	Megawatt

N_2O	Nitrous oxide
NAP	National Adaptation Plan
NDPMC	National Disaster Prevention and Mitigation Committee
NESBIA	North Eastern Software & Business Innovation Association
NGOs	Non-Government Organizations
NHSO	National Health Security Office
ONEP	Office of Natural Resources and Environmental Policy and Planning
PAO	Provincial Administration Organization
PC	Principle Component
PCA	Principle Component Analysis
PCC	Primary Care Cluster
PCU	Primary Care Unit
PHO	Provincial Public Health Office
PPP	Public Private Partnership
PWA	Provincial Waterwork Authority
REO	Regional Environmental Office
REO	Regional Environmental Office
RID	Royal Irrigation Department
RCP	Representative Concentration Pathway
SAO	Sub-district Administration Organization
SD	Standard Deviation
SHPH	Sub-district Health Promotion Hospital
SPSS	Statistical Package for the Social Sciences
SSPs	Shared Socioeconomic Pathways
THB	Thai Baht
TOD	Transit-Oriented Development
UBA	German Environment Agency (Umweltbundesamt)
UCS	Universal Coverage Scheme
UHI	Urban Heat Island
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
V	Vulnerability
WHO	World Health Organization

Chapter 1
Introduction

1.1 Rationale and Justification

Urbanization and climate change are the global megatrends that unprecedentedly grow their impact on human well-being. Particularly, medium-sized cities are home to most of the world's vulnerable urban populations (Birkmann et al.,2016). Still, their infrastructure will likely not grow in tandem with development as well as have received less priority, insufficient capacity and limited access to resources for proactively addressing climate resilience. Even though these challenges are inevitably important, the interaction of the two megatrends at a local scale in a forward-looking manner is not common practice. This fact is even more significant for public healthcare, which needs to be safe, accessible, and ensures high quality of care in any situation. World Health Organization (WHO) explicitly recognizes the importance of climate change and disaster risk/vulnerability assessment by considering changing climate in the future and interconnected critical infrastructure (WHO, 2020b).

Like other infrastructure systems, a health care service is one of the pull factors that induce more development and settlements in an area. Unaware and insufficient understanding of possible climate-related hazards in the future may lead to investment in health care services in hazard-prone areas, which manifests in high exposure of the health care facilities and health population in a hazard-prone area. Vice versa, lacking integration of future-oriented climate risk-informed spatial planning, urbanization often presses cities to compromise hazard-prone areas for development demands. When there are people, there is a need for health care services. This dilemma could exacerbate a local public health service to deal with high service demands due to urbanization and confront intensified climate-related hazards at the same time. This kind of health care service nightmare has been embarked in our memory, such as the devastated Hurricane Katrina in 2005, the Bangkok flood in 2011, and Hurricane Sandy in 2012. Recently 2019 prolonged drought in Thailand forced a hospital to ask for clean water donation instead of blood (Surin Hospital, 2019). In this regard, understanding the future impact of urban development, climate-related hazards, and their interaction could help the local public health service shift their operation paradigm from facility-based to spatial-network hybridization with a future-oriented perspective.

Remarkably, the collision of urbanization and climate-related disaster risk signifies cities in South East Asia (Yuen & Kong, 2009; Marks,2018), especially in medium-sized cities. More and more cities in various parts of Thailand are rising and completing with the national metropolitan. Among these, Khon Kaen city is a rising star. Not only perceived as the (*de facto*) capital city of the Northeastern region of the country, the city also plays a key role in the Great Mekong sub-region (GMS). Like other growing cities, Khon Kaen city gets economic advancement benefits from urbanization on the one hand but faces classical urban problems such as social inequality, environmental degradation, insufficient infrastructure, etc., on the other hand. Not having to wait for the future; currently, the city confronts more frequent repeatedly flooding and considerable water supply scarcity impact. However, Khon Kaen city is quite well equipped with public health services but overwhelming with internal and external service demands. Urbanization is not the only pressure that pressed a major challenge to the health care service here, but the climate-related disasters, especially floods and water scarcity. Therefore, vital questions are emerging and worth exploring how Khon Kaen city's public health service could address these simultaneous development challenges and climate stress.

Although Thailand has a clear and comprehensive climate change adaptation strategy at national and (some) sectoral levels, the country still lacks a framework for integrating climate resilience to long-term local development prospects and critical infrastructure operations from the city-wide perspective. Especially in the public health sector, the current sectoral practice is limited within a facility boundary and human health impact landscape rather than integrating with a city-wide and service network perspective.

This research offers a collaborative scenario planning framework to help the local public health service address the potential impact of climatic and non-climatic change interactions. The framework encompasses the local public health care to tailor and operationalize their climate resilience and adaptation target(s) in the long-term future, considering the deep uncertainty of the bandwidth of possible future conditions. This instrument enables the local stakeholders to manifest their future urban development envisions and future climate trajectories and debate on a spectrum of possible futures and their intertwined potential impact on the local public health services. Through collaborative scenario planning with a highlighted backcasting approach, the local stakeholders determine their own desirable future versions and shape the way how to realize them by the end of 2037[1]. Then, composite indicators serve as an innovative element in assessing the potential impact of future climate-related hazards that helps to track climate resilience interventions in both spatial-based settings and network-based operations.

This research provides evidence that public healthcare can shift its planning and operation paradigm to pursue climate resilience. The case of Khon Kaen city demonstrates to the world that collaborative and integrative future-oriented climate resilience planning could enable political buy-in and robust policy design and decision-making. With the contest of this planning framework in Khon Kaen city, the study packages the whole planning process as Health

[1] According to the 20-year National strategy timeframe

Integrative Climate Resilience and Adaptation Future (HICRAF). HICRAF is a novel collaborative future-oriented integrated scenario planning process that closes gaps between global climate trajectories and local climate adaption, as well as strategically operationalize climate resilience in urban public health service. Hence, this study demonstrates how HICRAF could fulfil the climate resilience ambition of the local public health care and revitalizes climate risk/vulnerability assessment practice at the local level.

1.2 Research questions

This research aims to address *how urban development change and climate-related hazards change impact Khon Kaen city's urban public health services in 2037?* This research question will be answered by responding to the three defined sub-questions as follows:

1. What are possible and plausible futures of urban development pathways and climate-related hazards and their interaction?
2. What is the potential impact of urban development pathways and climate-related hazards on the local public health service?
3. How does the local public health service operationalize the potential impact and climate resilience target(s) under the collision of urban development change and climate change in the future?

1.3 Research objectives

This research explores an integrative planning framework encompassing a collaborative scenario planning framework. The framework encapsulates the combination of future development visionary and downscaling climate projections as well as their intertwined potential impact on the local public health services. The conceptual research framework of this study shows in Figure 1. The expected outcomes of this research should inform and enhance the understanding of the future potential impact of climate-related hazards on Khon Kane city public healthcare services in 2037 and layout how the local public healthcare shall operationalize and realize their desirable climate-resilient futures. Hence, the main objectives of this study are as follows:

1. To collaboratively **outline the bandwidth** of possible future urban development change and climate-related hazards change, considering their interaction and potential impact on Khon Kaen city's urban public health service in 2037.
2. To **tailor composite indicators** for assessing potential impacts of climate-related hazards on Khon Kaen city's local public health service in 2037.
3. To **assess and operationalize the future potential impact** of climate-related hazards on the public health service of Khon Kaen in 2037 under stakeholders selected

plausible (Trend) and desirable (Desirable) scenarios by adhering to the desired climate resilience target(s).

1.4 Scope of the study

- Spatial aspect: Khon Kaen city (Mueang Khon Kaen district)
- Temporal aspect: 2037 (in line with 20-year National strategy timeframe)

1.5 Conceptual Framework

Figure 1 shows the conceptual framework of this study. To answer the research questions requires combining two scenario planning approaches commonly used in Future studies, explorative and normative scenario approaches. This research begins by exploring the future conditions of Khon Kaen city in 2037. With evidence-based data analysis and stakeholders' collaboration, possible urban development change and climate change are laid out as a bandwidth of future conditions. The possible spectrum of urban development change and climate change are overlaid in the scenario matrix. With the integration of the normative scenario approach, the stakeholders decide which scenario they would like to use as a plausible scenario for climate-resilient planning and set target(s) based on their climate risk perception. To shape a desirable future scenario, the stakeholders define and appraise potential spatial planning-based measures to minimize the potential impact in the future response to the specified target(s). Thus, scenario storylines are elaborated considering interactions among three systems of interest (urban development, climate change and public health). Next, the IPCC AR5 climate risk concept is applied as a backbone of the composite indicator development. The composite indicator serves as a tool for the potential impact assessment of the two scenarios by operationalizing a non-compensable relationship among Hazard, Exposure, and Vulnerability. The assessment outcomes can then be used to identify gaps and transition steps as if Khon Kaen public health service would like to depart from today to the climate-resilient future(s) by looking backwards from the targets and future standpoints. This outcome would allow the formulation of an implementation roadmap, which is a key result of the backcasting process.

1.6 Structure of the dissertation

This dissertation is structured into seven chapters: Introduction, Theoretical background and concept, Study area, Methodology, Results, Discussion, and Conclusions. Key features of each chapter can be described as follows.

Chapter 1 Introduction - establishes the context, background, and importance of the research topic. It addresses current problems, knowledge gaps, and vital debates on the research topic. This chapter also states the research questions and objectives as well as a synopsis of the research design and methodologies.

Chapter 2 Theoretical background – provides robust literature and indication for debating and addressing knowledge gaps relevant to this research. This chapter can be divided into seven sections, 1) Collision of the global megatrends, urbanization and climate change, and their interaction at a local level; 2) Climate vulnerability & risk assessment – Is it time for revitalization?; 3) Health care and climate vulnerability assessment; 4) From vulnerability to resilience; 5) Climate resilience in healthcare – What lies beyond a facility fence?; 6) Composite indicators – never-ending debate or revitalizing agent towards climate-resilient public health care?; 7) Re-unification of backcasting scenarios planning and health futures.

Chapter 3 Khon Kaen city - presents Khon Kaen city as a single case study of this research. This chapter preliminary contextualizes Khon Kaen city in multiple aspects through geographical characteristics, administration and institution arrangement, socio-demographic milieu, economic and infrastructure development; environmental, natural resources, and disaster risk management; land use and spatial planning practices; public health care setting; mainstreaming of climate change adaptation in Thai public healthcare.

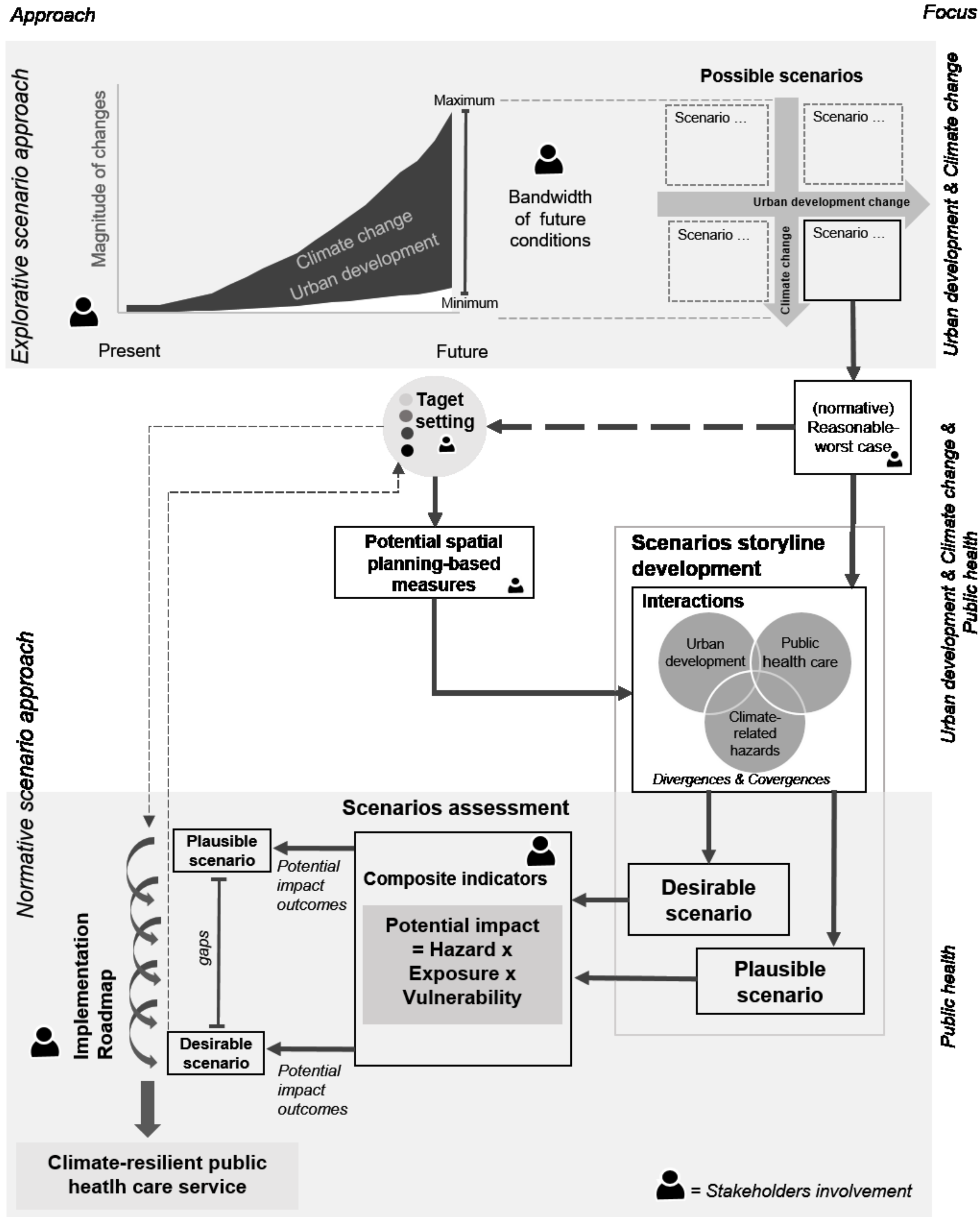
Chapter 4 Methodology - provides a clear and detailed elaboration of the methodological framework and how multiple methods play roles in different phases of the collaborative scenario planning approach: Phase I Shared understanding, Phase II Forecasting, Phase III Backcasting, Phase IV Implementing, and Phase V Following up.

Chapter 5 Results – reports the research results, which aligned with the phases determined by the research methodology framework. Both qualitative and quantitative results illustrate with excerpts from the data originally derived from the research process. This chapter highlights statements, key relevances and significant findings in responding to the research questions.

Chapter 6 Discussion – centres around key findings and implications of the research results towards different target groups. This chapter offers a commentary on the research results, highlighting critical argumentations and emphasizing the scalability of this research discovery to other cities and across sectors.

Chapter 7 Conclusions – summarises main findings & lessons learned discovered in this dissertation. It highlights the key contribution of this research to the field of knowledge, acknowledges limitations, sets out recommendations for policy and practices, and invites further research studies.

Figure 1. 1 Conceptual framework



Chapter 2
Theoretical background and concept

This chapter presents the relevant theoretical background and concept of this research. The content organizes into seven topics in response to the research questions and methodologies used in this study. The thematic issues flow from - an understanding of the collision of global megatrends, urbanization and climate change, and their interactions with urban climate adaptation - to pave the way for exploring the new frontier of climate vulnerability/risk assessment in health sector. After cultivating the climate risk concept and its implications, the following sections emphasize a connection between vulnerability and resilience, resilience concept and characteristics, and context of climate resilience in the health sector. The last two topics debate the application of composite indicators and backcasting approach for operationalizing climate risk/potential impact assessment.

2.1 Collision of the global megatrends, urbanization and climate change, and their interaction at a local level

"Urbanization and climate change are co-evolving in such a way that populations, often in densely packed urban areas, will be placed at much higher risk from climate change." (UN-HABITAT, 2011)

Natural and man-made hazards disproportionally propagate impacts on society. Among a wide range of hazards, climate-related hazards emerge as hybrid harms in which urban development plays a key role as a cause of the problem and victim at the same time. Besides the natural dynamic of global climate change phenomena, anthropogenic greenhouse gas emissions, particularly in the urban sector, are responsible for the unprecedented speed of unpleasant global and local climate conditions that trigger extreme droughts, convective events, floods, etc. At the same time, especially in developing countries, unplanned (or insufficient planning) urbanization is a major driver and exacerbates the degree of climate-related hazards, shaping urban development in the future.

Particularly in urban health care, climate change poses direct and indirect impacts on health concerns that disproportionally affect the population, especially the vulnerable ones. Direct impacts can be a greater likelihood of injuries, diseases, illnesses, and deaths. Indirect impact can cause poor health outcomes and disruption of health care system associated with technical, environmental and socio-economic factors (WHO 2015b:2; Ebi et al., 2018a).

Climate-related hazards could directly cause infrastructure damages and overwhelm the facility's capacity. Particularly growing medium-sized cities, a compound of climate-related hazards and urbanization challenges modified service demands, service quality and service capacity of the local public health service.

Myriad studies investigated the impact of either independently climate change or urbanization on a particular system or sector. Distinguishtly, Garschagen & Romero-Lankao (2015) focus on the interaction between the two megatrends globally. They articulate that urbanization is often perceived as negative in the context of climate change in terms of exposure and sensitivity while underrating their contribution to vulnerability reduction and promotion of resilience at the economic scale. Still, urbanization poses constraints for growing cities in low and middle-income countries, which have tremendous challenges in building their adaptive capacity to be ready and prepared for climatic and non-climatic challenges. In a local context, despite an increasing number of case studies assessing vulnerabilities and adaptive capacities in specific cities across the globe (UN Habitat, 2011), many of the causal relationships between urbanization and climate change, especially vulnerability components, are still insufficiently comprehended (Romero Lankao & Qin, 2011; Cardona et al., 2012: 76).

Interaction between global climate change and a considering system can be conceptualized as a typically cause-effect relationship with highlighting feedback loop, i.e. positive, negative, and neutral. The concept of a causal effect relationship between climate-related hazards on the system of interest is often simplified and explained in the form of climate impact chains. Climate drivers (changing temperature and precipitation patterns) generally induce climate-related hazards, leading to floods, urban heat stress, and water supply scarcity in an urban area, especially in a hot city. These positive effects from global & regional climate could theoretically cause loss and damage to the city and its socio-economic development. Most impact analysis often neglects the feedback loop of urban development to local and global climate. However, many investigations, especially in urban heat studies, attempt to highlight the extension of positive urban feedback to global and regional climate layers. Wiesner et al. (2018) enclosed clear signals of urban land cover influences local microclimate, especially air and surface temperature, humidity (evapotranspiration), and wind. Nonetheless, the pronounced urban effects on local precipitation due to Urban Heat Island (UHI) effect, aerosols (as cloud nuclei), and increased surface roughness are unclear and highly uncertain, but a significant impact of the orography on heavy precipitation should be emphasized (Wiesner et al., 2018; Yan et al., 2016). Urbanization reduces permeable surface and vegetation, increases urban runoff, shortens the times to reach the peak runoff and lowers discharge capacity. However, the overall percentage and distribution of impervious surfaces also influence the local and regional flood risk (Feng et al., 2021). Impermeable surfaces of urban areas prevent water infiltration and limit local underground water replenishment (Gwenzi & Nyamadzawo, 2014), however, at the same time, leakage of water supply and wastewater infrastructure generates large amounts of underground water recharge (Lerner, 1990; Wakode et al., 2018).

Many studies stress the effect of urban expansion on a modified local climate. Chapman et al. (2019) provide a piece of evidence that urban growth and climate change have an additive effect due to higher local temperature than climate change alone. Therefore, anthropogenic urban heating in hot cities, especially from air conditioners, should be underlined, particularly its significant positive feedback on urban warming (which could reach 20 % in a residential area) (Takane et al., 2019). Urban albedo is another positive feedback of urban settlements to the higher climate system. More urbanized cities show lower albedo than the less urbanized ones. Decreases in albedo contribute to increased air and surface temperature that characterize the UHI (Trlica et al., 2017; Tang et al., 2018). Therefore, conversion of cropland or rural area to less vegetation land cover of urban settlements could reduce albedo, thus creating a warmer urban environment (Spangmyr, 2010; Carrer et al., 2018). Using roofs and pavements with high solar reflectance can also mitigate summer urban heat islands, improving outdoor comfort (Akbari et al., 2012). However, Krayenhoff et al. (2018) found that the interaction between urban expansion and near-surface temperature across the US does not display linear additive interaction. Even though these adaptation measurements may help cool down the local climate in the daytime, evening and nighttime, the warming effect remains. Notwithstanding, the linkage between urban and regional and global climate interaction is still relatively primitive (Zhao, 2018). Furthermore, an urban area also produces biochemical and chemical positive feedback to the global atmosphere through emissions of Carbon dioxide (CO_2), Methane (CH_4) and Nitrous oxide (N_2O) from fossil fuel combustions and agricultural activities (Prentice et al., 2015). In parallel, urbanization might decrease agricultural-related GHG emissions (negative feedback) but declined vegetation or cropland also means loss of local (seasonal) carbon stock.

Granting that physical interaction between urbanization and climate change may theoretically prevail, it is insufficient to understand urban socio-economic vulnerability, which depends on development choices in different future pathways. However, it enables comprehension of the collision of the two megatrends, urbanization and climate change, as health determinants at a local level. Understanding climate change and urbanization interactions informs local risk/potential impact assessment and encapsulates matches and mismatches among climate change policies, spatial planning, and public health service operations in order to reach overarching climate resilience objectives.

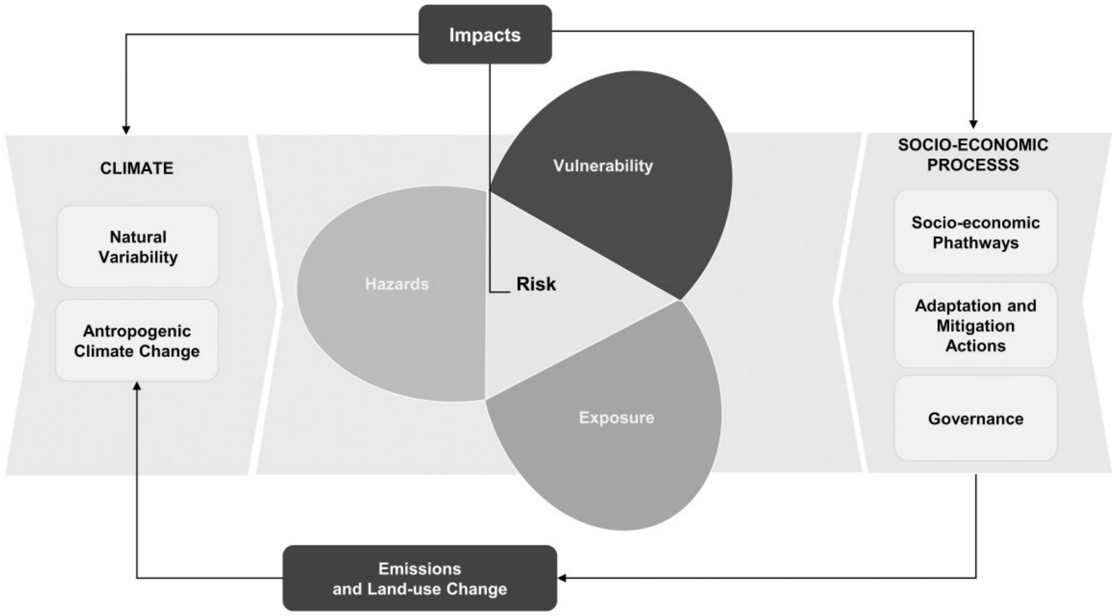
2.2 Climate vulnerability & risk assessment – Is it time for revitalization?

For almost two decades, scientific communities, practitioners and policymakers have drawn their attention to climate vulnerability and risk assessment studies. Efforts in mainstreaming climate vulnerability and/or risk in planning and policy monitoring are inevitable, especially in Global north countries where the assessments serve as legal requirements or become a common practice, such as national adaptation plan (NAP), Environmental Impact Assessment, Strategic Environment Assessment. However, there are various definitions and applications of risk across disciplines.

In principle, risk analysis traditionally defines risk as a function of impact (consequence) and likelihood (probability) (Carey & Curtis, 2012). In the essence of climate adaptation, the global community heavily adopts the IPCC Fifth Assessment Report (AR5) climate risk definition and framework (IPCC, 2014b), which reframes its previous framework from vulnerability and exposure focus (IPCC, 2001; 2007) to risk outcomes and risk component interaction that bridged the climate change and disaster risk management together (Oppenheimer et al., 2014). Therefore, the IPCC AR5 determines climate risk as *"… probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. Risk results from the interaction of vulnerability, exposure, and hazard. In this report, the term risk is used primarily to refer to the risks of climate-change impacts"* (IPCC, 2014a). Meanwhile, the term **impacts** refer to the consequences or effects of risks to natural and human systems (IPCC, 2014a). This research does not seek to reframe the scope or definition of climate risk but rather adopts the IPCC AR5's climate risk concept, resulting from hazard, exposure, and vulnerability interaction, characterized by climatic and non-climatic drivers & dynamics. (see Figure 2.1). However, this study can not estimate the likelihood of the impacts in the future; thereby, the term "***Potential impact"*** is adopted to operationalize the future climate risk. The key definitions of IPCC (2014a) climate risk elements show in Annex 1.

Among climate risk components, ***Climate-related hazard*** refers to a potential occurrence of hydrometeorological events/trends that may cause loss of life, injury, or other health impacts, as well as damage and loss to properties, infrastructures, livelihoods, service provisions, ecosystems, and environmental resources. In IPCC's (2014a) definition, **exposure** implies a spatial perspective, referring to the presence or location of people or assets in a potentially affected area. Exposure is manifested by environmental and socio-economic drivers in multiple levels of governance and spatial planning (Cardona et al., 2012). In comparison to Hazard and Exposure, elaboration of **vulnerability** is more complex. According to O'Brien et al. (2007), the vulnerability can be profounded at the starting point and endpoint. The first one is called contextual vulnerability, referring to the inability to cope with shocks or changes. The latter see vulnerability as outcomes or consequences at the end of the adaptation process, called outcome vulnerability.

Figure 2. 1 Schematic of climate risk concept and relationships



Source: (Oppenheimer et al., 2014:1046)

There are two main key elements explaining vulnerability, sensitivity[2] to harm and lacking capacity to cope and adapt (IPCC, 2014a). *Sensitivity* is the term that represents a degree to which a system easily reacts or is affected by climatic and non-climatic changes. The effect may be, either adversely or beneficially, to the properties, function, and goal of a system. However, *Sensitivity* often refers to negative features or weaknesses of the system of interest. *Capacity* expresses the system's characteristics associated with vulnerability reductions in both the short-term and the long-term. Several studies scrutinized distinguish between *Coping capacity* and *Adaptive capacity,* such as Birkmann (2011a), Saldaña-Zorrilla (2007), and Cardona (2012:72). Nevertheless, it can be concluded that *coping capacity* aims to manage shocks and maintain a system's status quo and its functions in the face of hazards or shocks shortly after adverse conditions (*ex-post*). Meanwhile, *adaptive capacity* involves changes and requires learning and reorganization processes to better deal with expected future shocks or hazards (*ex-ante*) (Birkmann, 2011b; Cardona, 2012:73; Parsons et al., 2016:1). Adaptive capacity usually reflects vulnerability outcomes (Birkmann, 2011b; Berman et al. 2012: 91; IPCC,2014a; Parsons et al., 2016: 1; UBA, 2017). Adaptive capacity is tied to what could be implemented in the future and estimated its potential outcomes in vulnerability reduction by applying existing measurement approaches and instruments (Greiving et al., 2015). This is because future changes are neither observable nor measurable in the present time of

[2] The terms sensitivity is overlap with susceptibility the term oftern used to operationalized vulnerablity in disaster risk reduction. Susceptibility (or fragility) describes the predisposition of elements at risk to harm (Birkmann et al., 2015).

assessment. Coping capacity and adaptive capacity, although different, are connected (Berman et al., 2012). It should be noted that the capacity to cope does not directly translate to the capacity to adapt (Birkmann, 2011a; Cardona, 2012:73) but is often discerning as part of adaptive capacity (Saldaña-Zorrilla, 2007; Cardona, 2012:72). Distinguishing between coping capacity and adaptive capacity is not only a temporal aspect (Brooks et al., 2005:2) but also variation in terms of interventions and institutional arrangement (Birkmann, 2011a:815).

Climate risk derives from interaction among hazards, exposure and vulnerability, which deeply depends on socio-ecological dynamics and processes. Missing one of these determinants, the risk is not materialized. In other words, a hazard occurs in an area of neither exposure nor vulnerability; then there is no risk. In contrast, there are vulnerabilities and exposure without risk. Therefore, risk can be conceptualized as a probability of the consequences of a multiplicative function of hazards, exposure, and vulnerability (UNISDR, 2009; Lavell et al., 2012); see equation 1. However, vulnerability can be seen as specific interaction with a particular hazard event to generate risk (Cannon, 2006; Cutter et al., 2008), such as an exposed population might be vulnerable to floods but not water scarcity. Moreover, robust evidence shows that increasing vulnerability and exposure are induced by negative outcomes of mismanagement and unplanned socio-economic and environmental development (Cardona et al., 2012). Even though not all vulnerability components can be measured but applicable to be assessed and operationalized through a mixture of quantitative and qualitative methods (Greiving et al., 2015).

$$\text{Risk} = \text{Hazards} \times \text{Exposure} \times \text{Vulnerability} \qquad \text{-------- Equation 1}$$

2.2.1 Beyond place-based vulnerability

This dominant vulnerability/risk concept is based on a place-based concept in which vulnerability is largely defined by “local” physical exposure to the potential hazards (Wisner et al. 2004: 49). However, Etzold & Sakdapolrak (2016) argued that vulnerability should not exclusively address socio-spatialities through the place-based concept or solely operationalize based on the place-based vulnerability assessment. From a functionality perspective of a critical infrastructure network, people/systems may be vulnerable to hazards even though they are not physically exposed to the potential hazards. The potential impact can be observed through the disruption of services and supply chains across scales and territories. With interconnected critical infrastructure networks, it could be the case that cut-off from trans-local circuits of lifeline infrastructure might be worse than the local impact (Etzold & Sakdapolrak, 2016). Moreover, this beyond “the local” perspective is also reflected during the post-disaster management phase, where the affected areas obtain coping capacity via external supports.

With prominent progress of urbanization where a society heavily relies on critical urban infrastructures which are tightly interconnected, climate-related hazards could profoundly affect the system elements and functions beyond its physical existence in the “local” scope of consideration. To unleash the concept of vulnerability from theoretical domination of place-based concept and bridge the gaps between vulnerability and criticality intertwined, the suggestion of Etzold & Sakdapolrak (2016) in integrating the concept of polymorphy of socio-spatialities introduced by Jessop et al. (2008) in vulnerability research, could be a great alternative for operationalizing vulnerability/potential impact of the critical urban infrastructure. Jessop et al. (2008) reframed socio-spatial relations and dynamics into four domains territory (T), place (P), scale (S), and networks (N), the so-called TPSN framework. To ensure systematic investigation and understanding of the socio-spatial relation landscape, they also encouraged utilizing the TPSN matrix (see Table 2.1). Elaboration on the interrelationship among place, territory, scalar and networks could enable systematic identification and designation of risk mitigation and resilience strategies (Etzold & Sakdapolrak, 2016:246).

Table 2. 1 Polymorphy of socio-spatialities dimension introduced by Jessop et al. (2008)

Dimension of socio-spatial relations	**Operation**			
	Territory	**Place**	**Scale**	**Networks**
Territory *(Bordering, bounding, enclosure)*	Past, present, and emergent frontiers borders, boundaries	Distinct places in a given territory	Multi-level governments	Inter-governmental system, state alliances
Place *(Proximity, spatial embedding, areal differentiation)*	Core-periphery, borderlands, empires	Locales, milieux, cities, sites, regions, localities	Division of labor linked to differently scaled places	Local/urban governance, partnerships
Scale *(Hierarchization, vertical differentiation)*	Scalar division of political power (unitary state, federal state, etc.)	Scale as area rather than level (local through to global), spatial division of labor (Russian doll)	Vertical differentiation based on nested or tangled hierarchies	Parallel power networks, Non-governmental international regime
Networks *(Interconnectivitity, interdependence, transversal differentiation)*	Origin-edge, ripple effects (radiation), stretching and folding, crossborder region, inter-state system	Global city networks, polynucleated cities	Bundle of multiple networks hierarchies with interface entry points, System of system (SoS),	Networks of networks, spaces of flows, rhizome,

Source: Modified from Jessop et al., 2008: 393, 395

2.2.2 Conceptual paradox of vulnerability and criticality intertwined

It is important to be aware of the fact that boundaries of urban critical infrastructure systems are rather fluid (Keating et al., 2003) which does not limit by “local” exposure of the potential hazards under the context of place-based vulnerability. Although both network-based (criticality) and place-based concepts are completely/partially overlap spatial and time dimensions, a fundamental distinction between vulnerability and criticality is that vulnerability assessment focuses on weakness identification and evaluation to minimize or mitigate the weaknesses. Meanwhile, criticality assessment is a systematic process to identify and appraise the system of interests/assets based on their importance in maintaining the quality of function or missions (Decker, 2001).

The interaction of urbanization and climate change determines a greater degree of challenges to urban critical infrastructure service through increasing demands and complexities, but climate-related hazards also pose a greater threat to operating systems in the form of faults, failures, and errors. Urban critical infrastructures are complex holistic systems; such a failure, loss or disruption of its services could cause damage to society and the economy. Its cascading effects could occur across boundaries and scales, which are shared and interconnected through dependency and interdependency networks or supply chains (Rinaldi et al. 2001; Bouchon 2006; and Zio, 2016). Critical infrastructure always consists of System of Systems (SoS), which has multidimensional complexity, sub-system operational and managerial independence, emergent behaviour and evolutionary development (Bukowski, 2016: 84). With network operation nature, dependency and interdependency are the key features of critical infrastructure systems. Dependency refers to the unidirectional interrelation between two infrastructures in which the state of one infrastructure depends/influences the operation quality of the other. Interdependency reflects bidirectional dependencies between two or multiple infrastructures through various aspects such as physical, cyber, geographical, and logic (Rinaldi et al. 2001). The typical ultimate purpose of critical infrastructure is to ensure operating quality or “… ability to continuous and safe fulfilment the required functions in normal and abnormal operating conditions” (Bukowski, 2016: 85). Time-related system operation quality or time required to restore system performance to a satisfactory performance level is one of the key classical indications of system resiliency (Katina et al., 2014:14, Shafieezadeh et al., 2014: 209-210). Time-dependent reliability or dependability assessment is one of the standard approaches in operationalizing engineering system resiliency. There are numerous studies investigated in this field of research, such as Ouyang & Dueñas-Osorio (2012; 2014), Hu & Mahadevan (2016), Kong et al. (2019). Besides focusing on the function of time, Fekete (2011) also captured that critical proportion and critical quality could be generic screening criteria for criticality operationalization. In addition, Kruse et al. (2021) proposed two factors for critical infrastructure system operationalization 1) relevance of sub-systems which are determined through a degree of sub-sector connectivity and centrality, 2) relevance of dependencies which are described by the intensity of a potential cascading effect over time and severity of potential impairments over time.

Even though, in the field of system engineering, the terms risk, vulnerability and criticality are usually utilized for quantifying system performance and determining a state of system resiliency. But in the field of disaster risk research, which operationalizes vulnerability and risk based on place-based concept (Greiving et al. 2016; Etzold & Sakdapolrak, 2016), integration between vulnerability/risk and criticality shall be analyzed separately to ensure no confusion between the two concepts (Kruse et al., 2021). Despite the paradox of the two theoretical concepts, the rapid pace of urbanization and climate change echoes an urgent need for an integrative approach to address the reality of climate vulnerability/risk of critical urban infrastructure operating with spatial-network interwinds such as the public health sector.

2.2.3 Revitalization in need

Throughout the timeline, three prominent articles provide systematic review literature on the development and direction of climate vulnerability and risk assessments across scales, Mcdowell et al.(2016), Jurgilevich et al.(2017) and Ford et al.(2018). Mcdowell et al. (2016) summarized that the first generation of vulnerability assessment has focused on direct biophysical outcomes, while the second generation underlined more on biophysical drivers that contextualized vulnerability. Jurgilevich et al. (2017) reviewed a myriad of studies through the lens of exposure and vulnerability dynamics. Ford et al.(2018) focus on identifying gaps and opportunities in revitalizing vulnerability assessment. Even though the three literature reviews present different aspects of climate risk and vulnerabilities studies, they arrived at a similar conclusion that future-oriented climate vulnerability/ risk assessments addressing socio-economic changes are needed. Essential requirements for climate-risk assessment in order to shape adaptation policies adequately are as follows; consideration of recent and future risk components; high resolution of analytical outputs; streamlining participatory scenario planning approach (Mcdowell et al., 2016, Jurgilevich et al., 2017 and Ford et al., 2018.). However, a study that addresses all the requirements is rare, especially at a sub-national and local level.
Furthermore, integrating downscaling climate data and non-climatic drivers across scales is substantially challenging (Birkmann et al., 2015); yet neglects interactions (Ford et al., 2018). Since the outcome of adaptation policy can only be observed in the future, vulnerability assessment shall be future-oriented (Hinkel, 2011) and still a challenge do to so (Birkmann, 2013:100). Hence, participatory future-oriented potential impact assessment considering the interaction of climatic and non-climatic changes at a local level may be a passage for

revitalizing climate risk and vulnerability assessment research and policy decision-making (Ford et al., 2018).

2.3 Health care and climate vulnerability assessment

Climate vulnerability assessment, or usually referred vulnerability and adaptation assessments (V&A) in the health sector, has been conducted across national and sub-national levels for more than 20 years. The Shared Socioeconomic Pathways (SSPs) help the health sector understand future socio-economic changes that influence climate change adaptation challenges and GHG emission reduction opportunities (Berry et al., 2018:6). Despite the importance of future-oriented scenario planning, Berry et al. (2018) reported that only 58% of the assessments included projections of future health impacts due to climate change, either quantitative or qualitative. Moreover, WHO underpinned that vulnerability assessment in developing countries often misses future potential climate change impact elements because of lacking evidence.

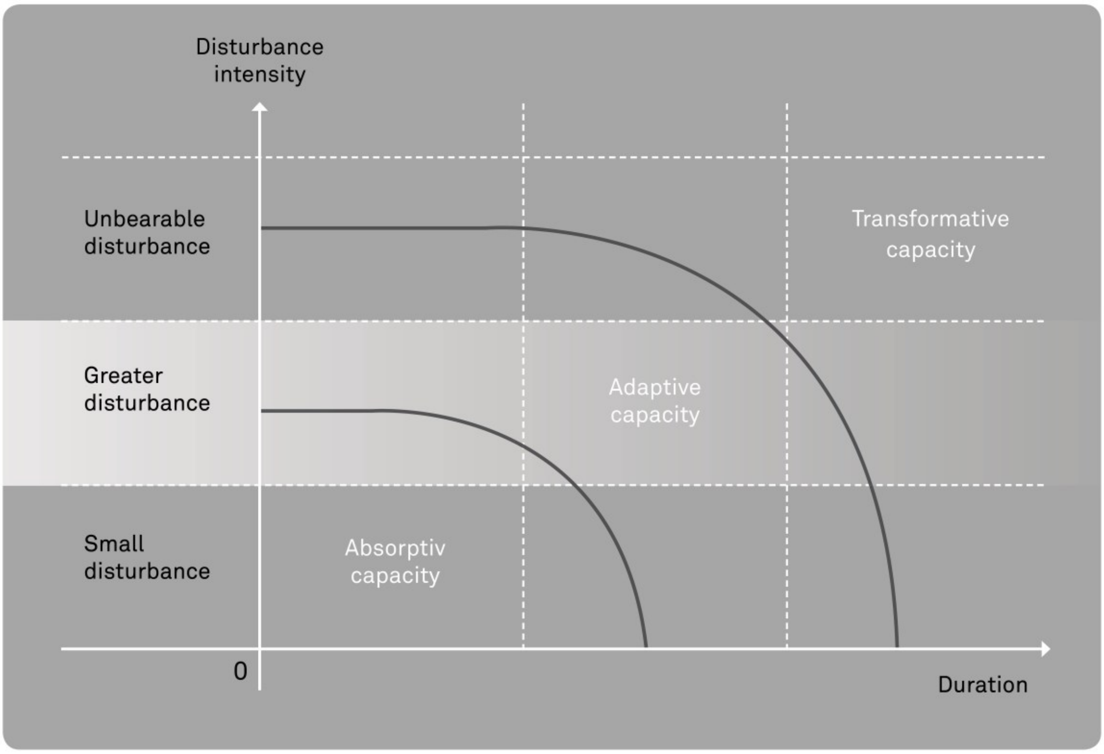
However, Berry et al. (2018) summarize technical and pragmatic challenges in conducting a vulnerability assessment in health sector. From a technical perspective, the key challenges are the following: resources and data limitation, lack of robust indicators for monitoring and evaluation of adaptation interventions, lack of harmonization of vulnerability assessment practice across scales, ineffective communication of uncertainty in climate projections, etc. Meanwhile, from a pragmatic point of view, key factors preventing mainstreaming climate change adaptation in the health sector are missing links between conventional short-term planning practice and future-oriented risk-informed planning; and too narrow and too specific investigation on certain health outcomes instead of a broader health system (Berry et al., 2018:10-14). Ebi et al. (2018a:3) also highlight that most vulnerability assessments do not consider the compound of day-to-day non-climate challenges and climate-related shocks and stresses, as well as inadequate to address climate-related impact on health determinants sectors. Nevertheless, vulnerability assessments can provide valuable input to foster climate-resilient health systems. Hence, the latest WHO guidance (WHO,2020b) emphasises the importance of understanding current and projected climate conditions, changes in health system demands (such as population growth, demographic changes) and anticipated health system capacity to build climate resilience at the health facility level. However, a concrete operationalization guideline still cannot be observed in the document.

2.4 From vulnerability to resilience

Berman et al. (2012) conceptualized that vulnerability and resilience are linked through coping capacity and adaptive capacity. Variation degree of vulnerability is tied to resilience of the systems (The Resilience Alliance, 2010:29-30). Application of resilience crossed beyond ecology and environmental and natural resources management studies and exploded to a different horizon of plannings such as health, climate change, and disaster risk management (Quinlan et al., 2016). Amid the global pandemic and recession of the global economy, which lies under the great wave of global climate change, “Resilience” gains more popularity than ever and is reframed as a new interpretation of sustainable development.

Resilience derives from the Latin term *resilire* and means to rebound. The term was first used in physics and mathematics to characterize a spring and describe the stability of materials and how it resists shocks (Davoudi et al., 2012). In the 1940s, the term was adopted into the field of psychology (Masten & Powell, 2003). Later on, it was extensively applied in ecology/ecological science by Holling (1973). Holling (1973) distinguished between two forms of resilience; Engineering resilience - bounce back to the status quo (Equilibrium) and Ecological resilience - bounce forward (Beyond equilibrium). With a co-evolving link between ecological and social systems, social-ecological resilience is perceived as an ability of social-ecological systems to change, self-organize and adapt or transform in response to external variables and disturbance regimes (Carpenter et al., 2001). Considering the nature of a constantly changing non-equilibrium system, Simmie & Martin (2010) argued that the socio-ecological resilience process is an evolutionary dynamic, so-called Evolutionary resilience. However, from the system threshold perspective, disturbance beyond the threshold could lead to system degeneration; within the threshold, disturbance could contribute to system transformation shifting to a new stage of equilibrium or new normal, so-called Transformative resilience (Hodgson, 2010). Based on these concepts, Béné et al., (2012) manifest resilience with regard to linkages between different degrees of system responses to intensities of shocks or changes. Resilience can be characterized into three stages, persistence, incremental adjustment, and transformational response. Lower intensity of disturbance, the system tends to release its absorptive (coping) capacity to enhance system stability and maintain its status quo. If shocks or changes exceed the system absorptive (coping) capacity, adaptive capacity is required to enhance the system’s flexibility through various incremental adjustments and changes as collective or individual. Ultimately, if the disturbance is unbearable, transformative capacity is triggered to enhance the alteration of primary function and structure/nature of the system. Besides shocks and responses relationship, Giovannini et al. (2020) highlight a conceptual correlation of temporal aspect and stages of resilience capacities. If the duration of exposure to low-intensity shock is relatively short, the system may react to the disturbance by using absorbing capacity. As the increasing of shock intensity and exposure duration, adaptive capacity will be unlocked for small or gradual changes. Eventually, as the shock intensity is too high and lasts too long, the system can transform and shift to another state of play, pathway, or behaviour, in order to avoid systems collapse (see Figure 2.2). Threshold determines how a system experience changes and transition over time. Nevertheless, threshold and transition are not simple and obvious to identify (The Resilience Alliance, 2010:27-28).

Figure 2. 2 Conceptual relationships between the variation of resilience capacities in responding to disturbance intensity and time exposure



Source: Adapted from Giovannini et al.,2020:7

2.4.1 Key attributions of resilience

Since the manifestation of Holling (1973), scholars have never stopped determining key characteristics of resilient systems. Countless of what so-called components, principles, key attributions, criteria, and indicators have been proposed from many disciplines to simplify the understanding and operationalise resilience of a particular system of interest. Despite medleys of discourse and contextualizations of resilience concepts across fields, resilience definitions and properties have never been universally agreed upon. This reality aligns with a fundamental contest of resilience that resilience of what? To what? For whom? What scale? And for what purpose? (Carpenter et al., 2001; The Resilience Alliance, 2010:13-14; Sellberg et al., 2017:5). These questions are central to resilient urban planning. In a city, resilience of both engineer & natural systems and complex socio-economic components is always tied to normative judgment, unclear system boundaries, and un-blinded from political power (Davoudi et al., 2012:304). A city is a complex socio-ecological system in which humans can intervene and alter system dynamics and cycle through interventions and foresight. Therefore, in addition to persistence (being robust), adaptability (being flexible) and transformability (being innovative), Davoudi et al. (2013) suggested preparedness (learning capacity) as the fourth key urban resilience component. In addition to a number of attempts to consolidate major convergence of key resilience characteristics, such as Bahadur et al.(2010) and Schipper & Langston (2015)**,** this study focuses on finding a common key characteristic of resilience in urban climate adaptation/disaster risk management in relation to the local health care operation perspectives.

2.4.2 Characteristics of urban climate disaster risk resilience

In the ocean of research and grey literature on urban climate resilience indicators development, there is no universal set or unified structure of indicators nor a standard methodology/approach in aggregation and evaluation. Different contexts, locations, and purposes; hence the indicators are incomparable and peculiar to do so (Quinlan et al., 2016:678-9; Tyler et al., 2016). Despite differences and diversity of resilience indicators, common characteristics and compositions of composite indicators in the field of climate/disaster risk can be summarized in Table 2.1.

Several cities around the world have been translating this board idea into practice by breaking down these attributions as composite indicators (e.g.Vulnerability sourcebook (GIZ, 2014)), a checklist of actions (UNISDR's Balance scorecard (UNISDR, 2015a)) or a list of measures/engineering solution for relevant sectors (e.g. City Resilience Index (The Rockefeller Foundation & ARUP, 2015)), rubric (ACCCRN's urban resilience framework (Taylor et al., 2012:317-9)). Nevertheless, the proposed urban climate resilience indicators are often absent of a future-oriented perspective of socio-economic development change in parallel with climatic change. Although the sets of urban climate resilience indicators or frameworks suggested key characters/attributions of resilience for specific sectoral and city-level policy, it is fair to state that these existing implications are inadequate for operationalizing resilience in linking overall spatial planning and local critical infrastructure network operation together.

Table 2. 2 Summary of suggested key attributions of urban climate change/disaster risk resilience

Indicators/Attributions	Definitions	Sources
Robustness	Resist (strong) and withstand external shock, impacts, uncertainty, changes without significant damage or loss of function, and quickly rebounded to normal operation states. Elaboration of robustness also covers making a provision to ensure safe failure is predictable, and loss of service is minimized even under failures	Godschalk (2003), Bahadur et al. (2010), The Rockefeller Foundation & ARUP (2015), Tyler et al. (2016), Meerow & Stults (2016)
Flexibility & Modularity	Ability to adjust, redistribute, reorganize, restructure, reassemble, and evolve in response to a wide range of circumstances changes of both spatially distributed and functionally linked	Tanner et al. (2009), Bahadur et al. (2010), Ahern (2011), Rodin (2014), The Rockefeller Foundation & ARUP (2015), Tyler et al. (2016), Meerow & Stults (2016)
Diversity	Presences of diversity options, functionalities of systems, networks, operation mode, infrastructures, and resources	Godschalk (2003), Bahadur et al. (2010), Ahern (2011), Rodin (2014), The Rockefeller Foundation & ARUP (2015), Tyler et al. (2016), Meerow & Stults (2016)
Redundancy	Ensuring spare capacity or reserved (back-up) resources/systems in order to accommodate shocks, disruption, surges in demands, especially in a case of no external support or interventions available	Godschalk (2003), Ahern (2011), Liao (2012), The Rockefeller Foundation & ARUP (2015), Tyler et al. (2016), Meerow & Stults (2016)
Resourcefulness	Ability to access/provision and mobilize assets and resources under shock/stress circumstances as well as capacity to restore systems functions aftermath through provision and coordination	The Rockefeller Foundation & ARUP (2015), Tyler et al. (2016), UNISDR (2015a)
Responsiveness	Abilities of systems to organize, rearrange and give feedback in with timely manner in order to take	Tanner et al. (2009), Liao (2012), Rodin (2014); The Rockefeller Foundation

Indicators/Attributions	Definitions	Sources
	appropriate actions for preparing, warning and responding to shocks, treats and extreme disruptions to ensure quick restoration in its aftermath	& ARUP (2015), Tyler et al. (2016), UNISDR (2015a), Meerow & Stults (2016)
Inclusiveness	Ensuring relevant social groups and stakeholders in planning and decision-making processes by taking their concerns and interests into account in order to assure equity, participation, cooperation and engagement	Godschalk (2003), Tanner et al. (2009), Bahadur et al. (2010), The Rockefeller Foundation & ARUP (2015), UNISDR (2015a), Meerow & Stults (2016),
Integration and coordination	Ensuring consistency and alignment across relevant operation systems, actors, institutions, networks in order to enable them to function or take actions collaboratively and collectively based on their interdependency and interconnectedness layers in both vertical and horizontal perspectives	Bahadur et al. (2010), Ahern (2011), Rodin (2014), The Rockefeller Foundation & ARUP (2015), Meerow & Stults (2016)
Learning capacity	Ability to internalize experiences and lessons learnt in order to avoid and cop with a current threshold of shock or failures, and further enhance capacity to adapt and transform in order to deal with the greater level of unexpected disruption as well as ability to retain knowledge over time	Godschalk (2003), Tanner et al. (2009), Bahadur et al. (2010), Tyler et al. (2016), UNISDR (2015b), Meerow & Stults (2016)
Awareness	Ability and willingness to constantly appraise, uptake new information for adjusting understanding of risks and invest in risk reduction	Rodin (2014), UNISDR (2015b)
Information	Availability and accessibility of relevant information and knowledge for ensuring mutual understanding of current and future risk scenarios among relevant stakeholders	Tyler et al. (2016), UNISDR (2015b), Meerow & Stults (2016)

2.4.3 Characteristics of urban infrastructure resilience

Urban infrastructures are socio-technical-ecological systems (Fox-Lent et al., 2015:210). Capacity to continue performing critical functions, although disruption is the summit of urban infrastructure. Conventionally resilience of urban infrastructure focused on the engineering resilience of an individual system component (Holling,1996) rather than considering interconnections and interdependencies of all urban systems as well as possible cascading effects (Fox-Lent et al., 2015:210). Traditional components of resilience are preparation (or anticipation), absorption (or resistance), adaptation, and recovery (Petit et al., 2013:1; Fox-Lent et al., 2015:210; Rosati et al., 2015:196). However, several scholars proposed resilience frameworks in the realm of critical infrastructure management. Petit et al. (2013) present the Resilience Measurement Index (RMI) consistent with the emergency and risk management cycle of the US critical infrastructure network (preparedness, mitigation measures, response capacities, and recovery mechanism). Meanwhile, Fox-Lent et al. (2015) matrices four key resilience characteristics with four management domains of any complex system, i.e. physical, information, cognitive and social, which are used as education and engagement tools in disaster risk management, so-called Resilience Matrix. Furthermore, Jovanovic et al. (2016) extended the application of Resilience Matrix through scenario planning perspective and multifaceted visualization as “Resilience Cube”. Despite the heterogeneity of resilience concepts applied in critical urban infrastructure, a question is still how do we operationalize, assess, and track resilience interventions of a particular sector which is highly complex in both spatial and network interconnectedness as well as heavily depending on other urban sectors functions, such as health care sector.

2.4.4 Resilience assessment and operationalization

Quantifying resilience has been actively researched in many disciplines such as ecological science, military planning, economics, development, climate change adaptation, and disaster risk reduction (Quinlan et al., 2016:682). The main purpose of measuring resilience is to simplify a complex system to enhance understanding, operationalization and track its progress toward overarching goals (Stirzaker et al., 2010). To quantify resilience, understanding the “resilience of what and to what” requires considering process–structure-function interactions across spatial and temporal scales (Allen et al., 2016:628-9). The Resilience Alliance (2010:5) provided five main stages of resilience assessment framework, starting with describing the systems by questioning resilience of what, to what?, identifying key issues, and defining scales. The second stage is understanding system dynamics in order to dissect a system change, states of the system, as well as its thresholds and transition. The third stage is revealing interactions of the system across scales, including possible cascading changes. The fourth stage is to evaluate system governance in both institutions and social networks. The final stage is executing the assessment through a synthesis of the findings of all stages iteratively, which then emerged transformation guideline as a by-product. The Resilience Alliance (2010) marked that a resilience assessment should be reviewed and revisited regularly as system dynamics change and as understanding grows.

Spatio-temporal resilience quantification is not fully developed. Lacking coupled spatio-temporal data and understanding its interaction across scales can cause difficulties in establishing a firm ground quantitative assessment method that enables transformation (Allen et al., 2016:633). An indicator-based approach with matrix analysis is one of the most popular methods for assessing resilience. However, Levine (2014) argued that numerically measuring resilience might not be practical in reality because resilience can only be verified in the occurrence of abrupt changes due to major natural hazards or extreme climate events. Jovanovic et al. (2016:2) also stressed that the indicators could be considered neither independent nor standardized in practice, but relative weighted aggregation and normalization is common. The calculation features allow comparison between critical infrastructure physical assets in the same region and characterized appropriate and effective measures for strengthening resilience (Petit et al., 2013; Jovanovic et al., 2016). Yet, lacking data, inconsistency among indicators and consensus on the specific indicators are typical obstacles in performing indicator-based assessments (Jovanovic et al., 2016:1-2).

2.5 Climate resilience in healthcare – What lies beyond a facility fence?

"WHO working definition of a climate resilient health system: A climate resilient health system is one that is capable to anticipate, respond to, cope with, recover from and adapt to climate-related shocks and stress, so as to bring sustained improvements in population health, despite an unstable climate." (World Health Organization, 2015b)

From a health care perspective, efficiency, quality, responsiveness, equity, outcomes and accessibility are fundamental and legitimate interests for public health operation and decision-making (Goddard & Jacobs, 2010:340). However, climate-related hazards push additional challenges to the health care sector in delivering these professional requirements. The concept of health system resilience has gained popularity in both academia and political discourses. Studies on health system resilience have increased significantly over the last ten years (2008-2019). In 2017 the publication on health system resilience increased by 62%; however, about 11% focused on climate change and 15% on disaster risk management (Biddle et al.,2020:1084). Biddle et al. (2020) found that most studies only emphasise absorptive and adaptive capacities and underrated transformative capacity aspects of resilience.

A checklist is a common tool for assessing the resilience of health care facilities, particularly in the context of climate change. For example, Paterson et al. (2014) developed a toolkit that consists of a checklist for officials who work in areas of emergency management, facilities management and health care services and supply chain management to identify gaps in climate change preparedness, direct allocation of adaptation resources and inform strategic planning to increase resiliency to climate change (Paterson et al., 2014:13097). The concept of resilience health care service delivery builds upon the robustness of a facility in dealing with any kind of disruptions and hazards, which centre around consideration of interconnectedness with health care determinants critical infrastructures. The Joint Commission developed a standard, Emergency Management in Health Care: An All-Hazards Approach (4th Edition), to guide health care facilities in managing their emergency response functionality based on a 96-hour sustainability rule. A health care facility is not obligated to hold out fully functional for 96-hours but is mandated to comprehend its capacity to manage and withstand emergency when there is no external support for at least 96 hours (JC, 2019). Although this approach focuses on the robustness (absorptive capacity) of the facility, hourly-based operational and decision criteria could enable an entry point in linking short-term response to more future-oriented planning beyond a facility boundary. A similar concept is also illustrated in Hiete et al. (2011) but narrowed down to scenario-based planning in the case of power outages in Germany. The study highlighted the direct and indirect impacts of electrical disruption and interdependency among main healthcare sub-sectors and its dependency on other relevant critical infrastructure sectors.

Under the Hyogo Framework for Action 2005-2015, the issue of safe hospitals was prioritized under the World Disaster Reduction Campaign 2008-2009 with the collaboration of UN International Strategy for Disaster Reduction (UN/ISDR) and the World Health Organization (WHO), through support from the World Bank. The campaign focused on improving the safety of hospitals and health institutions from natural hazards, especially reducing their physical vulnerabilities (WHO, 2009). WHO’s Safe Hospitals Initiative provided a comprehensive safe hospital framework, promoting an all-hazards approach. The program also suggested national-level indicators for monitoring a Safe Hospitals program (WHO, 2015a). Moreover, WHO & Pan American Health Organization (PAHO) (2015) also published a Hospital Safety Index (all-hazards assessment) for facility-level application. Based on the increasing evidence of climate change and its associated health risk, WHO released the Operational Framework for Building Climate-resilient Health Systems in 2015. The framework serves as a guiding framework for the health sector and its operational basis in health systems. The framework also promotes an application of climate resilience approach to health systems by addressing the importance of vulnerability assessment and climate-resilient and sustainable technologies and infrastructure (WHO, 2015b). The document recommends that a health care facility should systematically include future climate risks into health system service delivery, infrastructures, technologies and processes. The same year, the PAHO published SMART Hospitals Toolkit to enhance safety and green interventions for a health care facility. The toolkit contains a baseline assessment tool, a green checklist, a Cost-Benefit Analysis Tool, and a sustainability construction guide annex (Balbus et al., 2016:178).

To build on the Operational framework for building climate-resilient health systems and SMART Hospitals Toolkit, WHO disseminated a new guideline for health care facilities in 2020, WHO Guidance for Climate Resilient and Environmentally Sustainable Health Care Facilities. The guidance is meant for enhancing climate resilience and promoting environmental sustainability of health care facilities. The document explicitly addresses the need to understand current and projected climate conditions, health system demands and anticipated health system capacity (WHO, 2020b:23). Although the guidance underlined the importance of cross-sectoral actions on climate resilience, no concrete measures can be extracted from the document. The interventions proposed in the guidance are targeted health care facility managers, and the checklist format does not allow comparison among facilities; however, the proposed generic interventions can be adapted for all sizes and levels of health care facilities (WHO, 2020b:27).

Besides international guidelines, there are national toolkits for implementing climate resiliency and sustainability for health care facilities, such as Canadian Health Care Facility Climate Change Resiliency Toolkit and U.S. Sustainable and Climate Resilient Health Care Facilities Toolkit. The Canadian Health Care Facility Climate Change Resiliency Toolkit provides an online checklist of emergency management, facilities management, health care services and supply chain management. The checklist consists of 3 main sections, risk assessment, risk management, sustainable health care and climate change mitigation. This toolkit allows benchmarking among health care facilities possible (CCGHC, 2021). The US Sustainable and Climate Resilient Health Care Facilities Toolkit explicitly integrates future climate change scenarios into health care planning. With a web-based platform, health facilities can conduct climate-resilient planning around five key elements; 1) Climate Risks and Community Vulnerability Assessment; 2) Land Use, Building Design, and Regulatory Context; 3) Infrastructure Protection and Resilience Planning; 4) Essential Clinical Care Service Delivery Planning; and 5) Environmental Protection and Ecosystem Adaptations (HHS, 2018).

Furthermore, the US online platform supplements users with a handful of climate projection datasets and checklists for self-assessment of health facility climate-resilient. The toolkit also highlights the dependency and interdependency of health facilities and other critical infrastructure as well as consideration of non-climate stressors. Nevertheless, these frameworks, guidelines, and toolkits are comprehensive and detailed, but only US Climate Resilience Toolkit illustrates concrete steps and supporting features in integrating climate scenarios into a local context. Although US Climate Resilience Toolkit is the only one that addressed the land use planning issue, a spatial extension is still within the adjacent of a health care facility rather than linking with a city-wide health care network. In summary, most of these climate resiliency tools are in checklist format instead of index that allows tracking and benchmarking risk reduction in both individual health care facility and service network, as well as usually neglect health determinants sectors beyond a health care facility's fence.

2.6 Composite indicators – never-ending debate or revitalizing agent towards climate-resilient public health care?

Composite indicators have gained worldwide popularity as a tool for linking science to policy and practice, especially in climate change adaptation, climate resilience, and disaster risk management (Hinkel, 2011:198). Composite indicators are capable of capturing and summarizing the reality of complex and multidimensional phenomena, which allow evaluation state of affairs, track target implementation, enable cross-comparison, establish performance benchmarking, facilitate communication and promote accountability (Nardo et al., 2005:6; Becker et al., 2015:2; Talukder,2017:2; Hinkel,2011:203-204).

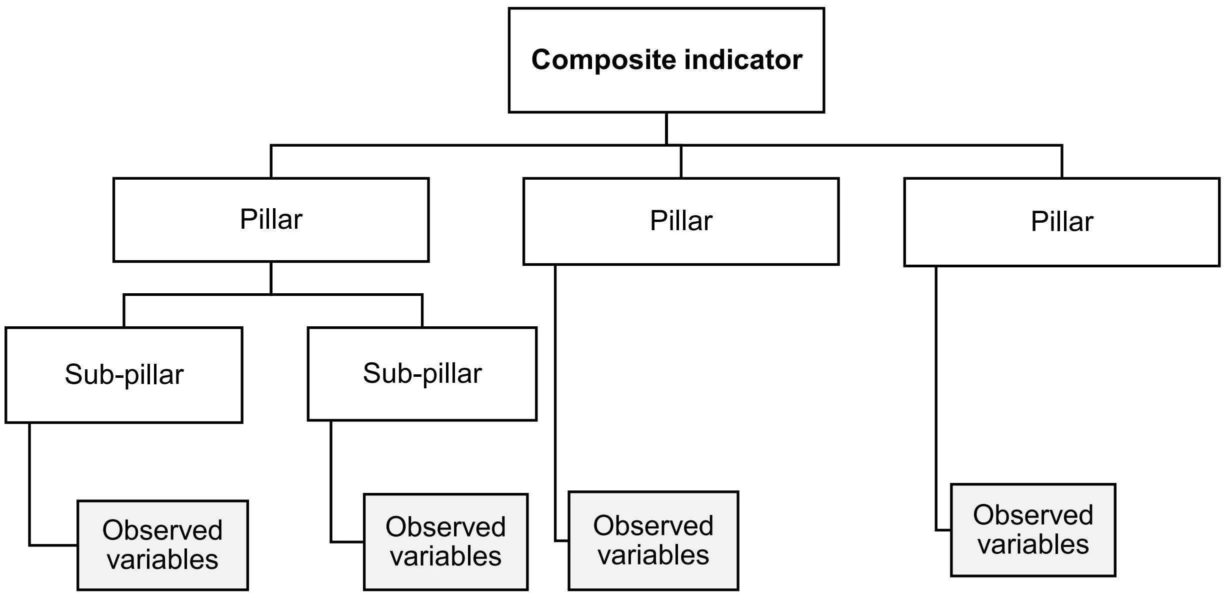
Since the 1990s, the composite indicators concept has been extensively used and growing as a key instrument in public discourse on development issues, especially in the international development sector (Paruolo et al., 2013; Becker et al., 2015,2017; Talukder et al.,2017;), for example, Human Development Index (HDI), Commitment to Development Index (CDI), Environmental Performance Index (EPI), Gender Empowerment Measure (GEM), Global Peace Index (GPI), etc. Nevertheless, the debate on the application of composite indicators never settled. The approach also receives strong methodological and pragmatic critiques, especially regarding statistical misconception (Paruolo et al.,2013:610; Becker et al., 2015:3), lack of transparency, raising false expectations, misleading policy messages, drawing simplistic policy conclusions (Nardo et al., 2005:6; Hinkel, 2011:198), missing of uncertainty and reliability estimations (Beccari, 2017). Comprehensive discussions of the advantages and disadvantages of composite indicators are reported in Nardo et al. (2005).

A composite indicator is a theoretical model of natural systems which reflects (some of) the characteristics of the reality and how the researcher or developer observes the reality. Thus, the model should fit the user's purpose and given objectives (Nardo et al., 2005:8). Composite indicators are aggregations (mathematic combination) of individual indicators (variables) that aim to operationalize different dimensions of the underlying concepts given by the objective(s) of the analysis (Nardo et al., 2005:7; Becker et al., 2015,2017). The composite indicator is an instrument for reducing complexities of non-measurable problems or phenomena into a measurable form (Nardo et al., 2005:8), such as complex phenomena or performance of countries/sectors/entities on human development, sustainability, governance, competitiveness, climate vulnerability, disaster risk, resilience, etc. (Becker et al., 2015,2017).

An indicator or sub-indicator must be structured in the way that the indicator and its sub-indicators are sufficient and appropriate to describe a latent phenomenon (Nardo et al., 2005:12) which bounds to a specific spatial scale and timeframe. The linkage or relationship among the indicators and sub-indicators should be theoretically sound (Birkmann, 2013:88;93). A comprehensive elaboration of an indicator development framework can be found in Maclaren (1996). Often, composite indicators are structured in the form of hierarchical "levels". Variables (indicators) that share similar conceptual characteristics are usually grouped as "pillars" or "dimensions". Pillars may also consist of sub-pillars as the developer see appropriate (see Figure 2.3) (Becker et al., 2015:14). Various indicators may have different units and measurements; thereby, normalization is required to allow aggregation possible (e.g. arithmetic, geometric) (Talukder et al., 2017:1). Aggregation of indicators is vital to ensure the composite index is combined in a meaningful way (Nardo et al., 2005:120). Normally, the variables are combined with a weighted average operation to give the resulting value of the composite indicator. Selection and application of weighting values for each variable can greatly impact the subsequent rankings, which often go unnoticed (Nardo et al., 2005:120; Becker et al., 2017:2). A possible misconception is that the weight assigned to a variable can be directly interpreted as a measure of variable's importance to the resulting value of the composite indicator (Becker et al., 2017:2). Sensitivity analysis shall be applied to ensure the reliability and robustness of composite indicator outputs (Becker et al., 2015:3). In spite of statistical dimensions do not necessarily represent or coincide with the theoretical influence of the indicators or sub-indicators on the phenomenon being assessed, revision of the set of the indictors or sub-indicators might be considered (Nardo et al., 2005:10,26). Furthermore, it is important to remark on a trade-off between compensability and hidden complexity or crucial properties of the system behind a single number (Nardo et al., 2005:6; Greco et al., 2018:67).

In disaster risk and climate vulnerability alone, Beccari (2017) identified 106 methodologies used and 2,298 unique variables based on 126 studies which diverse in terms of focuses (vulnerability, resilience, risk), approach (top-down, bottom-up, data collection), and scale (international, regional, national, local) (Parsons et al., 2016:3). Vulnerability is a theoretical concept, which can be operationalized or assessed instead of measuring it (Hinkel, 2011). Vulnerability often contains tangible and intangible characteristics that challenge reducing its complexity or generalized as a universal set of indicators for all levels and all hazards (Birkmann, 2013). Despite myriad of composite indicators and diversity of indicator construction methods (Parsons et al., 2016:1), Hinkel (2011:198) categorized six key aspects of climate vulnerability composite indicators as 1) identification of mitigation targets; 2) identification of vulnerable people, communities, regions, etc.; 3) raising awareness; 4) allocation of adaptation funds; 5) monitoring of adaptation policy; and 6) conducting scientific research. He concluded that vulnerability indicators are only appropriate for identifying vulnerable groups, areas, and systems exclusively at the local scales (Hinkel, 2011:198,206) because vulnerability is context-specific (O'Brien et al., 2007) and requires a forward-looking perspective. However, it is still challenging to operationalize a more sophisticated vulnerability assessment approach in a local context. Moreover, some intangible vulnerability characteristics are important but hard to quantify and capture, such as cultural or institutional aspects (Birkmann, 2013).

Figure 2. 3 An example of the hierarchy of composite indicator



Source: Adapted from Becker et al., (2015:14)

Although health sector has increasingly focused on evidence-based public health for supporting decision-making processes, conventional health care monitoring and evaluation (M&E) are insufficient to address projections of health impacts under different climate and socio-economic futures (Ebi et al., 2018b). Numbers of challenges restraint the introduction of climate resilience M&E in the health sector, such as lacking awareness and recognition of climate change impact on health outcomes, lacking long-term scenario planning and understanding of uncertainties climate projections and SSP; unaware of interaction with health determinants sectors, inadequate institution learning management, lacking recognition the importance of adaptation processes and outcomes (Ebi et al., 2018b). Ebi et al. (2018b) emphasize the need for indicators improvement to encompass comprehensive climate-resilient health systems in 3 realms: 1) climate-related risk elements, 2) population health and health systems at risk, and 3) adaptation processes and health system resilience.

It is fair to conclude that most M&E on climate resilience health service and delivery are rather in checklist format rather than a comprehensive and complex set of indicators that strategically address future climate change, development choices, and public healthcare capacity with spatial and temporal dimensions linkage of climate risk components. Nonetheless, a composite indicator should never be seen as an overarching goal; instead, it serves as a tool for initiating stakeholders discourse and drawing public interests and concerns (Nardo et al., 2005:7).

2.7 Reunification of backcasting scenarios planning and health futures

A desire to know what the future will bring and a willingness to change developmental paths create motivations for scenario planning (Höjer & Mattsson, 2000: 614). As a strategic planning tool, scenario approaches have been firmly rooted in the military before extending to corporate strategic planning, energy and technology foresight, and are particularly popular in sustainable development and environmental planning (Bradfield et al., 2005: 797; Moss et al., 2010:747-8). Although there is no consensus on the scenario typologies, future studies explore possible, probable and preferable futures (Börjeson et al., 2006:724). This classification can be formed as three central questions; What will happen? What can happen?, How can we realize the future we want?, these roughly correspond to predictive, explorative, and normative scenario planning (Börjeson et al., 2006:725,730).

- Predictive scenarios aim to predict what is going to happen in the future in one way or another based on the concepts of probability and likelihood. Predictive scenarios primarily draw up the most likely development that enables to plan in response to expected situations.

- Explorative scenarios aim to explore possibilities of situations or developments from various perspectives in response to the what-if question. Explorative scenarios are usually elaborated with a long time horizon, which allows for structural and profound changes (Börjeson et al., 2006):727-8.
- Normative scenarios focus on how desirable futures can be realized, from escalating marginal adjustments to transformation change. Backcasting is a usual approach for normative scenario planning which often prospect a long time horizon, e.g. 25–50 years in order to be long enough to make room for transformational changes (Börjeson et al., 2006:729)

Nevertheless, these scenario-planning approaches are not necessary standalone. Explorative and normative scenarios can be integrated (van Vliet & Kok, 2015:43) and framed through a backcasting process to strategically identify robust and effective actions from a long-term perspective. Explorative scenarios sketch possibilities and define plausible futures by discerning broad ranges of uncertainties (Bigg et al.,2007; van der Voorn et al., 2017:2). Normative scenarios draw versions of desirable futures and work backwards to how desirable futures can be attained by alteration of today's actions (Robinson, 1990:822-3; Höjer & Mattsson, 2000:628-9). A combination of normative and explorative scenarios can be found (Börjeson et al., 2006:736-737), particularly in a novel application of backcasting approach (van Vliet & Kok, 2015:43) such as in regional, land use, and community planning (Star et al., 2016:90-91), resilience and sustainability planning (Iwaniec et al., 2020:8-9).

Backcasting or looking back from the future belongs to the normative scenario planning category as a way to articulate desirable futures and the way to reach them (Robinson, 1990: 821-822; Quist et al., 2011:883; Vergragt & Quist, 2011:748-749). The approach was firstly employed in energy planning studies in the 1970s, and then the term was introduced by Robinson (Robinson, 1990; Dreborg, 1996:81; Phdungsilp, 2011; 709, Quist et al., 2011;884). Around the 1990s, the application of normative scenarios planning shifted from energy planning to sustainability (Phdungsilp, 2011,p.709) and from researcher/expert-led to stakeholder participatory practices (Robinson et al., 2011). In the 1990s, participatory backcasting emerged and was carried out towards sustainable development in various domains and scales, such as climate policy, environmental management, industrial development, hydrogen economy, and urban and regional planning; from local to the international level (Quist & Vergragt, 2006; Patel et al., 2007; Shaw et al., 2009; Robinson: 2011; Vergragt & Quist, 2011; Rawluk & Godber, 2011; Van der Voorn et al., 2012; Carlsson-Kanyama et al., 2013; Iwaniec & Wiek,2014; Oteros-Rozas et al., 2015; Totin et al.,2018).

Backcasting is a practical approach for addressing highly complex problems, needs for major or transformation changes, involving a long-term time horizon for implementation, such as 50 years (Dreborg 1996; Vergragt & Quist,2011:748-749). Application of backcasting is especially useful when trend breaking, radical innovation, paradigm shift or transformation changes are required to proactively overcome problems or undesirable futures (Höjer & Mattsson, 2000;628-9; Vergragt & Quist, 2011:748-9; Korhonen & Granberg, 2020:2; Aoki et al., 2020:48) such as environmental degradation and climate change (Carlsson-Kanyama et al., 2013:10-1). In particular, the utilization of the backcasting approach in future city development planning inevitably demands embracing pluralistic ideas and reflecting a set of multiple value systems (Aoki et al., 2020: 62-3). Backcasting helps planners explore proactive solutions with long-term future-oriented perspective and transition management in order to overcome goal conflicts, resources deficiency, uncertainty, and congestion of short-term problems (Carlsson-Kanyama et al., 2013:11).

Many scholars portray backcasting processes as multiple steps or phases of actions, such as Robinson (1990:824), Weaver et al. (2000), Höjer & Pettersson (2011:820-1), and Quist et al. (2011:886-7). However, the process involves at least two major steps, 1) identifying objectives, future visions and desirable targets, and 2) backward analysis of how this desirable future could be achieved and operationalized. (Höjer & Mattsson 2000; Quist & Vergragt, 2006:1028-9; Quist et al. 2011; van Vliet & Kok, 2015:44-5). Backcasting also demands iteratively evaluation and revision of scenarios to interactively inform backcasted outcomes of the resolved challenges (Quist & Vergragt, 2006: 1031-3; Robinson et al., 2011). Although backcasting is useful for proactive and strategic future planning and enhances higher-order learning among stakeholders in different societal domains (Quist et al., 2011:p.894-5), integrating the approach into formal planning practice is not yet mainstream (Aoki et al., 2020:47). Major pragmatic difficulties in conducting and embedding backcasting into conventional policy development practices often occur, particularly in stakeholders' participatory backcasting processes. Besides, backcasting is cost & labour-intensive, time-consuming, and distressing in keeping stakeholders motivated throughout the iterative processes; overcoming human cognitive barriers to future envisioning (McKiernan,2017) and balancing between stakeholders' buy-in and process quality are immense challenges (Shaw et al., 2009; Robinson et al., 2011; Oteros-Rozas et al., 2015:13). In a future envisioning process, it is difficult to unbind experts and stakeholders from their cognitive bias on present knowledge, paradigms, interests, needs and values to more systematic exploration and transformation of long-range futures (Robinson et al., 2011; Vergragt & Quist, 2011:750; Höjer & Pettersson, 2011: 820-821; McKiernan,2017; Butler et al., 2020). Moreover, spatial and temporal complexity is often a core limitation for local stakeholders in conceptualizing spatio-temporal dynamics among contradicting scenarios (Bradfield et al., 2005; Birkmann et al., 2015:64). To ensure buy-in proposal, a strong emphasis on legitimacy and collaborative learning may push the focus of backcasting to process quality rather than a formation of sufficient and radical measures to achieve the targets set (Larsen & Gunnarsson-Östling,2009; Robinson et al., 2011; Höjer & Pettersson, 2011: 820-821). To close these cognitive and pragmatic gaps, van der Voorn et al. (2012) suggested highlighting intermediate events that bring about a desirable future in order to lay out a transition from the state of the present to projected trends and desirable futures. Moreover, Vergragt & Quist (2011:753) invited to bridge the gaps between expert-led backcasting, which often reaches policy objectives (Höjer & Pettersson, 2011; Kok et al., 2011) and participatory backcasting, which usually gains more buy-in (Robinson et al., 2011; Quist et al., 2011). Nevertheless, participatory backcasting is often perceived as experiments rather than systematically leading to follow-up, spin-off and implementation in line with the target (Quist et al., 2011:894-895). Thus mainstreaming a backcasting approach in a formal planning process, government support and facilitation is vital (Quist et al., 2011:894-895).

Scenario planning is an essential tool for exploring potential consequences of a variety of responsive and adaptive actions and interactions among physical, environmental and societal systems in such a deep level of uncertainties and complexities of climate change (Moss et al., 2010:747-748; Kok et al., 2019:643-645). Scenarios encompass long-term future-oriented policies for disaster risk management and climate change adaptation (Birkmann et al., 2015:65), covering predictive, explorative and normative elements and also qualitative and quantitative approaches (Börjeson et al., 2006:730). The introduction of scenario planning in climate change analysis evolved from being heavily influenced by probabilistic modelling of physical climate-related parameters (IPCC, 1992) to focusing instead on the plausibility of the scenarios, including narrative-based storylines of socio-economic conditions associated with multiple ranges of emissions scenarios at a global level (IPCC 2000; 2001). The latest generation of IPCC scenario emphasises the combination of SSPs with climate projections (Representative Concentration Pathways: RCP), allowing consideration of socio-economic diversity and regional variability (IPCC, 2014c; Moss et al., 2010; Wilkinson et al., 2013). Although forecasting and exploratory scenario approach dominance in climate change adaptation studies (van der Voorn et al., 2017:2), backcasting has been firstly integrated with IPCC climate change mitigation storylines (Carlsson-Kanyama et al., 2013:10-11).

Robinson et al. (2011) demonstrated early attempts of integrating participatory interactive backcasting in climate change adaption in the Lower Mainland of British Columbia, Canada that involves climate downscaling to a regional and local level, comprehensive vulnerability assessment, urban development change, land use change and 3D generative visualization of alternative futures. The paper provides very good lessons learned in applying participatory backcasting on a climate impact assessment; however, articulating climate change adaptation measures to achieve the target in the given timeframe is still unclear. Despite the fact that, the application of backcasting in climate change impact analysis and adaptation at the local level is limited (Carlsson-Kanyama et al., 2013:10-11), a prominent manifestation of backcasting in climate change adaption revealed in Van der Voorn et al. (2012), Carlsson-Kanyama et al.(2013), Van der Voorn et al. (2017) and Iwaniec et al. (2020). Van der Voorn et al. (2012) demonstrate the application of backcasting in adaptive management policies and strategies in Breede–Overberg coastal region in South Africa. Carlsson-Kanyama et al.(2013) apply participatory backcasting in order to develop visions of climate adaptation in two Swedish municipalities. Van der Voorn et al. (2017) report on a comparative study of Backcasting-Adaptive Management (BCAM) methodology application in three regions of different continents, the South African Breede–Overberg Catchment, the Mississippi Estuary-New Orleans region, USA and the Dutch Rhine-Meuse Estuary. Iwaniec et al. (2020) demonstrate a nexus framework of participatory backcasting in resilience and sustainability planning for the case of the Central Arizona-Phoenix region, USA. Among the three studies, Iwaniec et al. (2020) is the only study that prevails spatio-temporal dimension and linkage between future climate change, urban development change, land use dynamic, and participatory scenarios assessment. The paper shows strong connections between researcher-driven and participatory approaches and cycling between explorative and normative perspectives in scenario planning, but streamlining climate resilience to urban sectoral operation through composite indicators is still missing.

Attributable to climate change on urban public health is growing; this trend underscores the urgent need for strategically risk-informed planning with a future-oriented perspective. Backcasting approach prevails opportunities for health sector to embody uncertainties and complexities of climate change and future development choices for climate-resilient health service and delivery at the local level with stakeholders participatory and gaining political buy-in. Even though, in health sector, scenario planning, including the backcasting approach, has been recognized by WHO to explore the relationships between health, societal and environmental development since the early 1990s (Taket, 1993). However, the backcasting approach has not been systematically used across WHO domains. Some backcasting elements appear in WHO works, such as country cooperation strategies (CCSs) and long-term disease elimination frameworks. Relatively short-term conventional planning practice with earmarked donor contribution and demands dependency often does not enable the organization in long-term planning for future health. Nevertheless, WHO Western Pacific explicitly emphasises the backcasting approach as a key instrument for shifting operations and addressing resilience of healthcare services and infrastructure opposes disaster risk, climate change, and environmental change (WHO, 2019). In addition to WHO works, only a few studies applied the backcasting approach in health care, for example, food waste management options within the Irish Maternity Service (Ryan-Fogarty et al., 2017); planning for the AI-enabled Health Care System (American Hospital Association, 2019); transformation of healthcare service to digitalization (Gjellebæk et al., 2020); designing the collective futures of healthcare for space(Pau & Hal, 2020); herd-immunity approach in Swedish COVID-19 policy (Korhonen & Granberg, 2020). Among these studies, Korhonen & Granberg (2020) and Pau & Hal (2020) demonstrate such a unique application of the backcasting approach; the former integrates the approach in very short-term planning (less than three years) while the latter is an exotic spatial context, planet Mars. Among these works, there is no explicit application backcasting in elaboration and assessment of climate-related impact and climate-resilient of the public healthcare service and facility come to the surface.

This literature review prevails that the current understanding of the interactions between urban development change and climate change in the local context, considering urban infrastructure operation & functionality in the forward-looking, is still not advanced. There are obvious missing links between global climate trajectories and local climate adaptation scenarios that take stakeholders' normative consideration into account. Yet, the current vulnerability assessment is dominated by a place-based concept, which has a clear constraint when looking at network operation and functionality of urban systems. Especially critical infrastructure such as urban health care is often unfamiliar with long-term future scenario planning and has an insufficient understanding of uncertainties of climate projections and shared socio-economic pathways. Moreover, the existing sectoral climate resilient guidelines for public health facilities focus on facility-based measures and lack a concrete framework for future climate risk and climate-resilient targets operationalization from spatial planning and service network perspective. To nexus gaps across scales and systems demand a new generation of climate risk/vulnerability assessment tailor-made at the local level. Hence, this study aims to pave the new frontier of climate vulnerability/risk assessment by considering future climatic and non-climatic changes and their interactions. Furthermore, it investigates how the local public health service could operationalise their climate risk and resilient futures using Khon Kaen city as a case study. Intermixed backcasting approach and composite indicators serve as the main vehicle to inform the local public health services to be ready and prepared for climate change and urbanization megatrends and help the sector strategically operationalize their desirable climate-resilient future with collaborative future-oriented scenario planning.

Chapter 3
Khon Kaen city

Khon Kaen city represents a secondary growing medium-sized city in Southeast Asia. Since the 1960s, Khon Kaen arose as a regional urban centre due to the Thai government's anticommunist campaign during the Cold War (Sudhipongpracha & Dahiya, 2019; Kamnuansilpa et al., 2020). The city has been facing diverse and paradoxical challenges, for instance, an influx of rural-urban-urban migration, ageing society, unplanned urban expansion, mild urban sink, social inequity, digital transformation, environmental degradation and climate change. Khon Kaen city is a regional hub of financial, educational, administration, and public health services. The public health service of Khon Kaen city has been overwhelming with increasing local inhabitants and demands from neighbouring cities and countries. At the same time, climate change poses immense challenges to the local public health service operation, especially inevitable devastating floods and prolonged drought. This research aims to manifest how Khon Kaen city could proactively address the interaction between urbanization and climate change and its potential impact on the local public health service from a long-term future-oriented perspective. Hence, this chapter presents Khon Kaen city's background information to encompass the understanding of the case study in various aspects: physical geography, administration, social & socio-demographic, economic & infrastructure development, environmental & disaster risk management, land use, and public health care.

3.1 Geography

Khon Kaen (Thai: ขอนแก่น, pronounced [kʰǒ(ː)n kɛ̀n]) is one of the four major provinces (*changwat*) of Isan (or Northeastern region) of Thailand. Thai government categorizes Khon Kaen province as the central-northeastern part of the country and assigns it as the regional administrative centre. The province lies between 15 – 17 degree north latitude and 101-103 degree east longitude, elevation 150 – 840 m Mean Sea Level (MSL) (200 m on average) (Figure 3.1). With an area of 10,886 square kilometres (sq. km), the province is home to more than 1.8 million people (KKPSO,2020). Although Khon Kaen province holds the second biggest economy in the region, its Gross Provincial Product (GPP) per capita is the highest in Isan and sits at the 32nd place in the country. More than 88% of the provincial economic values are shared by industrial and services (in 2018) (NESDB,2020). Among 26 districts (*Amphoe*) of the province, Mueang Khon Kaen district, the so-called Khon Kaen city, is the heart of the province (and *de facto* capital of the region) administration, transportation, education, medical, and economy. With a size of about 953.4 sq. km (12 % of the total provincial area), 416,285 (2019) registered inhabitants, 436.64 inhabitants/sq.km population density, Mueang Khon

Kaen district is the densest populated area of the province. The district is divided into 18 sub-districts (*Tambol*) and 267 villages (*Mooban*). 65% of the population lives in municipal areas (KKPSO, 2020). Khon Kaen city is situated in the upper eastern part of the province, which lies upon the Korat basin with an average 150-200 m MSL elevation. Chi and Phong rivers flow and nourish the area. According to Köppen Classification, Khon Kaen is classified as a tropical savanna climate(Aw) which consists of three seasons, summer (February-May), rainy (Monsoon season) (mid-May – October) and winter (mid-October to mid-February). The average daily maximum temperature is about 32.8 °C, with an average rainfall of 1,246.8 mm annually (TMD, 2019).

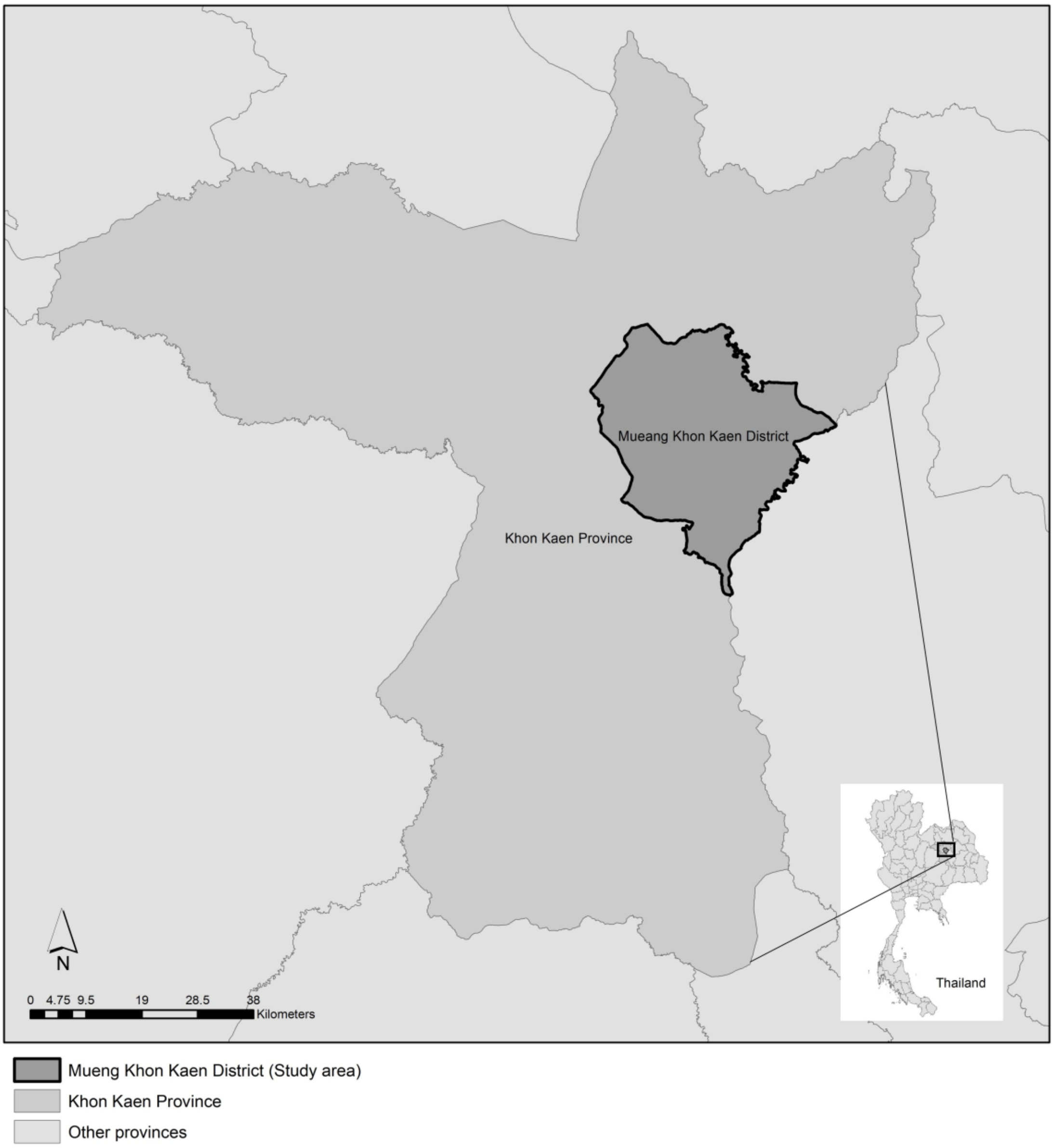
3.2 Administration and institution

Khon Kaen city is a pioneer area of administrative decentralization, from Bangkok to the poorest and most rural regions to fabricate an anti-communism campaign during the Vietnam-US war. Khon Kaen city functions as the northeastern regional coordinator of a branch of public institutions and private companies. The city is among the top national ranks and the backbone of regional development in basic infrastructure, education, and medical services.

The city's 18 sub-districts are administrated by 19 local administrative agencies[3], which can be further classified as one city municipality, two town municipalities, 11 sub-district municipalities and five sub-district local administrative organizations (Figure 3.3). Individual local government independently operates within their own territory but under the supervision of provincial administration. Sub-district local administrative organizations (SAOs or *Ao Bo Tor*) and Town municipalities (*Tessaban Mueang*) are oversight by the district chief, while City municipalities (*Tessaban Nakhon*) are under the direct supervision of the governor (KPI, 2007). From regional cooperation and international linkage perspectives, Khon Kaen city often serves as the Greater Mekong Sub-region (GMS) hub. Mekong Institute and Greater Mekong Sub-region Academic & Research Network and consular offices are also located in the city. More background information on Thailand's administrative structure can be found in Box 3.1 and Figure 3.4.

[3] Tha Phra district are taking care by two local administrative agencies, urban part of the area is administrated by Tha Phra sub-district municipality, while rural part governed by Tha Phra sub-district local administrative office.

Figure 3. 1 Map of Khon Kaen province, Thailand

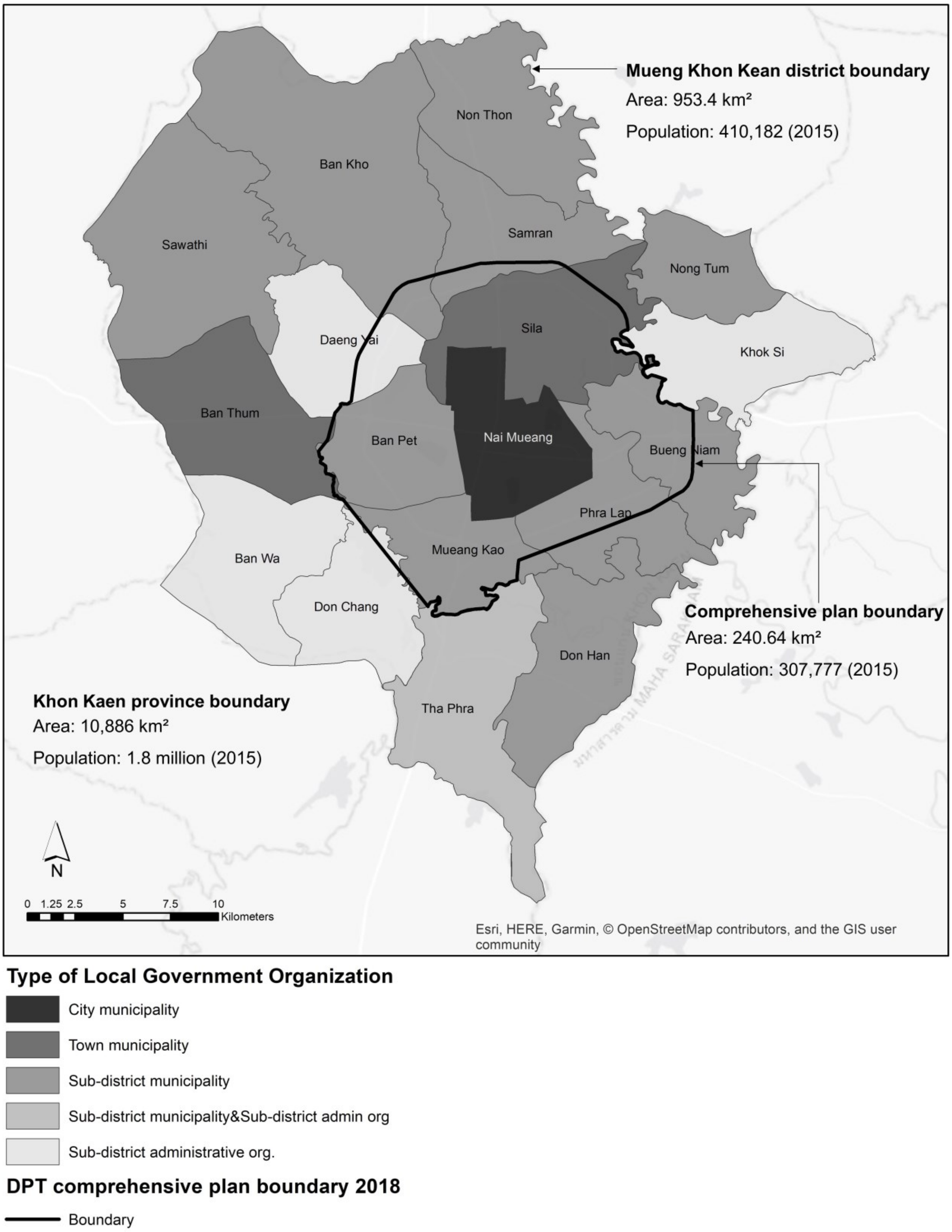


Source: Own illustration based on OCHA Service (2021)

Figure 3. 2 Khon Kaen city in panorama

Source: Own photo

Figure 3. 3 Mueang Khon Kaen sub-district boundary



Source: Own illustration based on DPT data 2018

Box 3. 1 Thailand administrative structure

Thailand is a unitary state administration. Under the National Government Organisation Act, B.E. 2534 (1991), the administration is divided into three levels[4], central administration, provincial administration, and local administration.

The central administration consists of the Office of the Prime Minister (equivalent status as a ministry), Ministries and Bureaus, and Departments. Each ministry and bureau is led by a minister, a member of the Council of Ministers. A bureau may affiliate with the Office of the Prime Minister or Ministries[5]. A department led by Director-General or Secretary-General may consist of divisions or government agencies[6]

The provincial administration consists of provinces (*changwat*). A province shall have secondary provincial administration as districts (*Amphoe*); both are affiliated with the Ministry of Interior. Each province shall have a Governor to take the policies and orders from the central government and implement them as appropriate to the local context. Under the supervision of a governor, a District Chief has power and duty to the civil service, promoting and supporting joint services of public agencies, as well as coordinating with the local administrative agencies. The central government appoints both a Governor and a District Chief.

Under the provincial administration, there are two local administration sub-units, a sub-district (*Tambon*) and a village (*Moo-Ban*). Even though the role of sub-district headman (Kamnan) and the village headman (Phu-Yai-Ban) is the District Chief's assistant, the community residents elect them for a 5-year term (re-election is possible). Then, the elected sub-district headman and the village headman are approved and officially appointed by District Chief[7]. As of 31 December 2018, there were 76 provinces, 878 districts, 7,255 sub-districts, and 75,032 villages[8] in Thailand.

Local administration consists of two forms of (elected) local governments, a general form and a special form.

1) General form local administration compounds of Provincial Administration Organization (PAO), Municipality, and Sub-district Administration Organization (SAO). The three types of local government agencies have the same division of administration;

[4] National Government Organisation Act, BE 2534 (1991), section 4.
[5] National Government Organisation Act, BE 2534 (1991), section 7.
[6] National Government Organisation Act, BE 2534 (1991), section 31,32,33.
[7] Local Governing Characteristics Act (No.9), B.E.2537 (1994).
[8] Notification of the Department of Provincial Administration: Subject Administrative Information as of 31st December BE 2561 (2018)

administrative branch and legislative branch. The local citizens elect the chiefs of both branches.

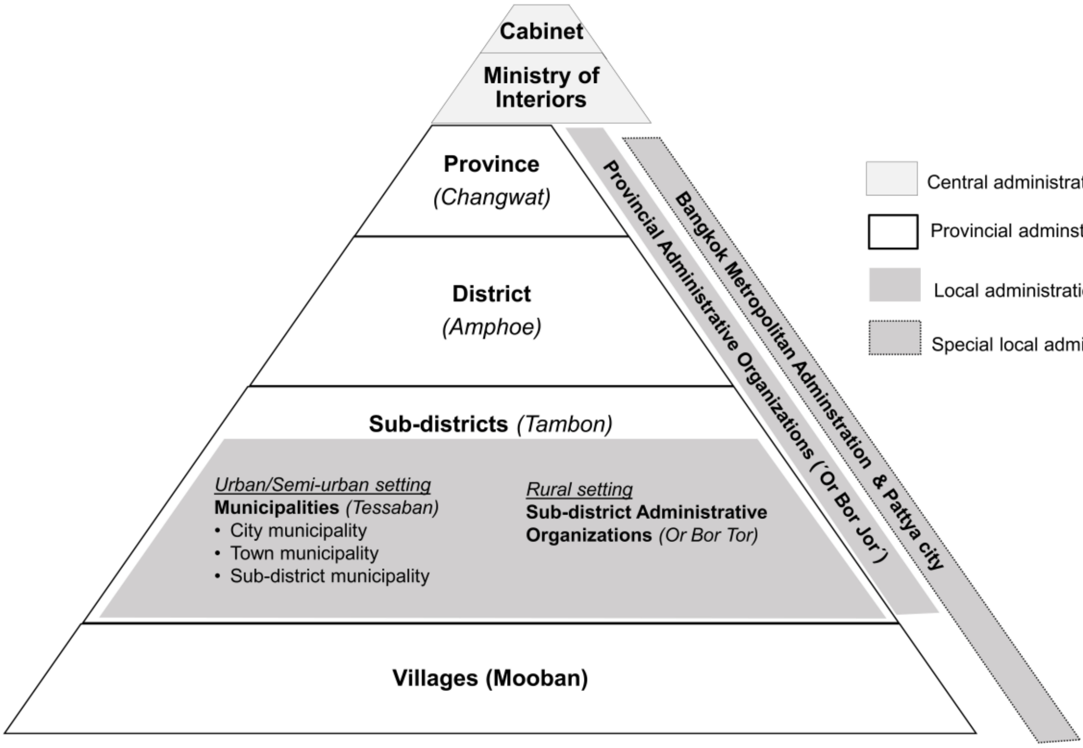
- PAO is the biggest local governmental body. It oversights provincial development and supports municipalities and SAOs, especially on transboundary issues such as utilities & infrastructure, waste management, amenity, culture, education, etc[9]. However, the Chief of PAO somehow respects the Governor's order and supervision.
- Municipality is a local government body of urbanized areas or clearly urban settlements or urban settings. The variant of municipalities can be categorized into three levels according to the population's size and local revenues determined by the Municipalities Act, BE 2496 (1953) and its 12th amendment BE 2546 (2003) as follows:
    - City municipality (*thetsaban nakhon*) : > 50,000 inhabitants and level of annual revenues
    - Town municipality (*thetsaban mueang*) > 10,000 inhabitants and level of annual revenues
    - Sub-district municipality (*thetsaban tambon*): A SAO which is being upgraded based on its income in respect to performing duties under the Municipalities Act. A sub-district municipality territory does not necessarily cover just one sub-district or needs to cover a whole sub-districts according to the municipality's name[10].
- SAO is a local governmental body, mostly in a rural setting, upgraded from the Tambon (Sub-district) Council. To become an SAO, the local government shall have at least 2,000 inhabitants under their administration and have no less than 150,000 THB annual revenue for three consecutive years[11].

2) Special form local administration is a local government found in significant localities, such as Bangkok, called Bangkok Metropolitan Administration[12] and Pattaya, called Pattaya City[13]. The governments of Bangkok and Pattaya arrange into two administrative divisions, an executive branch and a legislative branch. An elected governor leads Bangkok Metropolitan Administration; meanwhile, Pattaya is led by an elected mayor.

An illustration of Thailand's administration structure can be found in Figure 3.4.

[9] Provincial Administrative Organisations Act, BE 2540 (1997)
[10] Such as Thapra sub-district municipality of Meung Khon Kaen district
[11] Subdistrict Councils and Subdistrict Administrative Organisations Act, BE 2537 (1994)
[12] Bangkok Metropolis Administrative Organisation Act, BE 2528 (1985)
[13] Pattaya City Administrative Organisation Act, BE 2542 (1999)

Figure 3. 4 Thailand's administrative structure



Source: Own illustration

3.3 Social and Socio-demographic

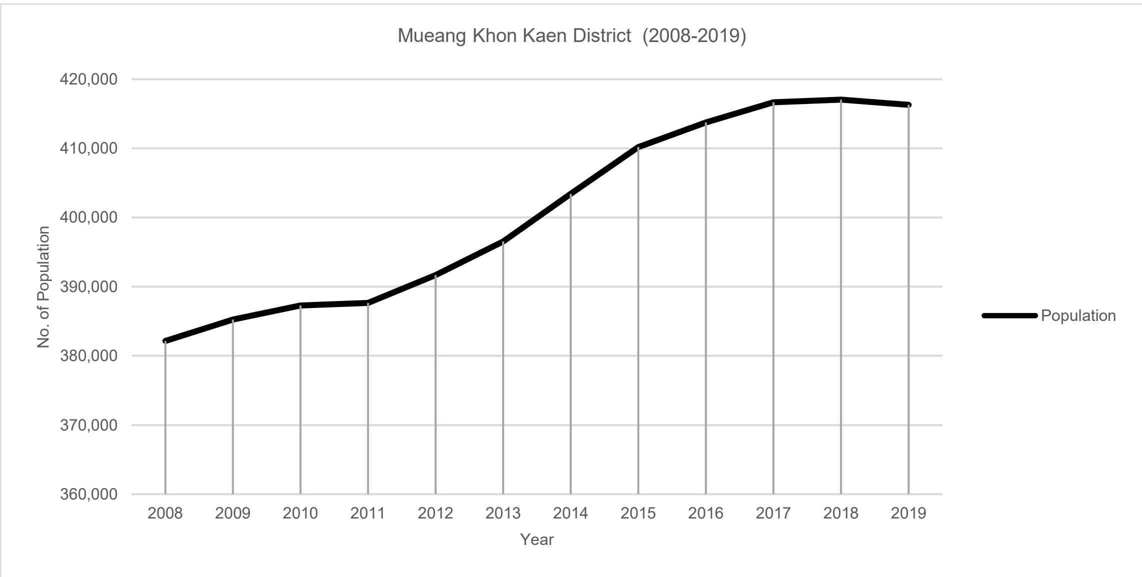
In general, the majority of the population of Khon Kaen Province belongs to the Phaw Thai (Isan Thai) ethnic group (subgroup Laos-Vieng) who migrated from the present-day Lao People's Democratic Republic around the 18th century. In urban agglomeration, the most of population is Chinese–Thai descent succeeds in commercial and services business (Yongvanit & Thungsakul, 2013). Nowadays, Khon Kaen city riches of Isan fusion of modern lifestyle and original Isan culture appearance through designs, architecture and culinary. Although a smart and livable city is a key strategy to induce the new S-curve of local development, the recent assessment of Onnom et al. (2018) found that less than 20% of the area found highly livable. The city is departing for digitalization, like other cities worldwide, to become smarter and sustainable. Left no one behind is the key motto of Khon Kaen smart city initiative. However, urban poor and inequality issues can be observed in the urban area, especially informal settlements along the railway tracks.

Since 2008, Khon Kaen's population has been significantly growing and reached its recent peak in 2018. 2019 is the first time the city's population declined by about -0.2%; however, an average growth rate is still positive in each local government's inhabitants, about 1.1% annually during 2008-2019 (Figure 3.5). Sharply decreased population occurred mainly in Khon Kaen

City Municipality area during 2018-2019. It could be one of the reasons why Khon Kaen City Municipality and its development partners are actively urging urban renewal projects. In contrast, a growing population significantly occurs in urban vicinity and rural areas (Figure 3.6). Particularly Ban Ped Sub-district municipality and Ban Thum Town municipality, the areas have been popular for middle-income inhabitants who usually commute to the city centre to study and work daily. Strong land speculation could be a key determinant of residential areas expansion toward agricultural land (Elinoff, 2017).

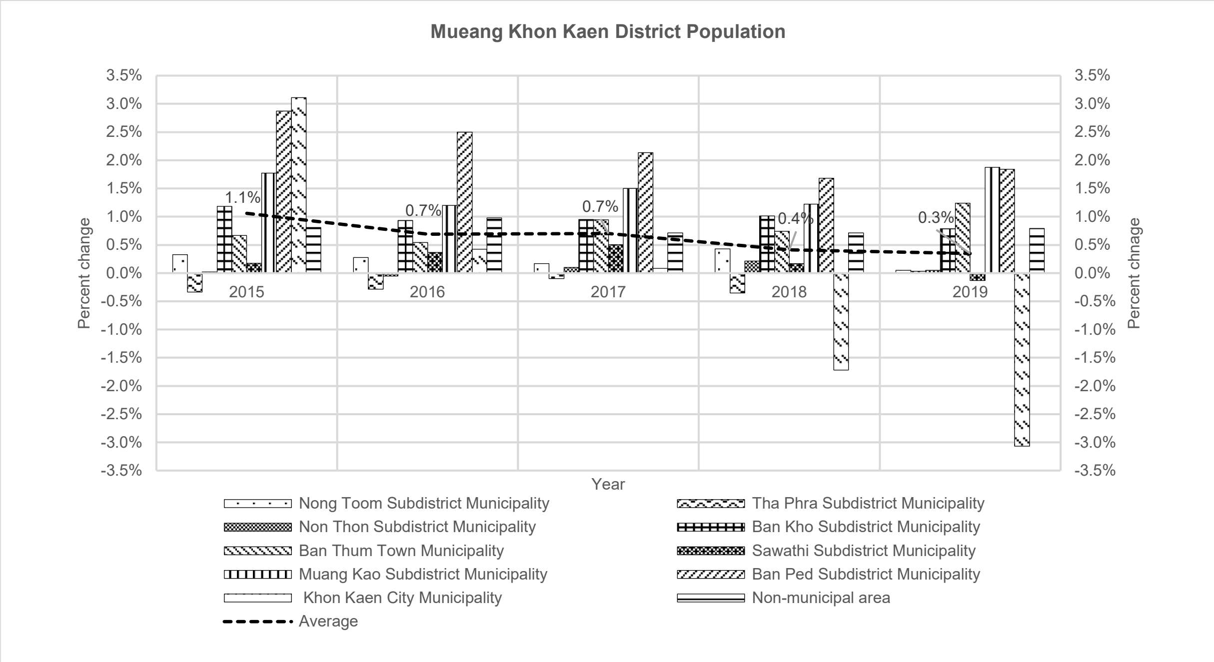
Contradicting to the increased population in rural areas, their agricultural livelihood might be gradually declined. The average age of farmers in Thailand is over 50-year-old (Phongsiri et al., 2017), and their children tend not to favour continuing their family agriculture practice and rural lifestyle but rather working and living in an urban setting and service sector. Similar to the national trend, urban expansion and ageing society has become clearer in Khon Kaen city. In 2019, Khon Kaen city had 10% of inhabitants who 65-year-old and older. Therefore, It is fair to state that Khon Kaen city is entering an ageing society (Figure 3.7). Moreover, a low birth rate and a decline in social value of the formal education system may significantly affect the local economic growth, which is largely shared by the education and service sectors due to fewer students' admission. For example, during 2015 - 2018, new student admission to Khon Kaen University has been decreasing by about 9.4% (KKU,2019). Despite these encounter growth signs, Khon Kaen city still expects growth from rural-urban and urban-urban migration. The National Statistic Office in 2015 (NSO, 2016) revealed that day-time commuters of Khon Kaen province are range as the 5th (6,110 people per day) on education and the 9th on working/job (18,190 people per day), yet taking 5,346 foreign workers of service and industrial sectors into account (DOL, 2018).

Figure 3. 5 Number of Mueang Khon Kaen district population during 2008-2019



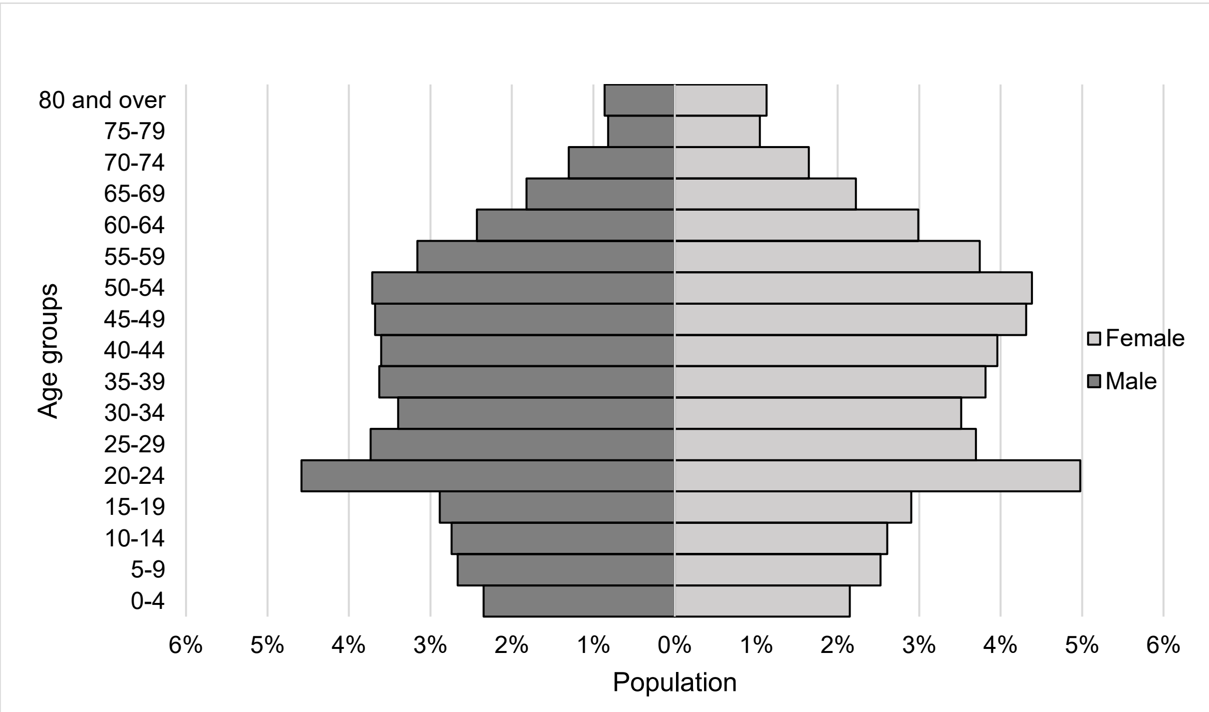
Source: Own illustration based on Khon Kaen Provincial Statistical Report 2016-2019 (KKPSO, 2013; 2018; 2020)

Figure 3. 6 Percent change of Mueang Khon Kaen district population during 2014-2019



Source: Own illustration based on Khon Kaen Provincial Statistical Report 2014-2019 (KKPSO, 2018; 2020)[14]

Figure 3. 7 Population structure of Meung Khon Kaen district in 2019



Source: Own illustration based on Khon Kaen Provincial Statistical Report 2019 (KKPSO, 2020)

[14] No data of Sila Town Municipality aggregated shown in the reports.

3.4 Economic and infrastructure development

Service, education, and industry are major sources of income for the city. As part of East-West Economic Corridor, economic cooperation program of the Great Mekong Sub-region (GMS), Khon Kaen has a great potential in logistics through multimodal transportation that provides domestic and regional connectivity such as bus terminal, international airport, railway, light rail transit (LRT), and freight distribution center (Wanitwattanakosol & Pongpatcharatorntep, 2015). To shape Khon Kaen city as compact growth, (vertically) densification of city center area and mixed-use with walkability concept shall go hand in hand with Smart mobility programme based on TOD approach. Therefore, LRT is a flagship investment that tackles traffic congestion and environmental problems that helps to boost economic development and sustainable redevelopment. The local governments cooperate splendidly on the development of LRT across the city. Five municipalities pool their financial resources to establish the Khon Kaen Transit System Co., Ltd under the framework of Khon Kaen Smart City (Phase 1).

Linking Khon Kean city economy to the global market may sound unlikely in the present context because not many world-class corporations have operation units/centre outside Bangkok. However, the Khon Kaen economy plays a significant role in the GMS market. Moreover, the city also attempts to promote local content and provide viable opportunities for young investors to uplift their local brands to the national and international markets. Furthermore, the city established a sub-sector incubation centre to promote local-made innovations and start-up businesses based on close cooperation among academia and private actors. The concept is to strengthen advanced education, medical, and service sectors as a major blood vein of the city economy. In addition, Khon Kaen city is one of the MICE cities (Meetings, Incentives, Conferencing, Exhibitions) in Thailand; medical tourism and hospitality industry are integrated to welcome, especially high-incomes international guests. Besides, TOD and Light Rail Transit (LRT) are expected to bring a new wave of economic development to Khon Kaen city. The railway system is another transportation mode that connects Khon Kaen city with neighbouring major cities in the region, although the railroad in Thailand is poor in service and infrastructure development in general.

Well-equipped infrastructures and good topography location are major winning factors for the city's economic growth. In Khon Kaen province, more than 95% of households have access to highly reliable electricity generated from the co-generation power plant (737 MW) and hydropower of the Ubonrattana dam (25.2 MW) (KKPAO, 2016). The majority of the water supply source of Khon Kaen city is discharged from the Ubonrattana reservoir via Pong River and partly pumped from Chi River. Due to a large underground salt dome, a small part of the city can use underground water as secondary water supply sources. Even though most households are under the Provincial Waterwork Authority (PWA) service network, a few areas still rely on village tap water. In terms of digital infrastructure, the city has good coverage with internet service, especially in the urban area.

Instead of grouping together with Roi-et, Mahasarakham and Kalasin province (assigned by MoI), Khon Kaen rather sees itself as fit with other major provinces along Mitrapap road, such as Nakhon Ratchasima, Udonthani, and Nongkai province, as Mitrapap economic partnership. Even though these four provinces are a good economic alliance, at the same time, they are also competitors due to similarities in resources and development agendas.

3.5 Environmental, Natural resources, and Disaster risk

Khon Kaen city is often referred to as a role model in many issues but environmental and disaster risk management, such as wastewater, air pollution, floods (pluvial & fluvial), and water scarcity, are not one of them. These problems have horizontal transboundary and vertical political dimensions. The tension between municipalities in the urban area and the downstream peri-urban municipalities due to water pollution occurs not only in drought season but throughout the year. Only 50% of the municipal wastewater of Khon Kaen City Municipality is properly treated, and the rest is directly discharged into the stream without proper treatment. Subsequently, downstream farmers could not use the water for their agricultural activities (especially aquaculture and fishery), yet mention awful odour caused nuisance to surrounding communities. However, there are discussions on increasing capacity and centralized wastewater treatment systems of the urban municipality as well as collecting fair wastewater treatment fees from water users. Unfortunately, negotiation among local governments and the local water work authority does not come to a conclusion soon. Furthermore, air pollution has recently become an environmental crisis in Khon Kaen city. A high level of PM 2.5 during high air pressure and close airflow are linked with traffic congestion, open burning, and unsustainable sugar cane harvesting practices nearby rural areas.

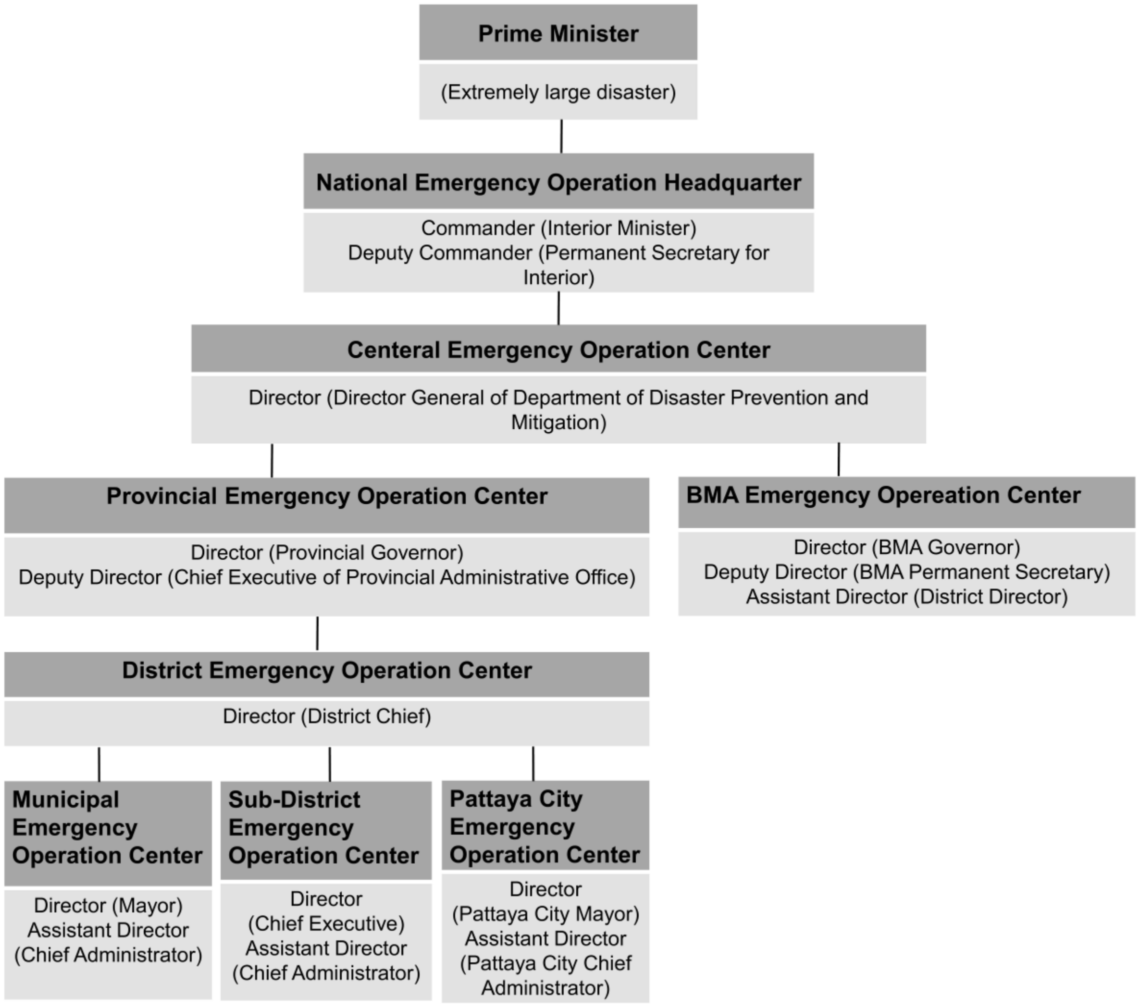
Compared to other cities in the province, Khon kaen city gets a great advantage of Ubonratta reservoir in terms of agricultural usage, urban water supply, and (fluvial) flood management. However, the water infrastructure is managed by Royal Irrigation Department (RID) and the Electricity Generation Authority of Thailand (EGAT), which the locals often criticize their mismanagement and insufficient local stakeholders' involvement in decision-making. When mentioned about caused water supply scarcity or major floods in the city, people frankly said they were not natural causes but mismanagement of the Ubonrattana dam operator(s). In terms of flood protection, even though there are walls and dikes along the Phong river, past experiences revealed that the water level could exceed the existing flood protection structure threshold. Low permeable surface and low drainage system capacity in association with blockage or narrow of waterways for making space for real estate and roads construction are major causes of urban inundations. Pluvial flood leads to conflicts in directing the water flow and controlling the watergate between municipalities, particularly Ban Ped Sub-district municipality and Khon Kaen City Municipality. To solve this critical conflict, the water in Nong Khot Lake and Bueng Thung Sang are periodically depleted before the rainy season with the supervision of the governor, as well as a technical study for improving the drainage system structure commissioned by the Khon Kaen Public Works and Town & Country Planning Office (KKDPT) was conducted.

It is frequently heard that the water level in the Ubonrattana reservoir, the main water supply source of the city, reached a dead storage level. Therefore, the agricultural sector must halt their second crops or aquaculture activities to make the water available for the urban water supply manufacturing and maintaining the ecosystem. However, this priority setting also brings a critical question to the food security of the overall sub-watershed areas and how the city could provide enough water supply for a higher number of inhabitants in the future. Marks (2017) showed that water shortage in Khon Kaen city is not uniform. The inner-city residences have better access to tap water than the rural poor or high-ground areas. This is yet to mention uneven climate change-related impact on vulnerable groups of the society, such as climate-related health impacts associated with water stress. More information about disaster risk management structure and mechanism in Thailand is shown in Box 3.2 and Figure 3.8.

Box 3. 2 Thailand disaster risk management

Thailand has a solid legal foundation for disaster risk management (DRM). The Disaster Prevention and Mitigation Act B.E. 2550 (2007) provides the main framework for DRM. Under the Ministry of Interior (MoI), the Department of Disaster Prevention and Mitigation (DDPM) was established in 2007 as the primary agency responsible for coordinating disaster risk management activities by all related organizations at all levels. The National Disaster Prevention and Mitigation Committee (NDPMC) is primarily responsible for decision-making and developing disaster risk management policies at the national level. Meanwhile, the Provincial Disaster Prevention and Mitigation Committee at the local level, chaired by the governor, is responsible for formulating the provincial disaster management plans under the guidance of the National Disaster Prevention and Mitigation Plan 2015-2020 (The plan has recently undergone a review through a participatory process). All provinces and local administrative bodies are mandated to develop respective disaster management plans for their jurisdiction at sub-national levels. The mechanism of disaster risk management in Thailand shows in figure 3.8.

Figure 3. 8 Mechanism of Disaster Risk Management



Source: National Disaster prevention and mitigation plan B.E.2558 (2015), (DDPM, 2015)

3.6 Land use and spatial planning

For approximately 20 years that Khon Kaen city has experienced unplanned urban expansion. A study on multi-temporal Landsat imagery found that during 1990-2015, the agricultural land cover was turned into a built-up environment of about 2 sq.km/year (Van Ninh & Waisurasingha, 2018). Nevertheless, in 2018, the draft comprehensive plan was prepared and proceeded in the legislative process by the Department of Public Works and Town & Country Planning (DPT). The land use features illustrated in the draft comprehensive plan cover 240.64 sq. km within the administrative boundary of 8 municipalities and two sub-district local administrative organizations, not the whole Meaung Khon Kaen district, see Figure 3.3.

The draft comprehensive plan is meant to serve for 20 years of local development, with a 5-year review and evaluation cycle. The plan projected that Khon Kaen city (within the draft comprehensive plan boundary) will accommodate about 661,900 inhabitants in 2035 or with a

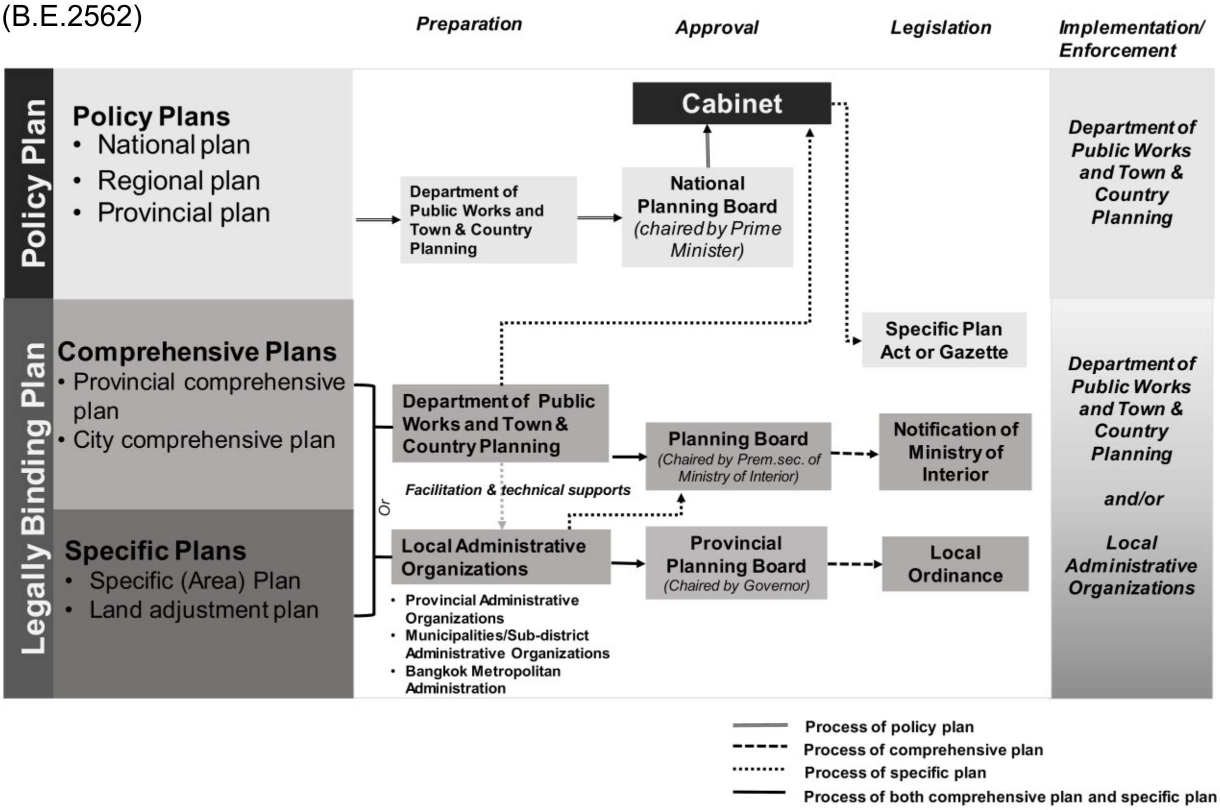
3.6% growth rate per year (on average). The development is concentrating on the existing CBD area. However, the development growth is expected to expand towards the North, South and West. Dense development can be seen along Mitrapap road (north-south) and Maliwan road (west) and the commercial development nodes in the northern part of the city. Outer ring road, aviation zone, and eastern irrigation for agricultural zone function as a buffer for slow down urban expansion. However, the western rural frontiers are flexible to be changed as residential areas. Meanwhile, on the eastern side, flood-prone area serves as agricultural land regulated as rural and agriculture conservation under land adjustment for agriculture law, except for the ribbon along the main road (Prachasamosorn rd.) (DPT, 2018). It is important to note that the draft comprehensive plan does not articulate the flood-prone areas as hazard-prone, but they are assigned and communicated as a rural and agricultural conservation zone. The proposition of land use types and visualization of the land use plan of the draft comprehensive plan is shown in Annex 2 and Figure 3.10.

According to the Town Planning Act B.E.2562 (2019), integration of disaster risk management is one of the key overarching objectives of land use planning. The law requires a comprehensive plan to consist of an open space plan and a water plan. However, neither a legal binding hazard map is available nor a clear guideline on how disaster risk management and future-oriented risk-informed planning are integrated into the comprehensive plan. Nevertheless, this attempt is still in the infancy of raising awareness and capacity development process. It is important to note that before the new law became effective, planning power was concentrated in the central government with control-oriented land use management. Therefore, the promotion of development or application of market-driven instruments is not conventional for Thai spatial planning. However, the new Town Planning Act aims to hand over more power to the provincial planning board and local governments, a landmark paradigm shift in Thai spatial planning. More information about Thailand's spatial planning landscape can be found in Box 3.3 and Figure 3.9.

Box 3. 3 Spatial planning in Thailand

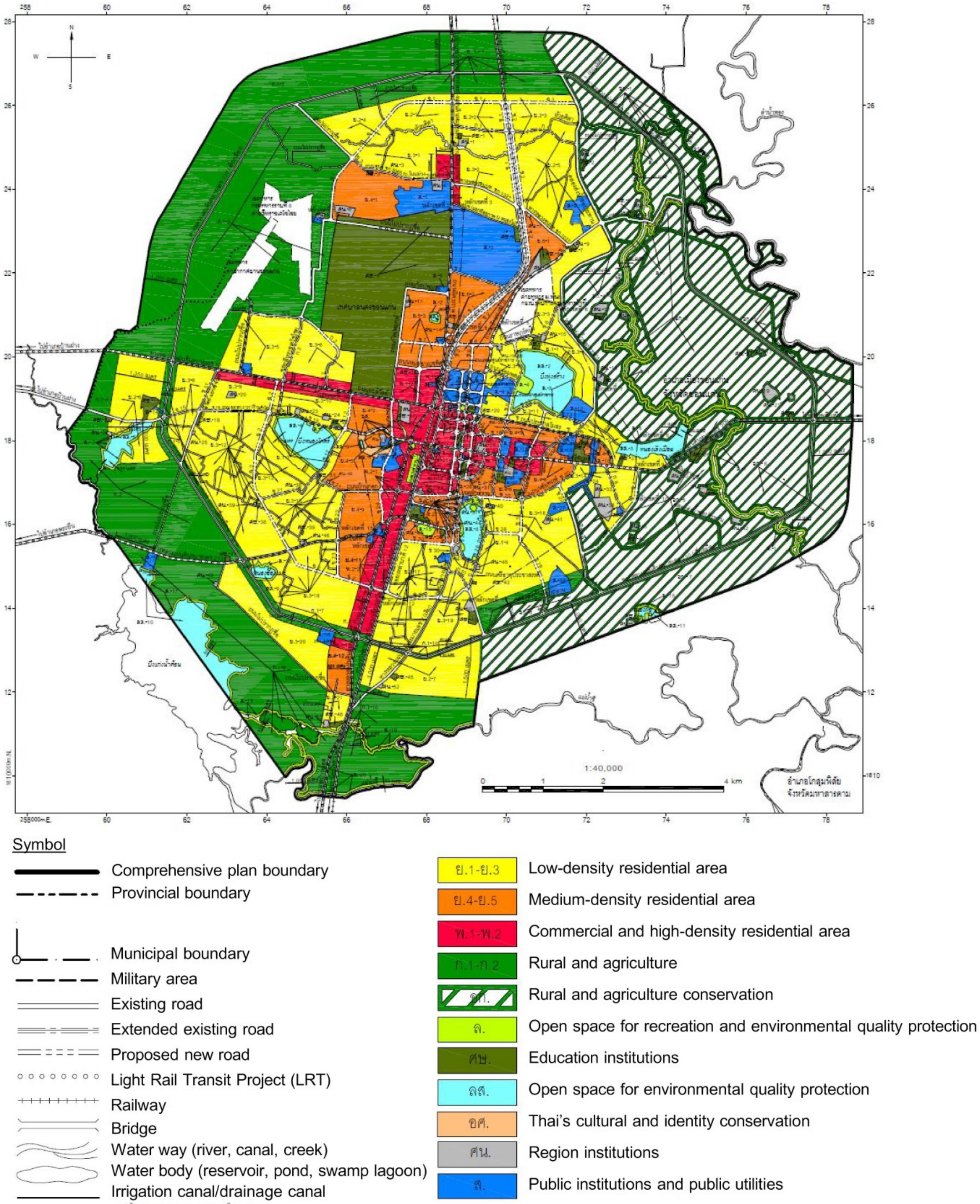
According to the Town Planning Act B.E.2562 (2019), Thai's spatial planning consists of two types of plans, policy plans and legally binding plans. The policy plans are categorized into three layers, national, regional and provincial levels. The policy plans serve as a strategic development framework and guideline for land use and urban development. The legally binding plans consist of comprehensive plans and specific plans. Meanwhile, the comprehensive plans outline in two layers, provincial and city comprehensive plans. The specific plan functions as a land use planning framework for urban development and conservation for a specific area. DPT is the responsible agency for preparing and implementing the policy plans. Local governments are responsible for preparing comprehensive plans under the technical supervision of DPT and ensuring public participation. The comprehensive plans must receive approval from the provincial planning board before enforcement as a local ordinance. However, if the local governments could not perform the tasks, DPT could lead the preparation process on behalf of the local governments. If the DPT prepares the comprehensive plan, it must be approved by the ministerial planning board before issuing a ministerial notification. The specific plan can be either prepared by local governments or DPT but must be approved by the ministerial planning board. After five years of implementation, local governments and/or DPT shall launch a plan review and evaluation process. In case there are no substantial changes in development and environmental circumstances, the plan can be renewed; otherwise, plan revision is needed.

Figure 3. 9 Thailand spatial planning structure according to Town planning Act 2019 (B.E.2562)



Source: Own illustration based on Town planning Act 2019 (B.E.2562)

Figure 3. 10 Land use map of the draft 3rd revised comprehensive plan of Khon Kaen city



Source: Modified from DPT, 2018

3.7 Local public healthcare

The city aims to become a regional medical hub based on its readiness in public and private health institutions, excellent medical centers, and top-class medical school and personnel. The medical hub serves both domestic demands and GMS & international clients. Khon Kaen city's health care system consists of 25 Sub-district Health Promotion Hospital (SHPH)[15], five Primary care center, one tertiary hospital, one health promotion centre, one university hospital, three municipal medical centers, one military hospital, one rehabilitation hospital, one psychiatry hospital, three private hospitals. This setting has not yet taken a number of private clinics, pharmacies all over the city, and the Ministry of Public Health (MoPH)'s non-medical care institutions into account. Among these, 22 SHPH, five Primary care center, and one tertiary hospital are under the Khon Kaen Hospital's Contracting Unit of Primary care network. Even though private hospitals, university hospitals, and a military hospital are part of the district public health system, but Khon Kaen Hospital CUP network is the heart of the local public health service under MoPH control. Khon Kaen Hospital (KKH) is a tertiary care hospital under MoPH. It is the uttermost important hospital in Khon Kaen city public health network and vital for the whole Khon Kaen province and northeastern region of Thailand. As an advanced-level referral hospital with five excellent centers[16], Khon Kaen Hospital has a capacity of 1,000 internal patient beds, 41 wards, and covers about 402,940 catchment population (2016). As the most advanced and trustworthy MoPH hospital in the area, Khon Kaen Hospital confronts an overcrowded patient problem as its business as usual (KKH,2016). Currently (2020), the hospital operates with 104% of its service capacity. According to the Deputy Director of Khon Kaen Hospital (Dr. Seksan Suwanpang), the work of primary care service (CUP units) under the Khon Kaen Hospital CUP network shares about 25 % of the network workload[17].

To address the overwhelming service demands of the CUP host, Khon Kaen Hospital has been strengthening the service capacity of its CUP units through a 10-year Primary care cluster development plan (2016-2026). The plan aims to empower and upgrade the SHPH or primary care unit to be a Primary care center, which provides more advance or more extensive treatment, equipment, and at least a full-time family doctor at the campus, while a typical SHPH uses family doctors in rotation, e.g. two times a week for doctor visits. Establishing 12 Primary Care Clusters (PCC) is expected to be completed by the end of the plan (KKPHO,2019). This strategy meant increasing service quality and gaining trust from locals in the public health facility in their neighbourhood, which could eventually reduce costs for the patients to come to the Khon Kaen Hospital and decrease overcrowded on-site service of the hospital by bringing

[15]Nongbaudeemhee SHPH, Nong Ya Phraek SHPH, Donhun SHPH, and Thapra SHPH are located in Khon Kaen Mueng district area but their operation are under Siridhorn hospital CUP network of Bann Had district.

[16] Accident, Cardiology, Cancer, Neonatal and Organs donation & transplant

[17] with 10% financial resources

service to communities. However, the main challenges of the plan are personnel management mechanism and health literacy of inhabitants, which are underlying problems of the public health system in Thailand in general. Nevertheless, Thailand has Community Health Volunteers (CHV), a key primary health care workforce that links clinical care and community-based long-term care through providing support in diseases control & surveillance and giving basic care services to the locals, including home visits, follow-up care, health promotion information, mental support, etc. (Primary Health Care Performance Initiative, 2018). More details regarding Thai's public health system can be found in Box 3.4.

Box 3.4 Thai Public healthcare system

Thailand is one of the world leaders in public health care through universal health coverage, health volunteer innovation, community-based health promotion, etc. Since the Decentralization Act 1999, the administrative structure of the Ministry of Public Health (MoPH) has been organized at central and provincial levels. Besides three technical departments' clusters on medical service, public health, and public health service and support, the ministry also grouped the 76 province service operations into 12 Area Health (AH). The AH structure aims to ensure policy alignment, seamlessly implementation of service plan, regular monitoring, and evaluation among the provincial public health offices. Each Provincial Public Health Office (PHO) is responsible for developing provincial public health plans & strategies, supervising, coordinating and supporting the implementation of public health and medical services within the province. Then the similar function cascades down to the District Public Health Office (DHO) of each local district. DHO oversees sub-district primary health units and coordinates with district-level hospital(s) (secondary or tertiary care hospitals) (MoPH, 2016). From the perspective of district public health care, a secondary or tertiary care hospital is the backbone of the system that serves as a host (CUP-host) of the district health service network. Meanwhile, PCUs or Primary care centers are frontier service units/nodes of the network that provide basic treatment, prevention, and health promotion in their responsible service (catchment) area /communities. The PCUs can upward refer sophisticated cases to a higher care service hospital through the referral system. The secondary or tertiary hospital in the district is usually assigned as a Contracting Unit of Primary care (CUP) with the National Health Security Office (NHSO) under the Universal Coverage Scheme (UCS). CUP-host supports its local service units/nodes by allocating financial & human resources, providing medical & non-medical supplies, and ensuring accountability in terms of cost and service quality control (Skolnik, et al., 2016; Kitreerawutiwong et al., 2017).

The CUP-host team is mainly the family medicine division of a secondary or tertiary hospital at a local level. A family medical care team is an interdisciplinary team that consists of family doctors, nurses, physical therapists, dentists, occupational therapists, and other health workers who provide home-based and community-based care in their service area or catchment population. One family medical care team may be responsible for 10,000 catchment population. The three teams of family medical care could be bundled as Primary Care Cluster (PCC). The implementation of CUP is under the supervision of the Contracting Unit of Primary care Board (CUP Board), receiving a policy agenda from the District Health Board (DHB) and regularly reporting to PHO (MoPH, 2016). It is important to note that a very small proportion of non-MoPH public health care facilities are managed by other ministries and local governments, such as municipal health care units, university hospitals, and military hospitals (Jongudomsuk et al., 2015).

3.8 Public health climate change adaptation policy in Thailand

The Office of Natural Resources and Environmental Policy and Planning (ONEP) within the Ministry of Natural Resources and Environment (MoNRE) functions as the core institution responsible for climate change in Thailand. ONEP's Climate Change Management Coordination Division (CCMC) acts as the national focal point for the United Nations Framework Convention on Climate Change (UNFCCC), the Green Climate Fund (GCF), as well as to the Adaptation Fund. An inter-ministerial committee and working groups were established to steer the overall planning on climate change management at the national level (GIZ, 2018).

Thailand's National Adaptation Plan (NAP) was built on the six priority sectors identified in the Climate Change Master Plan (2015–2050). The NAP aims to help Thailand become resilient and adapt to the impacts of climate change. NAP serves as a framework for mainstreaming adaptation into sectoral plans and strategies. NAP also provides a guideline for applying adaptation to government agencies' frameworks for budgeting and implementation, raising awareness and understanding within relevant sectors/actors, and developing resiliency measures and adaptation readiness for all stakeholders and levels.

The Ministry of Public Health has recently launched its National Strategy on Adaptation in the Health Sector 2017-2030 (HNAP) (MoPH, 2018). The HNAP has an overarching goal of reducing the citizen's morbidity and mortality, mitigating national impact and being Asia's hub in managing climate change-related health risks. HNAP consists of four strategic issues; 1) strengthening capacity and health literacy of community and people in coping with climate change-related health risks; 2) integrating capacity of all sectors to drive climate change management and implementation in the public health sector; 3) strengthening public health preparedness in addressing climate change to support the national economy, social and security; and 4) strengthening national public health system in addressing climate change align with international standards. To mainstream climate change adaption to public health, the sector plans to develop climate change-related health impacts surveillance and prevention mechanisms, enhance the public health system's capacity, and promote access to quality public health services. The actions focus on proactive addressing climate change-related health impacts on communities in vulnerable areas and populations at risk, especially emerging and re-emerging diseases, human heat stress, and other climate-related diseases.

This chapter encapsulates multi-facets of Khon Kaen city such as geographical features, administration and political institution, socio-economic, infrastructure development, environmental and disaster management, spatial planning, public health care, and climate change-related policy framework. In the next chapters, this study will reveal Khon Kaen city manifestation through multiple stakeholders' views based on a collaborative future-oriented scenario planning approach. This research presents and discusses the outcomes from stakeholders dialogues and planning exercises that resonate with stakeholders shared understandings and perceptions of Khon Kaen city and its futures, emphasising interactions between urbanization and climate change and their impact on the local public healthcare.

Chapter 4
Methodology

This study lays out the research methodology based on a collaborative scenario planning approach. The approach combines explorative and normative scenario planning methods to explore a bandwidth of possible futures and backcast desirable pathways through stakeholders participation and collaboration with the researcher[18]'s complementary inputs. This research derived a novel integrated collaborative future-oriented scenario planning framework that closes gaps between global climate trajectories and local climate adaption scenario, as well as strategically encompass climate resilience in public health service, so-called Health Integrative Climate Resilience and Adaptation Future (HICRAF). Khon Kaen city, a growing medium-sized city, serves as a single case study to demonstrate the development and application of HICRAF.

HICRAF planning framework is organized into five phases. Phase I *Shared understanding* aims to determine objectives & problem orientation and identify spatial and temporal boundaries, the scope of scenarios, and key stakeholders. Phase II *Forecasting* combines stakeholders aspirations toward future urban development and quantitative climate scenario analysis for sketching a bandwidth of possible future conditions. A scenario matrix was used to conclude contradicts future versions and identify a plausible future pathway from the stakeholders' points of view. Phase III is *Backcasting*. This phase enables target setting and potential impact mitigation strategies identification, which informed desirable scenarios formulation. This step highlights composite indicators development and potential impact assessment tailored for the local public health service. Phase IV *Implementing* portrays the implementation requirements leading to a transition from the baseline condition to the desired targets realization, considering the potential impact outcomes. The full cycle of HICRAF demands completion of ex-ante assessment & execution of the proposed actions (part of Phase IV) and monitoring elements (Phase V), which can not be demonstrated in this report because the completion of HICRAF requires real-world implementation of the proposed roadmaps, which is beyond this research setting, capacity, and timeframe.

The following sections provide a comprehensive elaboration of each phase, its subsequence steps and methods used. The research methodology framework shows in Figure 4.1.

[18] Wiriya Puntub

Figure 4. 1 Methodological framework

Phase	Process	Methods/Approaches used	System of interest: Urban development	System of interest: Climate-related hazards	System of interest: Public health care	Outputs
Phase I: Shared understanding	**Step 1** Problem orientation and scoping	Desktop research	■	■	■	Shared understanding of Khon Kaen city
		Spatial & temporal scoping	■	■	■	
	Step 2 Diagnose the current context of the systems & shortcoming development	Relevant plans and policies review	■	■	■	
		Stakeholder interviews	■	■	■	
		TOWS analysis	■			
Phase II: Forecasting	**Step 3** Future visionary and projection	Participatory envisioning exercise on future urban development change	■			Bandwidth of possible future conditions
		Future climate downscaling analysis		■		
	Step 4 Plausible (Trend) scenario storyline formulation	Possible scenarios construction & plausible (Trend) scenario identification	■	■		Possible scenarios matrix & a selected Trend scenario
		Interaction analysis	■	■		Trend scenario storyline
		Impact chain analysis	■	■	■	
		Plausible (Trend) scenario storyline elaboration (Matrix analysis) and validation	■	■	■	
Phase III: Backcasting	**Step 5** Target setting	Stakeholder survey on target identification	■	■	■	Targets
	Step 6 Desirable scenario construction	Literature and stakeholders inputs for spatial planning-based measures identification	■	■	■	List of spatial planning-based measures
		Local stakeholders validation & discussion on the proposed spatial planning-based measures	■	■	■	
		Stakeholders preference survey on the proposed spatial planning-based measures	■	■	■	Preferred spatial planning-based measures
	Step 7 Desirable scenario storyline formulation	Desirable scenario storyline elaboration (Matrix analysis)	■	■	■	Desirable scenario storyline
	Step 8 Scenarios assessment	Composite indicators development *(Literature, Experts interview, Experts survey)*	■	■	■	Composite indicators
		Local public health care units questionnaire survey & interviews			■	Scenarios potential impact outcomes
		Scenarios potential impact assessment			■	
		Composite indicators sensitivity analysis			■	Composite indicators robustness
Phase IV: Implementing	**Step 9** Determine implementation requirements	Gaps identification and road maps proposition	■	■	■	Climate-resilient roadmaps
	Step 10 Ex-ante assessment	Cost-benefits (incl. externality) analysis and feasibility analysis				
	Step 11 Implementation	Mainstreaming climate-resilient in urban development and public health care services				
Phase V: Following up	**Step 12** Monitoring and evaluation (Ex-post assessment)	Regulary review and policy impact evaluation				

4.1 Phase I - Shared understanding

Diagnosing the current context and needs of the systems of interest is crucial for scenario planning. This phase aims to conclude key relevances for envisioning possible futures through policy reviews and a series of stakeholder interviews. These inputs enable comprehension of the existing circumstances, power relations, goals and challenges of the study area. This phase consists of two main steps. Step 1 determines the objective(s) and orientation of the systems of interest (urban development, climate-related hazards and public health service). Step 2 diagnoses the current context of the system of interest and its shortcomings, trends and development dynamics. Details of each step are described as follows.

4.1.1 Problem orientation and scoping (Step 1)

The intensified potential impact of climate-related hazards and the dynamic of urbanization on the local public health service in Khon Kaen city were oriented as a problem of this study. Hence this research set urban development, climate-related hazards, public health service as the scope of systems of interest. The systems' spatial scope were identified based on their planning, operation practices, biophysical relationship, and spatial resolution of the available dataset.

In the aspect of urban development, the 3rd revised version of the draft comprehensive plan of Khon Kaen city (DPT, 2018) (refer as "the draft comprehensive plan") prepared by the Department of Public Works and Town & Country Planning (DPT) was used as a primary input for defining the spatial scope of urban development. Regarding climate-related hazards, this study scoped the global climate downscaling data to relevant sub-watershed for analyzing the following hydro-meteorological hazards, which currently and will signify urban development and public health service in the study area, i.e. fluvial flood, pluvial flood, and water supply scarcity. Although the input data constituted contradicting spatial boundaries, Mueang Khon Kaen district (Khon Kaen city) and Khon Kaen Hospital's CUP network area were considered to elaborate the potential impact of the local public health service. In a temporal aspect, 2037 was adopted as the future scenario endpoint according to the 20-year National Strategy of Thailand, a policy document directing every development layer of the country. Regarding a deep uncertainty of a long-term climate projection, this study applied a climate projection downscaling during 2021 – 2050 dataset to construct future scenarios of local climate-related hazards in 2037.

4.1.2 Diagnose the current context of the systems & shortcoming development (Step 2)

Diagnosis of the current and shortcomings development of Khon Kaen city was conducted by combining policy reviews and stakeholder interviews, which were then scrutinized using the TOWS analysis framework. Relevant plan and policy documents from national to local levels were reviewed (see Annex 16). Key stakeholders were interviewed in order to acquire knowledge of the status quo, shortcomings and strategic development of urban development, public healthcare, and climate/disaster risk management of the study area. This study identified stakeholders and experts based on their relevant roles, legitimate responsibility, politically significance, and in combination with the snowball technique. The identified stakeholders consist of representatives of the national government, provincial government, local government, private sector, and academia[19] (see Annex 3). A series of interviews were organized in both face-to-face and virtual meetings in March-July 2018. The inputs of 13 semi-structured stakeholder interviews were thematically summarized and conformed to a shared understanding of the system of interest (urban development, climate-related hazards, and public health service). Based on the policy document reviews and stakeholders interviews, strengths, weaknesses, opportunities and threats were extracted and organized in the TOWS matrix structure. The TOWS analysis result will then be integrated as a basis for future visioning in Phase II. Moreover, six representatives/experts of primary local critical infrastructures agencies (Annex 4) were interviewed to contextualize the understanding of the urban system operation.

4.2 Phase II - Forecasting

This phase highlights the explorative scenario planning component of the study. Forecasting techniques were applied to portray Khon Kaen city's in 2037 from both urban development and climate-related hazards points of view. This part aims to articulate a bandwidth of possible future conditions of Khon Kaen city through stakeholders' participation and co-production process. This phase consists of two main steps; future urban development envisioning exercise and climate projection analysis (step 3) and Trend (plausible) scenario storyline formulation (step 4), which are elaborated as follows.

[19] During the time of research (2017-2020), a prominent local civil society group/organization works on urban development or climate-related hazards can not be found in the study area.

4.2.1 Future vision and projection (Step 3)

This research deployed quantitative and qualitative techniques for stretching bandwidths of possible future urban development change and climate change in the study area as follows.

Step 3.1 Future urban development bandwidth: This study combined data-driven analysis and stakeholder participation techniques to envision how the development of Khon Kaen city will be like in 2037. Possible urban development bandwidth formulation comprises two elements: population change and land use change. Six local/provincial stakeholder agencies and one national planning agency were involved in the future urban development envisioning process (see Annex 5).

- **Population change bandwidth:** To stretch the population change bandwidth in 2037, this study adopted three population forecasting figures, two future population projection scenarios determined in the draft comprehensive plan prepared by DPT (2018) and one statistical extrapolation forecasting based on the demographic consensus reported by Khon Kaen Provincial Statistic Office (KKPSO) during 2008-2016 (KKPSO, 2017). A statistical extrapolation technique was also applied to compromise the discrepancies between DPT's population scenarios and the research timespan[20]. The three figures of the future population projections were presented to the stakeholders, then asked for their overall opinion regarding the possible maximum and minimum margins of Khon Kaen city's population changes in 2037. Stakeholders were offered to propose any trend breakers or different population trends besides the abovementioned propositions.
- **Land use change bandwidth:** To unfold the future land use bandwidth of Khon Kaen city, this study adopted the DPT's land use map (part of the draft comprehensive plan) as a medium for the future envisioning exercise, which enables the stakeholders to have a smooth transition from the present situation (2018) to the imagination of future urban development and land use change in 2037. Printed copies of the land use map, see Figure 3.10, were presented to the stakeholders. Stakeholders were requested to envision possible urban development dynamics & direction, prominence investment projects, and land-use change in the following snapshots, 2022, 2027,2032 and 2037, by addressing a distinction of possible minimum and maximum levels of development changes. The stakeholders expressed their idea through talking and drawing on the printed maps (different time snapshots used different printed maps). Verbal inputs were thematically analyzed in combination with the drawn land use maps. Visualizations of the bandwidth of possible future urban development (minimum-maximum range) of Khon Kaen city for every 5-year time spot until 2037 were laid out and presented to the stakeholders during the

[20] DPT population projections timespan is 2015 – 2035 which devided into 6 snapshots as following: 2015,2020,2025,2030,2032, and 2035 (DPT,2018: 4-35)

validation process (see Annex 5). A sample of stakeholder drawn land use maps can be found in Annex 6.

Based on the stakeholders' inputs, the bandwidth of future population change and land use change of the study area in 2037 were analyzed and visualized in the range of minimum and maximum bandwidth of possible changes. The intermediate result was presented to stakeholders to validate and collect additional comments through a series of individual discussions during 4-18 March 2019 (see Annex 5)[21].

Step 3.2 Future climate-related hazards bandwidth: This study adopted downscaling high-resolution (25 km x 25 km) and bias-corrected Global Circulation Model dataset under European community Earth-System Model (EC-EARTH) (more information about EC-EARTH at http://www.ec-earth.org). The downscaling dataset was generated and provided by Hydro – Informatics Institute (HII) of Thailand. The projected future climate under the Representative Concentration Pathways[22], RCP 4.5 and RCP 8.5 were selected to exhibit moderate and extreme climate scenarios during 2021 – 2050, covering at least a 30-year climate cycle. To bridge the gaps between global trajectories and local climate scenarios, formulation of the local climate-related hazards bandwidth in 2037 heavily involved local water management, disaster risk management practices, and consultation with the local experts (see Annex 7). This research combined the precipitation parameter of EC-EARTH downscaling and bias-corrected datasets, the present worst-case event and local water management practices for estimating the possible minimum and maximum magnitude and spatial extension of the local fluvial flood, pluvial flood, and water supply scarcity in the study area in 2037 according to the following processes.

- **Fluvial flood bandwidth**

  Occurrences of fluvial floods in the study area are highly characterized by upstream waterbody and water management infrastructures beyond the study area boundary. Therefore, the climate scenarios' spatial boundary must cover relevant sub-watershed defined by the local experts based on the local water management practice. Figure 4.2 shows the sub-watersheds included in the fluvial flood bandwidth analysis of this study, i.e. Lam Phaniang; Nam Phuai, Upper and lower part of Lam Nam Phong, Lam Nam Choen,

[21] It is crucial to remark that due to stakeholders internal organizational change caused of impossible to always have the same person from the same organization to participate in the following interview and exercise, however, all necessary information was communicated and recapped to the newly enrolled representatives.

[22] A Representative Concentration Pathway (RCP) is a greenhouse gas concentration trajectory adopted by the IPCC. RCPs are labelled after a possible range of radiative forcing values in the year 2100. RCP 4.5 is an intermediate pathway which radiative forcing is stabilised at approximately 4.5 W m-2 after 2100. RCP 4.5 is more likely than not to result in global temperature rise between 2 degrees C, and 3 degrees C, by 2100. RCP8.5, generally taken as the basis for worst-case climate change scenarios, which radiative forcing reaches greater than 8.5 W m-2 by 2100 and continues to rise for some amount of time (IPCC, 2014a).

Huai Sai Bat, and Third part of Lam Nam Chi. According to the current knowledge (2018), neither existing water model simulation study nor research has taken local water management practices into account in climate projection analysis conducted in the boundary mentioned above. Climate projection and deterministic analysis of precipitation parameters were integrated in order to formulate future fluvial flood bandwidth in consultation with the local water management experts. According to the deterministic approach, the record of the current worst-case fluvial flood level was adopted, 649.10 cm^3/s overflow discharge measured at Stream Gaging Station E.22B (river capacity 434 cm^3/s) on 21st October 2017 (HII,2019). The event marked the latest worst-case fluvial flood that Khon Kaen city experienced in the modern-day. With the assumption of structural flood protection measures failure, particularly flood barriers and dikes along Phong river, a fluvial flood could reach about 152 m MSL (contour line). With the overarching aim of potential impact reduction and the precautionary principle, this study suggested 152 MSL as the minimum fluvial flood (margin) of the bandwidth based on stakeholders and experts opinions. Meanwhile, the maximum bandwidth was derived from the projected precipitation datasets, RCP 4.5 and RCP 8.5. 99th percentile of maximum daily rainfall (of each month) of the climate project datasets was used as inputs for the local discharge calculation. Due to the lack of high-resolution geospatial data in terms of projected built-up areas and surface properties, a dimensionless unit-hydrograph technique was applied to transform rainfall to discharge of the study area. Detailed information about the dimensionless unit-hydrograph technique can be found in (Sherman, 1932 cited in Ramírez, 2010). Remarked here that there is no specific unit-hydrograph study conducted by Royal Irrigation Department (RID) for the study area specifically; therefore, the river profile assumptions and constant values of the nearby representative station in the same watershed, Stream Gaging Station E.29 Namphong (Hydrology Division, 2009:11) was applied for calculating discharge of the projected precipitation datasets at the Stream Gaging Station E.22B. Details of the calculation can be found in Annex 8-9. The estimated maximum discharge margin of fluvial flood bandwidth was interpolated to fluvial flood spatial extension in the term of Mean Sean Level. Based on Digital Elevation Model analysis (DEM) data[23], ArcMap 10.5.1 software was used to map and visualize the spatial extension of the minimum and maximum fluvial flood bandwidth scenarios that served as input for further the stakeholders' discussions.

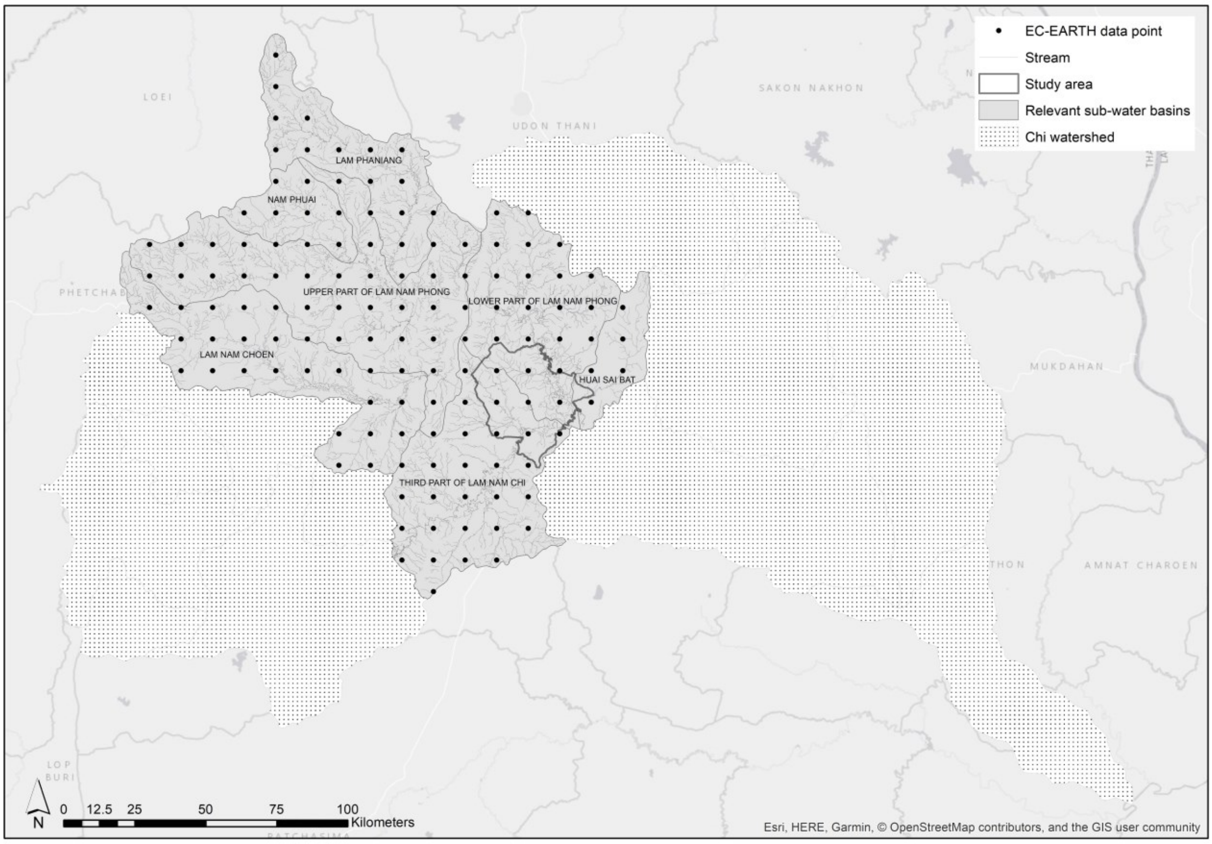
- **Pluvial flood bandwidth**

  Pluvial flooding problem in Khon Kaen city is mainly caused by the limited capacity of the drainage system, unplanned land use, and uncontrolled land cover change, which usually

[23] Thailand DEM from SRTM-4 re-interpoled at 300 m resolution, retrived from http://www.savgis.org/thailand.htm

increases sealed surfaces and blocks waterways. No strong regulation or benchmarks on a land excavation are also a cause of flooding after less than an hour of continuous heavy rainfall events in many city sections, even on high terrain. The current land use plan and the existing engineering proposal for improved city drainage systems could indicate local drainage capacity for the present climate conditions. Therefore, it is fair to imply that there is no guarantee of no pluvial flood in the future, even in a high elevated location or an area where never experienced pluvial floods before. Lacking high-resolution geospatial data and projected built-up areas are key limitations that do not allow the application of high-resolution pluvial flood simulation (e.g. FloodArea^{HPC} model), which provides greater detail of possible pluvial flood bandwidth in the future. Thus this study applied a conservative assumption that everywhere in the study area could have a chance of pluvial flooding regardless of its elevation level. In other words, the future pluvial flood bandwidth is binary, yes and no, as the maximum and minimum bandwidth margin.

Figure 4. 2 Sub-watershed boundary for the local climate scenario



- **Water scarcity bandwidth**

  The majority of the water supply in the study area is piped water manufactured and delivered by the local waterworks authority. However, raw water availability for water supply production depends on the reserved quantity of water of the upstream reservoir, while water supply quality is tied to upstream human activities. According to local experts, water supply situations can be monitored via average annual rainfall, which determines reserved raw water in Ubonrattana Dam. If the amount of annual rainfall is less than 1,100-1,200 mm/year in this region for four consecutive years, the water supply situation of Khon Kaen city can become serious. In this regard, the study arrayed the 90th percentile of average annual rainfall data of RCP 4.5 and RCP 8.5 datasets during 2021-2050, which then aligned with the adapted RID local drought index (see Table 4.1). Thereby, the four consecutive years with the amount of annual rainfall less than 924.2 mm/years shall be highlighted as a possible period of water supply crisis in the study area (see Annex 17). Although roughly indicating water scarcity periods is possible, it does not reasonably determine the spatial extension of urban water scarcity by climatic factors solely. The insufficient qualified raw water feed to the production system could cause intermittent water supply for the whole city in general; however, the effects are neither equally distributed nor can be able to certainly specified locations in the long-term future perspective. Nonetheless, it is quite certain that low water quantity usually causes low pressure in the pipe network, particularly in high ground locations, resulting in more technical difficulties and higher investment costs of water supply infrastructure and delivery. Thus, it is fair to assume that more severe intermittent water could often occur in high elevated areas than in the low flat terrain of the city. Although this study did not include a tech-sociological complex of critical infrastructure in the scenario formulation, a high-resolution dataset and specific engineering and technological research of the local water supply pipeline network and structure (e.g. life span, technology variations, investment) is highly recognized. In this regard, this research generally assigned the possible water scarcity bandwidth of the study area as a binary between yes (maximum) and no (minimum).

Table 4. 1 Local drought index adapted from RID standard value based on annual rainfall

Index	Annual rainfall (mm/yr)
Extreme drought	871.4
Drought	924.2
Quite drought	977.0 – 1,029.8
O.K. level	1,082.6 -1,135.3
Average	1,188.1
Good rain	1,240.9-1,346.5
Very good	1,399.3 -1,452.0

4.2.2 Plausible (Trend) scenario storyline formulation (Step 4)

Step 4 aims to outline possible future scenarios, identify a Trend (plausible) scenario, and formulate the Trend scenario's storyline by taking interactions among climate change, urban development changes, and their potential impact on the public health care service into account. The articulation and visualization of the Trend (plausible) scenario will then encompass the target setting and composite indicators development in the Backcasting phase (Phase III). In this regard, this section consists of four sub-elements, 1) possible scenario construction & plausible scenario identification; 2) interaction analysis; 3) impact chain analysis; 4) plausible scenario storyline elaboration (matrix analysis) and validation.

4.2.2.1 Possible scenarios (scenario matrix) and plausible scenario identification

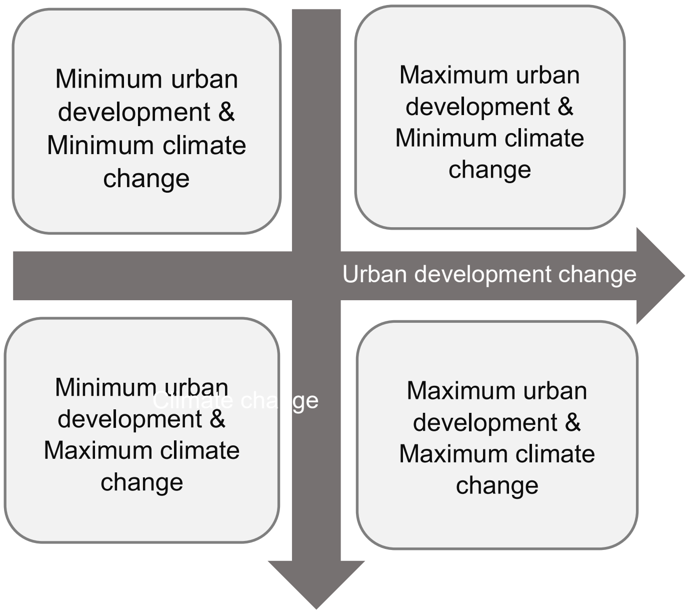
This research overlaid possible future scenarios of urban development changes and climate-related hazards, then framed them into a 2 x 2 scenarios matrix (see Figure 4.3) as follows.

1) Minimum urban development & Minimum climate-related hazards;
2) Maximum urban development & Minimum climate-related hazards;
3) Minimum urban development & Maximum climate-related hazards;
4) Maximum urban development & Maximum climate-related hazards.

Geospatial analysis was applied in order to overlay and intersect the core features of both future urban development change and climate-related hazard changes in the four scenarios. Visualization of the scenarios showed a broad overview of possible affected areas and exposed elements of the city according to the degree of urban development bandwidth and climate-related hazards bandwidth. The scenarios matrix was presented to 11 stakeholders in the individual discussion format. The stakeholders were the representatives from relevant stakeholder agencies, including various levels of government agencies (national, provincial, local levels), private sector, and academia (see Annex 5). Besides giving their expressions and comments on the four scenarios, the stakeholders were asked to select one scenario (among the four scenarios) representing the plausible future of Khon Kaen city in 2037[24]. The scenario which got a majority vote from the stakeholders will be defined as the plausible scenario or so-called "**Trend scenario**".

[24] Due to limited resources and reducing complexity on stakeholders cognitive thinking on the contradict scenarios, this study encouraged the stakeholders to select only one plausible scenario for proceeding extensive stakeholder participation process and potential impact assessment.

Figure 4. 3 Scenario matrix of future urban development scenarios and future climate change scenarios of Khon Kaen city



4.2.2.2 Interaction analysis

Initial elaboration and visualization of the "Trend scenario" have enabled interaction analysis between the future change of Khon Kaen city's urban development and climate-related hazards. The causal relationship concept was used to conceptualize the vertical and horizontal relationship between the local urban environment and regional & global climate layers. The cause-effect relationship analysis was a desktop-based conceptual analysis. Thereby, the interactions were explained through feedback loops; positive feedback loop reinforces and/or amplifies an effect; negative feedback loop is the conditions that diminish and/or dampen an effect, and neutral. Some lines of interactions may be neglected due to insufficient supportive evidence or literature. The interaction analysis helps to apprehend interrelationships among the system of interest, encompasses scenario storyline elaboration and the emergence of matches & mismatches of policies and plans implemented (& will be implemented) in the study area.

4.2.2.3 Impact chain analysis

Impact chain analysis was used to conceptualize how climate stimuli could propagate through the local public healthcare system caused direct and indirect impacts on its service operation. Semi-structured interviews with primary critical infrastructures and local hospital operators/managers were conducted to understand interdependency and dependency among the local public health care and other critical infrastructure domains of the impact chains (see Annex 4). The impact chain elaboration was visualized and used to articulate the potential impact of climate-related hazards on the local public health service. The impact chain was used for the scenarios storyline formulation and served as a medium to raise stakeholders' awareness and engagement in the following backcasting steps.

4.2.2.4 Matrix analysis and stakeholder validation of the plausible scenario storyline

Matrix analysis was conducted in order to capture possible interplay among the three systems of interest (urban development, climate-related hazards, and public health services) in a different zone of the study area. This study applied Matrix analysis to define possible convergences and divergences in both internal and interactional perspectives, which then informed "Trend scenario" storyline elaboration. Detailed elaboration and visualization of "Trend scenario" were presented to stakeholders in order to receive further suggestions and validation of the scenario through bilateral talk sessions. The stakeholders were key representatives from various institutions responsible for local urban development, disaster risk management, and public healthcare (see Annex 5). The elaboration of the scenario storyline will be used for justifying input data fed into the composite indicators in the following assessment process.

4.3 Phase III - Backcasting

After exploring What could happen?, this phase follows a common feature of backcasting in examining, What is the preferred future?; and How it can be realized?. This study outlines the backcasting phase into five steps as follows: target setting (step 5), desirable scenario construction (step 6), desirable scenario storyline formulation (step 7), and scenarios assessment (step 8).

4.3.1 Target setting (Step 5)

After presenting the "Trend scenario" to the stakeholders (step 4), a survey on potential impact perception was conducted via bilateral discussion format in order to define the desirable target(s) of potential impact minimization (Annex 5). Visualization of the "Trend scenario" was used for an individual stakeholder to draw the spatial extension of protection worthiness under the “Trend scenario”. From an overall urban operation perspective, the stakeholders discussed and expressed their choice of the anticipated level and desirable level of potential impact if the city has to deal with the "Trend scenario" from *very low* to *high* level. The description of the level of potential impact is shown in Table 4.2. It is important to note that the identified potential impact levels of both anticipated and desirable levels were neither absolute nor proved quantitatively by the current pieces of evidence; it conceptually provides a baseline and targets for desirable scenario storyline formulation and scenario assessment framework in the later steps.

Table 4. 2 Description of operational impact level

Impact Level	Operational Impact
Very low	All services can continue without any discernible impact or change
Low	• Some services may be reduced or suspended • Some advanced or special services may be cancelled • Services for non-priority client/section may be temporarily suspended
Medium	• Demand to obtain needed resources/supports from outside • Full implementation of conservation measures in order to sustain essential services • Shutdown of auxiliaries sections • Declare total diversion status or partial/total evacuation
High	• Discontinuity of essential services • All clients will be transferred to other/nearby service facilities/areas • Unable to deploy more than 50% of personnel responsible for the essential sections/services

Source: Adapted from University of Rochester, 2021

4.3.2 Desirable scenario construction (Step 6)

This step identified spatial planning-based measurements based on the stakeholders' suggestions, literature, and the researcher's[25] inputs with respect to the identified target(s) in order to minimize the potential impact of the “Trend scenario”. The potential spatial planning-based measurements were specifically proposed for each city zone through 3 main strategies; exposure avoidance, hazard mitigation, and capacity enhancement. Visualization of city-wide’s proposed spatial planning-based measurements was presented and discussed with a broader group of stakeholders through individual talks (5-13 February 2020) (Annex 5) and a workshop organized by local stakeholders (1 March 2020) (Annex 15). Meanwhile, the public health-specific measures were presented and discussed with the responsible agency, Khon Kaen Provincial Public Health Office (KKPHO) (17 March 2020). In the individual discussion sessions, the stakeholders apprised their preference toward each proposed measure through a Likert scale survey with the scale 1 (least preferred) to 5 (most preferred). The proposed measures which received an average preference score of less than 2 (low preferred) will be excluded from the “Desirable scenario” storyline formulation in the following step.

4.3.3 Desirable scenario storyline formulation (Step 7)

The “Desirable scenario” storyline was constructed by adhering to the preferred spatial-planning based measures/interventions (step 6). Possible convergence and divergence in both

[25] Wiriya Puntub

internal and interactional perspectives under the “Desirable scenario” were defined through **Matrix analysis** (iterative step 4), considering potential outcomes of the interplay among the three systems of interest (urban development, climate-related hazard, and public health services) in a different Khon Kean city zone. The result of the matrix analysis was used for the “Desirable scenario” storyline formulation, which then altered input data for composite indicators in the scenario assessment process. It is important to note that the distinction between “Trend scenario” and “Desirable scenario” are mainly urban development change and public health care operationalization rather than future climate conditions.

4.3.4 Scenario assessment (Step 8)

This study used composite indicators-based scenario assessment in order to evaluate the complex potential impact outcomes and operationalize the climate resilience targets of the local public health service. This step lays out the scenario assessment process for both "Trend scenario" and “Desired scenario” into four main elements, 1) composite indicators development, 2) questionnaire survey, 3) data analysis and interpretation, and 4) sensitivity analysis.

Step 8.1 Composite indicators development

This study developed a set of composite indicators based on IPCC AR5 (Oppenheimer et al., 2014) climate risk concept, without a configuration of the likelihood of the future climate risk (as debated in 2.2), where the potential impact is the non-compensable aggregation of hazard, exposure and vulnerability (see equation 1). The vulnerability pillar is a blending of sensitivity, coping capacity and adaptive capacity components, theoretically inseparable but operationalizable (Hinkel,2011). Therefore, in this research, the architecture of composite indicators was structured into three hierarchical layers, pillar, indicator, and sub-indicator. The pillar layer consists of 3 pillars, Hazard, Exposure and Vulnerability. Each pillar contains subsequent indicators (indicator layer), and then each indicator is usually comprised of sub-indicator(s) (sub-indicator layer). The structure of the composite indicators is shown in Figure 4.5. The composite indicator development process consisted of 2 elements: indicator identification and normalization & aggregation.

1) Indicators identification

This composite indicators’ goal is to assess the potential impact of future urban development change and climate-related hazards change, considering their interactions with the public health service of Khon Kaen city. The IPCC AR5’s climate risk concept was used to outline the composite indicators framework. The scope of indicators is the same as the overall scope of this study, in terms of spatial, temporal, focusing climate-related hazards, and type of health care service and network. The indicators’ selection criteria are their relevance in describing the potential impact of the local public health service, the availability of input data, and the promotion of local public health service to operate climate-resilient targets.

The future scenarios storylines (Trend scenario and Desirable scenario) determined the Hazard pillar and Exposure pillar indicators. Meanwhile, Vulnerability pillar-related indicators involved the combination of the review of case studies, research papers and relevant sectoral guidelines regarding disaster risk management for healthcare facilities (Table 4.3), climate impact chain analysis (step 2), and in-depth interviews with public health care experts and local public health care facilities managers and executives (Annex 10).

The health care experts survey was conducted in October-December 2019 to validate and assign weighting values for the proposed composite indicators (Annex 21). The experts were representatives of various public health policy decision-making agencies and hospital directors/managers responsible for or who had experiences with disaster risk management (Annex 11). For the Hazards pillar, the experts were asked to assign the weighting value between floods and water scarcity through a budget allocation approach. Meanwhile, ascending order prioritization technique was applied for each Vulnerability-related component e. g. 1st order is the highest priority, and 5th is the least priority. Since neither the experts nor technical standard is available to justify the weighting value of Exposure-related indicators; therefore, equal weight was assigned. It is important to note that the experts were offered to suggest additional indicators as they see appropriate. The equal-weighted scheme was also applied to demonstrate the influence of different normalization schemes on the potential impact of outcome values.

2) Normalization and Aggregation

This study considered IPCC AR5's climate risk concept and data properties as the key criteria for selecting normalization techniques and aggregation schemes for each composite indicator layer. Detailed elaboration of the selected normalization and aggregation schemes are summarized below and shown in Table 4.5 and Annex 12.

- **Sub-indicator layer:** Input data was derived from both the questionnaire survey and the given scenario storylines ("Trend scenario" or "Desirable scenario"). Distance to target normalization was applied to represent a fraction of the highest target value. The input data were classified into 0 to 4 in order to conserve the proportion and trackability of the original data. All sub-indicators under an indicator were calculated with equal-weighted arithmetic (additive) aggregation to represent an indicator.

- **Indicator level:** An indicator represents a value of at least one sub-indicator or an average value of many sub-indicators. Conceptually, individual indicators shall have a different degree of influent on the outcome of the potential impact pillar it belongs. Therefore, proportionately weighted normalization was used for the indicator layer; a single attribute value is divided by the sum total of the values of attributes. As stated in the prior section, weighted values were assigned based on the experts' judgement (Hazards and Vulnerability-related indicators) and equal-weighted (Exposure-related indicators). In addition to the experts-weighted normalization scheme, this study also provides a comparative configuration of the composite indicator-based potential impact assessment, in which all indicators operated through equal-weighted normalization. In terms of aggregation scheme selection, there is a possibility that at least one of the indicator's values may contain "0"; hence, arithmetic (additive) aggregation was operated. Thereby, the aggregated indicator values were transformed to the range of 0 to 4 in order to represent the pillar value.

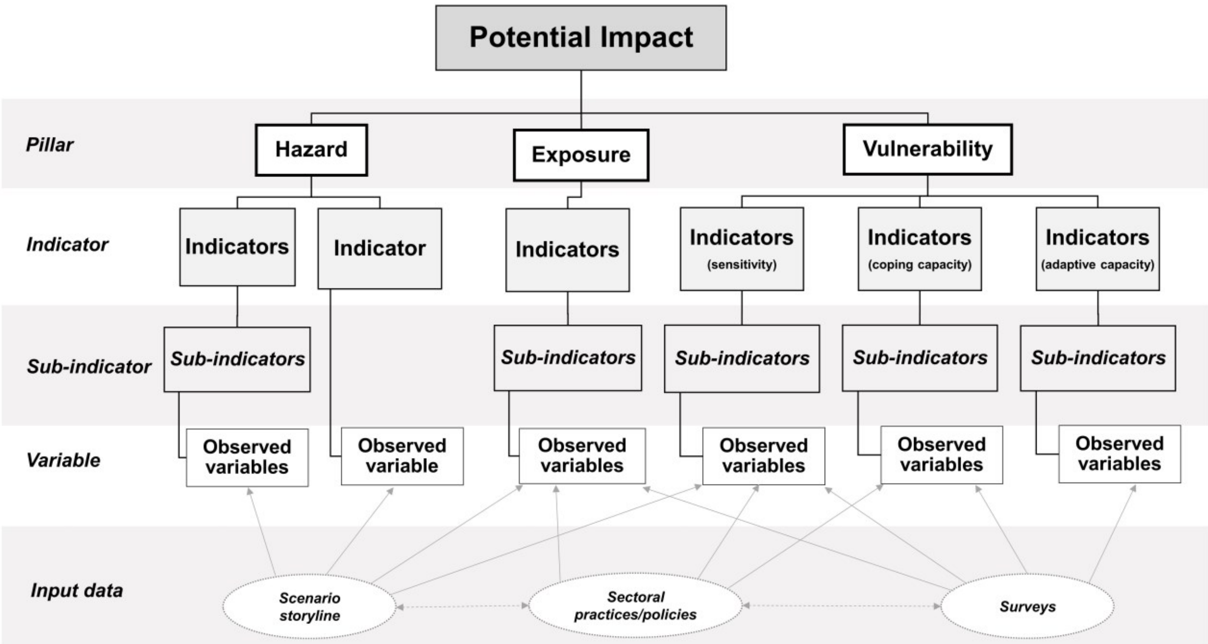
- **Pillar level:** According to the composite indicator framework, the potential impact is the multiplication of the Hazards, Exposure and Vulnerability pillar. Therefore, the absence of one pillar or being assigned as "0" in one of the terms meant no potential impact occurred. To this connection, the geometric (multiplicative) aggregation method was executed for this non-compensability relationship among the pillars. Proportionate equal-weighted normalization on the scale of 0-1 was used for the pillar layer. In this regard, the possibility of potential impact value derived from the set of the composite indicators must present in absolute term between 0 to 1. 0 mean no potential impact, and 1 is the possible worst potential impact. The value of potential impact outcomes was presented in an equal interval classification (Table 4.3) in order to demonstrate its scalability as a national or universal standard and enhance a broader scale of decision making, despite the theoretically unique local contexts of the study area. Hence, the list of possible potential impact outcome values based on the operation of Equation 1 (Hazard*Exposure*Vulnerability) showed in Annex 23. It is important to keep in mind the algorithm of multiplying numbers/decimals by a decimal (less than one); the multiplication output (product) will be smaller than the number being multiplied.

Table 4. 3 Equal interval classification of potential impact outcome values

Level	Value
High	>0.422 - 1.000
Medium	> 0.125 - 0.422
Low	>0.016 - 0.125
Very low	0.000 - 0.016

Note: (see the full list of possible values in Annex 23)

Figure 4. 4 Composite indicator structure



Source: Own illustration

Table 4. 4 Literature for public health care specific vulnerability-related indictors identifications

Types	Literature
Sectoral & standards/Practices/Guidelines	***International*** - WHO (2009); DOH-HEMS (2009); WHO (2015a); WHO (2015b); WHO & PAHO (2015); Relias (2008); Guenther, R., & Balbus, J. (2014); Health Research & Educational Trust. (2015); IROQUOIS (2018); HHS (2018); JC (2019); JC (2021); University of Rochester. (2021); HHS (n.d.); U.S. Healthcare & Public Health Sector Coordinating Councils. (n.d.a,b) ***Thailand*** - Design and Construction Division (2007); DMS (2018)
Case studies/Lessons learned	***International*** - Levinson, (2014); Palmer (2017) ***Thailand*** - Thammasat University Hospital (2012)
Academic publications	Goddard, M., & Jacobs, R. (2010); Hiete et al. (2011); Hollnagel et al. (2013); Braithwaite et al. (2016); Riaz et al. (2016); Kruk et al. (2017)

Table 4. 5 Normalization, weighting and aggregation used for composite indicator-based potential impact assessment in this study

Composite indicator layers	Aggregation schemes	Weighting schemes	Normalization schemes
Pillar	Multiplicative	Equal weight	Proportionate normalization (0-1)
Indicator	Additive	Equal weight & Expert weight	Proportionate normalization (0-4)
Sub-indicator	Additive	Equal weight	Distance to target normalization (0-4)

Step 8.2 Questionnaire Survey

The survey aimed to obtain primary input data from public health facilities in the study area in order to conduct the potential impact assessment according to the composite indicators framework. Meanwhile, the questionnaire fed the input data to Vulnerability and (partially) Exposure-related indicators, Hazard and (partially) Exposure-related indicators were obtained input data from scenarios storylines and the local public health facility operation practices/ sectoral policies.

The questionnaire was organized into five parts, 1) general information about a respondent, 2) current status and future service capacity exposure, 3) sensitivity, 4) coping capacity, and 5) adaptive capacity. The final draft of the questionnaire was test-run with five respondents who did not represent the target hospitals in the study area. After the test-run phase, a 35-pages long questionnaire (in Thai-local language) consisting of 84 items was sent out to all (36) public health facilities under the Ministry of Public Health (MoPH) in the area of Mueang Khon Kaen district (Annex 13) via multiple channels such as email, instant message platform, hand to hand, and post. The English translation version of the questionnaire is available in Annex 36. In addition to the questionnaire survey, purposive sampling in-depth interviews with 7 hospital representatives were conducted to capture emerging elements that maybe not be reported in the survey. The selected interviewees represent various health care service capacities and different zones of the city (Annex 14).

Step 8.3 Data Analysis

After receiving the completed questionnaires, all input data were then transferred to a digital (excel) spreadsheet format. A combination of the surveyed dataset and key features of the storylines of the scenarios were encoded and calculated the potential impact outcome in Microsoft Excel based on the abovementioned composite indicators structure and data aggregation & normalization schemes. Presentation of the potential impact assessment of the two scenarios (Trend scenario and Desire scenario) were reported in several aspects to enhance strategic communication with policymakers and stakeholders, such as area-based, service network, and service hierarchy.

Step 8.4 Sensitivity analysis

Principal Component Analysis (PCA) is commonly used for interpreting a relatively large series of data in a smaller number of components or dimensions that can be meaningfully interpreted while maintaining most of the variation in the dataset (Jollife & Cadima, 2016; Ringnér, 2008). Even though this study contains a small sample size, PCA can be useful for verifying the composite indicators' robustness through a data-driven approach, especially Vulnerability indicators, which comprise an extensive number of indicators compared to other potential impact pillars. The input data feed in PCA analysis derived from questionnaire survey without integrated scenarios storyline assumption to avoid zero variance in the dataset. This study conducted PCA by using Statistical Package for the Social Sciences (SPSS), a powerful software package for understanding large complex data sets. A PCA was performed using the "Dimension Reduction" option under the "Analysis" function of SPSS software. Inspection of sampling adequacy based on the Kaiser-Meyer-Olkin (KMO) and Bartlett's Test of Sphericity was checked. Criteria for selecting the optimal number of Principal Components (PCs) were either the PC has eigenvalues greater than 1 or 70-80% of total variance explained by all components. Reliability was analyzed in order to ensure that a measure should consistently reflect the construct that its measuring (Field, 2018: 821). Moreover, Cronbach's alpha coefficient was used to check internal consistency within each aspect of vulnerability elements. Communalities value was estimated the variance in each variable accounted for by the PCs. In terms of the correlation between the variables and factors, the structure matrix was analyzed. Regarding the correlation among the PCs based on Oblimin with the Kaiser normalization rotation method, the component correlation matrix was examined to ensure a correlation among PCs. Furthermore, this study also conducted a standard Pearson’s correlation analysis in order to measure the strength of a linear correlation among multiple variables (indicators) of the Vulnerability pillar.

4.4 Phase IV - Implementing and Phase V: Following up

This phase layouts essential steps to realize and monitor the targets. To complete backcasting planning cycle demands the determination of implementation requirements or roadmap (step 9), ex-ante assessment (Step 10), and mainstreaming climate-resilient in policy implementation and operations (Step 11). After years of implementation, Phase V, monitoring and evaluation or ex post-assessment (Step 12) shall be launched to track the policy implementation's progress in responding to the targets. As aforementioned, within this research timeframe, only step 9 was included in this study.

4.4.1 Determination implementation requirements (Step 9)

To lay out the implementation roadmap, gaps between "Trend scenario" and "Desirable scenario" as well as between "Desirable scenario" and the desired target(s) were identified. To bridge gaps between the scenarios and the targets, potential impact mitigation strategies were proposed with implementation timeframes for sequencing transition to the target(s) accomplishment by the end of 2037. The proposed public health-specific and city-wide roadmaps were sent to MoPH, KKPHO, DPT, and KKDPT to review and comment on their appropriateness as part of the validation process (June 2021). Comments and suggestions of the key political agencies were integrated and presented as policy recommendations.

In summary, this chapter maps the methodologies used and their subsequence phases and steps to operationalize HICRAF, an advanced future-oriented scenario-planning framework for climate-resilient public health care, which was tailored and tested in Khon Kaen city under the context of this research. HICRAF framework was outlined based on the collaborative scenario planning approach, which also intermixed the explorative and normative scenario method and composite indicators technique. The framework addresses the interaction between future development changes and climate changes and their potential impact on the local public health service. It offers the composite indicators-based potential impact assessment framework, which helps the local public health service operationalize its potential impact and backcasting its desirable future climate resilience. Even though HICRAF is built upon many existing profound concepts, its application is only in Khon Kaen city, Thailand. Limitations and invitations for further research on HICRAF are addressed in Chapter 6 Discussion and Chapter 7 Conclusions.

Chapter 5
Results

This chapter outlines the research results in four parts according to the collaborative scenario planning phases. The first section presents the understanding of the city's state of development and dynamics through the lens of key stakeholders. The second section articulates the bandwidth of possible future scenarios considering development change and climate change based on intermixed stakeholders' participatory and empirical scientific evidence. The third section illustrates stakeholders' aspirations in defining target(s) and a desirable future scenario of the Khon Kaen city manifested by backcasting approach. This section highlights the target setting process and explores key strategies that elaborate the desirable scenario of the case study area. Tailor-made composite indicator-based scenarios assessment framework and processes are also portrayed in this section. To complete the backcasting process, the fourth section presents the proposed roadmap, guiding Khon Kaen city's public health service to address the collision of urbanization and climate-related hazards from today's conditions to the future climate-resilient in 2037.

5.1 Khon Kaen city in a shared understanding perspective

Exploring the possible futures urban development pathways of Khon Kaen city, it is crucial to diagnose its current and forthcoming socio-economic development, power relationship, goals and challenges. Combination of policy documents review (see Annex 16) and inputs from 13 stakeholders who are representatives of multi-strata government institutions (national, provincial, and local), private sector, and academia (see Annex 3)) derived push-pull factors. The defined push-pull factors can be grouped into five aspects, Administration and institution; Social and socio-demographic; Economy/socioeconomic; Infrastructure development; and Environment and natural resources. These were then aligned and intersected under TOWS analysis structure. Existing, expecting, and emerging elements that shaped developments and dynamics of the study area were captured and illustrated in TOWS matrix, see Table 5.1 and Figure 5.1. Elaboration of the push-pull factors and the articulation of TOWS analysis can be as follows.

5.1.1 Push-pull factors

Khon Kaen city is and will face five key dilemmas in its societal, economic and environmental development. The city benefits from solidarity among local actors, creative power of young generations, and positioning as regional premier in administration and economic development that leads to leapfrogging the local development through smart city agenda with a vision to become a livable city. Nevertheless, a coexisting paradox of these positive pull factors is very clear. In contrast to solidarity and close cooperation, stakeholders strongly reflected fragilities among local governments and between local and provincial & national governments. While promoting a young and digital economy, the city has to deal with an ageing society and inequality. Although the city may be well equipped with infrastructures, high competiting with neighbouring cities that have the same resources and development agenda, Khon Kaen could lose its regional domination and economic magnetization power. Yet inconvenient truths on environmental quality are perceived as immense challenges for the city to reach a livable and sustainable city overarching goal.

1) Administration and institution – Solidarity & Fragility

Khon Kaen city plays a strong role as regional coordinator of the Northeastern region (or Isan) of the country, home to the regional branch of public institutions and private companies. With stable local politics and strong partnership on economic development among local governments, private sector and academic institutions, people recognize Khon Kaen city as a model of strong cohesion among local actors. These enabling environments promote the city to proactively design its own future development rather than passively float along with the central government policies. However, it does not mean the locals do not embrace the national guidance but rather tailor, negotiate, and monitor them to the best benefit of the locals. Even though the unity of key actors and institutions is one of the major strengths of the city, especially in economic development; nonetheless, high fragility among urban municipalities can be observed through conflicts in land use planning, disaster risk and environmental management, which some of the cases lead to court litigation. However, in most cases, the Khon Kaen province governor takes the role of conflict mediator and decision-maker on the local governments' transboundary issues, hindering the intermediate function of the chief of the Maueng Khon Kaen district. Yet, strong involvement of the private sector in driving local development leads to criticism about elite-led development and insufficient effort to ensure inclusiveness participation and equal representation of young generations, urban poor, and grassroots movement in the local planning and decision-making process.

2) Social and socio-demographic – Young & Old

As a transportation junction, education and medical hub of the region, the city always welcomes and accommodates visitors and domestic migration for education and job opportunities. Not only rural people from nearby provinces and regions, even people from the Great Bangkok Metropolitan Region, also look for a new fortune and escape from the capital chaos to a growing secondary city such as Khon Kaen city. Many high education institutions situated in Khon Kaen city is of the one reasons why Khon Kaen city citizens are relatively well educated than other cities in the region. With a strong matriotism sense, a young generation is often encouraged to use their knowledge and capability to push forward their hometown's betterment rather than move to Bangkok, especially the elite or upper-class groups network which usually graduated from the same high school (e.g. Khon Kaen Wittayayon School) and had higher education from aboard. Therefore, many current and upcoming development projects promote economic activities and infrastructures for young generations, particularly in order to revitalize shrinking wards. While the city's development is designed to attract a young and active population, the city must deal with the ageing society and economy, especially in the CBD and local farmlands. Instead of seeing these paradoxes as a negative force, private health care and hospitality sectors see ageing society as opportunities to incubate business chains in senior care.

3) Economy/Socio-economic: One step ahead or behind

Prompt infrastructures, business ecosystem, and good location are major driving factors attracting more external investment and enabling Khon Kaen city to be the Great Mekong Sub-region (GMS) economy and logistic hub. Although Khon Kaen city's economy plays a significant role in the GMS market, it has limited capacity to link with the international ones. Not many world-class cooperations have an overseas operation unit or centre in Khon Kaen city but are concentrated in Bangkok. The smart city initiative is the flagship policy outlining the city's future economy. Light Rail Transit (LRT) and Transit-Oriented Development (TOD) are promoted as the upcoming major development of the city, a future backbone for local economic renewal. However, this private sector-led public infrastructure development (fabricated by public-private-partnership) also raises critiques on conflicts of interests between benefits and public welfare. Apart from this smart mobility initiative, the Smart city policy framework also aims to keep its economy growing and attract the young generations who are workforce for the new digital economy and innovation incubation. In a non-welfare state, with greater economic development often comes greater living costs and disparities. High living costs and inequity have been resonating among the general public. Urbanization triggers land price speculation that finding an affordable house is an enormous challenge for the young generation and low and middle-income groups. This pressure often pushes them away from city centres and relies on daily commuting between inner-city and peri-urban zones. In terms of business competition, in the future, Khon Kaen city might not be able to maintain one step ahead of its competitors, especially neighbouring cities. Moreover, the local private sector also sees national and global business legacy as threats to local content businesses such as retail chains, modern trades, housing estates and hypermarkets. Besides, these huge outsider businesses, usually headquartered in Bangkok and taking the local market share, are criticized for contributing to local development less than the local corporates.

4) Infrastructure development – Leapfrog and inequality

The Smart City initiative is expected to serve as a vehicle for the leapfrog development of Khon Kaen city. Although Khon Kaen city is well equipped with infrastructure and utilities, good quality and reliable services are still concentrated in the city centre area, especially public transport, health care, water supply, and telecommunication. Since digital infrastructure plays a vital role in achieving the Smart City plan, the city must put immense effort into inhabitants' digital literacy, data standardization, and open data platform, which are essential to promote active citizens and prevent technological-induced inequality. The city addresses this potential digital disparity with the motto “Left no one behind”, but so far, it is criticized as just words with no solid policy and implementation.

5) Environmental and natural resources – Livable city and inconvenient truths

One of Khon Kaen city's overarching development goals is to become a livable city with economic prosperity; however, environmental and disaster risk management is often defined as threats that prevent the city from achieving its targets. Environmental and disaster risk management usually creates tension among municipalities, especially urban municipalities and rural or peri-urban municipalities. Air pollution recently became an environmental crisis between urban and rural settlements. For years, a high level of PM 2.5 during high air pressure conditions and close airflow are linked with open burning and unsustainable sugar cane harvesting practices from nearby croplands. Without integrated waste and wastewater management, conflicts often arise between Khon Kaen City municipality and nearby local governments. Among these unpleasant environmental issues, a fluvial flood is perceived as the most sophisticated climate-related hazard for the city to manage. Rural inhabitants and farmland are the first frontiers and the most affected by a fluvial flood. There are dikes along the Phong river, but the past fluvial floods proved their failures. To protect CBD, the heart of administration and economy, the rural settlements are typically asked to sacrifice their home and farmland to retain the overflow water. Yet, the inhabitants or local governments often face hardship accessing flood relief funds or reimbursement and compensation for loss and damages. The support from urban people is rather in-kind support or in the form of donation than a fair share of the impact/burden, which shall be agreed upon beforehand. There were cases where flood-affected areas felt frustrated about this climate injustice and destroyed the sandbags to let the water reach the city centre, hoping that urban people could feel their pain. Sometimes these conflicts could not be mediated by the governor but by the court of justice. With no formal hazard maps (or does not communicate as an official one) and a lack of integrated future-oriented planning, the LRT development towards a flood-prone area could accelerate urbanization and attract more growth in the fluvial flood-prone areas. Similar conflict also occurs in densely built-up areas. Low impervious surface and low drainage capacity associated with blockage or narrow waterways for making room for real estate and road constructions are major causes of repeatedly pluvial flooding after less than half an hour of heavy rain.

Besides too much water, too little water supply is also a major problem here. Water supply quantity and quality have been critically addressed recently, especially during prolonged droughts. Having no tap water for several weeks can be expected in some parts of the city. The local governments are usually warned to reserve water supply in community water tanks and deliver water to their residents via water trucks. Even though lacking qualified raw water for the water manufacturing process is the most critical problem, the inefficient and degraded pipe network infrastructure causes tremendous loss to the local water supply system. Hence, the water supply issue may become a crucial challenge in accommodating growing consumption in the future. This trouble is yet to mention uneven climate change-related impacts on vulnerable groups of society such as the elderly, low-income groups, or climate-sensitive sectors and infrastructures.

5.1.2 TOWS analysis

Even though most local governments prioritise basic infrastructure provision as a primary concern, Khon Kaen City Municipality aims to connect with the regional and global economy. However, in summary, the local governments in the study area share a common overarching development target of enhancing community empowerment, economic and cultural prosperity and environmental sustainability toward a livable city. This study conducted a TOWS analysis to contextualize the push-pull factors of the current local development pathways in order to inform future possible development scenarios. The TOWS matrix (see Figure 5.1 and Table 5.1) enabled the analysis of the reinforcement between internal strength and opportunities and potential exacerbation of internal weakness and threats from outside to Khon Kaen city development. The articulation of the TOWS analysis is as follows.

1) **Reinforce strengths and eliminate threats**

In the wave of globalization, Thai's government is committed to global development agendas and international environmental agreements such as Sustainable Development Goals, Climate agreements, etc., which cascade down to sectoral, provincial and local levels in the form of a key performance indicator (KPI). Hence it is fair to assume that these commitments could, directly and indirectly, bring a sustainable future to the city of Khon Kaen. Better education, digital infrastructure, and the turning wheel of digital generations could be considered as key opportunities in elevating decentralization to a higher tier in Thailand. In addition, big data plays a vital role in enhancing transparency and participation in local public policies. The data could also be used as a tool for planners and policy decision-makers in managing problems and interests through integrating data-driven and participatory decision-making processes, especially in inter-administrative boundary problems such as disaster risk management and environmental degradation.

In terms of participatory development, Khon Kaen city is the pioneer in the country and in establishing its own urban development think tank to be more active in designing and deciding on its own development paths rather than letting the national or sectoral government lead them by the nose. This radical movement echoes the city's voice that Thailand is not only Bangkok, but other cities with high capacity, such as Khon Kaen city, could become a game-changer in the regional market and innovation development. Thereby, domestic migration to Khon Kaen city tends to be more common in the future. More urbanized Khon Kane city could incentivize higher local employment, especially high skill workers, to support regional supply chains which are more stable than the global ones. With good infrastructure connectivity, urbanization of secondary medium-sized cities could help close gaps between urban and rural development disparities.

Many local institutions actively embrace digitalization and prepare for the AI revolution by creating enabling environment and ecosystem for employable population groups to be ready for the rapid change of technologies and have a good quality of life in Khon Kaen city. These capacity-building initiatives could be a solution to break the cycle that young local populations migrate to Bangkok and letting their children be raised by the elderly at home in a rural area, which has been perceiving as a usual tragedy in Isan society. With the clear sign of increasing elderly farmers, smarter agriculture technology may attract the young generation to improve farming practice efficiency and stay home with their families. Plus, the COVID-19 pandemic emphasises the role of rural and farmland as local food security and as a backup plan for those who lose their incomes and jobs in other sectors. Furthermore, Khon Kaen city could be a popular retirement destination for future elderly groups by combining medical care advancement and excellent hospitality. To grasp these opportunities, Khon Kaen city must succeed in improving environmental quality and disaster risk management, such as air and water pollution, traffic congestion, urban inundations, water supply scarcity, and insufficient blue-green infrastructures. However, gentrification and displacement due to making rooms available for high-income residents and blue-green infrastructure could be another side of the coin of these improvements.

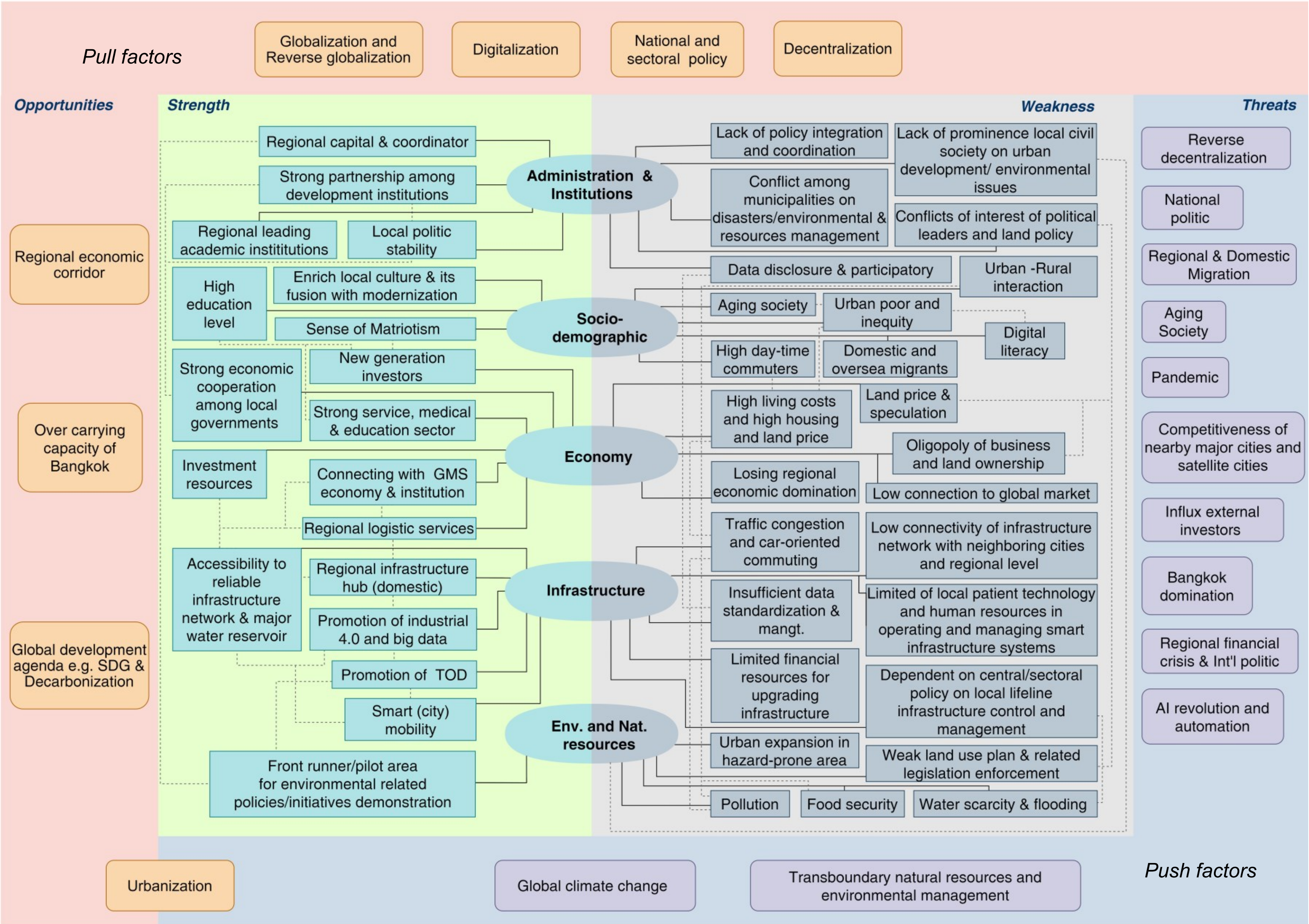
2) Potentially exacerbating factors and converting problems into opportunities

Thailand has been in the decentralization process since 1999, and the central government is trying to shift their role from actor to facilitator/babysitter for local governments, especially in technical aspects. However, the national government still untrusted local capacity and confines local liberty in financial management and policy direction. The implication of policies in Thailand still inclines towards a top-down approach and does not try hard enough to strengthen the bottom-up one. There are efforts to reflect the needs and problems of locals through public participation; however, it is often criticized as a bureaucratic ceremony rather than pursuing meaningful engagement from the citizen. Since 2014 the decentralization process of local government in Thailand seems to go backwards, under the shadow of a military government regime. The local government's power in deciding on their resources has been pulling back to provincial and central administrations.

Thailand's socio-economic development is sensitive to the global economy, especially export and tourism. The strong dominance of Bangkok and the affluent of business tycoons in retail chains and modern trades hinder the local business in the market share. Yet, neighbour major cities, those having more direct regional connectivity in both geography and infrastructure network, are considered as partners and competitors of Khon Kaen city at the same time. Moreover, the urbanization trend could bring more development to satellite cities and make them less dependent on Khon Kaen city economy and services. Therefore, maintaining economic domination in the regional market may be quite a challenge for Khon Kaen city in the future. To speed economic growth, Khon Kaen city might need to create local demands and expand their international market segments, despite COVID-19 triggering reverse globalization, which might lower the chance of business in Khon Kaen being part of global or regional supply chains. Yet, an influx of Chinese and Korean (nominee) investments in local land and the housing market could also lead to a greater level of speculations and the local economy's instability in the future.

Ageing society and better education are major determinations of increased dependency on foreign workers from neighbouring countries for labour-intensive industries and services. Moreover, a foreseeable wave of AI revolution and digitalization could also play a key role in shifting the local economy. However, the readiness of human capacity and ecosystem of Khon Kaen city (so does Thailand) is still in an infant stage and may not catch up with global or regional dominators in the near future. In the next decades, the older and poorer in a digital society may be possible for people and the overall city economy. Furthermore, intensifying climate-related hazards triggered by global climate change could exacerbate the underlying environmental problems, urban-rural disparities, socio-economic vulnerability (poor and/or aged), and inter-local government conflicts. Lacking a formal hazard map and future-oriented risk-informed planning could lead to mismatches between urban development and disaster risk management. These weaknesses and threats may prevent the city from achieving its development goal and make it more vulnerable to the negative impacts of climate change and urbanization in the future.

Figure 5. 1 Urban development push-pull factors of Khon Kaen city



Source: Own illustration

Table 5. 1 TOWS matrix of the case study area

TOWS matrix			**Opportunities (O)**	**Threats (T)**
			• Globalization and reversed-globalization • Global development agenda • Digitalization • Regional economic corridor • National and sectoral level policies • Decentralization • Over carrying capacity of Bangkok • Urbanization	• Pandemic • Ageing society • National politics stability • Reverse-decentralization • Migration (both domestic and GMS level) • Influxes of external investors • Competitiveness of neighbouring cities (major & satellite cities) • Regional financial crisis • International politic • AI revolution and automation • Centralization of Bangkok • Urbanization • Global climate change
Aspects	**Strength (S)**	**Weakness (W)**		
Administration and institution	• Regional coordinator (both national and GMS) • Strong partnerships among local development institutions, public-private-academic • Local politic stability • Regional leading on high education (in both national and GMS level)	• Lack of integrated urban development policy and coordination • Conflict among municipalities in disasters risk/environmental & natural resources management. • Conflicts of interests on local law enforcement, e.g. land use zoning • Lack of prominent local society on urban development/environmental issues • Public data management & disclosure	<u>**SO-T**</u> • Gradual shifts of decentralization and self-organization of local governments • Data disclosure and meaningful public participation • Polycentric urban development • Trust in local government	<u>**WT-O**</u> • Pull back power to the central and provincial government (reverse-decentralization) • Mismatched between policy and spatial planning • Difficulties in area-based integration, especially spatial planning and disaster risk management • Distrust between local and central/government

Social and Socio-demographic	• Enrich local culture and its fusion with modernization • Sense of matriotism of citizen • Well-educated inhabitants in the urban area	• Ageing society and low birth rate • High day-time commuters for working and education • Urban poor and inequity • Domestic and overseas migrants • Low digital literacy	**<u>SO-T</u>** • Higher quality of medical and elderly care business & social infrastructures • Improving medical care through digital technology • Increasing of high skill workers	**<u>WT-O</u>** • Increasing of elderly-urban poor • Insufficient elderly welfare and social infrastructure • Digital divided society • Climate-related health impact on the aged population • A greater urban-rural inequality
Economy/Socio-economic	• Smart city development agenda • Strong service, medical & education sector • Strong local private sector network • Strong cooperation among local governments on economic development • Attractiveness for business investment • Regional logistic services • New generation investors	• External or international business chains (e.g. hypermarket and modern trade) • Increasing living costs and housing price • Land price speculation • Mono-oligopolistic of business and land ownership • Low connection to the global markets	**<u>SO-T</u>** • Higher local employment in both public and private sector • Prominence in the GMS market niches • Export of local brands/innovations to the regional and global market • Innovation/incubation centre for young entrepreneurs • Economic and investment expansion	**<u>WT-O</u>** • Low international investment due to reverse globalization (and post COVID-19 economy) • Losing competitiveness to neighbouring cities • Losing market negotiation power to external/foreign investment business chains • Increasing international nominee investment • Higher alien workers in service and labour-intensive industry • Higher development of other GMS cities • Sensitive to global market change & politic

Infrastructure development	• Regional hub (domestic) • Good accessibility to a reliable infrastructure network and major water reservoir • High quality public and private health care services • Smart mobility strategy (e.g.TOD development) • Promotion of industrial 4.0 and big data	• Inefficient water supply infrastructure and poor drainage system • High dependency on sectoral policy on lifeline infrastructure management • Low connectivity of infrastructure network with GMS • Traffic congestion • Inefficient data management • Limited local technology and human resources in operating and managing smart infrastructure systems	**SO-T** • Data-driven public infrastructure management system • Economic of scale in urban infrastructure investment • Infrastructure integration with nearby cities and nodes • Open data & public participatory transformation • Transport-led urbanization • Smart social infrastructure for elderly	**WT-O** • Insufficient integration of critical infrastructure network at national and GMS level • Water supply crisis • Higher greenhouse gas emissions and air pollution • Slow or unsuccessful smart and livable city targets
Environmental and Natural resources	• Front runner/pilot area for environmental-related policies/initiatives demonstration	• Water scarcity and flooding • Urbanized flood-prone area • High dependency on food production from a rural areas and import • Pollutions (air, water, waste, wastewater) • High land speculation • Weak land-use and related legislation enforcement • Lacking/insufficient integration of spatial-based planning in disaster risk management	**SO-T** • Social-wide behaviour change and awareness on environmental issues • Cooperation and policy integration among municipalities in managing transboundary environmental problems and disaster risks • Smart (data-driven) natural resources and environmental management monitoring • Mainstreaming future-oriented risk-informed planning and disaster risk management • Public-private partnership on disaster risk management	**WT-O** • Urban-rural conflicts on natural resources and environmental management • Lacking integrated environmental and resources management among municipalities (esp. pollution and disaster risk reduction) • Increasing potential loss and damages due to climate-related hazards • More self-reliance on natural resources and food security • Effects of Mekong river crisis on local water management

5.2 Bandwidth of Possible Futures of Khon Kaen City

This section presents the process and the result of stakeholders' participatory scenario identification and construction. The scenario identification part is divided into two segments, urban development change bandwidth and climate-related hazards bandwidth. The second part articulates possible scenarios based on the identified bandwidths that enable the selection and construction of a plausible scenario for Khon Kaen city in the latter steps.

5.2.1 Urban development change bandwidth of Khon Kaen city in the future

This part presents stakeholders' participation and collaboration in formulating possible future urban development bandwidth based on possible trends of population change and land use change.

5.2.1.1 Population changes bandwidth

The study adopted two future population projection scenarios determined in the draft comprehensive plan (DPT, 2018) and the demographic consensus dataset reported by Khon Kaen Provincial Statistic Office (KKPSO) during 2008-2016 (KKPSO, 2017) as a basis for statistical extrapolation (linear) forecasting of the potential number of Khon Kaen city population in 2037. The year 2015 was used as a base year for the projection. It is important to note that the draft comprehensive plan defined Khon Kaen city's spatial scope, which partially covers ten local governments[26](not the whole Muaeng Khon Kaen district), or about 65 % of the Muaeng Khon Kaen district population. Since the draft comprehensive plan has been passed through political decision processes; thereby, this research adopted the draft comprehensive plan's boundary and expected population growth figures as a primary substrate for stakeholders' collaborative urban development forecasting exercise. The analysis shows that all three future population projections expected population growth at different pacing, 1.4%, 2.8% and 3.6% annually—the narrative assumption of these figures described in Box 5.1.

The proposed bandwidth of population growth in 2037 of Khon Kaen city, as shown in Figure 5.2 was presented and discussed with eight interviewees from six local stakeholder agencies and one national planning agency (see Annex 5). The discussion (in 2019) reveals that the majority of stakeholders agreed that Khon Kaen city will continue growing from now toward the end of 2037 with the bandwidth of population growth of 2.8% to 3.6% per year on average. No

[26] Khon Kaen City Municipality, Sila Town municipality, Samran Sub-district municipality, Mueang Kao Sub-district municipality, Phra Lap Sub-district municipality, Bueng Niam Sub-district municipality, Ban Ped Sub-district municipality, Ban Wa Sub-district local administrative organization, Tha Phra Sub-district Municipality, and Ban Kho Sub-district Municipality

one among the stakeholders anticipated that the population of Khon Kaen city would be declined or grow with a growth rate of 1.4% annually. Even though stakeholders expressed the population growth rates based on the draft comprehensive plan, this study generalized the growth rates to the whole district level boundary to ensure scale compatibility with climate-related hazards and public health care analysis in the later steps. It is important to remark data discrepancy in the draft comprehensive plan's population projection dataset. Ban Wa Sub-district local administrative organization and Tha Phra Sub-district Municipality/SAOs were not included in the draft comprehensive plan's spatial boundary; their number of inhabitants, however, were used to estimate population growth in the draft comprehensive plan and vice versa for Don Chang and Dang Yai Sub-district local administrative organisations. There is no explanation for this inconsistency in the document. This study tried cross-checking with a relevant KKPSO report. However, the report presents aggregated population figures of each municipality in Mueang Khon Kaen district, but sub-district local administrative organizations in the areas were rounded as non-municipal areas without detailed aggregation by local government organizations.

5.2.1.2 Land-use and development change bandwidth

The DPT's land use map (part of the draft comprehensive plan) served as a medium for the stakeholders future envisioning exercise. Eight representatives from six local stakeholder agencies and one national planning agency participated in the exercise (see Annex 5). The stakeholders were requested to envision possible urban development dynamics & direction, prominence investment projects, key driving factors, and changes in land-use types in a snapshot of 2022, 2027,2032 and 2037, respectively. The stakeholder expressed their idea through talking and drawing on the A4 size printed land-use maps[27] (see Annex 6). Voice records (with the verbal consent of the interviewees) and drawings were thematically analyzed and overlaid in order to create narration and visualization of possible land-use changes of every 5-year time step, from the present condition (2018) towards 2037 consecutively. For each future visioning snapshot, diversity and dissensus of stakeholders' inputs were consolidated and classified in the range of minimum and maximum levels of potential urban development changes. The draft elaboration and visualization of the future development change & land-use change of each time step (Figure 5.3.) were presented to stakeholders altogether with the figures of possible population bandwidth as part of the validation process (in 2019).

[27] The interviewee drawn his or her ideas on the printed map my himself/herself or asked the researcher (Wiriya Puntub) to do it on behalf of them.

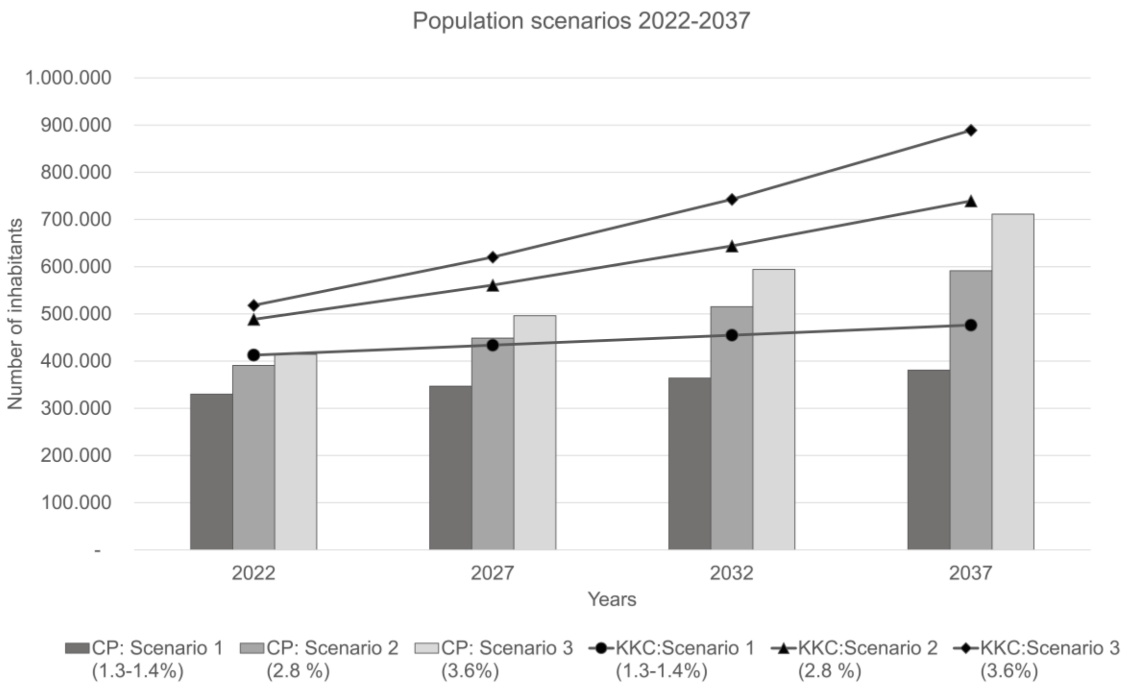
Box 5.1 Narrative of population growth projections

Low growth: Ageing society raises concerns at both the national and local levels. The growing population of Khon Kaen city might be lesser than the DPT's projections. In this regard, the historical population dataset from 2008-2016 was extrapolated with a linear forecast of 1.4 % per year population growth.

Medium growth: With potential public and private investment in the commercial, services, logistics and tourism industry, this scenario expected that the Khon Kaen city population might increase by 2.8 % per year.

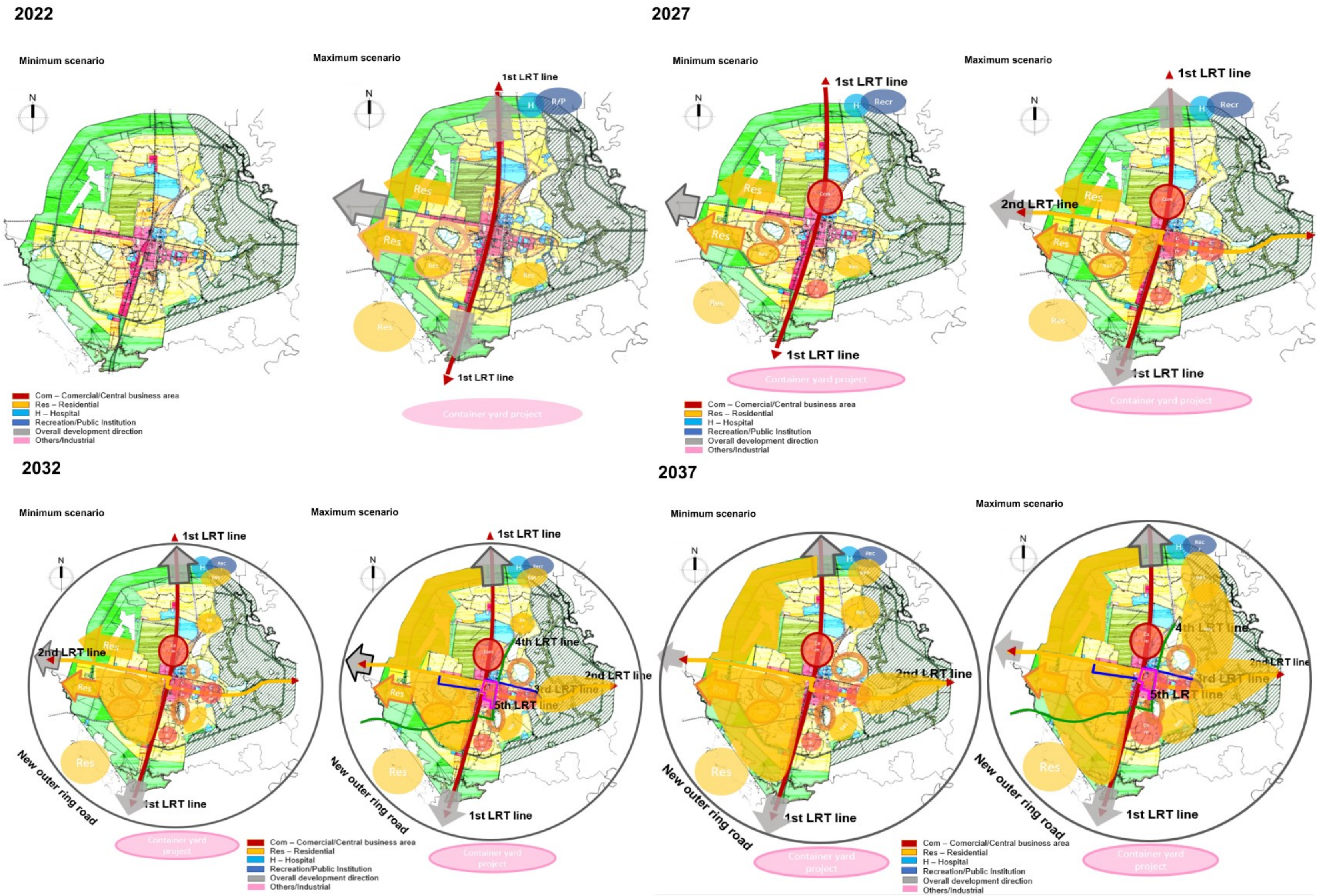
High growth: Higher local investment and expanding the local economy to GMS level could induce high population growth in Khon Kaen city. The role of Khon Kaen city as a premier regional hub for economy and services may attract more new inhabitants who are seeking employment and opportunities from neighbouring cities and countries. In this regard, the projected population could increase by about 3.6 % annually.

Figure 5.2 Bandwidth of forecasted population in Khon Kaen city during 2022 – 2037, within the scope of the draft comprehensive plan (CP) boundary (DPT,2018) and Mueang Khon Kaen District /Khon Kane city (KCC) boundary



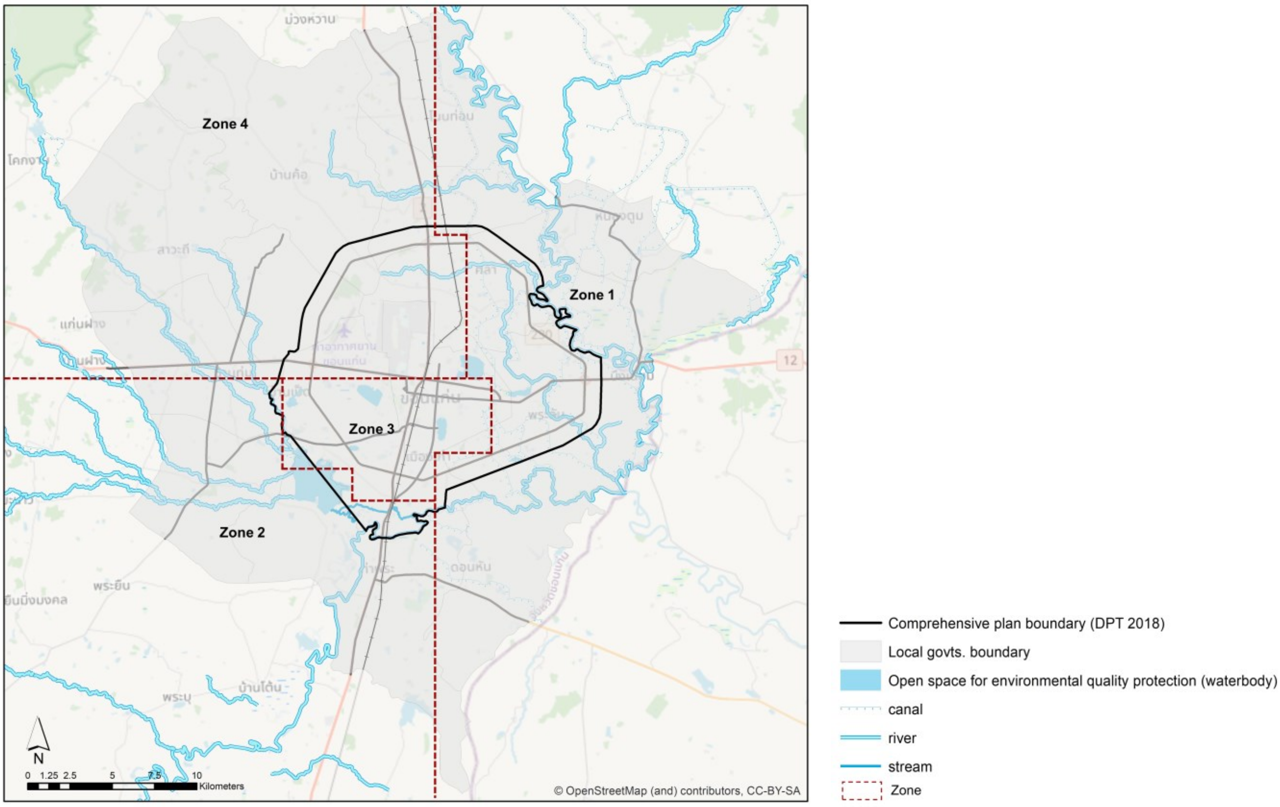
Source: Own illustration

Figure 5.3 Visualization of urban development bandwidths of Khon Kaen city during 2022-2037 based on stakeholders' inputs



To conceptualize spatial and temporal contradictory of possible future conditions, this research divided the city into four zones according to development, land use, and climate-related hazards profile; Zone 1 East and north-eastern area, Zone 2 Southern area, Zone 3 Central and south-western area, and Zone 4 Central north and north-western area (see Figure 5.4). In this regard, articulation of possible Khon Kaen city's land use and development change of each snapshot was aligned into minimum and maximum bandwidth as follows and summarized in Table 5.2.

Figure 5.4 Zone of Khon Kaen city based on urban development and potential hazards profile



Snapshot 1: Khon Kaen city's development bandwidth in (2018) – 2022

Minimum range: The minimum urban development change in the nearest projection was expressed by representatives from the planning agency (national and provincial levels). From their perspective, in 2022, the spatial development of Khon Kaen city will be in line with the draft comprehensive plan, which is meant to serve at least 5-year development changes before its review and revision cycle. Therefore, the enforcement of the agricultural land adjustment law and land use zoning was assumed to be fully effective in conserving Zone 1 to remain as agricultural and rural conservation areas. Meanwhile, the mixture between low-density residential areas and agricultural land can be found in Zone 2, especially the area beyond the existing outer ring road (bypass) which is dominated by farmland and rural livelihood. Junction of Mitrapap rd., (north-south), Maliwan rd. (west), and Srichan rd. (east) will be crowded with commercial use, government and public services, and high and medium-density residential development, particularly within the territory of Khon Kaen City Municipality, Ban Ped Sub-district municipality and some parts of Mueang Kao Sub-district municipality. Major land development of Zone 3 (especially the west-southern part of the city and eastern & southern adjacent to Khon Kaen City Municipality to the urban settlement section of Pralub Sub-district municipality and Mueang Kao Sub-district municipality) will be low-density residential characteristic. The landmark of the north-western part of the city remains Khon Kaen University and Khon Kaen international airport. In Zone 4, the medium-density residential area was expected in the northward of the university and the western part of Sila Town municipality. With the aviation regulation, high-rise building is prohibited in the northwestern part of the city; therefore, lands near the airport area are expected to remain agricultural areas with a potential to be developed as low-density residential areas.

Maximum range: Besides the planners, the majority of stakeholders anticipated a stronger signal of urbanization. The stakeholders anticipated upcoming major investment projects that will affect the city's land-use change, such as the extension of Khon Kaen international airport, land depot development, and the LRT project. The development of the LRT red line (north-south) will potentially induce an increase of the low-dense residential area towards the existing outer ring road in Zone 2. This mass transit is expected to attract more housing development for people who work in (light) industrial sites and logistic businesses in Tha Phra Sub-district municipality (southern part). At the same time, more inhabitants could be expected in Zone 3; thereby, a higher degree of medium density residential area could be found, especially surrounding Nong Kort Lake. Housing estate and condominiums will be a key densifying factor of this living quarter to be a medium density level. Scattered clusters of the residential areas in Ban Ped sub-district municipality and the area near Kaen Nakorn Lake may transform from low to medium density residential areas. Moreover, high land prices and strong land speculation in the inner-city may force middle-income families to live outside the city centre, where they can afford a decent house and daily commute by car to work and access public services concentrated in the city centre. Thus the expansion of low-density residential areas toward the western and northwestern agricultural frontiers is clear. This growth will go in the direction of Ban Thum Town municipality through Maliwan rd. (west), in connection with other satellite cities such as Ban Fang district. Despite a clear LRT red line development plan and the new branch of Khon Kaen University's hospital construction, an unclear signal of a significant land-use change in Zone 4 can be seen in this snapshot.

Snapshot 2: Khon Kaen city's development bandwidth in 2027

Minimum range: From the provincial planner's point of view, although several infrastructure investments could be realized in this time step, these developments may have no significant effect on land-use change. On the contrary, most stakeholders anticipated that minimum urban development change in 2027 would be a full implementation of maximum urban development change, which has been started in 2022. In this regard, substantial changes could be foreseen in Zone 2, Zone3, and the western part of Zone 4. This minimum level of land use change highlights the enlargement of the high-density residential areas induced by TOD development and LRT red line operation. This mass transit-led development may also occur surrounding Khon Kaen bus terminal 3 (the southern part of the city) and the Mitrapap rd.'s side (front gate) of Khon Kaen University (vicinity of Srinagarind (KKU) Hospital). In contrast, Zone 1 is the only area that may not have a significant land use change in this minimum scenario.

Maximum range: The maximum development range of Khon Kaen city of this time spot shares many common features of its minimum development range, except the LRT yellow line operation. Stakeholders emphasized the influence of the LRT yellow line in promoting the densification of the inner city quarter. LRT yellow line will increase CBD connectivity with the peri-urban areas and other satellite cities. At the same time, TOD development surrounding the LRT stations will accelerate the inner city's mixed-use, enhancing the smart and compact city vision of Khon Kaen City Municipality. In addition to the higher development in Zone 2 and Zone 4 as stated in the minimum development range, land use change in this maximum range will astoundingly occur in Zone 3. The eastern part of Zone 3, particularly the inner circle between Srichan rd. and Pracha Samosorn rd. could be transformed from a medium-density residential area to a high-density residential and commercial use. Meanwhile, in the western part of Zone 3, a higher degree of housing density can be expected toward the western side of the city. At this state, no stakeholders expressed concerns regarding the influence of the LRT yellow line on Zone 1's development.

Snapshot 3: Khon Kaen city's development bandwidth in 2032

Minimum range: The stakeholders outlooked that the minimum development level of this time step shares similar development features of maximum development in 2027, with adding some new elements in Zone 1, Zone 3 and Zone 4. In the western part of Zone 3, medium-density residential areas may emerge around Nong Kort Lake. At the same time, a higher degree of medium-density residential areas may enlarge from scattering cluster patterns to full coverage of the western side of Zone 3 toward the edge of the existing outer ring road. In other words, most of the urban settlements in Ban Ped Sub-district municipality may be intensified to medium density development. Besides a stronger signal of urbanization toward the western part of Zone 4, minor additional land-use changes may occur in its eastern segment of this zone, a few spots of medium density residential areas nearby the Bueng Thung Sang Lake area. The agricultural and rural conservation area in the northern part of Zone 1 may transform into low-density residential land use due to the magnetization of the new branch of the Khon Kaen university hospital. At this time spot, the stakeholders believed that the new outer ring road could be a new mark of urbanization boundary in the longer-term future, even though they could not give the detail of this new structure. Again, no stakeholders expressed concerns regarding the influence of the LRT yellow line on the land use change of Zone 1.

Maximum range: From the stakeholders' point of view, distinctions between the maximum range and the minimum one of this time step are the potential 2nd outer ring road (as the new urban boundary) and the operation of all (5) LRT lines. Completed construction and partially or fully operated LRT lines was defined as a key factor inducing residential areas' transformation in the western part of the city. In the eastern part of Zone 3, small residential areas surrounding Kaen Nakorn Lake could be denser (low to medium density). Moreover, the agricultural areas in Zone 4 could be transformed into low-density residential areas in 2032 to accommodate more inhabitants in the future. Once again, no stakeholders expressed concerns regarding the influence of the LRT yellow line and LRT green line on the land use change of Zone 1 and 2.

Snap shot 4: Khon Kaen city's development bandwidth in 2037

Minimum range: Minimum development level of this time step is perceived as the maturity of the maximum range of development in 2032, but excluding some LRT features. The planners (central and provincial planning agencies) anticipated that the LRT development plan might face barriers that may delay LRT Pink, Blue and Green lines operation. Hence, only 2 LRT lines (red and yellow) were expected to be included in the minimum development level in 2037.

Maximum range: The stakeholders envisioned that the maximum level of city development in 2037 would remain key features of its maximal development in 2032. However, all rural and agriculture conservation areas may turn to low-density residential areas in all directions. Particularly Zone 1, the extension of low-density residential areas may reach the edge of the existing outer ring road, despite being prohibited by laws. Nevertheless, it is important to mark that the degree of low-density residential area expansion might be lighter than other parts of the city.

It is clear that the stakeholders overlooked LRT development as a key factor leading and accelerating urban expansion to agriculture and rural conservation areas. With collaborative scenario planning, the researcher (Wiriya Puntub) complemented the stakeholders' inputs by including a possible influent of the LRT yellow line and LRT green line in converting the agriculture frontier and invasion of development to the flood-prone areas. This proposal is based on the assumption that, in the long-term, law enforcement might have to compromise with the housing needs and the right to be developed of the local inhabitants in flood-prone areas.

Table 5. 2 Bandwidth of urban development changes of Khon Kaen city 2022-2037

Bandwidth		Zone 1	Zone 2	Zone 3	Zone 4
(2018-) 2022	Minimum	Same as the draft comprehensive plan	Same as the draft comprehensive plan	Same as the draft comprehensive plan	Same as the draft comprehensive plan
	Maximum	Remain agricultural and rural conservation area	Development/operation of LRT red line (north-south) induces an increase of low-density residential development beyond the outer ring road (bypass), connecting with industrial areas and land depot in Tha pra sub-district area	• Similar to the Minimum development in 2022 • Transition from low-density to medium-density residential areas, especially surrounding Nong Krot lake and its nearby housing estate complex • Conversion of agriculture buffer to low-density residential areas • Expansion of very low-density residential areas from the edge of the existing outer ring road (bypass) toward other satellite cities in the west-south	• Development/operation of LRT red line • Construction of new KKU hospital (medical hub) • Promotion of recreation area (Puttamonthon Isan) and gastronomy businesses • Expansion of low-density residential area toward the west
2027	Minimum	Remain agricultural and rural conservation area	Similar to the Maximum development in 2022.	• Similar to the Maximum development in 2022 • Emergence of the commercial and high-density residential area surrounding the central bus terminal quarter (TOD area in connecting with LRT red line station)	• Similar to the Maximum development in 2022 • Transformation of the medium-density residential areas to commercial and high-density residential areas, surrounding the front gate of KKU university (connecting with LRT red line)
	Maximum	Most parts remain agricultural and rural conservation areas.	Similar to the Maximum development in 2022	• Similar to the Minimum development in 2027 • Development/operation of LRT yellow line • Expansion of commercial and high-density residential area covering the city section between Pracha Samosorn rd., and Srichan rds., and their adjacent • Strong expansion of denser degree of low-density residential areas toward the west	• Similar to the Minimum development in 2027

Bandwidth		Zone 1	Zone 2	Zone 3	Zone 4
				• Densification of medium residential areas surrounding Nong Krot lake and its nearby housing estate complex, and western adjacent of city core junction along Mitrapap rd,.	
2032	Minimum *(all zones: emergence of the potential 2nd outer ring road)*	• Extension of LRT yellow line through the area. However, the land use remains agricultural and rural conservation area due to the effectiveness of relevant laws enforcement. • Medium-density residential area in some part of the area nearby Beung Thung Sang (west and southern part of the lake)	Similar to the Maximum development in 2027	• Similar to the Maximum development in 2027 • Full coverage of the medium-density residential area in the west-south section of the existing outer ring road • The medium-density residential area surrounding Kaen Nakhon Lake	• Similar to the Minimum development in 2027 • Transformation of low-density residential areas to medium density residential areas of the central part of Sila town municipality, adjacent to KKU, and Ban Non-Muang, as well as TOD Tesco Lotus • Densification of the low-density residential area surrounding the new KKU hospital
	Maximum *(all zones: emergence of the potential 2nd outer ring road)*	• Similar to the Maximum development in 2022 • Conversion of agricultural and rural conversion areas along the LRT yellow line's strip to the low-density residential area	Similar to the Maximum development of snapshot 2027 but adding a new outer ring road	• Similar to the Minimum development of snapshot 2032 • Development of all 5 LRT lines, but not all of them are in full operation	• Similar to the Minimum development in 2032 • Full conversion of agricultural land (green buffer in the western and northern part) to low-density residential areas
2037	Minimum *(all zones: emergence of the potential 2nd outer ring road)*	Similar to the Minimum development in 2032 with enlargement of the low-density residential area along the strip of the LRT yellow line to reach the edge of the outer ring road	• Similar to the Minimum development level of snapshot 2032 • Expansion of the low-density residential area from Ban ped sub-district municipality towards the south edge of the new (2nd) out ring road circle.	• Similar to the Minimum development in 2032	Similar to Maximum level 2032
	Maximum *(all zones: emergence of the potential 2nd outer ring road)*	• Similar to the Maximum development in 2032. • Expansion of the low-density residential area reaches the edge of the outer ring road. However, the degree of density is lower than the residential strip along the LRT yellow line	• Similar to the minimum development level of snapshot 2037	• Similar to the Maximum development in 2032	Similar to Maximum in 2032

5.2.1.3 Validation of possible land-use and development bandwidth

This study conducted two rounds of stakeholders validation on possible future urban development bandwidth of Khon Kaen city, during March 2019 and February-March 2020, respectively (Annex 5). The first draft of Khon Kaen city's development bandwidth was presented and discussed with stakeholders to gain feedback and validation. All stakeholders agreed on the draft and no further substantial comments on the key features of the Khon Kaen city's future development bandwidth but rather deepened emphasis on specific issues as follows.

- **The emergence of a new development node**

Bann Thum Town municipality is situated outside the draft comprehensive plan boundary but increasing its attractiveness for housing and real estate development as a perfect place for people to work in industrial /warehouse areas and live not far from the city centre. Vice versa, people who work in the city but could not afford a house in the city centre area or who prefer to get away from urban stress can daily commute between the inner city and peri-urban area. A similar pattern can also be found in the southern part of the city. The north-western part of the city is not the best for agriculture due to low soil quality and limited irrigation system; therefore, housing and industrial development seem more suitable land use. However, the increasing popularity of development in peri-urban areas is a key challenge for the inner-city quarter to improve development densification and compact city strategy.

- **Believe in law and order**

Even though the LRT yellow line may trigger urbanization and induce more development in the flood-prone areas, but enforcement of the existing laws and flood risk concerns could result in preserving the areas along the east bank of Phra Khue stream and Phong river as a rural livelihood or transform to a very low-density residential area in a low pace. Therefore, the low-density residential area in this zone would meet the limit at the edge of the river's bank rather than fully extend toward the existing outer ring road, at least for the minimum bandwidth.

- **Population change and land-use change relation**

The stakeholders were also asked about the possible effects of different level population trends on the future land use change dynamic. Interestingly, the stakeholders believed that different population trends would not significantly affect land use types but rather their degree of change, particularly residential use. For example, the low-density residential area (yellow) of Ban Ped Sub-district municipality would eventually transform into a medium-density residential area (orange). However, different spectrums of the population trends may differ in the intensity degree of medium density area as darker or lighter shed of orange.

The inputs from the first stakeholders' validation process were integrated and visualized. Then the bandwidth of urban development change of Khon Kaen city in 2037 was presented again to a wider group of stakeholders representing central and provincial planning agencies, provincial government, local governments, private sector, academia, and civil society[28], as a part of the second validation process. 14 individual discussion sessions were organized during 5-13 February 2020 (Annex 5), and a stakeholder workshop[29] was held on the 1st March 2020 (see Annex 15). In this second stakeholder validation, all stakeholders agreed with no objection or further comments on urban development bandwidth. Nonetheless, there was a suggestion to include a non-registered population dataset in the population forecasting. Unfortunately, there is no concrete research or reports published by responsible agencies, specifically in the study area's scope. Therefore, the issue is then included as a suggestion for future study.

5.2.1.4 Possible urban development of Khon Kaen city in 2037

According to the stakeholders' participatory and validation, the possible bandwidth of Khon Kaen city's urban development in 2037 is visualized in Figure 5.5 and elaborated as the following:

- **Overall development and land-use change**

In 2037 Khon Kaen city remains its size as a medium growing city with a growth rate of about 2.8 – 3.6 per year on average. By the end of the 20-year national strategy timeframe, the city (according to Mueang Khon Kaen district administrative boundary) may accommodate around 739,380 – 889,084 inhabitants[30]. Nonetheless, these population figures yet take to account the non-registered population and daytime commuters who live outside the city core. Despite the fact that the local birth rate might decrease, redevelopment and infrastructure investment would attract young generations and employable populations from all directions to live and work in Khon Kaen city. The boundary between urban and rural life becomes obscured. The urban setting will continue to expand beyond the draft comprehensive plan boundary in almost all directions. Instead of the current outer ring road (bypass), the new (2nd) outer ring road could indicate the boundary of urban settlements in the future. Gaps between the minimum and maximum development range in 2037 are the degree of transportation infrastructure development and spatial expansion of urban residential areas towards the eastern part of the city; meanwhile, other key development features are indistinct. The following provides details of these spectral changes in each city's zone in 2037.

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[28] Civil society group was represented by Esan-Biz's role whose role however, not typical and radical civil society but rather act as a coordinator in bridging different parties and interest groups to discuss the future development of Khon Kaen under the umbrella of Khon Kaen's work Community for the Future Foundation

[29] The workshop was organized by Khon Kaen Community for the Future Foundation and College of Local Administration, Khon Kaen University (COLA) on the 1st of March 2020 at COLA

[30] If considerting the draft comprehensive plan (DPT,2018) boundary, there could be around 591,504- 711,267 inhabitants live in the plan area, or almost 1 time the number of local populations today (2018).

Zone 1 East and North-eastern

The areas are under the enforcement of the land adjustment for agriculture regulation and Khon Kaen city comprehensive plan to function as a rural and agriculture conservation area. This zone is well-equipped with irrigation infrastructure; thereby, rice farmers can do a second crop. Besides ageing farmers and lacking agricultural labours, local agriculture activities might be abandoned in the hands of young generations who tend to work in service and public sectors rather than continue family farming hereditary. Daily commuting will be more convenient. The LRT yellow line will provide the rural inhabitants access to public services and an urban lifestyle and induce more urban settings. The development may firstly densify along the strip of the LRT yellow line and then spread out. In addition to these key features, ***Minimum*** development changes in this zone are an expansion of relatively very low-dense residential areas towards the left edge of Phra Khue stream and Phong river. Meanwhile, the right-side of the riverbanks will remain preserved as rural and farmland. From the ***Maximum*** possible development changes point of view, very low-density residential areas may not stop at the left side of the riverbank but enlarge to reach the edge of the existing outer ring road. In 2037, the nearest rural frontier may be found farther from the existing outer ring road circle.

Zone 2 Southern

Zone 2 is an intermixed between residential areas and green buffers (agriculture area with potential to convert to residential area). The area interfaces industrial & logistic development in Tha Pra Sub-district municipality and the TOD development around the main bus terminal & commercial stripe along Mitrapap rd. This setting makes this zone fit for housing development for the industrial employees and middle-income groups who could not effort to live in the inner-city. As a result, all farmland located between the existing outer ring road (bypass) til the edge of the (potential) 2nd outer ring road may become low-density residential areas. Kaeng Nam Ton Lake is a nice blue-green infrastructure in which its surrounding areas could be quickly claimed or purchased by middle to high-income groups for housing development[31]. In this regard, this zone can expect a higher degree of residential development replacing the green buffer (farmland). Meanwhile, the area beyond the draft comprehensive plan boundary also is anticipated as low-density residential areas. Both minimum and maximum development levels share these key features. Except that the ***minimum*** development level expects the LRT red line to be operated and connected the areas with the inner-city, but the ***maximum*** development level ensures an additional LRT green line operation in this zone, which may accelerate the development in a flood-prone area/local vegetated floodplain.

[31] This anticipation is in line with the fact that the lake will be developed as a new local landmark in the near future (by RID).

Zone 3 Central and South-west

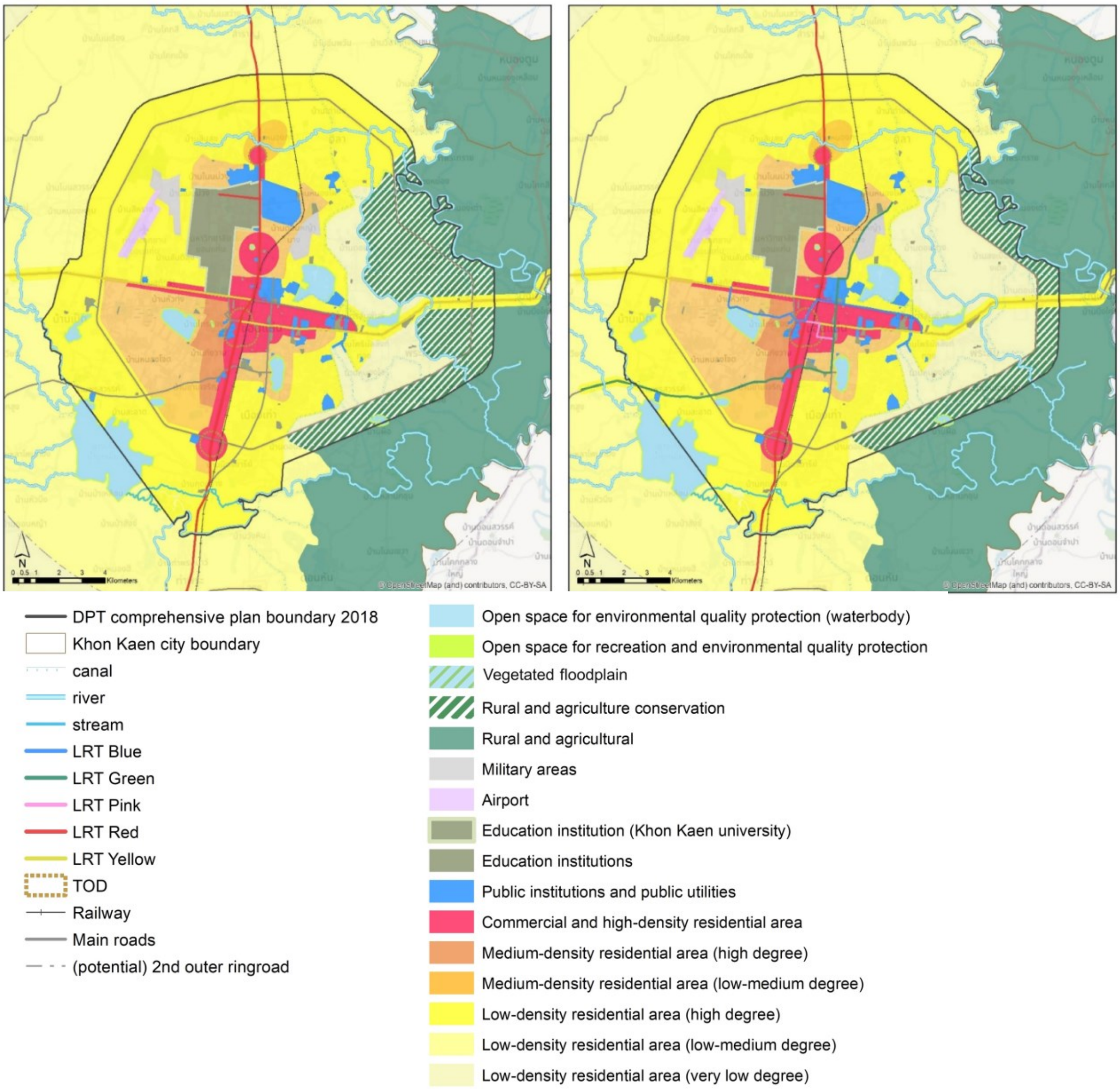
High-density residential and commercial areas will concentrate within the existing CBD, old town tracts and new TOD clusters. Next to the high density residential and commercial areas are medium-dense residential areas that cover most of the inner part of the existing outer ring road (bypass) in the southwestern quarter of the city. A higher densification degree of low-density residential areas can be expected in the transition zone between the area outside the existing outer ring road and farther east of Khon Kaen City Municipality boundary & urban setting of Pralub Sub-district municipality. LRT development is the key feature that distinguishes minimum and maximum future development levels of this zone. The ***minimum*** case assumes that only LRT red line and LRT yellow line will be completed and fully operated in 2037. However, an argument for ***maximum*** development is that all 5 LRT lines will be completed and cost-effectively operated at that time. Higher LRT connectivity may increase passengers' mobility and economic activities, although the key features of land use change in the inner city remain no substantial distinct from the minimum development level. The compact city concept will be realized through vertical growth and mixed-use in linking with LRT lines under the Smart City initiative, especially commercial stripe along Mitrapap rd. and TOD clusters in the city centre and the old town tracts (Srichan-Pracha Samosorn tracts).

Zone 4 Northwest and Central north

It will be (almost) no difference between the **minimum** and **maximum** urban development degree in this zone. Urbanization is anticipated beyond the draft comprehensive plan boundary by covering Ban Thum Town municipality, Samran Sub-district municipality, and Dang Yai Sub-district local administrative organization. Enlargement of low-density residential areas that transform farmland into housing will explicitly emerge to respond to increased demands such as light-industrial employees who work in the urban fringe and high-skill workers who commute daily to work in the city centre. When more people live there, a more economic of scale would be for infrastructures and public services. The closer to the city centre, the denser the residential area would be. The prominent commercial node in the northern side of this zone may be surrounded by medium residential areas connected with the university quarter's high-density commercial centre, where students have strong purchasing power.

Figure 5. 5 Urban development change bandwidth of Khon Kaen city in 2037

a) Minimum development change scenario b) Maximum development change scenario



5.2.2 Climate-related hazards bandwidths of Khon Kaen city in 2037

This research worked closely with the local experts to bridge the gaps between global climate trajectories and local climate scenarios (see Annex 7) in order to identify possible climate-related hazards bandwidths of Khon Kaen city in 2037. This study adopted bias-corrected and high-resolution downscaling (25 km x 25 km) of the Global Circulation Model dataset, the European Community Earth-System Model (EC-EARTH) under the Representative Concentration Pathway scenarios, RCP 4.5 and RCP 8.5, exhibiting intermediate and extreme climate scenarios during 2021 – 2050. This study focuses on three major hydro-meteorological hazards in the study area; fluvial flood, pluvial flood; and water scarcity. The result of the climate-related hazards bandwidths development is as follows.

5.2.2.1 Fluvial flood bandwidth

The minimum and maximum bandwidth of the possible fluvial flood scenarios of Khon Kaen city in 2037 can be described below.

Minimum bandwidth: The recent worst-case event, maximum discharge ever measured at Stream Gaging Station E.22B is 649.10 cm^3/s (river capacity 434 cm^3/s) which caused the flood level at 152 m from the mean sea level (MSL) occurred on the 21st October 2017 was proposed as minimum fluvial flood bandwidth by experts and stakeholders. The proposed minimum fluvial flood bandwidth assumes a possible failure of the existing and planned structured flood protection measures, e.g. flood barriers, dikes along Phong river, etc. As a result, 152 m MSL, the current informal local fluvial flood management threshold, was applied for further geospatial analysis as well as communication with stakeholders.

Maximum bandwidth: Precipitation parameters of the climate downscaling dataset under RCP 4.5 and RCP 8.5 of the focused sub-watersheds were analyzed. 99th percentile of maximum daily rainfall (of a calendar month) of both climate project datasets was used as inputs for the local discharge calculation with the dimensionless unit-hydrograph technique (see Annex 8-9). The result shows that there is a possibility that the Phong river will receive 803.67 cm^3/s (at Stream Gaging Station E.22B) in the future. In other words, the fluvial flood could reach 155 m MSL if the existing and planned structured flood protection measures were failed.

In this regard, Figure 5.6 visualizes the proposed bandwidth of possible fluvial flood based on 2D Digital Elevation Model (DEM), 152 -155 MSL and its possible spatial extension (2 dimensions) through Khon Kaen city in the future.

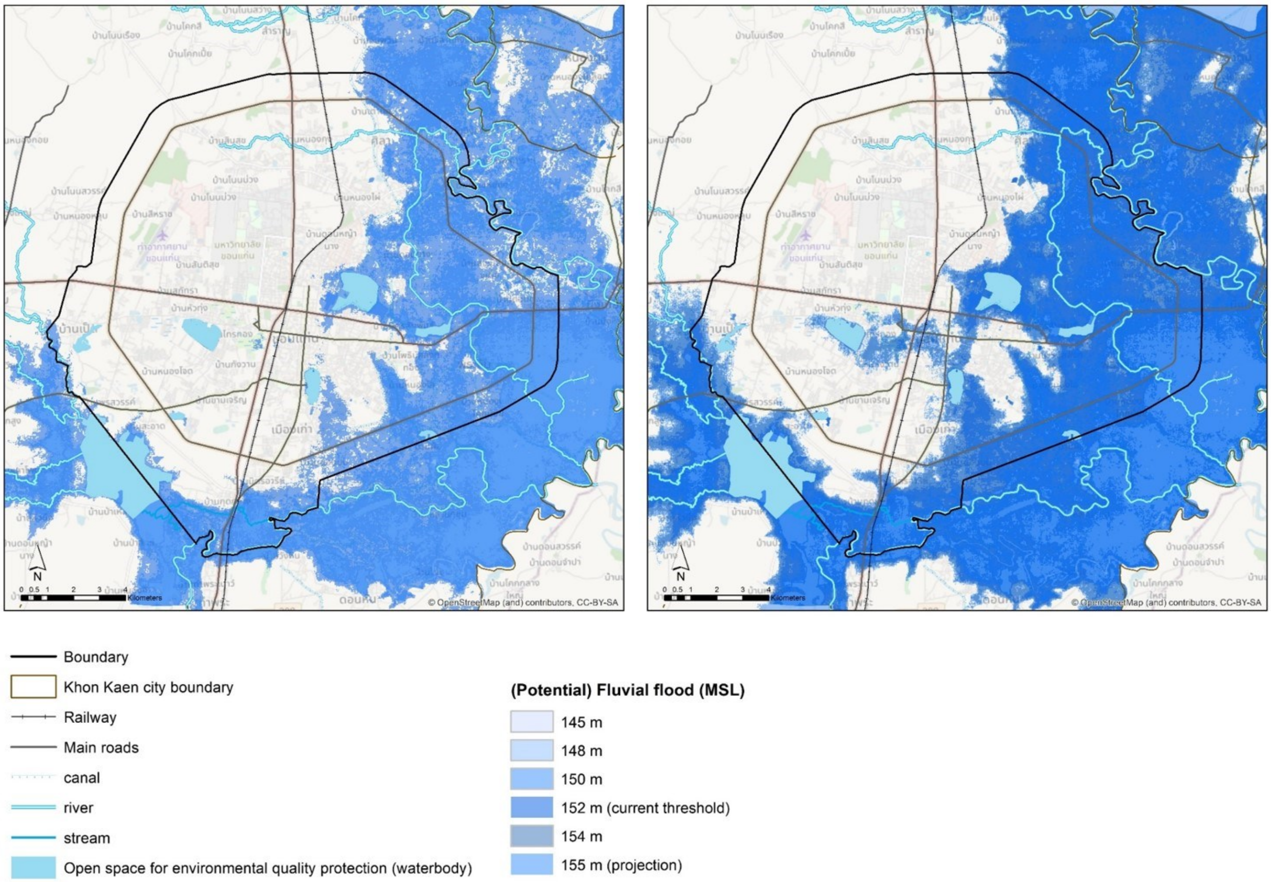
5.2.2.2 Pluvial flood bandwidth

As described in Chapter 4, too much rain is not the only cause of a pluvial flood in the study area, but it highly depends on the drainage system's capacity and land cover change. With the urban growth prospect, it is fair to assume that more sealed surfaces and built-up structures could prevent infiltration, accelerate the time of peak run-off, and block the waterway, leading to intensifying pluvial flood. Uncontrollable land cover changes and landscape modification are also key factors that induce urban inundation at the micro-level. Lack of technical benchmark in land excavation and flood-proof landscape design is a common cause of flooding after less than an hour of continuous heavy rainfall in Khon Kaen city, even in high terrain locations such as Khon Kaen University. Due to lacking a future-oriented high-resolution geospatial data, the study could not conduct such high-resolution pluvial flood simulation (such as applying the FloodArea^{HPC} software model), which allows specifying spatial extension of affected buildings and magnitude of pluvial flood in the future of the study area. Therefore, the study assumed that everywhere in the study area has a chance of pluvial flooding regardless of its elevation level. In other words, the proposed possible pluvial flood bandwidth in the future is binary of yes and no, as maximum and minimum levels.

Figure 5.6 Possible bandwidth of fluvial flood scenarios of Khon Kaen city in the future

a) Minimum climate-related hazard scenario (152 m MSL)

b) Maximum climate-related hazard scenario (155 m MSL)

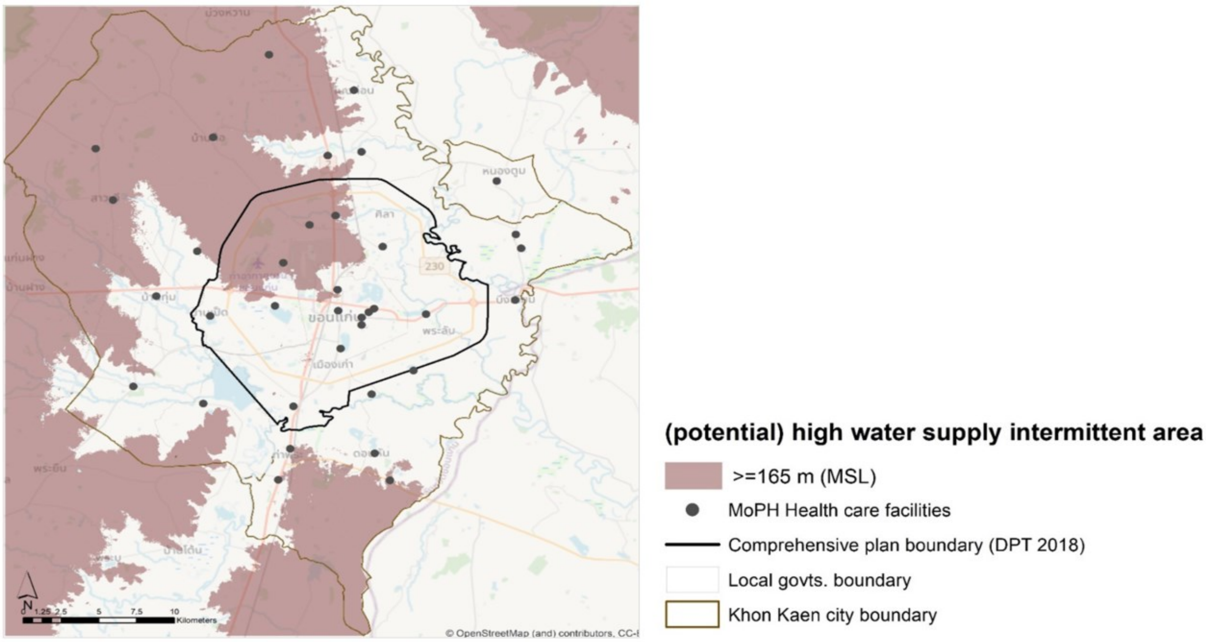


5.2.2.3 Water scarcity bandwidth

According to local water experts, Khon Kaen city almost fully relies on water resources from the Ubonrattana dam. Therefore, the city water supply situation can be monitored from an average annual rainfall value. Based on local practice, the water supply crisis usually depends on an average annual rainfall of less than 1,100-1,200 mm/year for four consecutive years. In this regard, the study arrayed the 90th percentile average annual rainfall of RCP 4.5 and RCP 8.5 climate projection datasets during 2021-2050, compared with the local drought index adapted from the RID (see Annex 17). Thereby, the four consecutive years with the amount of annual rainfall of less than 924.2 mm/year were highlighted as a possible period water supply crisis in the study area. Annex 17 shows that in the maximum case, Khon Kaen city might experience serious water scarcity for at least three major periods from the 2020s to 2030s. Moreover, the projection dataset revealed that the possibly longest consecutive period of no rainfall (less than 1 mm/day) is 144 -155 days, and the maximum daily temperature could reach 47.1 °C.

Drought could lead to insufficient qualified raw water feed to the production system, disrupting water supply manufacturing and delivery for the whole city. In general, the effects might not equally be distributed. However, to specify locations or spatial extension of the problem in a long-term perspective is required a separate study to understand the engineering and technological complex of the local water supply pipeline network. Regarding these limitations, this study assigned the bandwidth of possible water scarcity occurrence as a binary between yes (maximum) and no (minimum). Nevertheless, it is fair to assume that a low amount of water fed to the system could cause low pressure in the pipeline network, which generally relies on gravitational force. Therefore, high elevated areas could experience more technical difficulties and investment costs in water supply delivery than the low flat terrain. 165 MSL and higher were proposed to the stakeholders as possible locations where technical and investment concerns on water supply infrastructure and service delivery may exacerbate the water supply crisis (see Figure 5.7). Nevertheless, it is important to note that 165 MSL is not a benchmark but suggests a potential distinct degree of water scarcity exposure. Therefore, specific research on this matter must be further investigated.

Figure 5.7 High terrain area where potentially have technical and investment cost concerns on water supply infrastructure and service delivery of Khon Kaen city



5.2.2.4 Validation of possible climate-related hazards bandwidth

This study conducted two rounds of stakeholders and experts validation on the possible climate-related hazards bandwidth of Khon Kaen city in 2037 (see Annex 5). The bandwidths were visualized and elaborated to the stakeholders and experts. All stakeholders agreed with no objection or further comments but rather shared their experiences in dealing with the climate-related hazards and critiques on disaster risk management of responsible agencies.

5.2.3 Possible scenario construction and plausible scenario selection

5.2.3.1 Possible scenarios alignment

The 2 x 2 matrix was applied to combine the bandwidths of possible future urban development change and climate-related hazards into four possible scenarios as follows

1) Minimum urban development & Minimum climate-related hazards (Fig 5.8a);
2) Minimum urban development & Maximum climate-related hazards (Fig 5.8b);
3) Maximum urban development & Minimum climate-related hazards (Fig 5.8c);
4) Maximum urban development & Maximum climate-related hazards (Fig 5.8d).

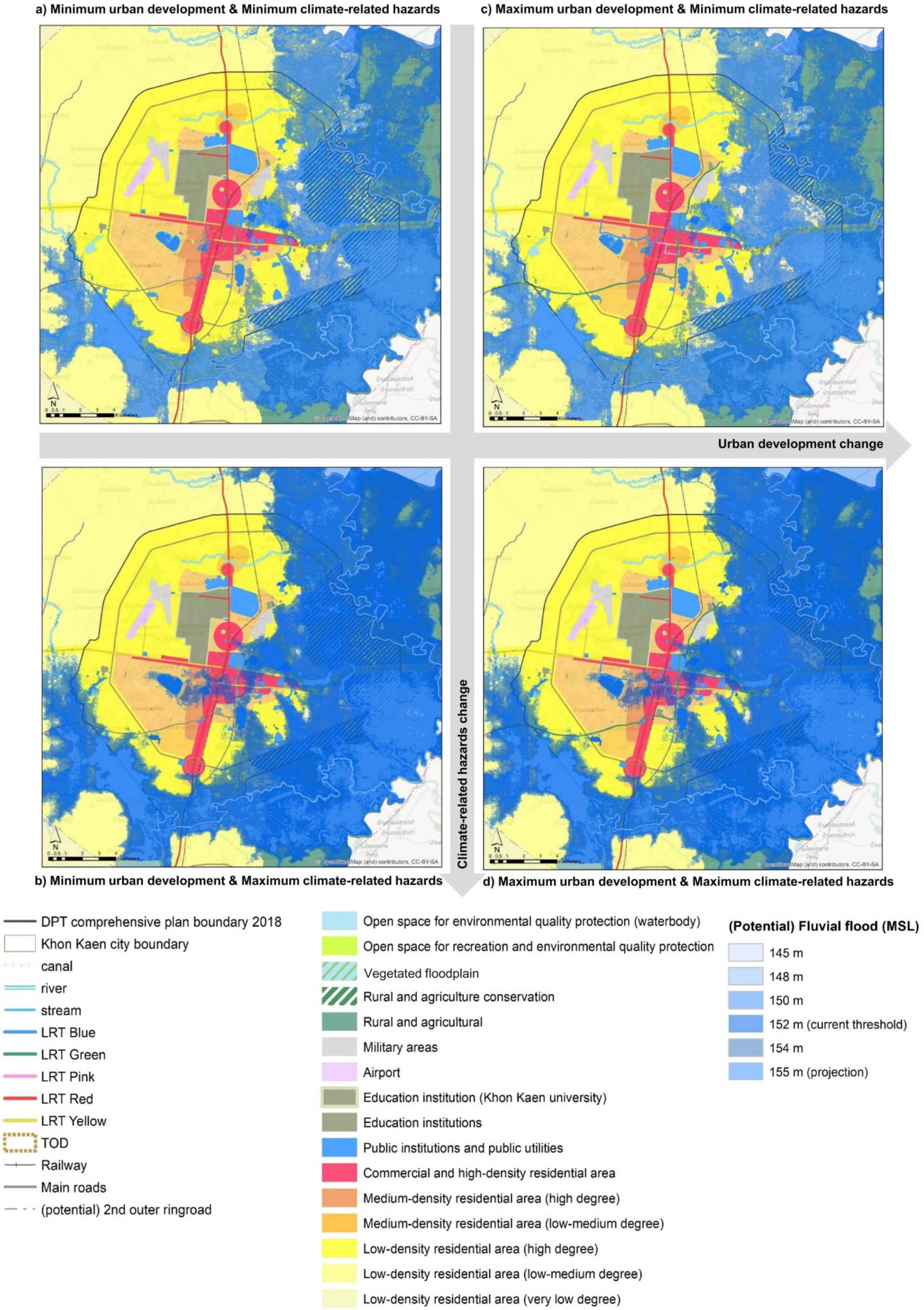
The possible scenarios of Khon Kaen city's urban development and climate-related hazards in 2037 were visualized and elaborated to 11 representatives of relevant stakeholder agencies through bilateral discussions, including central and provincial planning agencies, provincial government, local government, private sector, and academia (see Annex 5). All stakeholders have no objections to the proposed bandwidths and a combination of the proposed scenarios. Figure 5.8 shows the overlay between the future urban development changes and fluvial flood levels according to the proposed possible scenarios.

5.2.3.2 Plausible scenario selection

The study subjectively encompassed the plausible scenario selection based on stakeholders' preferences in potential impact mitigation rather than paying extensive focus on every scenario variation. This reduction ensures stakeholders motivation throughout the lengthy process of collaborative scenario planning under the context of this minimal research setting. Thus, the stakeholders (Annex 5) were asked to select one out of the four possible scenarios to represent a plausible Khon Kaen city development scenario under climate change context in 2037[32], the so-called "**Trend scenario**" (or stakeholders preferred/selected plausible scenario). The interview survey results show that 10 out of 11 stakeholders (or 91 %) chose the combination of maximum future urban development and maximum climate-related hazards as "Trend scenario" for this study. Only the provincial planning agency representative thought that the combination of minimum urban development & maximum climate change could be plausible in the future. Thereby, the majority of stakeholders selected overlay of maximum urban development change and maximum climate change. To set up the "Trend scenario" storyline, interaction analysis and impact chain analysis were conducted to enhance understanding and define key elements for the potential impact assessment of the local public health service.

[32] Due to limited resources and to reduce complication of cognitive thinking barriers of the stakeholders in contrasting slighly distinctions among the 4 scenarios

Figure 5.8 Overlay between the future development change and possible fluvial flood level according to the proposed possible scenarios



5.2.3.3 Interaction analysis

This study structured the interaction analysis between urban development and climate change of Khon Kaen city into two layers, city-wide and public health-specific. Firstly, this research analysed urbanization and climate change interaction based on their vertical and horizontal cause-effect relationship under the “Trend scenario”. The relationships were outlined into five key features 1) growing population and population density; 2) increasing consumption of natural resources; 3) increasing of built-up areas and impermeable surface; 4) increasing public transport network; 5) losing farmlands and rural environment. Secondly, this section aims to contextualize the interaction among urban development, climate change, and local public health service that is used for conceptualizing the climate impact chain and formulating the potential impact assessment framework for the local public health service in the later steps.

1) Urbanization and climate change interaction

The interactions between urbanization and climate change were explained in terms of feedback loops; positive feedback loop reinforces and/or amplifies an effect; negative feedback loop is the conditions that diminish and/or dampen an effect, and neutral. Some interactions may not be able to assign due to a lack of supportive literature or studies. Considering the causal relationship focused not only on the local climate system but also on how the urban sphere could influence regional and global climate. Figure 5.9 visualizes the interaction between future urban development and climate-related hazards of Khon Kaen city, which can be elaborated as follows.

- **Growing population and population density:** In theory, hazards are defined as a push factor that negatively impacts urban expansion. Many countries have legally withdrawn building rights or prohibited further development in the hazard-prone area and conserved the land for flood protection purposes (Greiving et al., 2018). However, in a growing city like Khon Kaen city, weak law enforcement and lack of accountability often lead to insufficient development control in urban proximity hazard-prone areas. Heavy land speculation is also a major force driving people to trade-off between a cheaper house and occasionally major flood events, which may happen or not happen once in a lifetime. In association with insufficient public awareness and risk communication, the short-term economic reason often wins over risk management. An increasing population usually demands more built-up structure and decreased permeable surface, leading to more exposed elements and possible prolonged duration and intensified climate-related hazards. In this regard, increasing population and population density has conceptually positive feedback to exacerbate the severity of hazards and the level of loss and damage to society. However, these interactions are often limited at the local level or downstream areas rather than extending to the regional scale.

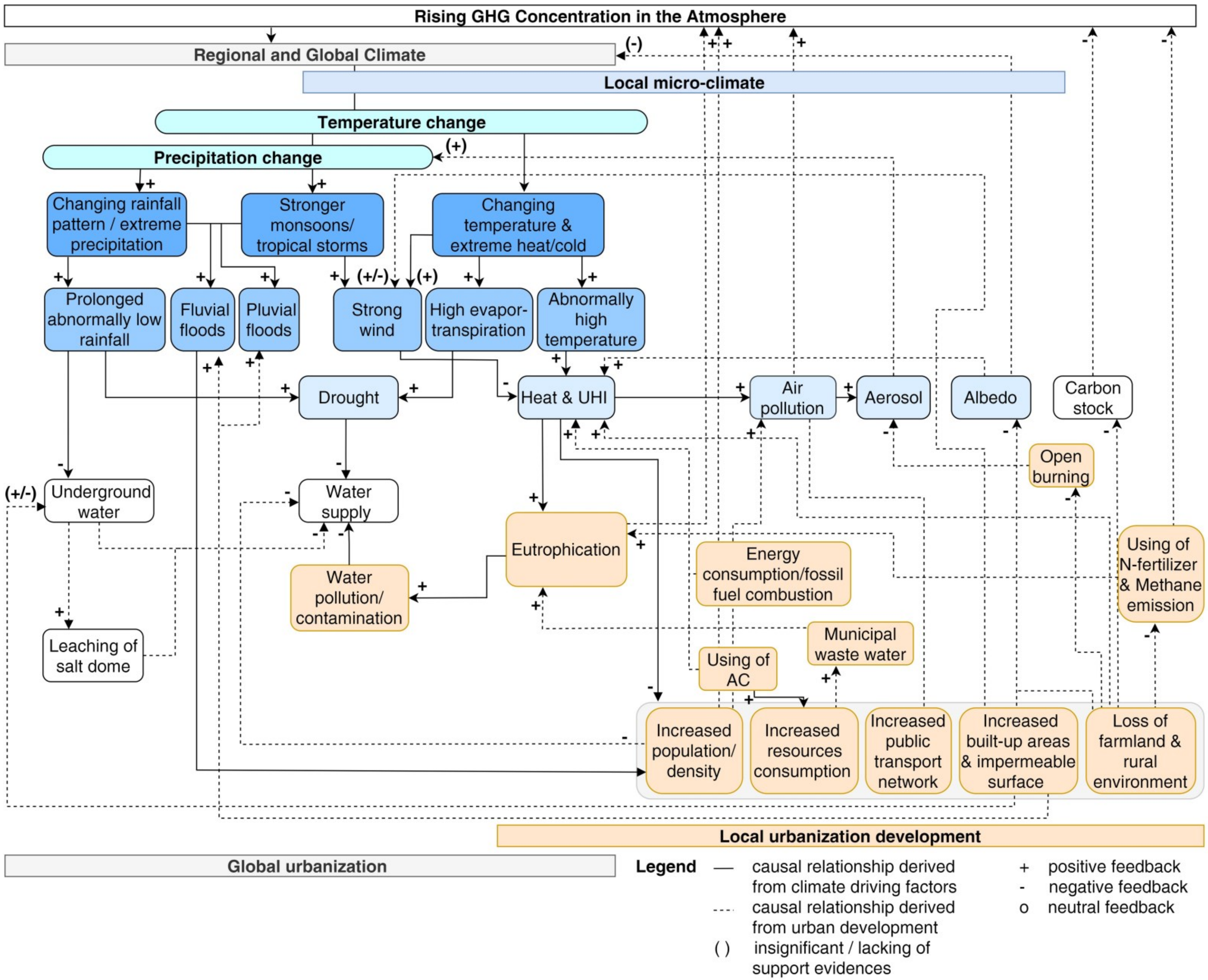
- **Increasing consumption of natural resources:** More people live in a growing city, and more metabolism of urban lifestyles drives increased natural resources consumption; thus, higher emissions and disposals. A city's intensive energy and resource consumption generates GHG emissions directly on-site and indirectly elsewhere. In Khon Kaen city, GHG emissions within the city boundary are mainly caused by direct combustion and emission from the local transportation, waste, agriculture sectors, and light-industry activities. These on-site (direct) GHG emissions send positive feedback to modified urban and, regional & global climate layers. In association with seasonal air inversion phenomena and high air temperature in the future, urban heat may worsen air pollution, especially in dense urban settlements, e.g. PM 2.5, which raises the locals' serious health concerns. As generally projected, the future extreme temperature of Khon Kaen city could potentially be 45-47 C°. However, this extreme heat has yet to account for heat emission due to a large air conditioner usage in the city. Chapman et al. (2019) report that this anthropogenic heat emission could have positive feedback on urban heat island effects that modify the local temperature on top of global warming alone. Moreover, according to Wiesner et al. (2018), the interaction of urban effects on local and regional precipitation due to anthropogenic aerosols acts as cloud condensation nuclei, urban heat island effect, and increased surface roughness may conceptually contribute to downwind local rainfall. However, the evidence in the following studies, Schlünzen et al. (2011), Yan et al. (2016) and Wiesner et al. (2018), show that this feedback loop is highly uncertain to assign. In the near future of Thailand and Khon Kaen city, a central wastewater treatment system is not common practice and is hard to be realized. Although 50% of municipal wastewater generated within Khon Kaen City Municipality is treated, and the majority of households and buildings have their own independent wastewater septic tanks, the water pollution issues have been publicly despicable. This problem is especially extreme during a dry season when heat triggers eutrophication while insufficient freshwater dilutes the pollution. Besides contributing to methane (CH_4) emission to the atmosphere and the nuisance of unpleasant smells, water pollution impacts also occur to the rural inhabitants whose livelihood depends on the water quality of natural water bodies. Vice versa, the water pollution/contamination due to the agriculture activities of the upstream farmland and aquaculture also significantly affects the quality of raw water for tap water manufacturing and underground water resources, which subsequently impacts the urban water supply system. In this regard, regional climate change is not the only factor triggering the local water scarcity, but urban wastewater management and rural agriculture activities are also major factors that negatively impact the availability of urban water supply.

- **Increasing built-up areas and impermeable surface:** Urban expansion modifies Khon Kaen city land cover. More built-up areas increase the roughness and impervious surface of the city. Built-up areas influence the micro-climatic process by changing the thermal properties of surfaces (e.g. sealed surface, heat storage capacity, reduced evaporation possibility) and contributing to increased roughness of the surface. Buildings impact wind speed reduction; however, local flow channelling can occur, especially within street canyons facing the larger water areas (e.g., a wide river). In addition, more urbanized Khon Kaen city shows lower albedo than its rural surroundings. Conversion of vegetation land or rural area to urban settlements could cause reduced albedo, contributing to increases in air and surface temperature that characterize the UHI. However, roofs and pavements with high solar reflectance can mitigate UHI at the local level and decrease the atmospheric temperature at the regional and global levels. Furthermore, the urban expansion of Khon Kaen city may increase the ratio and modify the impervious surface distribution, influencing the local and regional flood risk. Impermeable surfaces of urban areas also prevent water infiltration and limit local underground water replenishment. On the contrary, the leaking of Khon Kaen city water supply and wastewater infrastructure might generate a large amount of underground water recharge and possible contamination. In Khon Kaen city, balancing the underground water table is crucial in preventing the leaching of the underground salt dome, which may cause serious problems for the industry and agriculture sectors as well as secondary sources of the local water supply of the city.

- **Increasing public transport network:** Khon Kaen city is dissected by Mitrapap rd. and then cross-cutting into quadrant by Maliwan rd. and Srichan rd. Road transportation is currently the main transportation mode in the city. Nevertheless, the shortcoming investment in the public transportation network considered the mixed-use integration concept under TOD would significantly reduce air pollution and mitigate GHG emissions from motorized vehicles (in parallel with a cleaner technology). However, at the same time, a transportation network could accelerate urban expansion, especially in the rural frontiers and flood-prone areas of the city.

- **Losing farmland and rural environment:** Reducing agricultural areas generally creates negative feedback to the regional climate system in terms of less GHG emissions such as CH_4 and N_2O from rice cultivation activities and CO_2 from open burning. In contradiction, decreasing and losing farmland and rural environment means losing carbon stock and sequestration, and dropping flood retention capacity, meanwhile generating positive feedback to the local heat budget. These are yet mentioned socio-environmental effects such as food security, environmental health, biodiversity, etc.

Figure 5.9 Interaction between future urban development and climate-related hazards of Khon Kaen city



Source: Own illustration

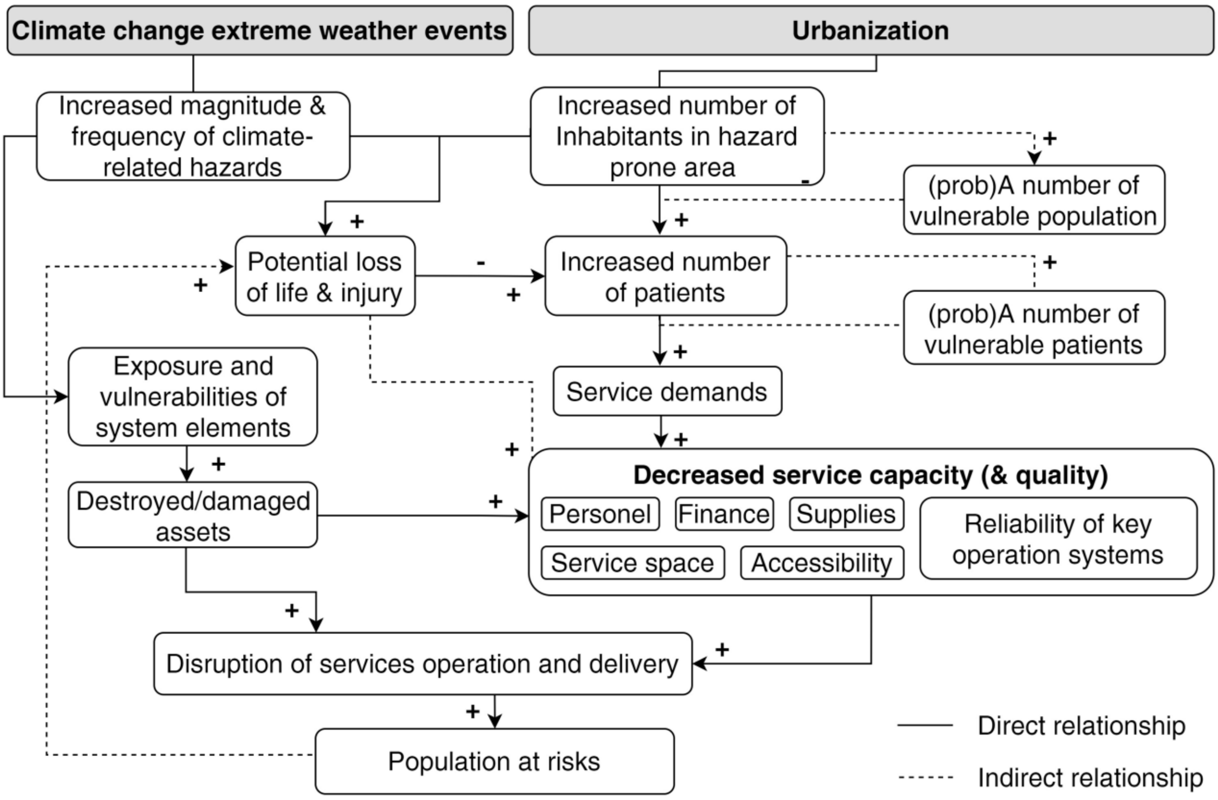
2) Interlinkage of urban development climate-related hazards and public health service outcomes

Interaction across biophysical scales between Khon Kaen city and broader climate layers are profoundly embedded in the city's socio-economics activities and land use changes. It is crucial to understand how the interactions imply and interlink with the local public health service. Health sector often finds difficulties relating themselves to the long-term perspective of climate change, which is beyond short-term response to hazards or medical-related issues such as heat stroke or climate-related emerged or remerged diseases. Figure 5.10 conceptualizes the interlinkages among urban development, climate-related hazards, and the local public health service in order to contextualize and operationalize how urban development and climate risk affect public health service and population health.

A demographical setting determines a public health service capacity, such as specialities, personals, financial resources, supplies, service space, accessibility, reliability of key operating systems, etc. A setting of public health care facility's service capacity mainly depends on the number of population in their service catchment area and its function in the service network. In theory, a more advanced hospital has more vulnerable patients under care, in terms of both acute level and quantity; meanwhile, patients in the hands of primary care units are fewer but require long-term/home-based care. The proportion and distribution of vulnerable patients are specific and depend on demographical structure, individual health conditions, and environmental health situations of a particular service catchment. However, it is fair to generalize that more varieties of vulnerable patients could be expected in a bigger and denser population than in the smaller and less dense populous one.

Global climate change triggers a higher intensity and frequency of climate-related hazards, affecting the demand and supply sides of local public health services. From a demand-side point of view, exposed inhabitants in hazard-prone areas can potentially be affected by climate-related hazards that cause direct or indirect effects on health outcomes. More loss and injuries could be expected in a highly-populated hazard-prone area, reflecting the need for public health services during hazardous situations. From a supply perspective, a high populated area requires a high health care service capacity in response to the size and complexity of service demands. At the same time, the health care working systems could be disrupted by climate-related hazards, which cause disruption/loss of services and subsequently put the population at risk. These interlinkages resonate that urbanization and climate change are and will take a toll on public health service delivery, safety and quality.

Figure 5.10 Interlinkage of urban development & climate-related hazards and public health service



Source: Own illustration

5.2.3.4 Climate impact chain analysis

Climate impact chain analysis was applied to conceptualize how climate stimuli propagate through the local public health care system from biophysical and socio-economic perspectives. The impact chain was structured based on literature and interviews with local health care facilities managers/directors. This study reviewed case studies on how hospitals were affected by climate-related hazards (e.g. Hurrican Sandy in 2012 and Katrina in 2005) and interviewed directors of public health care facilities both in Khon Kaen city and Thammasart hospital (Bangkok vicinity) where experienced hardship service demands and local major flood events (see the list of interviewees in Annex 10). Both inputs were scrutinized to identify and visualize system elements and their relationships under climate-related hazards context. The result of climate impact chain analysis shows in Figure 5.11 as well as elaborated as follows.

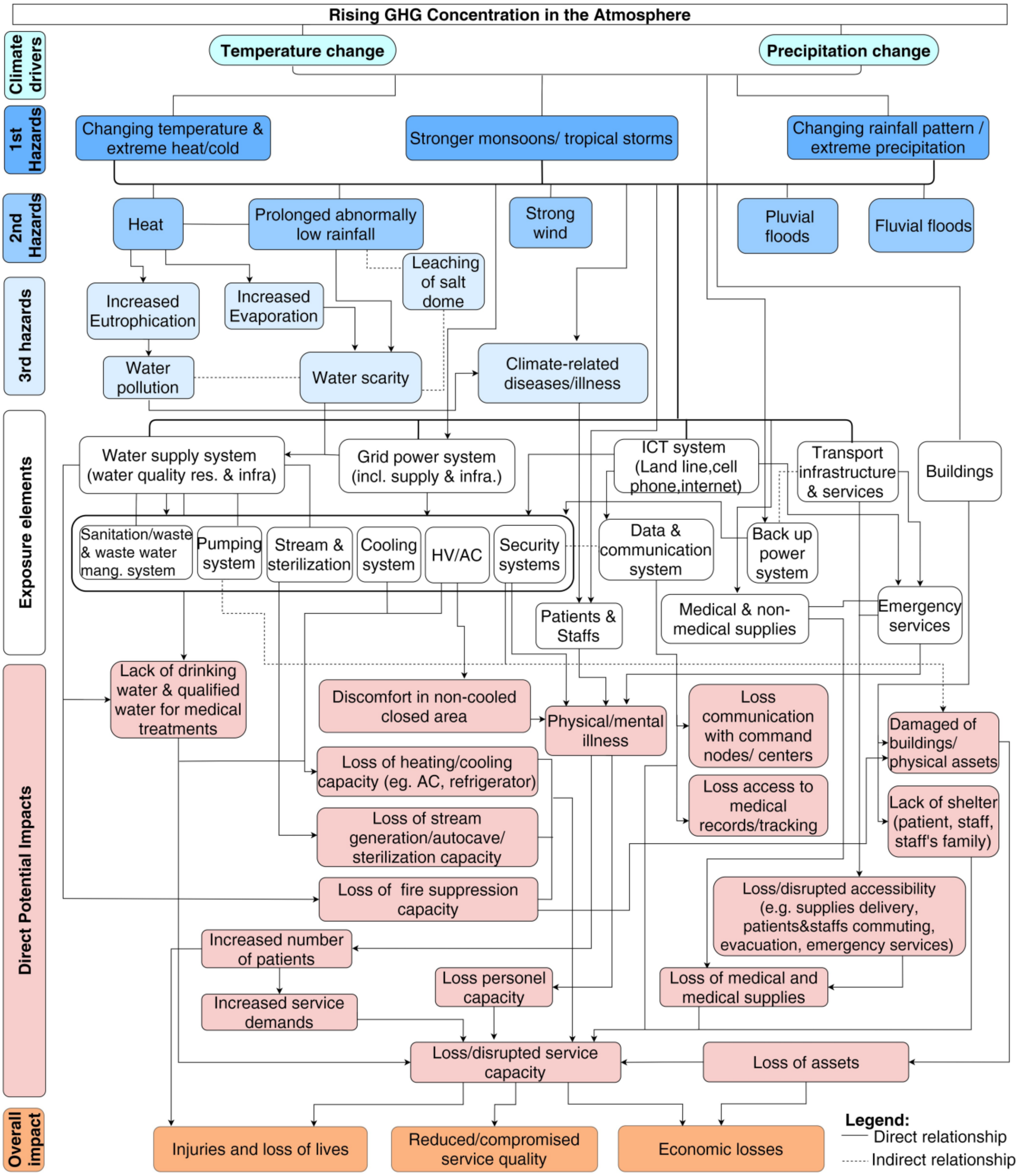
Rising GHG concentration at the global level alters temperature and precipitation magnitude and pattern at the regional and local levels. These climate signals trigger three main drivers of hydro-meteorological-related hazards; abnormal temperature (extreme hot &cold), stronger monsoons or tropical storms, and changing rainfall patterns or extreme precipitation. Abnormal high temperature is typically associated with heat episodes, high evaporation rate, and increased Eutrophication phenomenon, affecting increasing water demands, lowering water resources & supply, and inferior water quality. A prolonged abnormally low rainfall amount directly incites lesser water resources to cause falling water quantity inflow to local reservoirs. This chain of effects alters water supply quantity and quality and has a spillover effect on hydropower generation, which shares about 2-3 % of provincial electricity production (KKPAO, 2016). Moreover, a consecutively low rainfall means lower recharging of regional and local underground water tables. Unbalancing between discharge and recharge of underground water may trigger the underground salt dome's leaching; this effect cascades to the quality of the local water supply's alternative sources. Insufficient quantity and sub-standard water resources quality could cause intermittent water supply production and delivery to the settlements and public health facilities. Scarcity of qualified water supply directly affects medical services such as cleaning equipment, stream generation, sterilization, drinking water, dialysis, etc. In an emergency, water supply disruption could also result in loss of fire suppression capacity. Furthermore, extreme air temperature (heat) may increase heat stress-related illness and dehydration and could also amplify the eutrophication phenomenon, which causes water pollution. Water pollution could be linked to the spreading of digestive diseases and lowing incomes of the rural population whose livelihood depends on natural water resources.

Random hazards are mainly the cause of electricity supply disruptions (e.g. animals (rodents) and human-made (robbery of power wire or sub-standard telecommunication line installation which shared the same infrastructure)). However, rapid onset phenomena such as convective climate events are often reported as a cause of huge damage to powerlines and blackouts in wider service areas. Nevertheless, it could be such a rare case of a road damaged by flooding in Khon Kaen city, extending the effects on critical infrastructure laying above (powerline, telecommunication) and below (water supply, a small part of powerline, telecommunication) the road. Electricity power, telecommunication, and water supply are connected and interdependent on each other. However, electricity is always classified as the uttermost important critical infrastructure. Prolonged brownout or blackout of electricity emerges cascading effects on all sectors, especially health care services. Without electricity affects hospital's essential working systems operation, particularly tertiary service level hospitals (the most complex and sensitive one), such as sanitation facilities, power-dependent medical equipment, loss of pumping capacity, loss of heating and cooling capacity, loss of communication, limited access to online medical record and tracking, insecurity of locking system, etc. Besides electricity dependency, climate-related hazards could hit hard on Information and Communications Technology (ICT) infrastructure, such as base stations or cell sites, communication lines, yet taking into account underlying cyber-attack which could disrupt hospital information systems.

As a spine of other critical infrastructure delivery, road transportation infrastructure is paramount to the accessibility and mobility of people, goods, and services. Flooding, land subsidence, and a strong wind could trigger the destructive rapture of roads, railways, bridges, and collapses of line infrastructures above the road, which suspend local and regional mobility flows. In addition to the damage to physical structures, accessibility disruption due to inundation and blocked roads may create difficulties in the delivery of medicines, medical supplies, foods; operation of emergency services; evacuation of patients and medical staff; accessibility of patients to hospitals; commuting of medical staff from home to workplace or patient home visit services; accessing to clinic or pharmacy; reachability of fire brigades and external supports, etc. Furthermore, a gas station is also important for motorizing transportation and vital in electricity backout situations. If nearby gas stations are flooded, it is more difficult to acquire fuel for a diesel backup generator engines of a hospital. Besides this circumstance, the backup generator's exposure to floods also prolongs the inability of the local critical infrastructure and public health service operation.

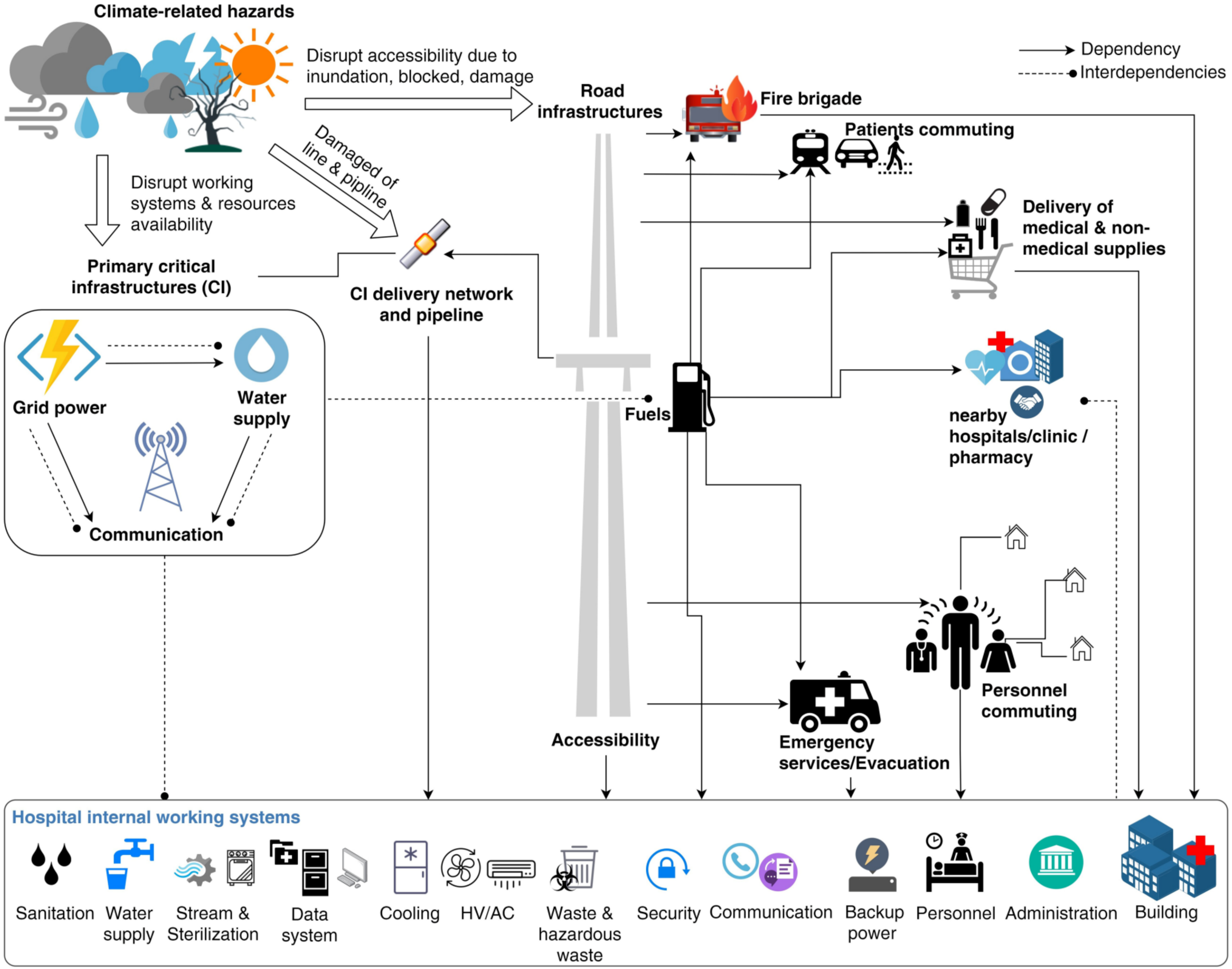
In addition to cascading effects due to the disruption of other critical infrastructure, the most direct impact of climate-related hazards on the public health care service is an invasion of flood into buildings or working stations, which causes the damage to building and operation systems as well as a loss of shelter for patients, staff, and staff's family (including their pets). During the math of hazards, a health care facility must be prepared for mass causality or overflow of patients and function as a "Lighthouse" for a community where inhabitants could shelter in the hospital until the hazard has passed. Nonetheless, a health care facility can provide the lowest gear of services without electricity; medical records can do offline and manually. For a primary care unit, keeping vaccine or certain medical supplies refrigerated are crucial under blackout. However, it should be fine as long as they can temporarily relocate the cooling-dependency medicine somewhere else in time, e.g. their own house or other health facilities. Unsurprisingly, the most critical resource for public health care services is clean water. Without clean water, most of the basic services cannot be performed aseptically. Nevertheless, accessibility is also crucial when a hospital is under crisis. Besides prompt for evacuation, accessibility of both patients and medical staff to a health care building or service areas is vital for sustaining services and replenishing essentials such as medical and non-medical materials, fuels, mobile power generators and waste disposal. Figure 5.12 visualizes the interrelationship of critical infrastructures by focusing on the public health care sector to supplement the understanding of their dependency and interdependency under climate-related hazard conditions.

Figure 5.11 Impact chain of public health facilities and services of Khon Kaen city



Source: Own illustration

Figure 5.12 Interrelationship of critical infrastructures with focusing on local public health care setting



Source: Own illustration

5.2.3.5 Trend scenario storyline articulation

Based on the understanding of urban development and climate-related hazards interaction as well as the climate impact chain of local public health care, **matrix analysis** was conducted in order to capture possible outcomes of the interplay among the three systems of interest (urban development, climate-related hazard, and public health services) in each zone of the study area. Possible convergence and divergence in both internal and interactional perspectives were defined (see Table5.3) and used for articulating "Trend scenario" storyline. Detailed elaboration and visualization of the draft "Trend scenario" were presented to stakeholders through bilateral discussion sessions and workshop format. The result showed that all stakeholders agreed on the proposed “Trend scenario” storyline and suggested minor supplementary details. Hence, the future of Khon Kaen city in 2037, according to “Trend scenario” storyline in city-wide and zonal perspectives, can be described as follows.

1) City-wide perspective

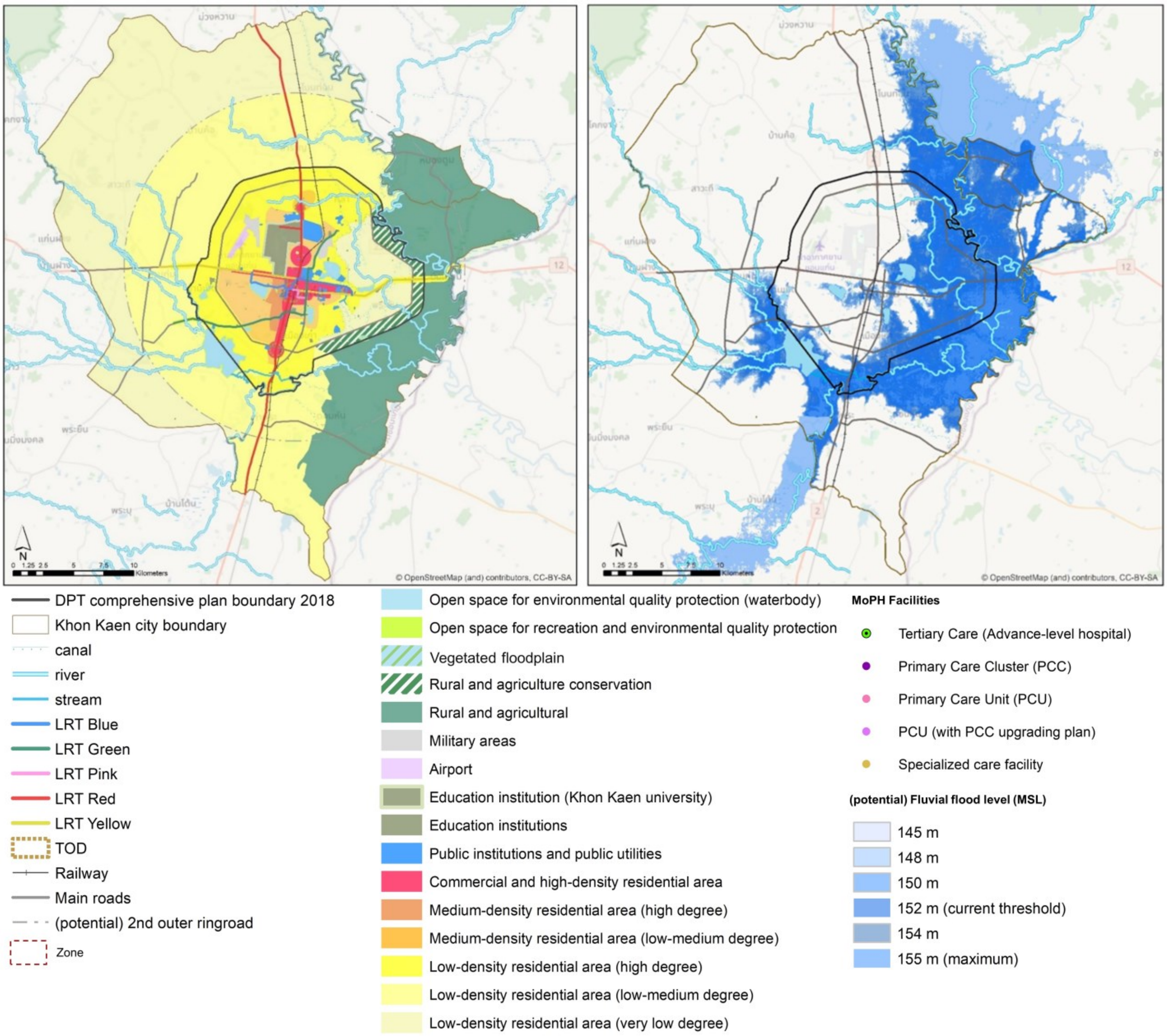
With a clear signal of urbanization, the city expected about 3.6 % (on average) of population growth annually. Although it is challenging to distinguish a boundary between urban and rural settlements, the potential) 2nd outer ring road could be the new indication of the urban-rural boundary. Expansion of low residential areas can be observed in all directions, except the eastern part of the city, where urbanization might be limited at the right edge of the first outer ring road. In responding to the upcoming flagship infrastructures and economic boosting projects under the Smart city strategy, compact commercial centre and denser residential areas can be expected in the city centre and TOD nodes along the LRT red line. Visualization of the future land use change under the “Trend scenario” shows in Figure 5.13. Floods and water scarcity are significant factors that affect local development. Fluvial floods at 155 m MSL can be anticipated to affect the eastern part of the city and may interrupt activities in the public administration quarter. Khon Kaen Hospital and several primary health care units could potentially be flooded or isolated due to water blockage accessibility. Moreover, a clear water supply scarcity trend can be foreseen as a major underlying threat to city development and its public health service in the future. Figure 5.14 illustrates the potential fluvial flood extension overlaid on Khon Kaen city's future land use under the “Trend scenario”.

2) Zonal perspective

Detailed elaboration of the “Trend scenario” storyline of each part of the Khon Kaen city in 2037 in terms of urban development change, climate-related hazards, and public health concerns can be articulated as follows.

Figure 5.13 Potential land use of Khon Kaen city under the Trend scenario

a) Land use under Trend scenario b) Fluvial flood map under Trend scenario



- **Zone 1 and Zone 2**

  Urban development change

The enforcement of the land adjustment for agriculture regulation and Khon Kaen city comprehensive plan might be compromised due to housing needs and the right to be developed in Zone 1. Thereby decreasing agricultural areas and rural livelihood might explicitly occur in this area. Daily commuting will be more convenient. LRT yellow line will provide the rural inhabitants access to public services & urban lifestyle and induce development in the area. The development may firstly densify along the strip of the LRT yellow line and then spread out. Very low-density residential areas will enlarge to reach the edge of the existing outer ring road. The closest farmland and rural life may be found farther from the existing outer ring road circle. Zone 2 will be transformed from agricultural domination to housing in response to the needs of industrial employees and middle-income groups who could not afford to live in the city centre. All farmland located between the existing outer ring road(bypass) til the edge of the (potential) 2nd outer ring road may turn into low-density residential areas. The surrounding areas of Keaeng Nam Ton Lake may be served for middle to high-income groups' housing. LRT red line will connect the areas with the inner city, while the LRT green line may accelerate the conversion of the agricultural frontier and local vegetated floodplains to be low-density residential areas in the future. However, these mass-transit investments promote urban expansion and sprawl rather than help the city reach their compact city development agenda.

Climate-related hazards challenges

Transportation-led development could trigger decreasing flood retention areas and increase the number of exposed inhabitants and elements at risk in the future. Strengthening dikes and raising the floodwall may be insufficient to confront the prospect of future fluvial flooding at 155 m MSL. On the contrary, dikes/walls rather prolong flood than its natural process. Yet, water could flow faster and more dreadful to downstream cities. Moreover, more urban development in the areas mean increasing sealed surface and decreasing vegetation and farmland. Hence, the areas may lose their capacity for drainage, flood retention, local climate regulation, food security, ecosystem service and biodiversity. Furthermore, prolonged drought will raise water supply scarcity concerns and amplify water pollution conflicts among local governments in the future if more sustainable solutions are not yet implemented.

Public health care concerns

Urban expansion in Zone 1 & 2 may induce more health care service demands to the local primary care units and Khon Kaen Hospital 2 (branch). However, LRT yellow line could make trips to the city centre more convenient. Instead of using the nearest health care units, people might rather go to Khon Kaen Hospital (1) to receive what they believe is a better health care service. This unexpected effect might undermine the local public health care network management's target of decentralizing the service and reducing the workload of Khon Kaen Hospital (1). Through the lens of future-oriented climate-related hazards scenarios, five public health care units could be affected by 155 m MSL fluvial flood, while another four public health care units could be isolated or limited accessibility. Therefore, it is fair to state that hospitals in these zones may also sit in a tight spot of locating in fluvial flood-prone areas and are responsible for more patients due to urbanization in the future. Technically, the public health care unit should not be located in a hazard-prone area; however, this practice contradicts the sector's mandate to ensure health care is accessible to all populations. Yet, chronic struggles in public health personnel management and procurement would continue pressing the local hospitals to a bare overload of work, which may negatively affect service quality.

- **Zone 3**

Urban development

All LRT lines will be completed and cost-effective operated as planned. The LRTs may induce growth in passengers' mobility, economic activities and degree of population density.

Compact city concept will be realized in this zone through vertical growth and mixed-use in linking with TOD, especially commercial stripe along Mitrapap rd. and the old town tracts (Srichan and Pracha Samosorn segments). TOD will play a key role in driving urban development altogether with mixed-use to incentivize compact urban lifestyle for the young generations and attract innovative investments. Next to high density residential and commercial areas are medium-dense residential areas, covering most areas located in the inner part of the existing outer ring road in the southwestern quarter. Moreover, a higher degree of low-density residential areas is expected to emerge in urban-rural transition areas between the existing outer ring road and farther east of Khon Kaen City Municipality & the vicinity of Pralub Sub-district municipality's urban settlements.

Climate-related hazards

The biggest TOD development is located in the central vegetated floodplain, which is supposed to be a vital part of inner-city flood retention and drainage management. Dense built-up areas disregarded waterways, and insufficient drainage system capacity & connectivity could cause worsening pluvial floods in the future. The current and upcoming drainage structure improvement is based on the historical trend of runoff rather than the future projections. In addition, more impermeable surface and inappropriate landscape changes and land excavation, especially road elevation, often cause urban inundation. As the heart of the city economy and administration, the area is always at the top priority to ensure water supply security. Therefore, water supply scarcity is perceived as a general concern in this area.

Public health care concerns

In contrast to the future population trend, the public health sector remains its zero-growth policy in terms of public health personnel capacity and marginality resources. Thereby, an overload of service is foreseeable as an underlying vulnerability of the local public health service even without a climate crisis. In the future, not only Hua Thung Primary Care Center has to keep an eye on inundation during heavy rainfall, but all health care units in this area should also pay attention to flood besides taking care of their patients. In terms of a fluvial flood, the inner-city may stay dry by sacrificing rural communities. Nevertheless, under the “Trend scenario”, the provincial administration quarter might heavily be flooded or isolated by fluvial flood 155 m MSL, under the condition that if the current protection measures were failed or mismanaged. Under this scenario, several key public health institutions and units may be directly affected and limited access due to floods, including Khon Kaen Hospital (1). Disruption of Khon Kaen Hospotial could lose not only the city public health services but also provincial and regional levels.

- **Zone 4**

Urban development change

The development of the LRT yellow line will accelerate urbanization on the western side of Zone 4. The LRT provides mobility and connectivity between the inner-city and outer development nodes and (light) industrial areas, especially in Ban Thum Town municipality, Samran Sub-district municipality, and Dang Yai Sub-district local administrative organization. The enlargement of low-density residential areas will transform farmland into housing in order to support the demands of both low and high-skill workers. More inhabitants, more economical of scale would be for infrastructure and public services investment. The area, where closer to the city centre, denser the residential area could be expected. The nearest commercial centre on the northern side of this zone may be surrounded by medium residential areas connected with the high-density commercial centre at the university quarter. The skyrocketing land price of the inner-city area pushes people to live in this zone; therefore, more housing estate developments for middle-income groups can dominate land use in this zone. However, limited public service to the area is a key concern, especially the intermittent water supply and inadequate connectivities of the public transportation network, specifically in the western-ward of this zone. However, the local water work authority stated that a major water supply investment would be implemented in this area.

Climate-related hazards

With topographical advantage, this area is considered the city's high elevated zone or a safer area in terms of floods. At the same time, Khon Kaen University has been blamed for intensifying a pluvial flood to Zone 3 because of not/insufficiently retaining the run-off and letting its gravitational flow along Maliwan rd. However, a high elevated topography is a disadvantage in terms of water supply delivery due to the higher cost per head for providing water supply infrastructure and service. Moreover, this high and dry zone also has insufficient natural/artificial water bodies/small reservoirs to sufficiently reserve water resources in a prolonged drought period. Therefore, land developers must push immense efforts and investment to attract new residences, even though the land price is relatively lower and safer from flood risks than in other zones.

Public health care concerns

Possible discrepancies between increasing population and public health service capacity can be emerged in this zone, especially in Ban Thum Town municipality. Extension of public health service capacity is not clearly anticipated in the future; therefore, over carrying capacity of the health care service can be expected in this zone. Moreover, the health care service in this area may be exacerbated by the potential impact of water supply scarcity in the future.

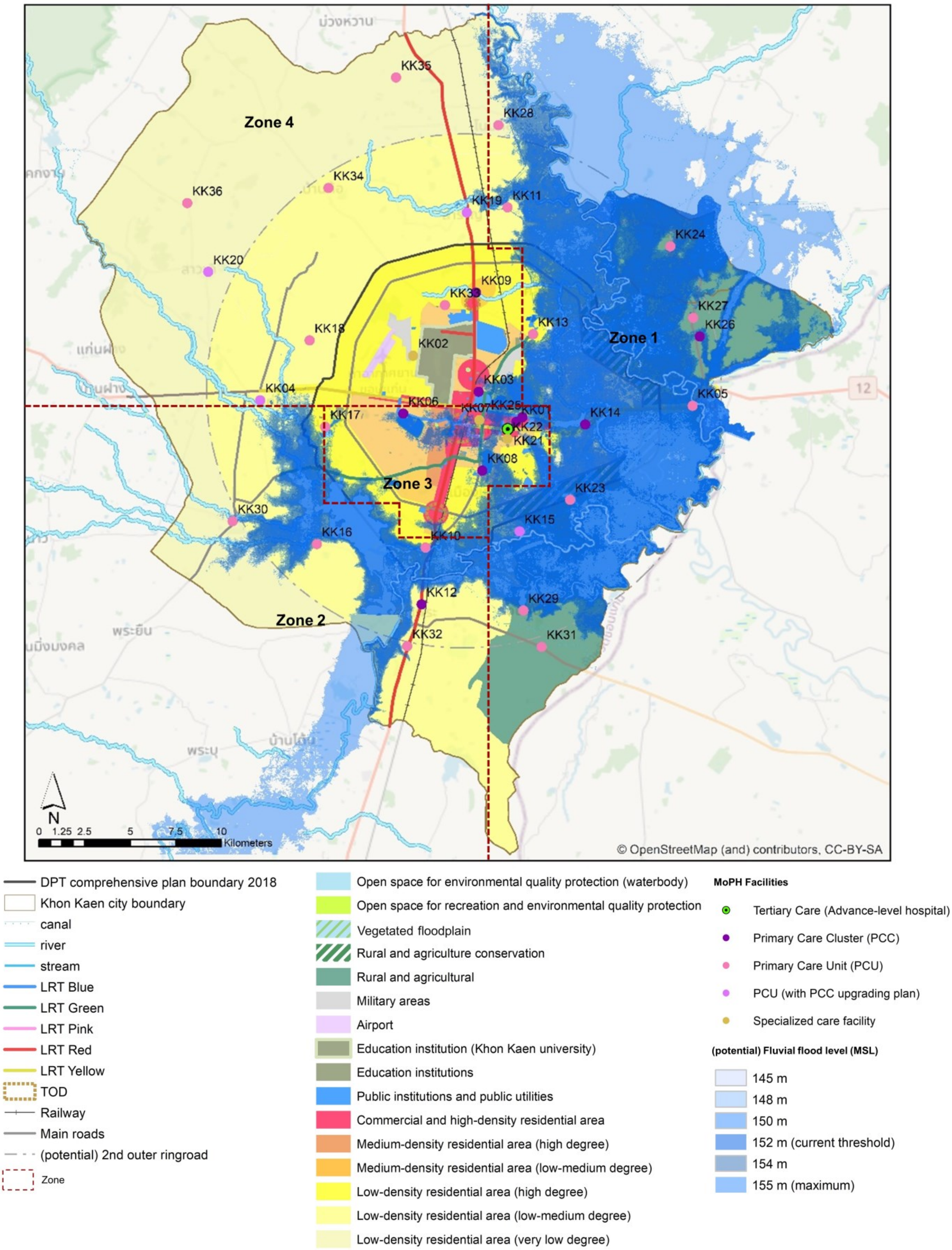
Table 5. 3 Matrix analysis of Trend scenario

Zone	Key features of the systems of interest			Convergence/Divergent
	Urban development	**Climate-related hazards**	**Public health**	
1&2	• Increasing population and urbanization • Conversion of agriculture and rural frontier to a built-up environment • Smart mobility – Introduction of a mass-transit system (LRT yellow line and green line) • Enforcement of land-use zoning (rural and agriculture conservation zone) and relevant regulations (e.g.Agricultural land readjustment gazette)	• Potential fluvial flood at 155 MSL • More intense pluvial flood • Improvement of a drainage system • Strengthen dike/flood wall	• Extension of service capacity and advancement of Khon Kaen Hospital 2 and SHPHs • Under staff problems & zero-growth policy *(personnel capacity)* • Inefficient procurement process and budget use	**Convergence** • Increasing public health service capacity in response to increasing population trend in the service area • Increasing of accessibility of public health care • Decentralizing workload out of Khon Kaen Hospital could result in declining overcrowded patients and traffic congestion in the inner-city area **Divergence** Sectoral divergence *Urban development:* • Promotion of compact city development but LRT development could lead to urban sprawl *Public health*: • Discrepancy between increasing service demand due to urbanization and zero growth policy may negatively affect service quality *Climate-related hazards:* • Current (structural) protective target is 152 m MSL, while a potential fluvial flood could be reached 155 m MSL Interactional divergence • Mass transit development (LRT) leads to urban expansion in flood-prone areas • Local governments outweigh economic development over disaster risk reduction

Zone	Key features of the systems of interest			Convergence/Divergent
	Urban development	**Climate-related hazards**	**Public health**	
				• Urbanization leads to more inhabitants and built-up environment in flood-prone areas • High service public health capacity located in hazard-prone areas (e.g. Khon Kaen Hospital 2, Primary care clusters)
3	• Strong increasing of population and urbanization • Compact and mixed-use development • Mass transit system (LRT) investment and TOD development • Densification of residential and commercial areas	• Potential fluvial flood at 155 m MSL • More intense pluvial flood • Improvement of a drainage system based on past hazard events	• Stable or low rate of increased service capacity and advancement of public health service • Overload of service demand in comparison to service capacity • Under staff problems & zero-growth policy *(personnel capacity)* • Inefficient procurement process and budget use • Enhancement of service capacity and accessibility	**Convergence** • Better accessibility to public health care • Higher workload of public care units in the inner-city areas **Divergence** <u>Sectoral divergence</u> *Public health*: • The discrepancy between increasing service demand and zero growth policy may negatively affect service quality *Climate-related hazards:* • Current (structural) protective target is 152 m MSL, while the potential fluvial flood could reach 155 m MSL • Lack of future-oriented perspective in drainage system improvement <u>Interactional divergence</u> • Insufficient public health service capacity in response to increasing population (induced by urbanization) in the service (catchment) areas • Densification leads to a more impermeable surface and blockage of the waterway, which may be a major cause of a prolonged pluvial flood, exacerbating traffic congestion, damage and disruption of public health care operation and services

Zone	Key features of the systems of interest			Convergence/Divergent
	Urban development	**Climate-related hazards**	**Public health**	
				• High public health service capacity located in hazard-prone areas or potentially be isolated (limited accessibility) in the case of 155 m MSL flood • No automatically alternate care site or redundancy of a second medical supply warehouse available in the case of Khon Kaen Hospital is severely affected by climate-related hazards
4	• Increasing population and urbanization • Conversion of agriculture and rural frontier to housing and light industrial use • Limiting public service and connectivity of mass transit system • Insufficient provision of public services in responding to the future population trend	• Safer zone • Potentially prolonged water scarcity • Possible pluvial flood due to an inappropriate land cover change or landscape modification • Insufficient and inefficient water supply infrastructure provision	• Stable or low rate of increase in service capacity and advancement of public health service • Overload of service demand in comparison to service capacity • Under staff - Zero growth policy *(personnel capacity)* • Inefficient procurement process and budget use	**Convergence** • Higher workload of primary care units • High dependency of primary care unit on Khon Kaen hospital **Divergence** Sectoral divergence *Urban development:* • Car-oriented transportation • Insufficient public service in response to the increasing population • Limited mass-transportation connectivity *Public health*: • The discrepancy between increasing service demand and zero growth policy may negatively affect service quality Interactional divergence • Insufficient public health service capacity in response to increasing population trend in the service area • Inadequate water supply for population and public health care services

Figure 5.14 Visualization of Trend scenario in the case of fluvial flood 155 m MSL



5.3 Backcasting

This section is divided into two main parts, desirable scenario construction and scenarios assessment. The desirable scenario construction aims to define a strategic way to minimize the potential impact of urban development and climate-related hazards interactions on local public health operations. Therefore, target setting in terms of potential impact acceptability was defined by stakeholders in both spatial extension and system operation perspectives. Based on the desired target(s), spatial planning-based measures that potentially minimise potential impact were defined and apprised its preferences by stakeholders in both city-wide and public health-specific aspects. Matrix analysis was applied at this state again in order to frame the interplays among the system of interest and encompass a desirable scenario construction. In the vista of scenario assessment, composite indicators were tailored to assess the potential impact on the local public health service. This research combined a questionnaire survey and scenario storylines in order to operationalize the composite indicator-based potential impact assessment of both the “Trend scenario” and the “Desirable scenario”. The results were presented in multiple aspects, area-based, network service, and service hierarchy of Khon Kaen city’s public health care settings. The scenarios' potential impact outcomes will be scrutinized to formulate a road map that examines crucial steps in achieving the desired target in the later step.

5.3.1Target setting

"Trend scenario" was perceived as a baseline for stakeholders to appraise their potential impact acceptability. Visualization of the "Trend scenario" was presented to stakeholders and allowed them to draw the spatial extension boundary of protection worthiness. The stakeholders also discussed and expressed their anticipation and desirable level of potential impact in the system operation perspective if the city has to deal with the "Trend scenario", from *very low* to *high* level of potential impact, based on the description shown in Table 4.2. It is important to emphasize that even though the targets are neither absolute nor proved quantitatively by today's pieces of evidence, they conceptually informed potential impact mitigation targets and encompassed the development of composite indicators for the potential impact assessment.

Bilateral discussion sessions with eight relevant stakeholders (who represent central and provincial planning agencies, a local government, private sector, academia, provincial disaster risk management office, provincial natural resources and environmental office, provincial public health office, and Khon Kaen Hospital (see Annex 5)) revealed a unified perception towards a spatial extension of protection worthiness but slightly diverse in terms of an overall urban systems operation as follows.

5.3.1.1 Spatial extension perspective

Although pluvial flooding is conceived as a short-term event that typically lasts no longer than a day, the stakeholders perceived the issue as a manageable problem. Meanwhile, the water supply scarcity is perceived as an invisible threat and more harmful than floods that have a visible spatial extension that they can see. However, the stakeholders have a strong awareness of water supply criticality to urban systems operation. In the view of local government, academia, and provincial planning agency, the collision of the current magnitude of water stress with the future number of inhabitants, according to the “Trend scenario”, could cause the city’s socio-economic development breakdown. However, the city frequently experienced water scarcity; thereby, importing pottable water and promoting underground water usage are now common practices for the locals. Thus, water scarcity may sound critical, but stakeholders believed the city could find external supplies and tighten water-saving measures.

The locals have a strong reaction to fluvial floods than other climate-related hazards. Besides its magnitude and spatial extension, a flood could stay in the area for longer than one month, costing significant loss and damage to the local economy and livelihoods. Generally, the local stakeholders perceived that the main causes of major floods in Khon Kaen city are monsoons and Ubonrattana dam's mismanagement associated with the failure of local flood protection structures. Importantly, fluvial floods raised not only inter-local government conflicts but also the opposition between rural and urban inhabitants. As informally accepted as a current fluvial flood threshold by the locals' institutions. The stakeholders resonated 152 m MSL as a preferred worst-case impact level, which the city had experienced and could make the potential impact under control with their baseline capacity. All stakeholders agreed that the dike along Phakue stream should be the first fluvial flood protection structure; however, if the dike were failed, the central CBD area must be highly protected at all costs, as the city's last stand. In such an unprecedented event that the city may be unable to protect its CBD, the city's west quarter highland could serve as shelters or even relocation sites for affected inhabitants as it used to be in the 1980s. Figure 5.15 shows the spatial extension protective target, which the stakeholders roughly defined.

5.3.1.2 Operational perspectives

Seven out of eight stakeholders believed that the city operation system would not completely fall apart under the “Trend scenario” but rather shut down auxiliaries services/sections and remain to sustain essential operating systems. However, the city can not fully self-reliance amid crises; thus, obtaining needed resources and support from outside is required. If evacuation is necessary, it is possible to go for an in-city relocation option, especially in the safer part, the northwest side of the city, such as Khon Kane University. Nevertheless, the provincial planner thought that the Trend scenario's impact could lead to discontinued critical services. Therefore, evacuation might be possible, and retreat may go beyond the city boundary. In this regard, the stakeholders expected that the potential impact level of urban operation systems under the “Trend scenario” could be in the range of *medium* to *high* level (see Figure 5.16). In the desired protective target point of view, seven out of eight stakeholders (including Khon Kaen hospital representative) framed that under the “Trend scenario”, the city should be able to minimize the potential impact to a *low* level and embrace residue impacts by temporarily suspended non-priority services urban system operation. Nevertheless, the KKPHO’s representative believes that the city should aim to minimize the impact to *very low* level, that all services can continue without any discernible impact or change. Figure 5.16 shows the potential impact acceptability and preferred protective target of different stakeholders.

Figure 5.15 Spatial extension of the protective target under the Trend scenario defined by the stakeholders

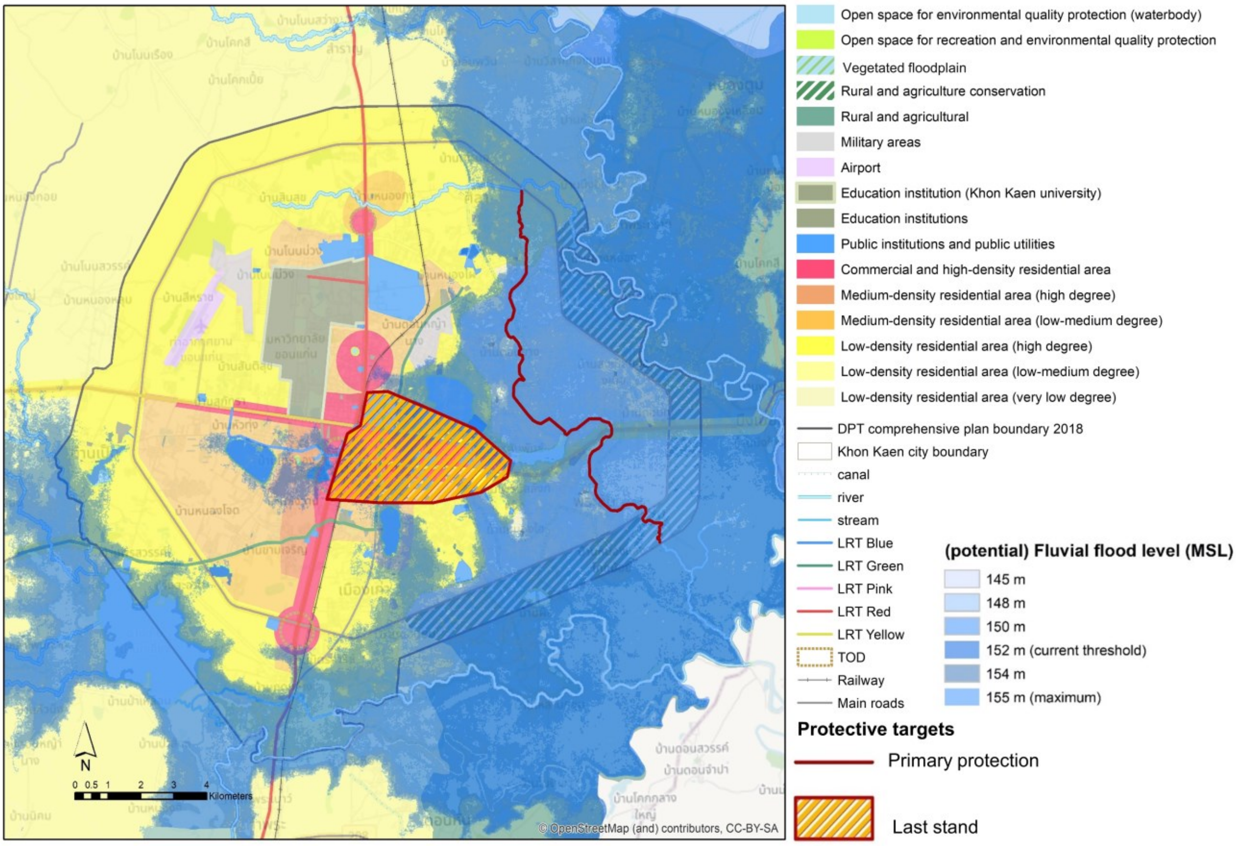
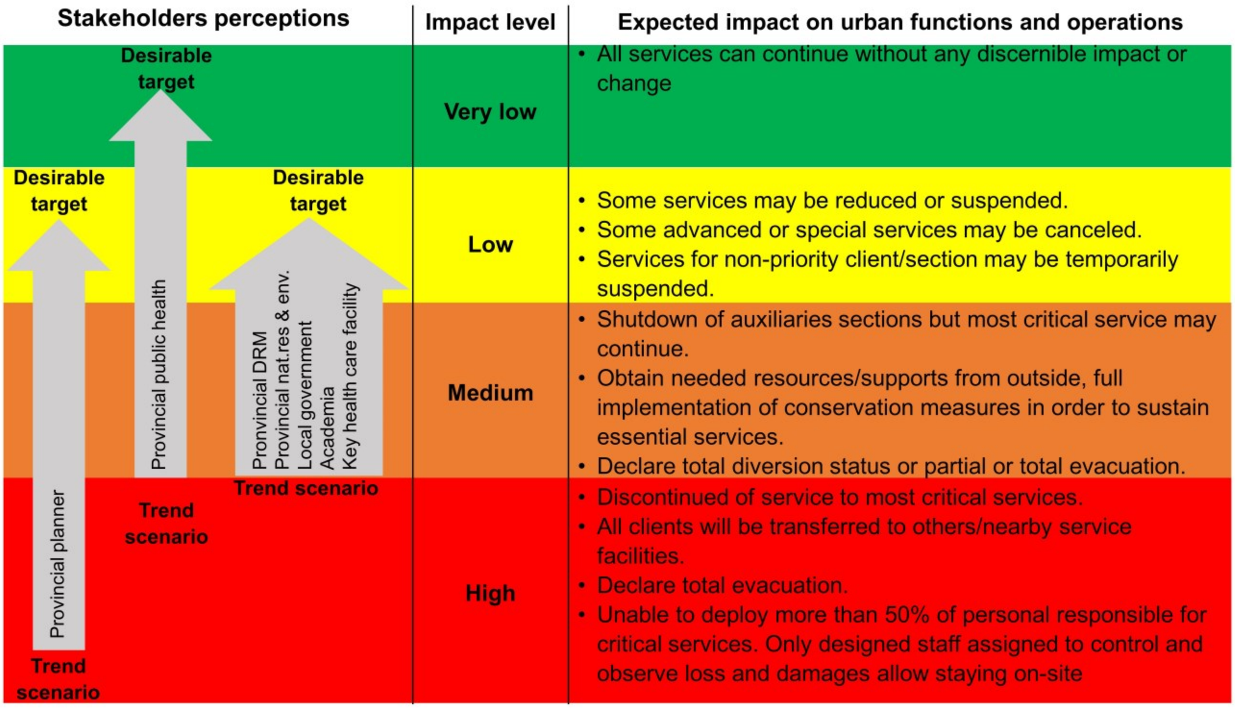


Figure 5.16 Potential impact acceptability and desirable target(s) in terms of urban operation system expressed by different stakeholders



5.3.2 Desirable scenario construction

City-wide and public health-specific measures were derived from literature and local stakeholders' inputs to encompass the desired target(s) in minimizing the potential impact of climate-related hazards on Khon Kaen city's public health service. Spatial planning-based measures and innovations were suggested for each city zone through exposure avoidance, hazard mitigation, and capacity enhancement strategies. The set of the proposed city-wide measures was presented and visualized to stakeholders during individual discussions (5-13 February 2020) and a stakeholder workshop (1 March 2020) (see Annex 5). Meanwhile, the public health-specific measures were presented to the KKPHO on 17 March 2020. The stakeholders were asked to express their preference for each proposed measure during the discussion through a Likert scale survey with a scale of 1 (least preferred) to 5 (the most preferred level). The proposed measures which received an average preference score of less than 2 (low preferred) were excluded from the "Desirable scenario" storyline. In this regard, the result of stakeholders-led spatial planning-based measures identification and appraisal can be presented as follows.

5.3.2.1 City-wide perspective

1) Collaborative spatial planning-based measures identification

Spatial planning-based measurements were specifically designed for each zone of the city based on the combination of stakeholders' inputs and literature. 24 potential measures can be grouped into three main aspects, exposure reduction, hazard mitigation, and capacity enhancement. Details elaboration of each aspect of the measures is as follows. Summarization and visualization of the measures tailored for each city zone are shown in Table 5.4 and Figure 5.17-22.

- **Exposure avoidance**

Exposure avoidance-related measures consist of six measures, 1) promotion and enforcement of formal planning instruments, 2) provision of hazard map, 3) reduction of development attractiveness in flood-prone areas, 4) discourse on impact sharing and compensation scheme, 5) relocation and 6) selective retreat. Planning agencies (both the central and provincial offices) and the local water management agency proposed strengthening the execution and enforcement of formal instruments to limit more development in the fluvial flood-prone areas, such as land use zoning under the DPT comprehensive plan and the agricultural land adjustment regulation. Meanwhile, the private sector and academia highlighted the importance of risk communication in raising awareness and promoting participatory decision-making on disaster risk management. Hazard map shall be developed based on scientific-based evidence, thus integrated as a key instrument for all planning levels. Since the major flood in the past, a formal discourse on flood management conflicts has never taken place in order to relieve tensions among local governments on flood management. Therefore, representatives from the provincial planning agency, a local government, and the private sector agreed that the impact/burden-sharing scheme should be publicly discussed to explore how the next flood could be efficiently and fairly managed. Mass transit provision often leads to more development, and more inhabitants live in hazard-prone areas due to lower land prices and good access to public services. Therefore, the researcher[33] proposed limiting the development of the LRT network toward flood-prone areas and implementing retreat strategies to reduce exposure. Possible retreat strategies could be relocation to safer areas, buyout programmes, or selective retreat of sensitive or critical infrastructures.

- **Hazard mitigation**

Hazard mitigation strategy consists of 13 measures. The representatives from government agencies proposed vegetated floodplain conservation and enhancement of flood retention capacity and connected its network as key hazard mitigation measures. They also emphasized the need for drainage system improvement through engineering solutions and enforcement of municipal regulations to withdraw building rights in waterway areas as well as implementation of land excavation and land reclamation law. Revision of the land management-related regulations must base on scientific evidence and stakeholder consultations to ensure transparency and acceptability. From the private sector point of view,

[33] Wiriya Puntub

the conservation of vegetated floodplain and flood retention areas could generate co-benefits with the local tourism, such as water sport and eco-agriculture tourism. Although blue-green infrastructure development could be effectively implemented through Public-Private Partnership (PPP), legal limitations need to be removed to enable these investments, especially on government-owned land. Moreover, the researcher[34] suggested integrating Low Impact Development (LID) solutions to improve local surface permeability in public/private spaces and building design on top of the existing building code requirements. Furthermore, to minimize drought amplified water pollution in Khon Kane city, integrated municipal wastewater management and infrastructure were suggested to be executed and monitored by stakeholders.

- **Enhance capacity**

Interestingly, stakeholders underlined what should be prohibited or controlled in the hazard-prone areas but merely addressed opportunities to redirect the development towards the safer zone of the city. Particularly the northwestern side of the city (Zone 4), although the area is safer from fluvial flood, the area is relatively low in popularity for economic development and housing due to limited water resources and accessibility to reliable water supply, as well as low connectivity with the city centre. Enhancing the attractiveness of the safer zone is a promising solution for spatial planning-based disaster risk management. Therefore, the researcher proposed that public services, especially water supply, should be well equipped to support private investment in both housing estate and hypermarket development in order to stimulate economic activities in the area. The government institutions or public utilities may consider having service branches or sub-coordinate offices in this area to support more inhabitants in the future. Zone 4 could even serve as an alternate operation site if the primary office or headquarter in the hazard-prone areas were severely damaged (as part of Business Continuity Management). Importantly, the area should be well-connected with the LRT network in order to link with the city centre and more remote satellite cities.

[34] Wiriya Puntub

Table 5.4 List of proposed spatial planning-based measures for minimized potential impact in city-wide perspective

	Aspect	**Potential spatial planning-related measurements**	**Potential flagship projects**	**Zones**			
				1	**2**	**3**	**4**
Exposure avoidance	Formal planning instruments	1. Reinforce enforcement capacity and accountability of the land use zoning and relevant regulation (s)	Pre-requisite actions	✓	✓	✓	✓
	Hazard map	2. Develop publicly accepted hazard map(s) and promote public communication and awareness-raising on the hazard map		✓	✓	✓	✓
	No further development	3. No LRT service (LRT yellow and green lines) in the flood-prone areas		✓	✓		
	Impact sharing agreement	4. Initiate impact (burden) sharing agreement on flood management		✓	✓	✓	✓
	Managed retreat	5. Encourage flood-prone area's inhabitants to relocate to safer-zone, e.g. throughout the existing affordable housing scheme or buyout programme		✓	✓		
		6. Introduce selective retreat/stabilize the service capacity of critical infrastructures		✓	✓	✓	
Hazard mitigation	Vegetated floodplain (s) conservation	7. Promote vegetated floodplain conservation, e.g. natural protection zone, biodiversity promotion/education centre	Biodiversity education centre	✓	✓	✓	
	Increasing water retention capacity	8. Obtain more flood retention areas (e.g. civil contract)	Blue-green infrastructure development	✓	✓	✓	
		9. Link (small) water retention networks		✓	✓	✓	✓
	Promotion of eco-agro tourism	10. Promote water sports activities and investment	- Eco-agricultural tourism - Greenery & healthy corridor	✓	✓		
		11. Promote eco-agricultural tourism		✓	✓		
	Blue-Green infrastructure	12. Promote blue-green infrastructure development and integration	Blue-green infrastructure development	✓	✓	✓	✓

	Aspect	Potential spatial planning-related measurements	Potential flagship projects	Zones			
				1	2	3	4
	Increasing surface permeability	13. Promote Low impact development (LID) integration on development projects, e.g. Blue TOD or Spong district	- Blue TOD - Spong district			✓	
	Drainage system improvement	14. Reinforce municipal regulation in withdrawal right of building in vegetated floodplain and waterway areas				✓	
		15. Revise land excavation and land reclamation law(s)/regulation(s)		✓	✓	✓	✓
	Water pollution elimination	16. Improve municipal regulation and local governments' cooperation in integrated wastewater management	Pre-requisite actions	✓	✓	✓	✓
Enhance capacity	Increasing water supply capacity	17. Improve water supply system and delivery network accessibility and efficiency	Pre-requisite actions	✓	✓	✓	✓
		18. Increase capacity of in-city small water supply reservoirs	Blue-green infrastructure development	✓	✓	✓	✓
		19. Link (small) water reservoirs network					✓
	Safer-zone development promotion	20. Promote housing (real estate) development projects	Housing complex & new business center				✓
		21. Increase connectivity between the safer zone and the inner-city by extending the LRT yellow line and LRT green line	Public transport network extension				✓
		22. Link Khon Kaen city with surrounding satellite cities					✓
		23. Promote new business centres and hypermarkets	Housing complex & new business centers				✓
	Provision of public service in the safer-zone	24. Decentralize and enhance service capacity of public institutions and utilities	New branches of public institutions/services				✓

Figure 5. 17 Comparision of future urban development change of Khon Kaen city among the comprehensive plan and scenarios

a) DPT comprehensive plan (version 2018) b) Trend scenario c) Desirable scenario

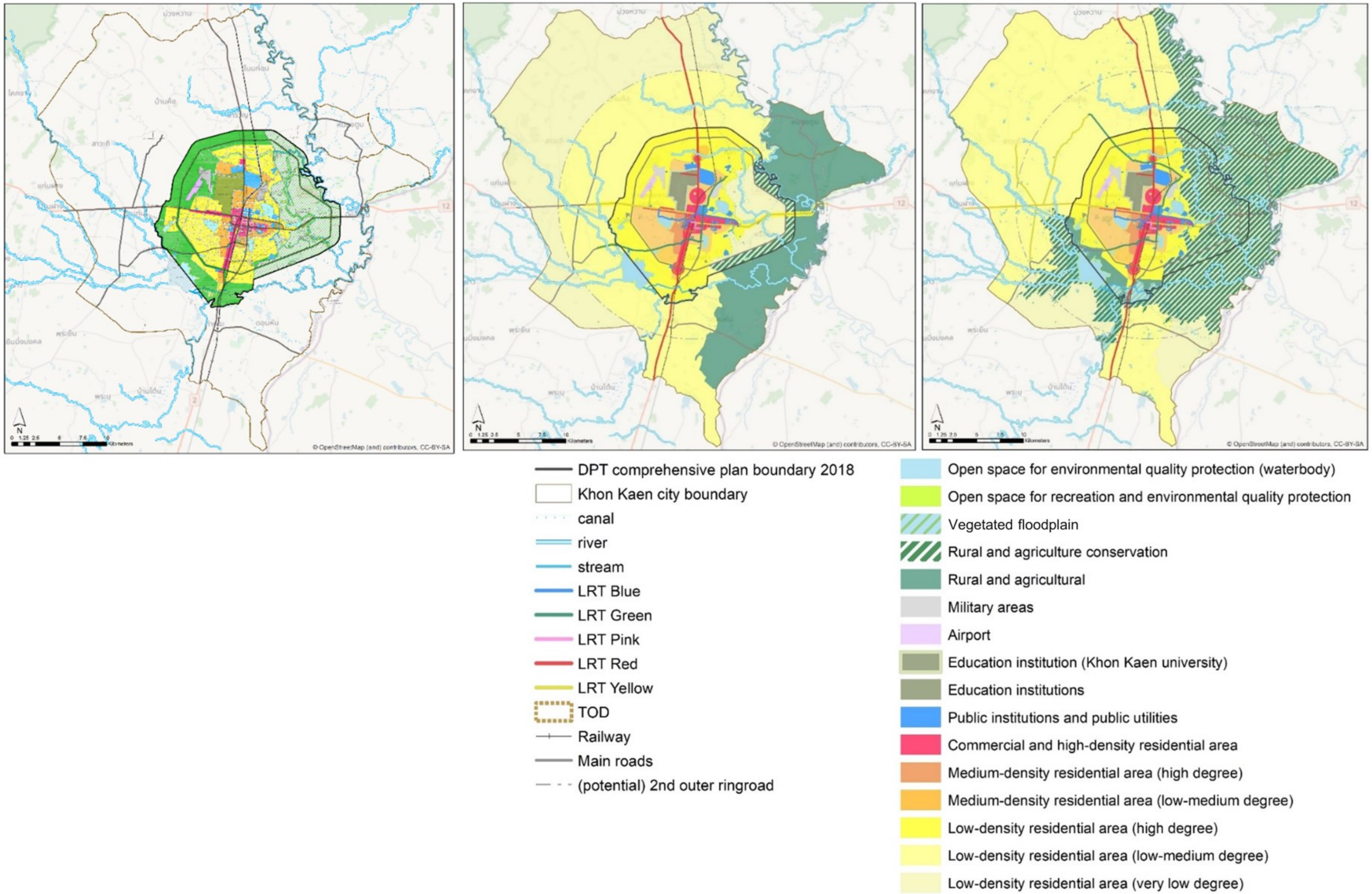


Figure 5.18 Proposed future land-use of Khon Kaen city in 2037 based on the proposed spatial planning-based measures

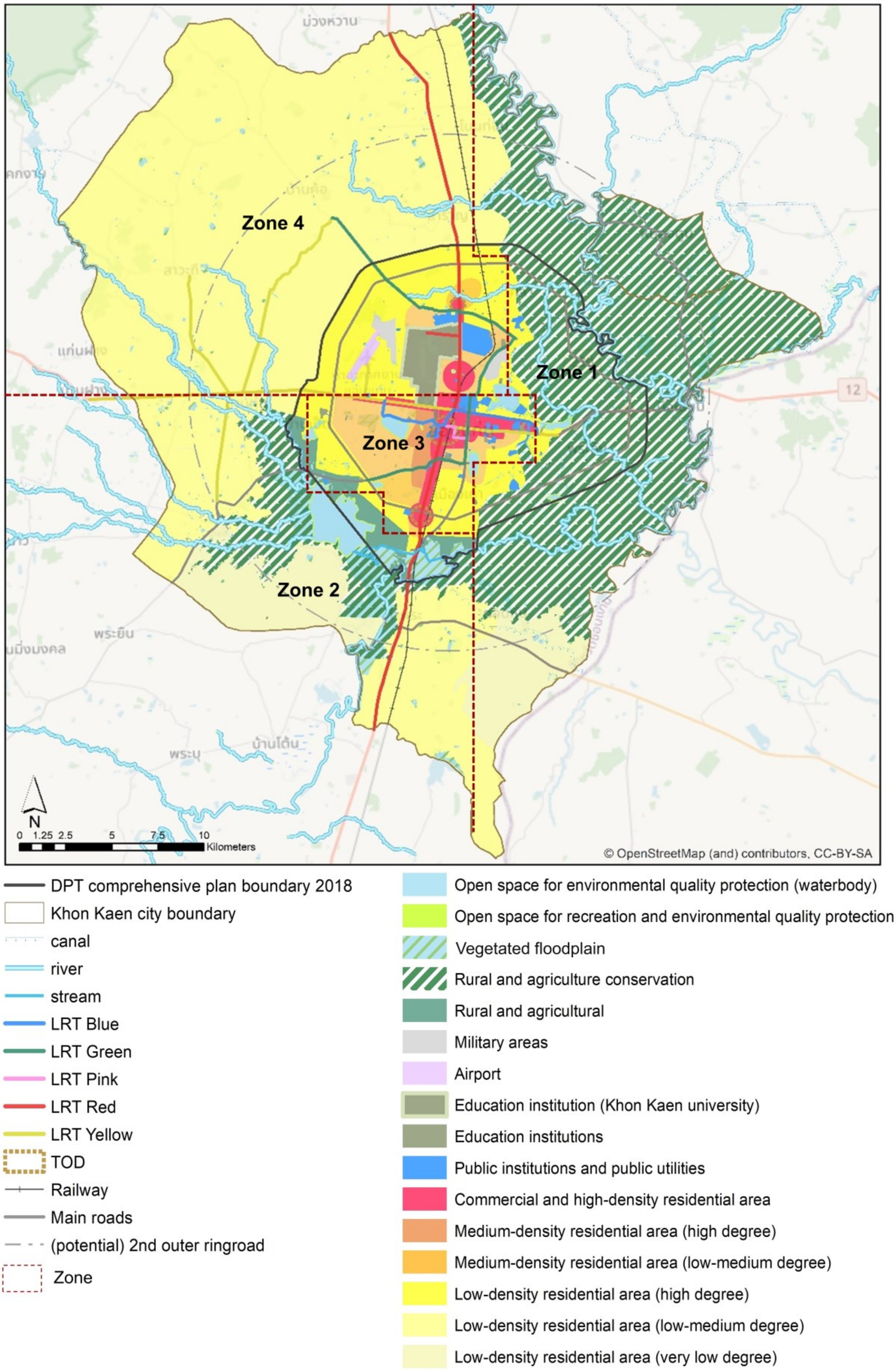


Figure 5.19 Possible flagship projects based on the proposed spatial planning-based measures

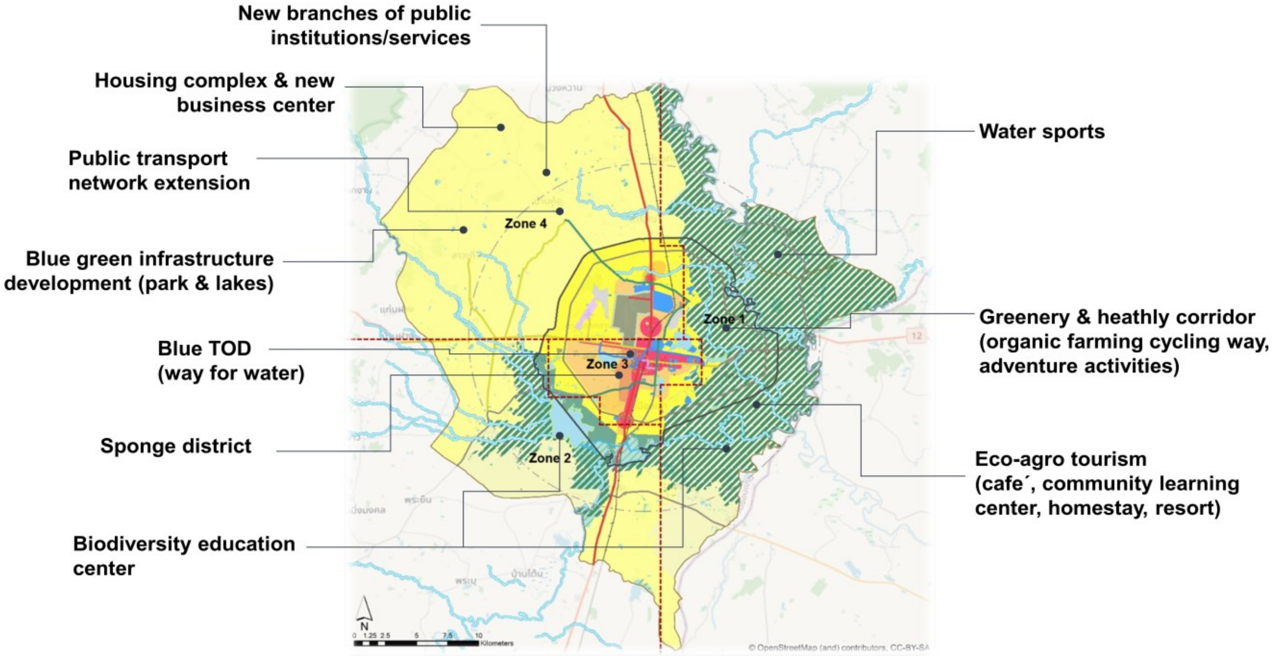


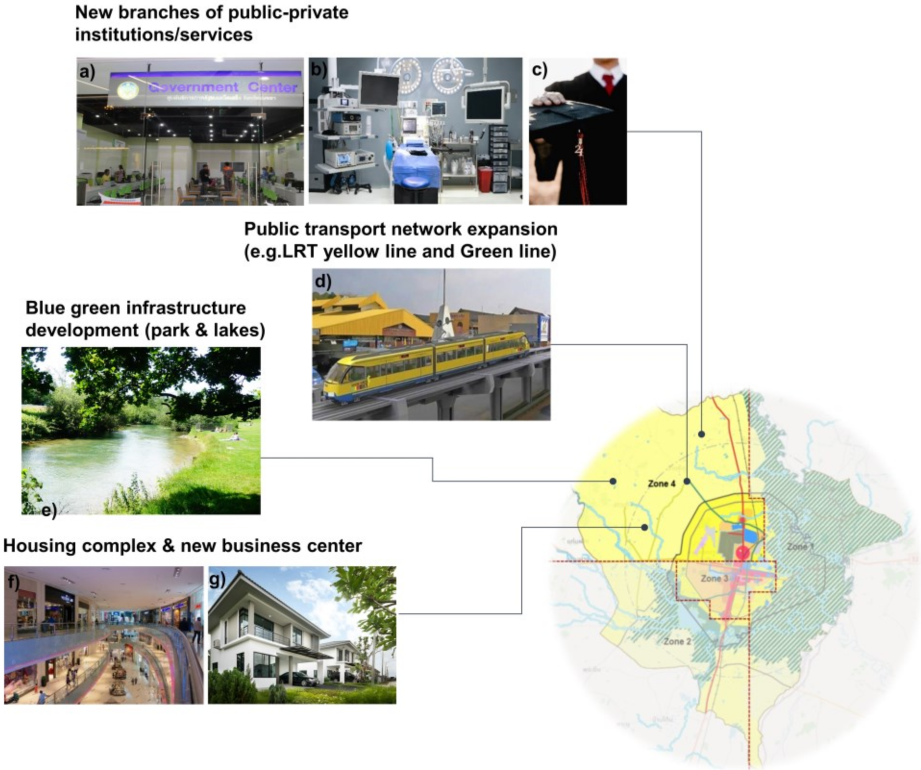
Figure 5.20 Potential flagship projects in Zone 1 & Zone 2

Source: a) Meekin farm,2021; b) Kostiantyn Li, 2020; c) Joshua Tsu, 2021; d) Malachi Brooks, 2019; e) มูลนิธิสิ่งแวดล้อมศึกษาเพื่อการพัฒนาอย่างยั่งยืน, 2020; f) Own photo; g) Suhyeon Choi,2018

Figure 5.21 Potential flagship projects in Zone 3

Sources: a) Avoid Obvious Architects, 2021; b) Siemens, 2020; c) Avoid Obvious Architects, 2021

Figure 5.22 Potential flagship projects in Zone 4



Sources: a) Gimyong News, 2018; b) Endobariatric Endohospital, 2021; c) Zachary Olson, 2021; d) Khon Kaen Municipality cited in Thailand Property News, 2019; e) Own photo; f) Mostafa Meraji, 2019; g) Patreeda, 2019

2) Preference appraisal of the proposed measures

11 stakeholders participated in the appraisal of the proposed measures through the Likert scale survey (see Annex 5). It is important to highlight that the local government representatives of a specific city zone participated in the survey and expressed their views on the measures relevant to their responsible area. Moreover, the local government representatives also allow assigning their preference on the measures implemented outside or less relevant to their territory if he/she is capable of doing so. For example, the Ban Thum Town Municipality representative has extensive working experience in all city zones, and the Khon Kaen City Municipality representative has a broad overview of city-wide development.

The appraisal result revealed that the proposed measures gained a high level of preference from stakeholders, 4.2 (out of 5.0) on average. The capacity enhancement related measurements received the highest average Likert score, 4.4, followed by Hazard mitigation and Exposure avoidance, 4.2 and 3.8, respectively (see Figure 5.23 and Annex 18). The majority of the measures obtained a relatively high (4.0-4.6) preference score from the stakeholders, except for increasing water retention capacity (3.6) and managed retreat measures (3.0). Among the less popular measures, relocation to the safer sites (2.9) and selective retreat (3.0) are the least preferred.

Exposure avoidance measures should be a prerequisite before implementing other actions. However, limiting development in flood-prone areas of a growing city like Khon Kaen city may face challenges that typically take a toll on political popularity and cost to society due to lacking risk governance. The possible conflict of interests of the local governments in keeping the flood-prone areas un (low) developed while pursuing economic prosperity was raised during the discussions with stakeholders. The local governments in Zone 1 emphasised their rights to be developed; thus, the measurements that limit the development in the areas received a low preference level from local governments' representatives in a flood-prone areas compared to other stakeholders. Compared to other aspects of the proposed measures, the stakeholders assigned the least preference score to this category of actions, especially managed retreat strategies. Buy-out program provoked concerns about rural inhabitants' livelihoods and the local government's capacity to conduct this costly and emotionally sensitive issue like relocation. The selective retreat of critical/sensitive infrastructures was recognized as necessary, but resilient upgrading or minimizing service capacity were perceived as more variable solutions. The stakeholders gave a bold emphasis on the provision and communication of hazard map(s). Although stakeholders addressed a strong concern regarding political tension and conflict of interests in a hazard map development process, it is possible to have a hazard map that is accepted among stakeholders and the public. Science-policy debates on developing the local hazard map should be established to ensure that every party sees the same picture, obtains a mutual understanding of the problems, and seeks appropriate risk communication strategies. Moreover, the establishment of a fair impact/burden sharing discourse was considered the most preferred measure in this exposure avoidance aspect. The majority of stakeholders demanded to shift from the current reactive compensation scheme, which causes a high degree of conflicts among the rural and urban inhabitants, to be more proactive and justice in disaster risk management. A local flood taxing scheme or survivor fund may help address climate justice at the city level. In contradiction to other stakeholders, the provincial disaster risk management agency, the direct responsible agency, disagreed with initiating the new scheme but favouring the existing compensation one.

From the perspective of Hazard mitigation measures, the stakeholder highly preferred the proposed measures, with a score of 4.2 on average. The stakeholders strongly supported the idea of vegetated floodplain conservation, water sport and eco-agriculture tourism promotion, blue-green infrastructure integration, the introduction of Low Impact Development, enforcement of relevant local regulations to make way for water, and city-wide improvement wastewater management. Vegetated floodplain conservation and greenery & healthy corridors in Zone 1 and 2 were perceived as no-regret measures and obtained a very good response from stakeholders. Ensuring public participation in the proposed measures was the only concern voiced by academia in order to avoid the emergence of gentrification, displacement, and social and environmental justice problem. In dense urban settlements zone (Zone 3), integration of blue-green infrastructure and Low Impact Development innovation through Sponge district and Blue TOD (way for water) were received as innovative ideas to improve the urban environment of the inner-city especially drainage capacity, permeability and urban heat condition. However, technical and investment feasibility have to be explored to ensure cost-effectiveness and sustainability. Besides integrating grey and blue-green infrastructure, the root of the problems that keep repeating themselves is clarity and enforcement capacity on land cover change relevant legislations. Lacking a local benchmark on land excavation and land reclamation prevents the local governments from exercising and enforcing their legal power to withdraw building rights on the waterway areas. To bridge this gap, evidence-based studies should be conducted by a neutral party without conflict of interest. Yet, mutual understanding among stakeholders, especially land developers/investors, on increasing drainage capacity is paramount in mitigating the urban inundation problem. Contrary to other proposed measures in this category, the stakeholders assigned less preference score to increase water retention area/network-related measures, especially local governments in the flood-prone areas. The stakeholders perceived heavy land price speculation, government procurement procedure and legal framework as barriers preventing the realization of proposed measures, particularly on the financial aspect, such as civil contracts for flood retention land acquisition.

Enhance capacity measures were the most preferred by the stakeholders. The stakeholders' only concern was government land availability to establish service branches or offices of public institutions and utilities to stimulate decentralization and development to the safer zone (Zone 4). However, a private sector representative suggested that land donation from private owners sounds possible for new public service centre development due to the co-benefits of boosting the new economy and housing markets of the surroundings. The proposed measures in stimulating development in Zone 4 should take water supply provision as a prerequisite to ensure water security for new inhabitants and economic activities. Nevertheless, government agencies' representatives emphasized that increasing the number of small local water reservoirs and linking them together are also essential; otherwise, the area could not shine its attractiveness for housing and economic development.

In addition to an overall stakeholders perspective, this study also explored commonalities and differences between stakeholders who represent local governments and other groups in order to underline possible relations between the spatial scope of responsibility and preference level of the proposed measures. Figure 5.24-25 and Annex 19 exhibit that two groups of stakeholders shared similarities in voting a high preference for all capacity enhancement measures and most hazard mitigation-related measures while not favouring retreat strategies. However, the analysis showed different views of the two stakeholders groups on strengthening water retention capacity measures. The local governments' group has relatively less preferred the following measures, enforcement of regulations, provision and endorsement of hazard maps, and no extension of LRT in flood-prone areas. Meanwhile, the non-local government group showed a significantly less preference for relocation than the local governments' group. At the same time, the non-local government group expressed a slightly lower preference score on vegetated floodplain conservation, promoting blue-green infrastructure, and water supply system improvement compared to the local governments' stakeholders. Moreover, linear regression analysis showed the representative from local governments have more similar thoughts within the group on the preference of the proposed measures than the non-local government group, with the R-squared value of 0.25 and 0.11, respectively (see Annex 19a).

Figure 5.23 Stakeholders' preference for the proposed potential spatial planning-related measures

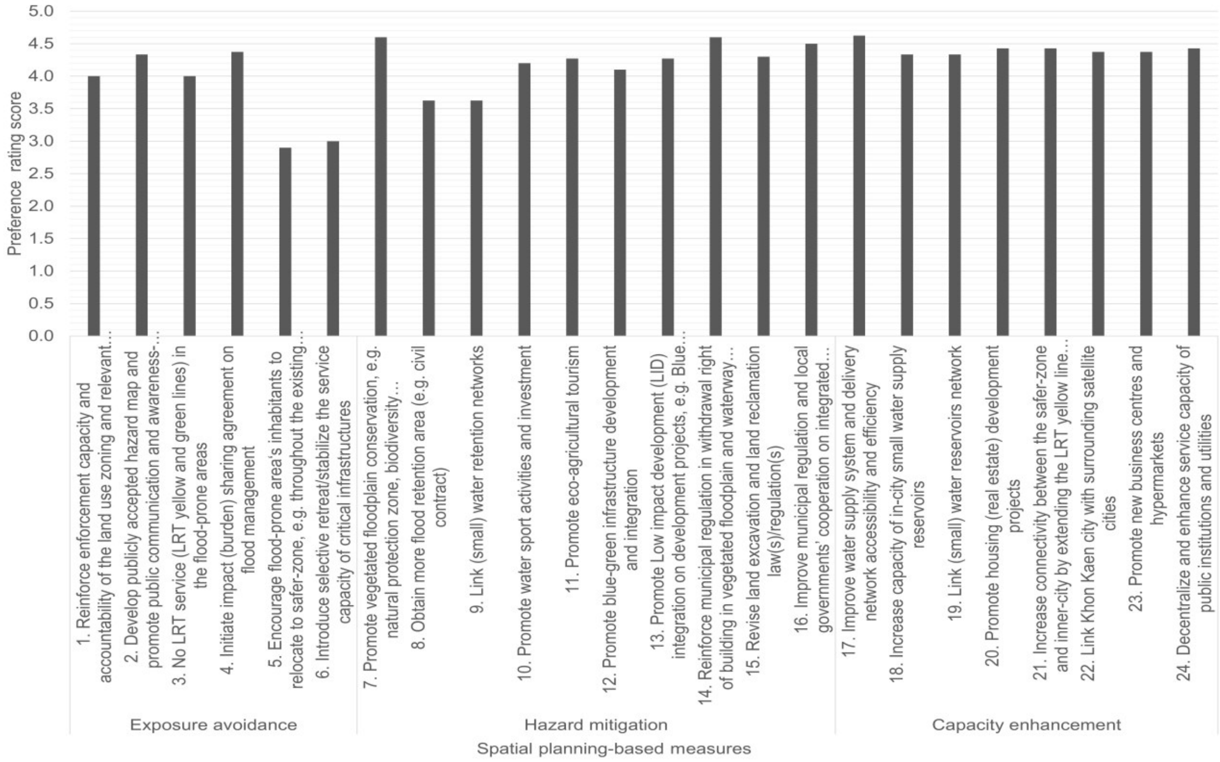


Figure 5. 24 Local governments' preference for the proposed potential spatial planning-related measures

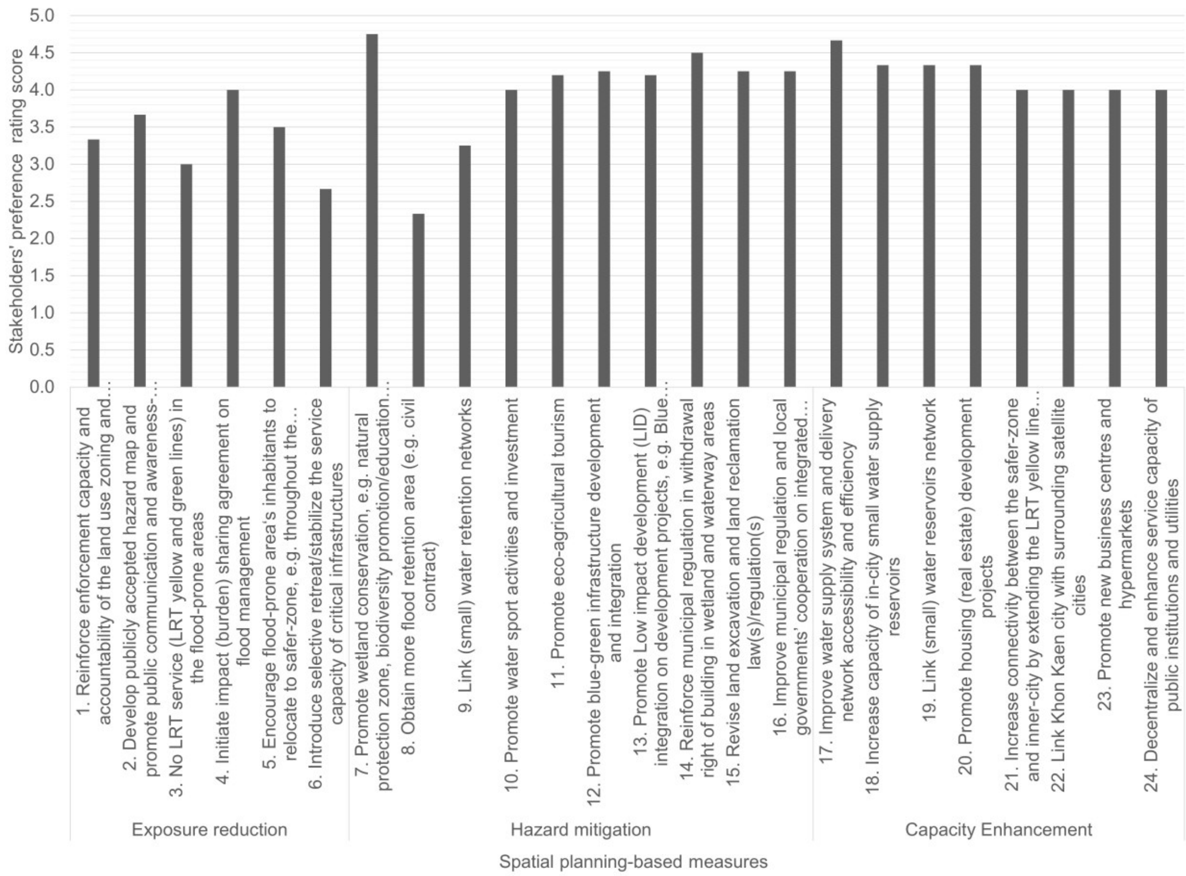
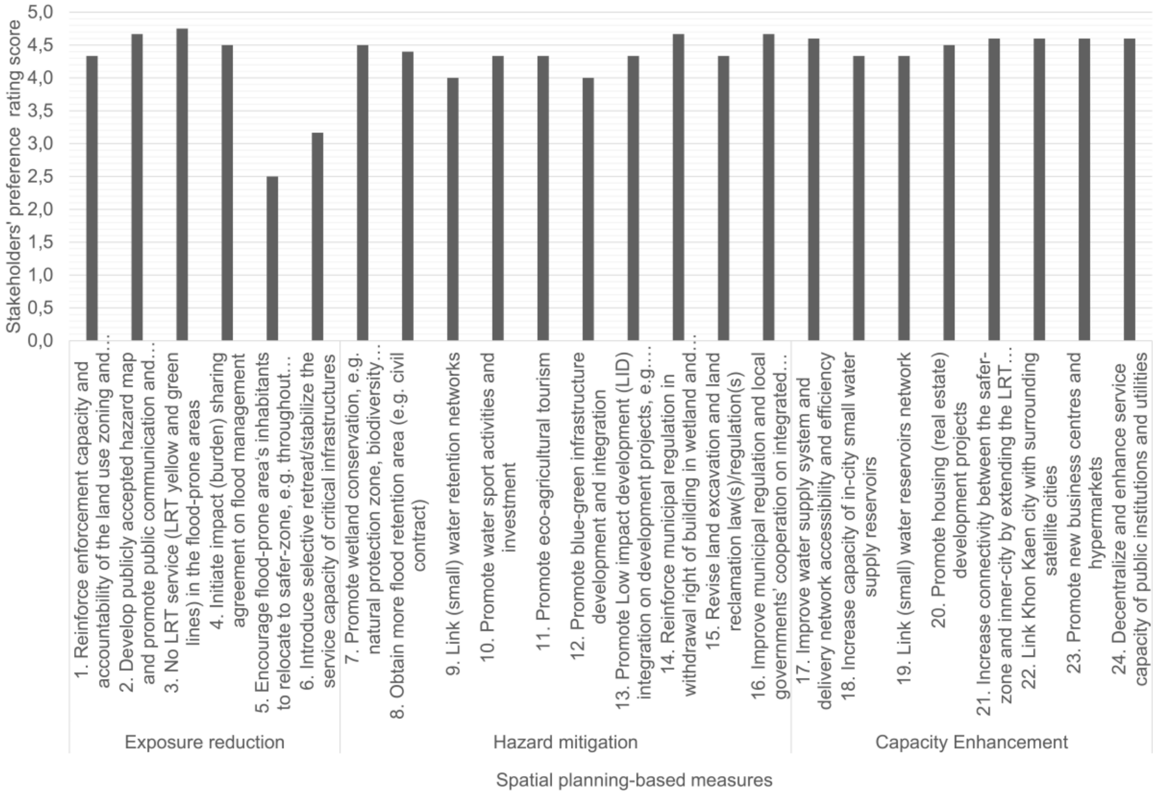


Figure 5.25 Non- local government stakeholders' preference on the proposed potential spatial planning-related measures



5.3.2.2 Public health-specific perspective

1) Spatial planning-based measures identification

Despite the fact that the proposed spatial-based planning measures generally received positive feedback from a city-wide development point of view, this does not mean the public health sector automatically prefers the measurements. This study reckons the spatial-network hybrid characteristics of the local public health operation; therefore, the proposed spatial planning-based measures were justified to align with the local public health care practices and contexts. The proposed spatial planning-based measures for the local public health service were categorized into two aspects, exposure reduction and capacity enhancement, see Table 5.5. Visualization of the proposed spatial planning-based measures for the local public health service showed in figure 5.26.

- **Exposure reduction**

Meanwhile, the provision and advancement of the local public health services are based on a short-term demographical trend in a particular service area. Site selection criteria partially concern historical flood events and land availability. These factors usually pose a dilemma to the MoPH in ensuring the health care accessibility and safety of a public health unit. Government-owned or donated piece of land is often situated in a flood-prone area[35].

[35] The current hospital location selection criteria considers the hospital buildings to be higher than the historic flood level. However, there are cases that a hospital itself might not be flooded but surrounded by floods, thus losing accessibility, which eventually affected service operations.

More advanced service-level health care units located in the hazard-prone area means the public health care service network could be susceptible to hazards. To ensure the alignment with city-wide measures[36], no new hospital or public health unit should be built in a flood-prone area, as well as service capacity of the existing health facility located in hazard-prone areas shall be limited, e.g. Khon Kaen Hospital 2, in order to reduce exposure of the local public health care service and its population health. For the high flood risk areas, selective retreat should be introduced in order to relocate a health facility/unit to a safer area. However, a major concern for implementing such a managed retreat strategy contradicts the public health care mandate in ensuring accessibility and service availability.

- **Capacity enhancement**

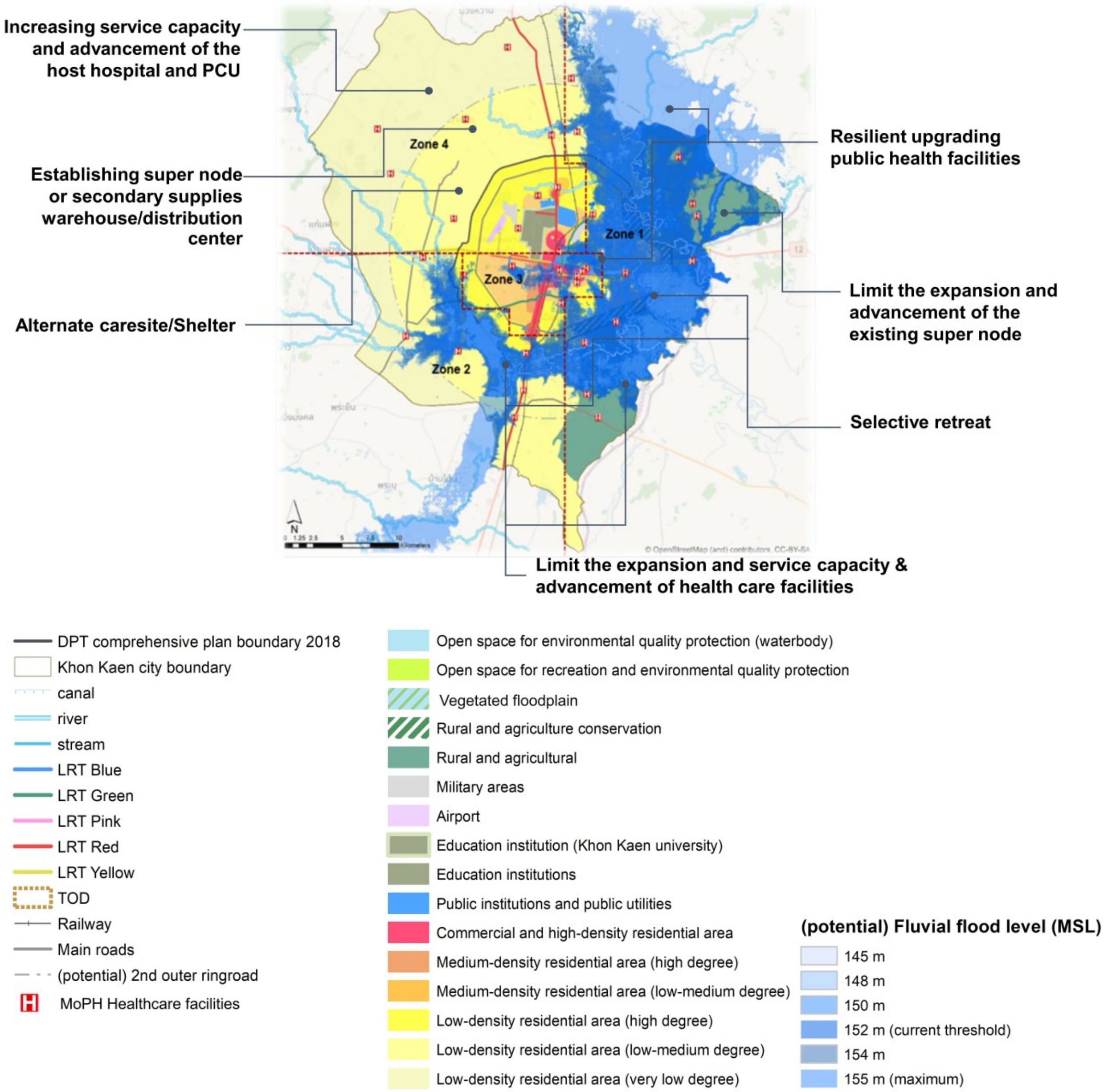
Based on the “Trend scenario”, Khon Kaen Hospital and other major public health institutions might potentially be surrounded or directly flooded in the future. An alternate care site or supernode should be assigned as secondary service node/units located in the safer zone (Zone 4). This measure promotes redundancy of the service network and reduces work overload of Khon Kaen Hospital (CUP host). This action also helps reduce possible trips of patients to the city-center, resulting in mitigated traffic congestion. Spatial development re-direction and provision of public health care have to go hand in hand in order to ensure the achievement of climate resilience target (s). The city shall have a clear development agenda to make the hazard-prone unattractive while the safer zone is more popular. Then selective retreat of the public health care service and increased service capacity in Zone 4 (where there are currently low service demands) could be feasible. If managed retreat strategy is not possible, resilient upgrading of health care facilities and their working systems is vital, especially in Zone 1, 2 and 3. Undoubtedly, an individual public health facility assumably benefits from city-wide hazard mitigation measures, e.g. improvement of land cover change control, low impact development, provision of a water reservoir network. Although this study did not include a detailed analysis of the microscale of hazard mitigation measures through design and engineering solutions such as the LID and landscape design of each public health care unit, their necessity for resilient upgrading is well recognized and will be addressed in the proposed roadmap in the later steps.

[36] Limiting an advance mass transit system and enforcement of land zoning regulation, and promotion of green corridor, vegetated floodplain conservation, and food security led rural life conservation in Zone 1 and Zone 2

Table 5.5 List of proposed spatial planning-based measures for public health sector

Strategies		Potential spatial planning-related measurements	Zones 1	Zones 2	Zones 3	Zones 4
Exposure reduction	Safer location	1. Limit the extension of services of the supernode in a flood-prone area	✓	✓		
		2. Introduce selective retreat for high-risk public health facilities	✓	✓	✓	
		3. Limit further provision of service capacity in flood-prone areas	✓	✓	✓	
Enhance capacity	Resilient upgrading	4. Introduce resilient upgrading of health facility building and working system operation	✓	✓	✓	✓
	Service balance	5. Increase service capacity and advancement of primary care units outside flood-prone areas (safer areas)				✓
	Enhance Redundancy	6. Assign a supernode of the CUP-host as a secondary service centre/unit or supply warehouse outside the flood-prone areas				✓
		7. Assign alternate care site(s) outside flood-prone areas				✓

Figure 5.26 Proposed spatial planning-based measures for the public health sector



2) Preference appraisal of the proposed measures

The proposed exposure reduction and capacity enhancement measures were discussed with Khon Kaen Hospital (CUP host) (16 March 2020) and presented to Khon Kaen Provincial Public Health Office (KKPHO) (17 March 2020) for appraising their preference for the proposed measurements. The Likert scale was applied to assess the preferences of KKPHO[37].

KKPHO expressed a wide range of preference levels on the proposed measures, from the lowest to the highest (see Figure 5.27 and Annex 20). However, an overall average preference rating score is a medium level (3.2 out of 5). In contradiction to the city-wide perspective, the local public health care prefered exposure reduction-related measurements (3.7) more than capacity enhancement (2.7). KKPHO gave the highest and high preference level to caping service capacity by no new primary health care units in flood-prone areas (5.0), and limiting service capacity or advancement of Khon Kaen 2 hospital (which is located in a flood-prone area) (4.0). It is important to note that even though the KKPHO favoured capping and limiting capacity or advancement of health care services in flood-prone areas. Their support argumentation was rather cost-efficiency than responding to urban development change or disaster risk management concerns, especially in the case of Khon Kaen Hospital 2[38]. Meanwhile, relocation of health care facilities to the safer areas received the lowest score (2.0) in this category. With lacking long-term and high-resolution demographic projection in each health care service zone of the city, KKPHO could not position their opinion on the provisioning of new or increasing advancement and service capacity of health care units in safer areas.

Moreover, KKPHO cannot also give their view on the proposed measures on establishing a supernode as a secondary service centre or secondary supply warehouse of Khon Kaen Hospital in the safer areas, but threw the ball to Khon Kaen Hospital; thereby, the measure received a *medium* level of preference. Khon Kaen Hospital representative supported the idea of having a supernode and secondary medical supply warehouse as contingency units in the safer zone. A supernode and the secondary warehouse could reduce the Khon Kaen Hospital's workload and minimize unnecessary trips of the patients and delivery of medical supplies between the inner-city and western and north-western wings of the city. Therefore this measure could become a promising no-regret measure. However, a more detailed appraisal of this option needs to be evaluated, particularly its cost-benefits and externalities. To make use of the existing facilities, the Nong Kung Town health promotion centre could

[37] direct responsible agency supervising Khon Kaen city's public health network operation

[38] The hospital was established under the protonage of the late superior abbot of Sirithammikawas temple through land donation and construction costs. After the late superior abbot passway, his followers' prestige has been dramatically declined, which affected the financial flow for operation and maintance fo the hospital, which planned to rely on public donation to the temple. Instead of lifting the headquarter's workload and a financial burden (Khon Kaen Hospital)'s as planned, Khon Kaen hospital 2 became budgetary and operation distress in terms of operation and maintenance cost due to not economic of scale to have a hospital in low population density area.

serve as a supernode and secondary medical supplies warehouse for Khon Kaen Hospital's CUP network.

As a primary public service, provisions of health care services following demands and ensuring accessibility (where people live) is their primary concern. Fluvial flood typically hampers the local people's livelihood but does not dramatically take people's lives or devastate property as hurricanes or earthquakes. Thus, people rather temporary move to a shelter/field hospital nearby the affected area (e.g. on the road or nearby school) rather than alternate care sites far away from their houses. Even though the local public health facilities have to temporarily close due to hazards, external support from the local governments and a disaster risk management network will arrive as soon as possible. The health care service, especially PCU, is more flexible during a crisis due to non-complicated services and care. PCUs personnel can commute and visit their patients at home by boat or other alternative modes of transportation during flooding. However, more prolonged hazards could cause more impact to be bedbound/medical dependency patients. When people do not move, public health services have to stay. Hence, the provision of alternate care sites in the safer zone (Zone 4) seems not an option for Khon Kaen city in KKPHO's opinion. Thus, this measure received the least score (1.0). Nonetheless, resilient upgrading sounds like a promising option that addresses concerns of service operation and disaster risk management for the public health facility in hazard-prone areas; hence, the KKPHO favoured this measure with a score of 4.0.

In conclusion, city-wide stakeholders have no objection and highly preferred all the proposed spatial planning-based measures and perceived them as strategies for fulfilling the desired target to minimise the potential impact of climate-related hazards in the future. By linking the city-wide and public health-specific spatial planning-based measures together, all measures were integrated into the "Desirable scenario", except those related to service capacity advancement and provision of alternate care site(s) outside the hazard-prone area. In this regard, the visualization of preferred measures is summarized in Figure 5.28.

Figure 5.27 KKPHO's preference for the proposed potential spatial planning-related measurements

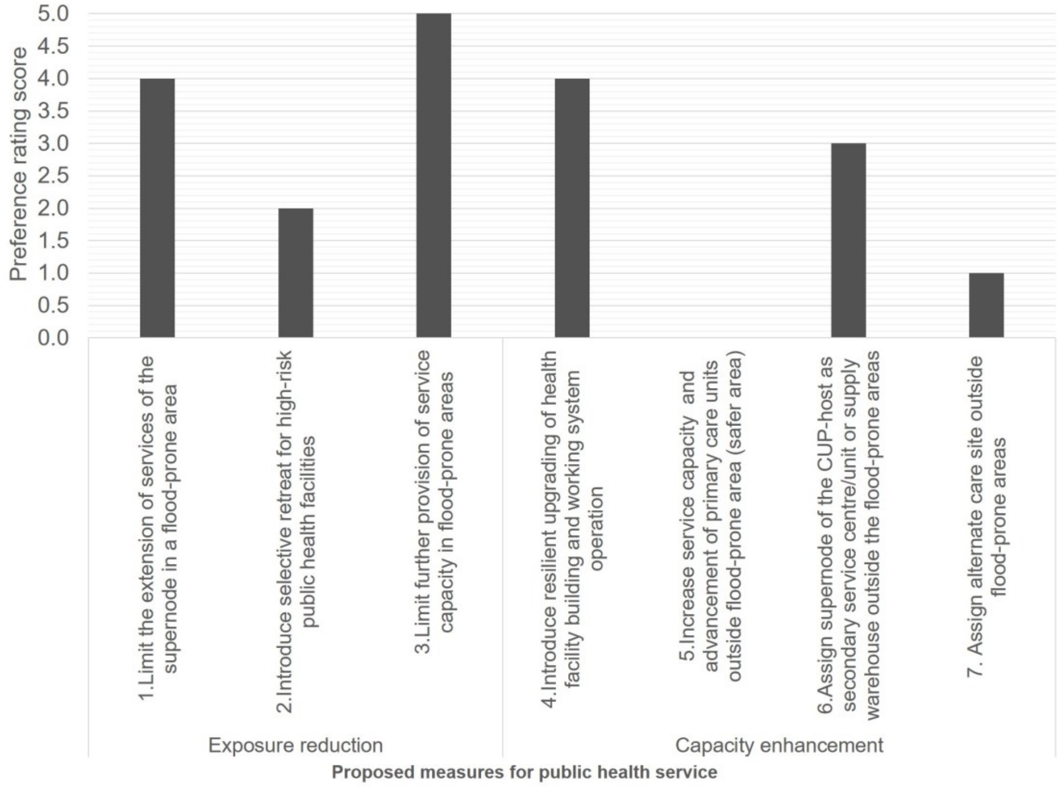
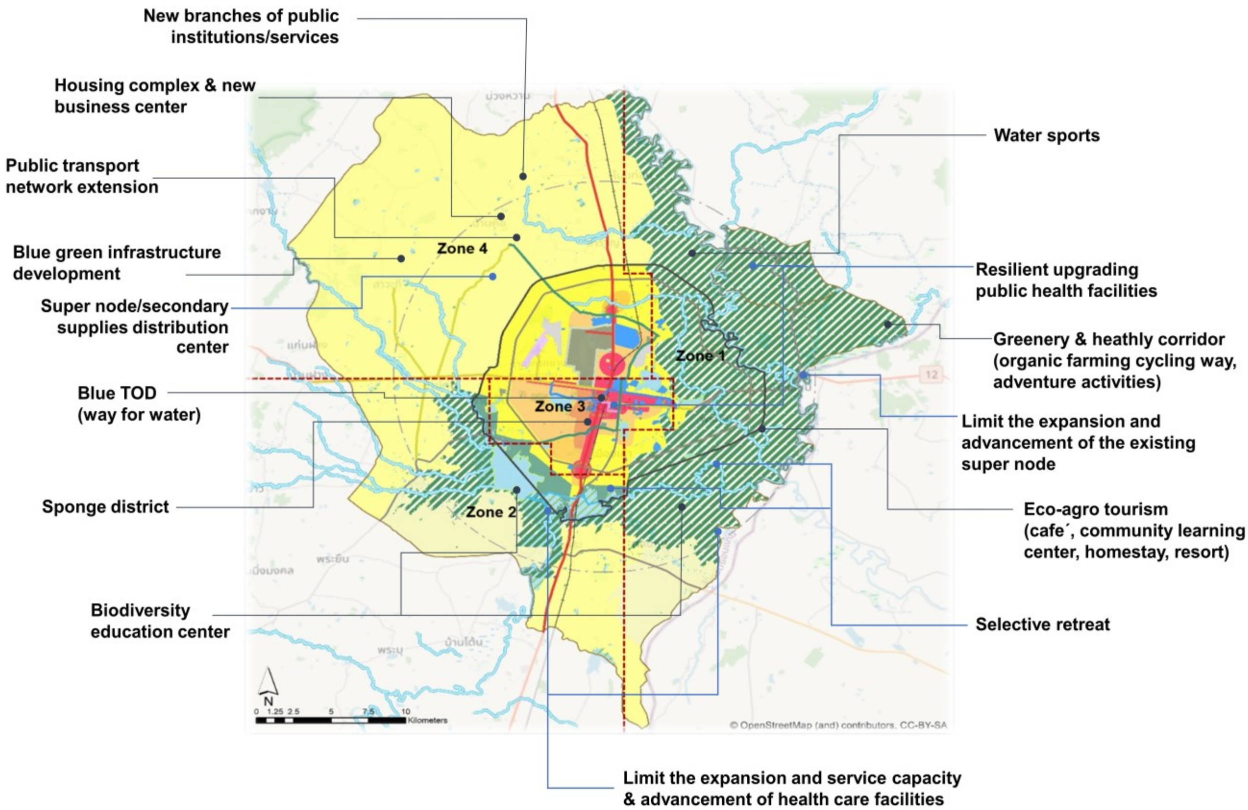


Figure 5.28 Visualization of stakeholders preferred spatial planning-based measures for minimizing the potential impact of climate-related hazards of Khon Kaen city public health care



5.3.2.3 Desirable scenario storyline formation

The “Desirable scenario” was developed based on the main features of urban development and climate-related hazards described under the “Trend scenario” combined with city-wide and public health-specific preferred measures. This research recognizes that the local public health management highly depends on socio-demographic changes and settlement dynamics induced by urban development. Therefore, preferred city-wide measures conceptually contribute to overall climate-related hazard mitigation and contextually determine exposure and vulnerability of the local public health services. Meanwhile, the public health care facility and network operation mainly drives and controls their internal exposure and vulnerability of working systems and population health. ***Matrix analysis*** was applied to reveal convergences and divergences, resulting in interplays among the three systems of interest in different Khon Kaen city zones, enabling the “Desirable scenario” storyline formulation. The combination of the preferred spatial planning-based measures and articulation of matrix analysis are as follows and in Table 5.6.

Desirable scenario storyline

- **Fluvial flood-prone area (Zone 1 and 2)**

To limit urbanization in the flood-prone areas, only the enforcement of relevant laws and regulations is not enough, but investment in LRT yellow line and LRT green line need to be diverted out of the areas. Instead of housing and real estate development, promoting agro-eco tourism & environmental-friendly recreation activities shall be core market-driven strategies boosting the local economy while protecting agricultural areas, functioning as the city’s flood retention. To systematically address the possibility of 155 m MSL fluvial flood level, a hazard map should be available and used for risk communication and participatory decision-making. As an outcome of these city-wide actions, the slow pace of development and population growth in the flood-prone area might be expected. These changes could contribute to relatively low health care service demands, which respond to the zero-growth policy of public health human resource management. Therefore, there is no need for further extension of service capacity and the advancement of services of the existing public health units or establishing new public health care infrastructure in flood-prone areas. In these zones, public health units exposed to 155 m MSL fluvial floods should be mandatory to implement structural and non-structure resilient upgrading measurements. If resilient upgrading does not significantly minimize the potential impacts, retreat strategies may come to play. From a public health perspective, promoting blue-green infrastructure development could help mitigate hazards and reduce the number of direct injuries and loss of life due to flood risk. The measure also enhances the local population's environmental health and well-being, reducing service demands and costs to the health care sector and society.

- **Dense urban settlement (Zone 3)**

Khon Kaen city invests in blue-green infrastructures to make way for water, especially in densely built-up areas to deal with floods (pluvial and fluvial). This measure integrates with changes in land cover-related regulations and improvement of the drainage system and networks across local administrative boundaries. Moreover, the city also commits to removing technical and legal barriers to appropriate land use and land-cover change regulation, providing formal hazard maps, considering future-oriented climate-related hazards in planning processes, and opening flood management discourse as a centre of urban climate-resilient strategies. Meanwhile, densification and mixed-use magnetize more economic activities and people to the inner-city areas. Demand for public health services is anticipated to rise in response to this socio-demographic change and economic growth. This prevalent trend aggravates Khon Kaen Hospital, which is already overloaded with service demands and all public health units in the CUP network highly depend on its management and operation. Although increasing permeable surface and improving a drainage system and water retention capacity could cut the peak of inundation in this zone, it is fair to state that no one can guarantee the success of the city-wide measures. However, under the possibility of 155 m MSL fluvial flood events, Khon Kaen Hospital and other healthcare facilities in this zone can be isolated or surrounded by water and hampered by repeatedly pluvial floods. However, instead of introducing retreat strategies, resilient upgrading to enhance individual health care units' coping and adaptive capacity seems appropriate.

- **Safer zone (Zone 4)**

With topographical advantage, the area considers a safer zone from fluvial flood risk. More development and housing shall be redirected from the flood-prone areas (Zone 1&2) to this safer zone. Adhere to an increasing population; this zone is assigned as a new development node of the city's economic development by extending the mass transit network, decentralised service of public institutions, and public amenity developments. The city substantially invests in water infrastructures in this area in order to serve the increasing demands of new inhabitants and economic activities. These changes aim to increase the liveability and popularity of settlements in this zone. Nevertheless, the local public health sector hesitates to streamline its operation to adhere to the desired city-wide development orientation. Instead of establishing new public health facilities or increasing the advancement of the existing primary health care units in this zone in order to respond to the increasing service demands of future inhabitants, assigning an existing high capacity public health unit to be a supernode or secondary medical supply centre could be a practical alternative.

Table 5. 6 Matrix analysis for desirable scenario formulation

Zone	Key features of the systems of interest			Convergence/Divergent
	Urban development	**Climate-related hazards**	**Public health**	
1 & 2	• Limiting urbanization in flood-prone areas • No LRT service (yellow and green lines) in the flood-prone area. • Enforcement of land-use zoning and relevant regulations • Introduction of retreat strategy • Promotion of organic food and agro-eco tourism and recreation	• Potential fluvial flood at 155 MSL • More intense pluvial flood • Improvement of a drainage system based on future-climate risks and urban development changes • Strengthen the existing dike/flood wall • Provision of hazard map and risk communication • Increase water retention capacity • Promotion of blue-green infrastructure development and vegetated floodplain conservation • Selective retreat to the safer area	• Limiting the extension of services of the supernode (Khon Kaen Hosptial 2) in a flood-prone area • Limiting further extension or service capacity in a flood-prone area or potential isolated areas • Resilient upgrading of health facility building and working system operation • Selective retreat • Inefficient procurement process and budget use • Under staff - Zero growth policy *(personnel capacity)*	**Convergence** • Stabilizing public health service capacity and advancement in response to a slow rate of population growth in the flood-prone areas • Adherence between public health service demand and limited service capacity (in response to zero growth policy) • Increasing public health service quality • Resilient upgrading of public health care facilities infrastructures and working systems in flood-prone areas • Promotion of better environmental health and environmentally friendly rural economy development **Divergence** Interactional divergence: - (If the city could not limit urbanization in flood-prone areas, increased service demands might be over the local public health service capacity in the flood-prone areas)
3	• Strong increasing of population and urbanization development • Compact and mixed-use development	• Potential fluvial flood at 155 MSL • More intense pluvial flood	• Limiting further extension or service capacity in a flood-prone area or potential isolated area (no further development)	**Convergence** • Promotion of livable city development with blue-green infrastructure and mixed-use integration

Zone	Key features of the systems of interest			Convergence/Divergent
	Urban development	Climate-related hazards	Public health	
	• Development of mass transit system (LRT) • Densification of residential and commercial uses	• Improvement of a drainage system with future-oriented planning • Provision of hazard map and risk communication • Increase water retention capacity • Promotion of blue-green infrastructure and integration of Low Impact development • Withdrawn building right in waterway area • Revision and enforcement of the relevant land excavation and land reclamation law(s)	• Resilient upgrading of health facility building and working system operation • Selective retreat • Inefficient procurement process and budget use • Under staff - Zero growth policy *(personnel capacity)* • Overload of service demand in comparison to service capacity • Inefficient procurement process and budget use	• Reduce blockage of the waterway, which caused the prolonged pluvial flood, thus reducing traffic congestion • Potentially mitigate the magnitude of hazards • Resilient upgrading of health facilities infrastructure and working system in hazards-prone areas **Divergence** Sectoral divergence *Public health*: • Discrepancy between increasing service demand and zero growth policy may negatively affect service quality *Climate-related hazards:* Interactional divergence • Insufficient public health service capacity in response to increasing population trend in the service area • The main proportion of public health care service capacity is agglomerated in hazard-prone areas, which could be flooded or isolated in 155 MSL flood. Yet, no assignment of alternate care site
4	• Increasing population and promoting urbanization development • Conversion of agriculture and rural frontier to housing and light industrial	• Safer zone • Provision of water reservoirs and water storage infrastructure	• Assignment of a supernode as a secondary service centre/unit or supply warehouse of Khon Kaen hospital in the safer zone.	**Convergence** • Promotion of livable city development with blue-green infrastructure and mixed-use integration • More development in the safer zone

<table>
<tr><th rowspan="2">Zone</th><th colspan="3">Key features of the systems of interest</th><th rowspan="2">Convergence/Divergent</th></tr>
<tr><th>Urban development</th><th>Climate-related hazards</th><th>Public health</th></tr>
<tr><td></td><td>• Increasing connectivity between the safe-zone and the city centre by extending the LRT yellow line and green line
• Promotion of new business centre and hypermarkets
• Decentralizing and increasing capacity of public institutions and utilities</td><td>• Promotion of blue-green infrastructure and integration of Low Impact Development
• Revision and enforcement of relevant land excavation and land reclamation law(s)</td><td>• Under staff - Zero growth policy (personnel capacity)
• Inefficient procurement process and budget use</td><td>• Reduction of traffic congestion in inner-city areas
• Promotion of decentralization
• Increase redundancy of public health service network
Divergence
<u>Sectoral divergence</u>
Public health:
• The discrepancy between increasing service demand and zero growth policy, consequent to service quality
Climate-related hazards:
• -
<u>Interactional divergence</u>
• Insufficient public health service capacity in response to increasing population trend in the service area</td></tr>
</table>

5.3.3 Scenarios assessment

The composite indicators approach was applied for potential impact assessment of "Trend scenario" and “Desirable scenario”. The scenario assessment process consists of three main elements, composite indicator development, potential impact analysis, and sensitivity analysis, described in the following sections.

5.3.3.1 Composite indicators development

This study developed the set of composite indicators based on the IPCC AR5 climate risk concept, where the potential impact is the non-compensable aggregation of hazard, exposure and vulnerability. The architecture of composite indicators is structured into three pillars, hazard, exposure and vulnerability. Meanwhile, Hazard and Exposure pillars are determined by physical characteristics of the system of interest; Vulnerability pillar is a blending of sensitivity, coping capacity and adaptive capacity components, which are theoretically inseparable but operationalizable. The structure of the composite indicator can be seen in Figure 4.4. The set of composite indicators and sub-indicators were identified based on key relevant elements illustrated in the impact chains analysis (section 5.2.3.4), scenario storylines (section 5.2.3.5 & 5.3.2.3), and literature (Table 4.4), experts and local practitioners interviews (Annex 10). Thus the proposed list of indicators was reviewed and suggested weighting values by public health care experts (Annex 11, 21). The list of composite indicators, weighting values, and sub-indicators used for the potential impact assessment of this research are shown in Table 5.13. Description and justification of these indicators, sub-indicators and their classifications can be found in Table 5.7-5.9.

1) Composite indicators

This set of composite indicators consists of three Hazard indicators, two Exposure indicators, and 17 Vulnerability indicators. Input data was proportionally classified with a rating score of 0-4 in order to reflect its contribution to potential impact outcomes in coherence with the desired target(s) defined by the stakeholders (section 5.3.1). The details of the composite indicators are examined as follows.

1.1) Hazard indicators

According to IPCC’s (2014a: p.1766) definition, this study defined Hazard as climate-related physical events/trends/their physical impacts which may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, service provision, and environmental resources. The Hazard indicators were determined based on climate-related hazards bandwidth (section 5.2.2). Thus, Flood (H1) and Water scarcity (H2) were assigned as hazard-related indicators. This research further categorized sub-indicators as Fluvial flood (H1.1), Pluvial flood (H1.2), and Water scarcity (H2.0) according to the local climate-related hazard profile. The input data were derived from the climate-related hazard bandwidth (section 5.2.2), which is ordinally classified on a 0-4 rating scale (*very low* to *high*). Description and justification of these sub-indicators values can be found in Table 5.7.

Table 5. 7 Details and justifications of Hazard pillar indicators

Indicators	Sub-indicators	Data source(s)	Rating score
H1: Fluvial Flood	H1.0: Fluvial Flood	Scenario storyline	4 - <=152 - 155 m MSL 2 - >=152 - 155 m MSL 0 - >155 MSL
H2: Pluvial Flood	H2.0: Pluvial Flood	Scenario storyline	4 – Possible 0 – No possible
H3: Water scarcity	H3.0: Water scarcity	Scenario storyline	4 – Possible 0 – No possible

Justifications

- **Fluvial flood (H1.1)**: Corridor of fluvial flood under climate-related hazard bandwidth of Khon Kaen city (see section 5.2.2.1) is used to classify the hazard's magnitude. The occurrence of fluvial flood level <=152 to 155 m MSL is classified as having a high level of the hazard, followed by >=152 to 155 m MSL, and >155 m MSL as medium and low. The flood magnitudes' rating score is proportionately classified as 4, 2, and 0.
- **Pluvial flood (H1.2)**: According to the climate-related bandwidth (see section 5.2.2.2), the occurrence of a pluvial flood is binary, yes and no. In this regard, the sub-indicator is assorted into 2 classes, (1) possible to experience a pluvial flood and (2) no possibility to experience a pluvial flood, with a rating score of 4 and 0.
- **Water scarcity (H2.0):** As described in section 5.2.2.3, the possibility of a water scarcity episode is binary, yes or no. Therefore, this sub-indicator is categorized into 2 classes, (1) possible to experience water scarcity and (2) no possibility to experience water scarcity, with rating scores of 4 and 0.

1.2) Exposure indicators

According to the IPCC (2014a: p.1765), exposure means the presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected. Therefore, in this study, Exposure indicators were characterized based on public health care facility's buildings locations (E1) and the position of their vital working systems (E2). Exposure of buildings is distinct among the three considered hazards based on the possible future climate-related hazards bandwidth, fluvial flood (E1.1), pluvial flood (E 1.2), and water supply scarcity (E 1.3). Exposure of working system (E2) can be further broken down to the location/position of primary working systems (E2.1) and location/position of reserved (secondary) working systems (E2.2). The input data were derived from climate-related hazards bandwidths as well as a questionnaire survey of the local public health facilities. The input data were ordinally classified on a 0-4 rating scale. Description and justification of these sub-indicators values can be found in Table 5.8.

Table 5. 8 Details and justifications of Exposure pillar indicators

Indicators	Sub-indicators	Data source(s)	Rating score
E1: Exposure of public health facility's building(s)	E1.1: Exposure of public health facility's building(s) to fluvial flood	Scenario storyline (GIS analysis)	4 - Flooded or possible to be flooded 2 - Not flooded, but possible to be isolated or limited accessibility 0 - Neither flooded nor be isolated and limited accessibility
	E1.2: Exposure of public health facility's building(s) to pluvial flood	Scenario storyline (GIS analysis)	4 - Located in a repeatedly (pluvial) flooded area 2 - Not located in a repeatedly (pluvial) flooded area but possible to be flooded due to development-induced landscape/land cover change 0 - Neither located in a repeatedly (pluvial) flooded area nor possible to be flooded due to development-induced landscape/land cover change
	E1.3: Exposure of public health facility's building(s) to water scarcity	Scenario storyline (GIS analysis)	4 - Located at 165 MSL and higher, 2 - Located lower than 165 MSL 0 - Not located in the study area
E2: Exposure of Working systems	E2.1 Exposure of primary working systems[39]	Survey	4 - Located at <3m from the ground level or lower 0 - Located at >= 3m from the ground level (2nd floor) or higher
	E2.2 Exposure of secondary working systems[40] [41]	Survey	4 - Located at <3m above the ground or lower 0 - Located at >= 3m above the ground or the height of 2nd floor or higher

<u>Justifications</u>

- **Location of public health care building (E 1.0):** Input data of the location of public health facility/building sub-indicator (E1.0) was derived from geospatial analysis of the scenario storylines, which illustrated the presence of public health facilities/buildings to the climate-related hazards as the following:

[39] 1) Electricity power control center;2) Liquid fuel (vehicle, water pumping, cooking etc.);3) Computer/Server control center;4) Internet control center;5) Telephone/Radio control center;6) Document/Medical record archive;7) Drinking/ Potable water storage;8) Water filter or purification system;9) Tap water;10) Drainage system;11) Pumping system;12) Wastewater treatment system;13) Solid waste center;14) Infectious waste center;15) Hazardous waste center;16) Infectious waste incineration point;17) Medical radiology and imaginary center;18) Morgue;19) Food and nutrition storage;20) Medicine and pharmaceutical storage center;21) Blood bank;22) Medical gases and liquid oxygen supply storage/center;23) Dispensable medical supplies storage;24) Parking lots

[40] 1) Backup power source (s) (CHP, renewable energy);2) Liquid fuel (vehicle, water pumping, cooking etc.); 3) Computer/Server control center;4) Telephone/Radio control center; 5) Tap water; 6) Water filter/Purification; 7) Wastewater treatment system;8) Waste management system; 9) Medicine and dispensable medical supplies (incl. Medical gases, blood); 10) Food and nutrition storage;11) Document/Medical record archive;12) Multipurpose space/spare room; 13)Morgue;14) Parking lots

[41] This study assumed that the secondary internet working systems are attached with/or located in the same position as computer and server.

- *Fluvial flood(E1.1):* Based on the possible bandwidth of fluvial flood scenarios (Figure 5.6) reveals 3 different exposure typologies of the local public health care buildings 1) Flooded or possible to be flooded, 2) Not flooded but possible to be isolated or limited accessibility; 3) Neither flooded nor be isolated and limited accessibility. The rating score assigned to these variations of exposure is 4, 2, and 0, respectively.
- *Pluvial flood(E1.2):* Even though this study cannot identify the spatial extension of the potential pluvial flood area in the future, as mentioned in section 5.2.2.2; the current pluvial flood hotspots were taken into account. Therefore, exposure of local public health care buildings to the potential pluvial flood in the future is categorized into 3 levels 1) Located in a repeatedly (pluvial) flooded area, 2) Not located in a repeatedly (pluvial) flooded area but possible to be flooded due to development-induced landscape/land cover change, 3) Neither located in a repeatedly (pluvial) flooded area nor possible to be flooded due to development-induced landscape/land cover change. The rating score assigned to these variations of exposure is 4, 2, and 0, respectively. It is important to note that based on conservative assumption, therefore, 0 was not assigned to the participating hospitals.
- *Water scarcity(E1.3)*: Similar to the pluvial flood that this study cannot identify the spatial extension of the potential water scarcity in the future, as mentioned in section 5.2.2.3. But the current water intermittent hotspots were taken into account in order to diversify the level of exposure within the study area. Even though there are no current studies or research to specify water scarcity hotspots in the study area, the local water management experts have no objection to using the contour line at 165 m MSL to represent a general topographical limitation of water supply delivery in the study area. Therefore, the local public health facilities' water scarcity exposure classifies into 2 levels, 1) Located at 165 m MSL and higher, and 2) Located lower than 165 m MSL, with rating scores 4 and 2, respectively. According to the bandwidth of climate-related hazards, the city is assumed to experience water scarcity as a whole due to network-based water supply. Thereby, no participating hospitals in the study area were assigned as 0 for this sub-indicator.

- **Location/position of primary working systems (E 2.1) and Location/position of and reserved (secondary) working systems (E 2.2):** Exposure of internal 26 primary working systems and 14 secondary working systems are determined by their location/position within/outside a local public health facility depending on specific characteristics of the systems in response to flooding. According to the MoPH expert[42], at least 3 meters from the ground or the 2nd floor of a building is considered a general recommendation for avoiding flood reaching critical operation systems or equipment. However, a trade-off between disaster risk preparation and appropriateness for day-to-day operation shall be further debated. In this regard, this study assumes that locations of working systems at 3 meters from the ground or 2nd floor or higher of a public health care building are considered as safer locations/positions for the essential working systems (rating score 0). In the case that the presence of working systems below 3 meters from the ground level is considered as high exposure with a rating score 4. For the working systems reported as off-site operation and not under the direct control of the health care facility, this study assumes that it is located in a safe location somewhere else (rating score 0). Nevertheless, some critical working system elements could not locate or store in the public health facility's building due to fire protection or hygiene regulations, e.g. diesel fuels for a backup generator or solid waste/biohazard waste. However, a safer location of these resources needs to be secured and contained to avoid cascading effects. Nonetheless, the study does not include such an extensive elaboration of exposure of critical infrastructures that the local public health depends on into account in this set of composite indicators. However, their dependency and interdependency are clearly addressed in the Vulnerability pillar. It is important to note this study does not include exposure of the working systems to direct or indirect water supply scarcity-related effects due to insufficient supportive input data in the study area.

1.3) Vulnerability indicators

Based on the IPCC's climate risk concept (Oppenheimer et al., 2014), this research implied vulnerability as the local public system's inclination to be adversely affected by external pressures or changes such as urban development and climate-related hazards. Vulnerability comprises three core elements; sensitivity (or susceptibility), lack of coping capacity, and lack of adaptive capacity. The input data were derived from a questionnaire survey and relevant policies or sectoral benchmarks. The input data were ordinally classified in 0-4 rating scale. Description and justification of these indicators and sub-indicators values can be found in Table 5.9.

1.3.1) Sensitivity(-related elements)

WHO (2007) defines health care service delivery shall ensure accessibility, coverage, quality and safety. The effective provision requires trained staff working with the right medicines and equipment and adequate financing.

[42] Mr.Watthana Suthiranart, Special professional architect, Design and construction division, Department of Health service support, Ministry of Public health (Interview date: 05.02.2020)

"Good health services are those which deliver effective, safe, quality personal and non-personal health interventions to those that need them, when and where needed, with minimum waste of resources" (WHO 2007)

Narrow down to the public health-specific context; this study implies sensitivity as a state of public health care service and operation that is easily affected or reacts to urban development change and climate-related hazards stimuli given to the properties, function, and goal of the system. Over carrying capacity, variety of vulnerable patients, deficits of available resources and malfunction/disruption of the working system could make public health services likely to be fragile and adversely affected by urban development change and climate-related hazards. Moreover, the public health sector also highly depends on and is interconnected with other critical infrastructures & urban domains. Altogether with literature (Table 4.4) and discussions with the local health care experts (see Annex 10), sensitivity elements of vulnerability indicators in the context of this study were characterized into five major indicators; Over carrying capacity (V1); Variety of vulnerable patients (V2); Resource insufficiency (V3); Poor system conditions and maintenance of working systems (V4); and Downtime of essential working systems (V5). This set of indicators comprises nine sub-indicators structured based on the input data derived from the survey combined with public health sector policy framework such as financial and human resources management schemes.

1.3.2) Coping capacity and Adaptive capacity(-related elements)

Building on the IPCC AR5 (Oppenheimer et al., 2014) and UBA (2017) definitions, this study interprets coping capacity as the ability of people, institutions, organizations, and systems to use available skills, values, beliefs, resources, and opportunities, to address, manage, and overcome adverse conditions in short to medium term. Meanwhile, adaptive capacity means the ability of systems, institutions, humans, and other organisms to adjust, moderate or avoid potential damage and to exploit opportunities or respond to consequences through both incremental actions and transformational changes of fundamental attribution of the systems, which usually reflects the future vulnerability end-point (outcome).

By recognising the relationship and differences between coping capacity and adaptative capacity (see Chapter 2), this study streamlined the capacity component of the Vulnerability pillar as lacking key attributes of climate resilience (coping capacity and adaptive capacity). Hence, the capacity-related indicators consist of 12 indicators based on the literature, public health care experts/practitioners interviews and lessons learnt from famous case studies of public health facilities affected by climate-related hazards in Thailand and in the case study area (Table 4.4 & Annex 10). These composite indicators can be grouped as five coping capacity-related elements (i.e. lack of flexibility & modularity; lack of diversity of suppliers; lack of redundancy; lack of responsiveness; lack of resource mobilization; and lack of integration and coordination) and six adaptive capacity-related elements (i.e. lack of information; lack of preparedness and risk transfer; lack of participation and inclusiveness; lack of capacity development; lack of mainstreaming climate-risk in planning process; and lack of monitoring and evaluation). The identified composite indicators represent both spatial and network dimensions of the local public health service. It also reflects key properties and characteristics of an overall working system and dependency & interdependency among units of Khon Kaen Hospital CUP network as well as the whole public health service network to other health determinant sectors. These 11 indicators are comprised of 40 sub-indicators structured based on input data derived from the survey combined with public health sector policy and management practices.

Table 5. 9 Details and justifications of Vulnerability pillar indicators

Indicators	Sub-indicators	Data sources	Vulnerability Rating score
V1: Over carrying capacity	V1.0: Balance between service capacity and service demand	Survey	4 - No, having service demand more than service capacity 2 - Yes, having service demand equal to service capacity 0 - Yes, having service demand lower than service capacity
V2: Variety of vulnerable patients	V2.0: Variety of vulnerable patient types 1) Respiratory ventilator/Oxygen-dependent or Dialysis dependent 2) Disability and self-movement difficulty 3) Elderly 4) Infant/Toddlers (0-5 year-old) 5) Pregnancy women 6) Long-term medication/treatment dependency 7) Local language proficiency 8) Mental illness 9) Others	Survey	4.0 - >= 8 types 3.5 - 7 types 3.0 - 6 types 2.5 - 5 types 2.0 - 4 types 1.5 - 3 types 1.0 - 2 types 0.5 - 1 type 0.0 - No vulnerable patients
V3: Resource insufficiency	V3.1: Insufficiency of financial resources for BaU operation	Survey	4 - Insufficient financial resource for BaU operation (deficit) 2 - Sufficient financial resource for BaU operation (but no surplus) 0 - A surplus financial resource for BaU operation
	V3.2: Insufficiency of health care personnel for BaU operation	Ratio of healthcare personnel per population in a service area or other figures indicated by the interviewees	4 - Yes 0 - No
V4: Poor system conditions and	V4.1: System conditions	Survey	4 - Impaired/Dysfunction (Out of order)

Indicators	Sub-indicators	Data sources	Vulnerability Rating score
maintenance of (26) working systems[43]			2 - Fair (O.K.) 0 - Good
	V4.2: System monitoring and reporting	Survey	4 – No 2 – Yes, but implemented irregularly 0 – Yes and implemented regularly
	V4.3: Availability of trained staff/technician for system maintenance and reparation	Survey	4 – No 0 – Yes
	V4.4: Availability of maintenance resources	Survey	4 – No 2 – Yes, but insufficient 0 – Yes and sufficient
V5: Downtime of essential working systems[44]	V5.0: Maximum downtime of essential working systems[45]	Survey	4.00 - >4 days 3.43 - >2-4 days 2.86 - >1-2 days 2.29 - >12-24 hrs 1.71 - >4-12 hrs 1.14 - >1-4 hrs 0.57 - <1 hrs 0.00 - Never
V6: Lack of flexibility & modularity	V6.1: Flexibility and modularity of key (18) working systems [46]	Survey	4.00 – Very Low/None 2.67 – Low 1.33 – Medium 0.00 – High **Note:** see the rating scale definition in the justification section
	V6.2: Connectivity(-ability) of essential working system with external devices/systems	Survey	4.00 –None and never aware of it 2.67– Low (No, but having a plan/under consideration) 1.33 –Medium (Yes, only for particular working systems) 0.00 – Very High (Yes, all working systems can be connected with external devices/ systems)
	V6.3: One-stop service area with the highest protective level (in the case of hazards or high level of emergency)	Survey	4 – None and never aware of it 3 – Low (No, but under discussion or drafting plan) 2 – Medium (Yes, having a plan, but no implementation) 1– High (Yes, having a plan, and conducting plan review/ drill(s), but

[43] 1) Electricity power control center; 2) backup power source (s) (e.g.CHP, renewable energy); 3) Liquid fuel (for a backup generator, vehicle, water pumping, cooking etc.); 4) Computer/Server control center; 5) Internet control center; 6) Telephone/Radio control center; 7) Document/Medical record archive; 8) Drinking/ Potable water storage; 9) Water filter or purification system; 10) Tap water; 11) Drainage system; 12) Pumping system; 13) Wastewater treatment system; 14) Solid waste center; 15) Infectious waste centre; 16) Hazardous waste center; 17 Infectious waste incineration point; 18) Medical radiology and imaginary center; 19) Morgue; 20) Food and nutrition storage; 21) Medicine and pharmaceutical storage center; 22) Blood bank; 23) Medical gases and liquid oxygen supply storage/center; 24) Dispensable medical supplies storage; 25) Multipurpose space/spare room; 26) Parking lots

[44] 1) Electricity power control center; 2) A backup power source (s) (e.g. CHP, renewable energy); 3) Liquid fuel (for a backup generator, vehicle, water pumping, cooking etc.); 4) Computer/Server control center; 5) Internet control center; 6) Telephone/Radio control center; 7) Drinking/ Potable water storage; 8) Tap water; 9) Drainage system; 10) Pumping system; 11) Drainage system; 12) Waste management system (solid waste, infectious waste, hazardous waste) 13) Medicine and pharmaceutical storage center; 14) Dispensable medical supplies storage; 15) Linens; 16)Stationary; 17)Food & Nutrition; 18)Vehicle; 19) Safe accessible routes

[45] within the past 5 years (2014-2019)

[46] 1) Electricity power control center; 2) Backup power source (s) (e.g. CHP, renewable energy);3)Computer/Server control center; 4)Internet control center; 5)Telephone/Radio control center; 6)Water filter/Purification; 7)Tap water; 8)Pumping system; 9)Wastewater treatment system; 10)Waste management system (incl. solid waste, infectious waste, hazardous waste); 11)Medicine and dispensable medical supplies (incl. Medical gases, blood); 12) Linin service; 13)Food and nutrition; 14)Multipurpose space/spare room; 15)Personnel management; 16)Vehicles; 17)Safe access route; 18)Personnel commuting service

Indicators	Sub-indicators	Data sources	Vulnerability Rating score
			no/insufficient resources for implementation) 0 – Very high (Yes, having a plan, conducting plan review/ drill(s), having sufficient resources for implementation)
V7: Lack of diversity of suppliers	V7.0: Diversity of suppliers of key (19) working systems[47]	Survey	4.00 – Very low/none 2.67 – Low 1.33 – Medium 0.00 – High **Note:** see the rating scale definition below
V8: Lack of redundancy	V8.1: Availability and capacity of (15) primary backup systems [48]	Survey	4 – Very low/none 3 – Low 2 – Medium 1 – High 0 – Very High **Note:** see the rating scale definition in the justification section
	V8.2: Procurement of special vehicle type (e.g. Boat, amphibian, helicopter, drone) for carrying goods and passengers during emergency or hazards	Survey	4.00 – None and never aware of it 2.67 – Low (no, but having a plan/under consideration) 1.33 – Medium (yes, own purchased or contracted service providers but lack of regular technical checkup) 0.00 – Very High (yes, own purchased or contracted service providers with regular technical checkup)
	V8.3: Alternate safe accessible route(s)	Survey	4.00 – None and never aware of it 2.67 – Low (No, but having a plan/under consideration) 1.33 – Medium (yes, surveyed and designed alternate safe accessible route(s) but lack of regular maintenance) 0.00 – Very High (yes, surveyed and designed alternate safe accessible route(s) as well as conducting regular maintenance)
	V8.4: Procurement of a secondary backup system	Survey	4.00 – None and never aware of it 2.67 – Low (no, but having a plan/under consideration) 1.33 – Medium (yes, own purchased or contracted service providers but lack of regular technical checkup) 0.00 – Very High (yes, own purchased or contracted service providers with regular technical checkup)
	V8.5: Standard procedure for	Survey	4 – No 0 – Yes, manual (written) recording

[47] 1) Electricity power control center; 2)Backup power source (s) (e.g. CHP, renewable energy);3)Computer/Server; 4)Internet; 5)Telephone/Radio; 6)Water filter/Purification; 7)Tap water; 8) Underground water; 9)Pumping system; 10)Wastewater treatment system; 11)Solid waste management system (incl. infectious waste, hazardous waste); 12)Medicine and dispensable medical supplies (incl. Medical gases, blood); 13) Linin service; 14) Office stationary; 15)Food and nutrition; 16)Multipurpose space/spare room; 17)Personnel management; 18) Vehicles;

[48] 1)Backup power source (s) (e.g. CHP, renewable energy);2) Liquid fuel; 3) Computer/Server 4)Internet; 5)Telephone/Radio; 6)Water filter/Purification; 6)Tap water; 7)Drinking water sources; 8)Wastewater treatment system; 9)Waste management system (incl. solid waste, infectious waste, hazardous waste); 10)Medicine and dispensable medical supplies (incl. Medical gases, blood); 11) Linin service; 12) Office stationary; 13)Food and nutrition; 14)Multipurpose space/spare room; 15)Personnel management

Indicators	Sub-indicators	Data sources	Vulnerability Rating score
	recording a patient medical data in the case of no IT service		
	V8.6: Using of runners (courier) as a backup for getting help from outside during communication systems failures	Survey	4 – No 0 – Yes
	V8.7: Shelter(s) on-site for staff and family in the case of hazards	Survey	4 – No 2 – Yes, but no designated places and supportive facilities in advance 0 – Yes with designated places and supportive facilities in advance
	V8.8: Assignment of alternate care site(s)	Survey	4 – None and never aware of it 3 – Low (no but under discussion or drafting plan) 2 – Medium (Yes, having a plan but no implementation) 1– High (Yes, having a plan, conducting plan review/ drill(s), but no/insufficient resources for implementation) 0 – Very high (Yes, having a plan, conducting plan review/ drill(s), having sufficient resources for implementation)
V9: Lack of responsiveness	V9.1: Resources conservation plan implementation	Survey	4 – None and never aware of it 3 – Low (no, but under discussion or drafting plan) 2 – Medium (Yes, having a plan but no regular review and drills) 1– High (Yes, having a plan, regular review/drill(s), but no/insufficient resources for implementation) 0 – Very high(Yes, having a plan, regular review/drill(s), and having sufficient resources for implementation)
	V9.2: Responsive plan for slow-onset climate-related hazards	Survey	4 – None and never aware of it 3 – Low (no but under discussion or drafting plan) 2 – Medium (yes, have a plan but no regular review and drills) 1– High (yes, have a plan, regular review/drill(s), but no/insufficient resources for implementation) 0 – Very high(yes, have a plan, regular review/drill(s), and have sufficient resources for implementation)
	V9.3: Business continuity plan implementation	Survey	4 – None and never aware of it 3 – Low (no, but under discussion or drafting plan) 2 – Medium (Yes, having a plan but no regular review and drills)

Indicators	Sub-indicators	Data sources	Vulnerability Rating score
			1– High (Yes, having a plan, regular review/drill(s), but no/insufficient resources for implementation) 0 – Very high(Yes, having a plan, regular review/drill(s), and having sufficient resources for implementation)
	V9.4: Contingency plan implementation	Survey	4 – None and never aware of it 3 – Low (no, but under discussion or drafting plan) 2 – Medium (Yes, having a plan but no regular review and drills) 1– High (Yes, having a plan, regular review/drill(s), but no/insufficient resources for implementation) 0 – Very high(Yes, having a plan, regular review/drill(s), and having sufficient resources for implementation)
	V9.5: Surge personnel capacity plan implementation	Survey	4 – None and never aware of it 3 – Low (no, but under discussion or drafting plan) 2 – Medium (Yes, having a plan but no regular review and drills) 1– High (Yes, having a plan, regular review/drill(s), but no/insufficient resources for implementation) 0 – Very high(Yes, having a plan, regular review/drill(s), and having sufficient resources for implementation)
	V9.6: Evacuation plan implementation (both partial and full evacuation)	Survey	4 – None and never aware of it 3 – Low (no, but under discussion or drafting plan) 2 – Medium (Yes, having a plan but no regular review and drills) 1– High (Yes, having a plan, regular review/drill(s), but no/insufficient resources for implementation) 0 – Very high(Yes, having a plan, regular review/drill(s), and have sufficient resources for implementation)
	V9.7: Self-help	Survey	4.00 – No plan, no necessary workforce and resources for self-help, only rely on external supports 2.67 – Low (Yes, having necessary workforce and resources for initial self-help while waiting for external supports) 1.33 – Medium (Yes, having necessary workforce and resources for protecting properties and working system with a minor need for external supports) 0.00 – High (Yes, having necessary workforce and resources for protecting properties and working system with no external supports needed)

Indicators	Sub-indicators	Data sources	Vulnerability Rating score
V10: Lack of resource mobilization	V10.1: Availability and accessibility of financial resources for disaster risk preparation	Survey	4 – No/Insufficient and difficult to acquire the resources from external sources or donation 2 –Insufficient but not difficult to acquire the resources from external sources or donation 0 – Sufficient and no need to acquire the resources from external sources or donation
	V10.2: Volunteer and external help management plan implementation	Survey	4 – None and never aware of it 3 – Low (no, but under discussion or drafting plan) 2 – Medium (Yes, having a plan but no regular review and drills) 1– High (Yes, having a plan, regular review/drill(s), but no/insufficient resources for implementation) 0 – Very high(Yes, having a plan, regular review/drill(s), and having sufficient resources for implementation)
	V10.3: Availability of resources for reconstruction /reparations and lag time for resuming to full operation	Survey	4.00 – No financial resources 2.67 – Low (Yes, having financial resources but >1 year of delay/waiting time for reparation and resuming full operation) 1.33 – Medium (Yes, having financial resources but <=6 months of delay/waiting time for reparation and resuming full operation) 0.00 – High (Yes, having financial resources but <=1 month of delay/waiting time for reparation and resuming full operation)
V11: Lack of integration and coordination	V11.1: Existence and efficiency of internal Board of committee/working group on disaster risk management	Survey	4.00 – None and never aware of it 2.67 – Low (no, but under discussion) 1.33 – Medium (Yes, having regular meetings but lack of resources and efficient coordination) 0.00 – High (Yes, having regular meetings with sufficient resources and efficient coordination)
	V11.2: Specific coordinator on disaster risk management	Survey	4.00 – None and never aware of it 2.67 – Low (no, but under discussion) 1.33 – Medium (Yes, having clear designed coordinator (s) but disaster risk management is not his/her main task) 0.00 – High (Yes, having clear designed coordinator (s) who disaster risk management is his/her main task)
	V11.3: Patient referral and transfer agreement with other hospitals	Survey	4 – No 0 – Yes

Indicators	Sub-indicators	Data sources	Vulnerability Rating score
	V11.4: Agreement and exercise on partial or full patient evacuation to other hospitals/facilities	Survey	4 – No 0 – Yes
	V11.5: Availability of automatically channels or systems for communicating and coordinating with utilities and key suppliers	Survey	4 – No 2 – Yes, partially/not all key utilities/suppliers 0 – Yes, all key utilities/suppliers
V12: Lack of Information	V12.1: Availability and accessibility of local hazard map and climate-related disaster risk database	Survey	4.00 – No and never aware of it 2.67 – Low (aware of the information but limited accessibility) 1.33 – Medium (aware of and access to the information but does not use it for risk communication with relevant stakeholders) 0.00– High (aware of and access to the information and use it for risk communication with relevant stakeholders)
	V12.2: Availability and accessibility of local future population and development projection dataset for long-term service planning	Survey	4.00 – No and never aware of it 2.67 – Low (aware of the information but limited accessibility) 1.33 – Medium (aware of and access to the information but does not use it for service planning) 0.00– High (aware of and access to the information and use it for service planning)
	V12.3: Availability and accessibility of information on local future climate-related disaster risks (floods and water supply scarcity)	Survey	4.00 – No and never aware of it 2.67 – Low (aware of the information but limited accessibility) 1.33 – Medium (aware of and can be able to access the information but does not use it for risk management planning) 0.00– High (aware of and can be able to access the information and use it for risk management planning)
V13: Lack of preparedness and risk transfer	V13.1: Availability plan and long-term investment for increasing climate-related hazards resilience	Survey	4 – None and never aware of it 3 – Low (no, but under discussion or drafting plan) 2 – Medium (Yes, having a plan but no implementation) 1– High (Yes, having a plan, but no/insufficient resources and coordination for implementation) 0 – Very high (Yes, having a plan, sufficient resources and coordination for implementation)
	V13.2: Climate-related hazards risk insurance	Survey	4 – None 2 – Yes, but not cover all types of climate-related hazards

Indicators	Sub-indicators	Data sources	Vulnerability Rating score
			0 – Yes, cover all types of climate-related hazards
	V13.3: Build Back Better plan implementation	Survey	4.00 – None 2.67 – Low (no, but under discussion or drafting plan) 1.33 – Medium (Yes, having a plan and regular plan review, but no/insufficient resources and coordination for implementation) 0.00 – Very high(Yes, having a plan, regular plan review, sufficient resources and coordination for implementation)
V14: Lack of participation and inclusiveness	V14.1: Community participation in disaster risk management planning	Survey	4.00 – Internal process and not involve the community in planning and exercise 2.67 – Involve the community in the plan exercise process 1.33 – Involve the community in the planning process but irregular exercise the plan with communities 0.00 – Involve the community in the planning process and conduct exercises together regularly
	V14.2: Disaster risk management planning and exercise with utilities, suppliers and other relevant agencies	Survey	4 – None and never aware of it 3 – Low (no, but under discussion or drafting plan) 2 – Medium (Yes, have a plan but no implementation) 1– High (Yes, have a plan, but no/insufficient resources and coordination for implementation) 0 – Very high(Yes, have a plan, sufficient resources and coordination for implementation)
V15: Lack of capacity development	V15.1: In-house capacity building and awareness-raising on the importance of future climate-related disaster risk and resilience	Survey	4 – None and never aware of it 3 – Low (no, but under discussion or drafting plan) 2 – Medium (Yes, having a plan but no implementation) 1– High (Yes, having a plan, but no/insufficient resources and coordination for implementation) 0 – Very high(Yes, having a plan, sufficient resources and coordination for implementation)
	V15.2: Training on working with no-electricity or limited resources	Survey	4 – None and never aware of it 3 – Low (no, but under discussion) 2 – Medium (yes, <1 time a year) 1– High (yes, at least 1 time a year, but having insufficient resources and coordination) 0 – Very high (yes, at least 1 time a year and have sufficient resources and coordination)
V16: Lack of mainstreaming	V16.1: Mainstreaming disaster risk management in an	Survey	4 – None and never aware of it 3 – Low (no, but under discussion or drafting plan) 2 – Medium (Yes, having a plan but no implementation)

Indicators	Sub-indicators	Data sources	Vulnerability Rating score
climate-risk in planning process	action plan or budget plan		1– High (Yes, having a plan, but no/insufficient resources and coordination for implementation) 0 – Very high(Yes, have a plan, sufficient resources and coordination for implementation)
	V16.2: Integration of the future climate-disaster risk information in the system maintenance plan and reparation budget	Survey	4 – None and never aware of it 3 – Low (no, but under discussion or drafting plan) 2 – Medium (Yes, having a plan but no implementation) 1– High (Yes, having a plan, but no/insufficient resources and coordination for implementation) 0 – Very high(yes, having a plan, sufficient resources and coordination for implementation)
V17: Lack of monitoring and evaluation	V17.0: Monitoring and evaluation	Survey	4.00 – None 2.67 – Low (no, but under discussion or drafting plan) 1.33 – Medium (Yes, having a plan and regular plan review, but no/insufficient resources and coordination for implementation) 0.00 – Very high(Yes, having a plan, regular plan review, sufficient resources and coordination for implementation)

Justifications

- **Over carrying capacity (V1)**: Many public health care units in Thailand face an overcarrying capacity problem, especially tertiary service-level hospitals. The service demands are usually greater than the number of services/beds available. The impacts of a bed capacity problem can be significant such as downgraded service quality, increased length of time waiting for services, patient &staff satisfaction, and eventually, population health at risk (Health Catalyst, 2019). Moreover, limited service capacity interrupts workflows of health care services in both Business as Usual situations and sensitivity to harm under emergencies or hazards. In this regard, general self-appraisal on balance between service capacity and service demand is used as a sub-indicator (V1.0).

- **Variety of vulnerable patients (V2)**: WHO (2020a) defines children, pregnant women, elderly people, malnourished people, and people who are ill or immunocompromised as vulnerable groups who take a relatively high share of the disease burden associated with emergencies and when a disaster strikes. However, Srisasalux (2013) categorizes vulnerable groups in the context of Thai's health care based on physical capacity (e.g. pregnant women, elderly, children, physical disability, high acute patients, critical chronic disease patients, etc.) and decision autonomy (decision autonomy - e.g. pediatric patients, dementia patients, mental disorder, etc., and limited decision autonomy – e.g. prisoners, enlisted soldiers, illegal immigrants, illegal sex worker, drug users, and etc.). Besides physical perspective, social determinants of health also significantly contribute to health vulnerability (e.g., financial, legal, environmental, and behavioural factors, as well as lack of transportation, substance abuse, and education and literacy issues) (Marder, 2018). Nevertheless, this study focused on health care operation and management efforts in terms of medically complex and social determinants that cause treatments and services complications during an emergency or hazardous circumstances such as respiratory ventilator/oxygen-dependent, dialysis-dependent, disability and self-movement difficulty, elderly, infant/toddlers (0-5-year-old), pregnancy women, medication treatment dependency, local language proficiency, mental illness, and others. The variety and quantity of vulnerable patients determine the complexity of treatment, care, and rehabilitation. However, neither standard nor index is available, which allows comparison among health care units regarding the degree of burden due to the typology and quantity of vulnerable groups. Therefore this study used a variation of vulnerable patients (within a service area) to represent sensitivity elements of health care services. In other words, with more varieties of vulnerable patients under care, a public health care unit must deal with more complex treatments & care and time constraints, especially under a hazard strike.

- **Resource insufficiency(V3):** Conventional resources insufficiency in BaU situation determined climate-related hazards sensitivity of a public health care unit are financial resources and human resources.
  - **Financial resources (V3.1):** In the landscape of Thai's public health care, despite positive outcomes of universal health care coverage, which prevents Thai people go bankrupt due to medical expenses, the state-run hospitals have been facing a financial crisis for almost a decade. In 2017, 558 public hospitals reported financial deficits and huge debts, especially secondary and tertiary hospitals (Thaipublica, 2017). Financial constraints cause a direct impact on health care operation and delivery of services through difficulties in procurement of resources and payment of running costs, including medical and non-medical supplies, staff salary, payment of utility bills, etc. Moreover, a financial deficit in normal operations puts a public hospital/health care unit in a tight spot during a climate-related crisis. Therefore, financial resources insufficiency of a local public health care unit in usual operation is selected to represent economic sensitivity.
  - **Human resources (V3.2):** Shortage and inequitable distribution of health personnel are the core weaknesses of the Thai public health system. Opposite to the increasing demand for health care services under the universal health care scheme, zero growth in the civil service sector and medical education system cause work overload in the entire health workforce (Barria,2020). For example, a nurse in the SHPH provides not only medical treatments and health promotion, she/he is also responsible for administrative tasks such as financial accounting or even acting as a security guard. Distracting from the main responsibility of the key health task force may affect patients' service quality and

satisfaction. Even though the Thai government put more permanent positions to incentivize the health care workforce who works under COVID-19 crisis, more long-term solutions are still missing. Apparently, personnel shortage has highly impacted the disruption of workflow, which could be worsen under climate-related hazards situations when health personnel have to sustain the service and respond to a disastrous strike at the same time.

- **Poor system conditions and maintenance of working systems (V4):** Ensuring a good condition and well maintenance of essential working systems is paramount to assure continuity of health care service workflow, especially in emergencies. Maintenance also affects several non-core activities of hospitals, such as supplies, accessibility, and security. However, in developing countries, a public health care unit often lacks an engineer /manager who specifically oversights and regularly monitors the systems. Amid emergencies or hazards, poor condition and maintenance of essential working systems could put strong pressure on a hospital/public health care unit's operation under crisis. Therefore, current system conditions (V4.1), system maintenance monitoring & reporting (V4.2), and availability of trained staff/technicians for system maintenance and reparation (V4.3), as well as the availability of maintenance resources(V4.4), were selected as sub-indicators representing sensitivity aspects of essential working systems.
- **Downtime of essential working systems (V5)**: Downtime or outage duration refers to a period of time that a system fails to provide or perform its primary function (Wikipedia,2020). Whether planned or unplanned, downtime can affect an entire system or may only impact a single application (JCI, 2020). A non-functioning system can completely paralyze public health care services. This disruption can be fatal if a patient's life relies on the running systems. This time-based threshold (absolute time or relative time) is usually used to track availability loss (Vorne, 2020) and monitor resuming time to normal operation. In this study, the maximum downtime experience of each essential working system in the past five years (during 2014-2019)[49] was estimated by the managerial level of a health care facility. Based on the survey result, an average downtime of each essential working system is benchmarked with the level of effects that occurred to essential working systems, representing a degree of sensitivity-related vulnerability of this study. It is important to note that this research also differentiated the downtime benchmark of different health care service hierarchies (see Table 5.10-5.12).
- **Lack of flexibility & modularity (V6):** The concepts of flexibility and modularity are championed as ways to adapt to future uncertainties (Schank et al., 2016), especially for the complex system, whereby the system is decomposed into several sub-systems (modules) (IGI Global, 2020). Modularity often refers to a characteristic of a system that has functionally

[49] This study recognized that this historical downtime records could not directly determine the future distruption of the essential working system, but it can be used as a baseline for the potential imapct operarationalization.

interdependence within and independence across modules (Baldwin & Clark, 2000) or imply to a degree of system modules that can be separated, reassembled, scalable, reusable as well as consisting of isolated, self-contained elements (Schank et al., 2016). Modularity can be a subset of flexibility, but modularity generally involves creating fixed boundaries of modules and their interfaces. Meanwhile, flexibility has a broader meaning, refers to the ability to change or be changed easily according to the situation or ability to readily adapt without breaking (Schank et al., 2016; Cambridge dictionary, 2020). From a resilience perspective, flexibility (and/or modularity) is usually mentioned as the ability in adjusting, redistributing, reorganizing, restructuring, reassembling, and evolving in response to wide-range of changing circumstances of both spatially distributed and functionally linked (Tanner et al., 2009; Bahadur et al., 2010; Ahern, 2011; Rodin, 2014; The Rockefeller Foundation & ARUP, 2015; Tyler et al., 2016; Meerow & Stults, 2016). In this study, lack of flexibility & modularity attributes to local public health care represented through three sub-indicators; flexibility & modularity of 18 essential working systems[50] (V6.1) (see description of flexibility and modularity level as below; connectivity (ability) of key working system with external devices/systems (V6.2); and assignment of a one-stop service area with the highest protective level (V6.3).

Description of flexibility and modularity levels of public health care service working systems

Level	Descriptions
No/insignificant	The working system can NOT be moved, or adjusted, or modulated its elements or functions.
Low	The working system can be moved, adjusted, or modulated its elements or functions by using special equipment/devices or by specialist supervision or specialist supervision. Likely, the working system may have lower efficiency or productivity after moving, adjusting, or modulating its elements or functions.
Medium	The working system can be moved, or adjusted, or modulated its elements or functions by specialist supervision or specialist supervision and/or using special equipment/devices. Likely, the working system remains the same level of efficiency or productivity after moving, adjusting, or modulating its elements or functions.
High	The working system can be moved, or adjusted, or modulated its elements or functions by users and/or using typical available equipment/devices. Likely, the working system remains the same level of efficiency or productivity after moving, adjusting, or modulating its elements or functions.

- **Lack of diversity of suppliers (V7):** In the resilience perspective, diversity is mentioned as the presence of diversity options, the functionality of systems, networks, operation mode, infrastructures, and resources. However, appraisal of a diversity of functionality of systems, networks and infrastructures requires advanced knowledge or specialist to organize the assessment. Nevertheless, a variety of options for resource acquisition for essential working systems could reflect through supplier diversity. Supplier diversity is simple enough and

[50] 1) Electricity power control center; 2) Backup power source (s) (e.g. CHP, renewable energy);3)Computer/Server control center; 4)Internet control center; 5)Telephone/Radio control center; 6)Water filter/Purification; 7)Tap water; 8)Pumping system; 9)Wastewater treatment system; 10)Waste management system (incl. solid waste, infectious waste, hazardous waste); 11)Medicine and dispensable medical supplies (incl. Medical gases, blood); 12) Linin service; 13)Food and nutrition; 14)Multipurpose space/spare room; 15)Personnel management; 16)Vehicles; 17)Safe access route; 18)Personnel commuting service

allows self-assessment by the local public health units where usually health care personnel are not trained or well trained as a system engineer or supply manager. It is common for a health care unit to monitor their stockpile and define triggers and thresholds for supplies replenishment. However, looking for alternative sources for maintaining operation during a crisis is still overlooked, especially in areas where never have experience coping with hazards or threats before. Supplier diversity is present when an organization's contracts for goods and services feature various businesses (Health Research & Educational Trust, 2015). Besides of benefits of increasing competition and widening the supplier pool, diversity of suppliers is valuable when a health care unit has to deal with emergencies and hazards. At the same time, demands for medical and health care needs are also increased. The efficiency and effectiveness of operational processes in the health care supply chain are expected to reduce the impact of greater losses, especially victims (Syahrir et al., 2015). World major catastrophic events such as COVID-19 pandemic, the Great East Japan Earthquake or the Bangkok flood 2011 proved the great regret of depending on single sourcing. The impacts were cascading down through supply chains especially manufactural facilities, source materials or products from suppliers in risk-prone areas or logistic infrastructure. In this regard, a variety of options for meeting the needs of medical and health services in the health care supply chains is very important. In this study, lacking diversity is considered the lack of supplier diversity of key essential working systems and unreadiness of structures or managerial schemes that allow more than one source of supplies to feed to the operating systems. The description of level of diversity of suppliers of the 18 public health care essential working systems[51] used for self-assessment of the local public health care unit shows below.

Description of the level of diversity of suppliers of public health care essential working systems

Level	Descriptions
No/insignificant	Single supplier or monopoly
Low	2 or multiple suppliers are available only in the case of an emergency/hazards or business as unusual. No contract and supportive technical structure/management system are agreed upon / installed in advance.
Medium	2 or multiple suppliers are available only in the case of emergency/hazards or business as unusual. Contract and supportive technical structure/management system are agreed upon / installed in advance.
High	2 or multiple suppliers are available in both emergency/hazards and business as usual. Contract and supportive technical structure/management system are agreed upon and installed in place.

- **Lack of redundancy (V8):** The simplest term for redundancy is a backup or adding extra components, which become necessary in the case of a mishap or hazard. Spare components or extra resources play a majority role in reducing chances of system failure. Redundancy is

[51] 1) Electricity power control center; 2)Backup power source (s) (e.g. CHP, renewable energy);3)Computer/Server; 4)Internet; 5)Telephone/Radio; 6)Water filter/Purification; 7)Tap water; 8) Underground water; 9)Pumping system; 10)Wastewater treatment system; 11)Solid waste management system (incl. infectious waste, hazardous waste); 12)Medicine and dispensable medical supplies (incl. Medical gases, blood); 13) Linin service; 14) Office stationary; 15)Food and nutrition; 16)Multipurpose space/spare room; 17)Personnel management; 18) Vehicles

very important for risk management of critical systems regarding reliability and availability improvement (Ow, 2018). Therefore, local public health care units must ensure spare capacity or reserved (back-up) resources/systems in order to cope with shocks, disruptions or surges in demands and be able to sustain operation without external supports or interferences (Godschalk, 2003; Ahern, 2011; Liao,2012; The Rockefeller Foundation & ARUP, 2015; Tyler et al., 2016; Meerow & Stults, 2016). This study captured redundancy (availability & capacity) of key 15 working systems[52] in terms of time threshold linked to the level of effects that occurred to public health care service working systems after an emergency or disruption begins (V8.1), which was evaluated by the local public health care managers (see Table 5.10-5.12). For the system features where temporal measurement does not provide a quantitative redundancy threshold, availability and qualitative measures were checked by the public health care managers, namely - alternative types of vehicles (e.g. boat, amphibian, helicopter, drone) (V8.2); alternate safe and accessible route(s) (V8.3); procurement of secondary backup systems (V 8.4); alternate procedure for medical recording(V8.5); options in the case of communication failure(V8.6); shelter for staff and family(8.7); as well as an assignment of alternate care site (V8.8).

- **Lack of responsiveness (V9):** According to the Cambridge dictionary (2020), responsiveness refers to the quality of reacting to something or someone, especially a quick or positive reaction. In the context of climate and disaster risk resilience, responsiveness implies the ability of a system to organize, rearrange and give feedback in a timely manner which allows preparation, warning, and responding actions to shocks and disruptions and restore order to the normal state of operation (Tanner et al., 2009; Liao, 2012; Rodin, 2014; The Rockefeller Foundation & ARUP, 2015; Tyler et al., 2016; UNISDR, 2015a; Meerow & Stults,2016). From the engineering or computer science, or clinic perspective, responsiveness can be quantified *change* over a particular pre-specified time frame (Husted et al., 2000). However, this study did not consider the responsiveness of performance or feedback of an individual sub-system or functional unit of public health care. Instead, this research reflects a lack of responsiveness through the availability and implementation of plans, enabling a (whole) public health care unit to react to climate-related hazards appropriately and timely. Thus, sub-indicators representing vulnerability caused by responsiveness deficits are the implementations of the following plans; resources conservation plan (V9.1); slow-onset hazards response plan (V9.2); business continuity plan (V9.3); contingency plan (V9.4); surge personnel capacity plan (V9.5); evacuation plan (both partial and full evacuation) (V9.6); and self-reliance capacity (V9.7).

[52] 1)Backup power source (s) (e.g. CHP, renewable energy);2) Liquid fuel; 3) Computer/Server 4)Internet; 5)Telephone/Radio; 6)Water filter/Purification; 6)Tap water; 7)Drinking water sources; 8)Wastewater treatment system; 9)Waste management system (incl. solid waste, infectious waste, hazardous waste); 10)Medicine and dispensable medical supplies (incl. Medical gases, blood); 11) Linin service; 12) Office stationary; 13)Food and nutrition; 14)Multipurpose space/spare room; 15)Personnel management

- **Lack of resource mobilization (V10):** Resource mobilization is the ability to secure resources/supports from resources/support providers and to mobilize them appropriately in order to ensure the continuation of service (Seltzer, 2014) under shock/stress as well as restore order and function of systems after the math (The Rockefeller Foundation & ARUP, 2015; Tyler et al., 2016; UNISDR,2015a). In this regard, a public health care unit needs to acquire financial resources (investment) and workforce (staffing) for coping shocks/disruptions and restoring services from the impact. Therefore, the assessment on the level of availability and accessibility of financial resources for climate-related hazard preparation (V10.1), volunteer and external help management plan (Vc10.2), and availability of resources for reconstruction /reparations against lag time for resuming to full operation (V10.3) are used for indicating resource mobilization.
- **Lack of integration and coordination (V11):** Lillrank (2012) summarized that coordination is the arrangement of roles and tasks into an organized whole, while integration is a combination of several specialized and differentiated resources and contributions to create an output that is a system consisting of several parts. Each part needs to contribute to the output, but also submit to the demands of the whole. Both attributes are crucial for public health care operations, either in normal circumstances or under threats. A public health care unit needs to ensure consistency and alignment across relevant operation systems, actors, institutions, networks in order to enable them to function or take collective action based on their interdependency and interconnectedness layers, both within an organization and external stakeholders such as community, utilities, and other disaster risk management agencies. In this regard, this study defined key components representing integration and coordination to minimize the potential impact of climate-related hazards in public health care. Thus, the sub-indicators can be laid out as the followings, existence and efficiency of an internal managerial body on disaster risk management (V11.1), disaster risk management coordinator (V11.2), patient referral and transfer agreement (V11.3), partial or full patient evacuation drills with other hospitals (V11.4), and real-time or almost real-time coordination with utilities and key suppliers (V11.5).
- **Lack of Information (V12):** Information plays a central role in disaster risk management. With the advancement of technology, lack of information is no longer a major obstacle to disaster risk reduction (Subedi, 2010). However, in developing countries such as Thailand, data availability and accessibility create huge gaps across development levels, yet poor data management and integration in both vertical and horizontal layers, especially in disaster risk reduction. This study focuses on capturing basic requirements for the public health care unit to ensure the understanding of the current and anticipatory future of climate change and development change and how these affect their operations and assets, enabling them to strategically work with communities and relevant stakeholders. To this aspect, availability, accessibility, and application of the following information were used to indicate an adaptive

capacity element of public health care vulnerability, such as availability and accessibility of hazard map and climate-related hazards database (V12.1), local future population and development for long-term service planning (V12.2), information on local future climate-related hazards in the service area (V12.3).

- **Lack of preparedness and risk transfer(V13):** Preparedness refers to a set of precautionary measures or actions to deal with a potential risk or avoid negative outcomes. Preparedness is good linkages with responsiveness such as early warning, contingency planning, stockpiling of equipment and supplies, development of arrangements for coordination, evacuation and public information, and training and field exercises (UNDRR,2020). Nevertheless, ensuring preparedness enhancement for future risk is crucial and needs a long-term planning and investment perspective beyond emergency response. Long-term strategic planning and investment are essential for public health service, not only by minimizing negative outcomes in the emergency management phase but also by increasing resilience through Build Back Better approach and risk transfer in the recovery phase. To this matter, this study reflects a crucial element of the local public health service vulnerabilities through a deficit in preparedness and risk transfer such as availability plan and long-term investment for increasing climate-related hazards resilience (V13.1), provision of climate-related hazards insurance (V13.2), and build back better plan (V13.3).

- **Lack of participation and inclusiveness (V14):** Quick & Feldman (2011) conclude the distinction between participation and inclusion. Participation is a collective effort to increase public input-oriented to the content of programs and policies. Inclusion is creating a community involved in coproducing processes, policies, and programs for defining and addressing public issues with deliberation and diversity. These properties are required for successful disaster risk management. Disaster risk reduction is beyond the capacity of one organization; multi-stakeholders involvement and collaboration are required (Zubir & Amirrol, 2011). Especially, disaster risk management of a public health care unit needs cooperation and support from many relevant actors within and outside their service area boundary in co-producing plan & policies, pooling resources, and conducting the emergency response exercises such as communities, local government, utilities, suppliers, upper administration agencies, urban (spatial) planner, etc. Therefore, lacking or insufficient community participation in disaster risk management planning (V14.1) and inclusiveness of utilities, suppliers and other relevant agencies in disaster risk management planning and exercise (V14.2) were defined as key attributions that amplified vulnerability.

- **Lack of capacity development (V15):** Besides a plenty number of definitions given by international aid agencies, UNDP provides a comprehensive definition of capacity development as capable individuals, organizations and societies which play a vital role in the successful reduction and management of disaster risks (UNDP, 2010). This study focuses on the organizational capacity development of a public health care unit derived from a collective action of individuals in the organization (Zamfir, 2017). Therefore, implementing in-house capacity building and awareness-raising on the importance of future climate-related hazards and resilience (V15.1) and provision of training on working with limited resources, e.g. no electricity and no clean water (V15.2), shall be examined to reflect the vulnerability of a local public health care unit. These attributes practically reflect the ability of a public health care unit to internalize knowledge, skills, and experience to improve and transform for dealing with a greater level of unexpected disruptions and retain knowledge over time.

- **Lack of mainstreaming climate risk in planning process (V16):** The recent concept of vulnerability is shifted from a determination of risks to a future-oriented approach that considers a spectrum of possible futures by taking uncertainties into account (Greiving et al., 2015). Future-oriented risk-informed planning enables the development of strategic planning on disaster risk reduction based on robust decision making. Therefore, lacking mainstreaming climate-related hazards in a health care unit’s action plan and budget plan (V16.1), as well as the integration of future climate risk information in system maintenance and reparation plan (V 16.2), are clear indications of the vulnerability of a local public health care unit under the future climate challenges.
- **Lack of monitoring and evaluation (V17):** Monitoring and evaluation mechanism plays a critical role in defining progress and achievement of disaster risk management policy and actions (UNISDR, 2015b). Evidence and experiences of ex-ante and ex-post scenarios can help avoid maladaptation, improve learning capacity, and invest efficiently (Katich, 2011). In this regard, the availability and implementation of monitoring and evaluation on disaster risk management (17.0) is a crucial indicator representing a public health care unit’s vulnerability.

Table 5. 10 Area-based: Level of effects that occurred to public health care service working systems after emergency or disruption begins *(average value)*

Note: The level of effect refers to the Annex 24 (d) : 1 = Very low ; 2 = Low ; 3 = Medium ; 4 = High

	Operational Hours After Emergency Begins	**Day 1**				**Day 2**	**Day 3-4**	**Day 4+**
		0-1 hr.	2-4 hr.	5-12 hr.	13 -24 hr.	25-48 hr.	49-96hrs	> 96 hrs
Power	Disruption of electricity (grid power)	2	2	3	3	3	3	3
Water	Intermittent of pipe water & no water storage	2	2	3	3	3	4	4
Fuel	Loss of fuels (gasoline)	2	2	2	3	3	3	3
Communication	Disruption/failure of computer system or server	2	2	3	3	3	3	3
	Disruption/failure internet	2	3	3	3	3	3	3
	Disruption/failure of landline, cell phone, satellite phone/radio	2	3	3	3	3	3	3
Waste management	Disruption of solid waste management system (including infectious waste, hazardous waste, etc.)	2	2	2	2	2	3	3
	Disruption of wastewater management system	1	2	2	2	2	3	3
Supplies	Shortage of food supplies, nutrients, and drinking water	1	2	2	3	3	3	3
	Shortage of medicine and medical supplies	2	2	3	3	3	3	3
	Shortage of linen	1	1	2	2	2	3	3
	Shortage of office supplies	1	1	1	2	2	2	3
Staff	Unable to deploy more than 50% of personnel	1	2	2	2	3	3	3
Accessibility	Loss of safe accessibility and vehicles	2	2	2	3	3	3	3

Table 5. 11 Primary health care level: Level of effects that occurred to public health care service working systems after emergency or disruption begins *(average value)*

Note: The level of effect refers to the Annex 24 (d): 1 = Very low ; 2 = Low ; 3 = Medium ; 4 = High

	Operational Hours After Emergency Begins	**Day 1**				**Day 2**	**Day 3-4**	**Day 4+**
		0-1 hr.	2-4 hr.	5-12 hr.	13 -24 hr.	25-48 hr.	49-96hrs	> 96 hrs
Power	Disruption of electricity (grid power)	2	2	3	3	3	3	3
Water	Intermittent of pipe water & no water storage	2	2	3	3	3	3	4
Fuel	Loss of fuels (gasoline)	2	2	2	3	3	3	3
Communication	Disruption/failure of computer system or server	2	2	3	3	3	3	3
	Disruption/failure internet	2	3	3	3	3	3	3
	Disruption/failure of landline, cell phone, satellite phone/radio	2	2	3	3	3	3	3

	Operational Hours After Emergency Begins	Day 1				Day 2	Day 3-4	Day 4+
		0-1 hr.	2-4 hr.	5-12 hr.	13 -24 hr.	25-48 hr.	49-96hrs	> 96 hrs
Waste managem ent	Disruption of solid waste management system (including infectious waste, hazardous waste, etc.)	2	2	2	2	2	3	3
	Disruption of wastewater management system	1	2	2	2	2	3	3
Supplies	Shortage of food supplies, nutrients, and drinking water	1	2	2	2	3	3	3
	Shortage of medicine and medical supplies	2	2	3	3	3	3	3
	Shortage of linen	1	1	2	2	2	3	3
	Shortage of office supplies	1	1	1	2	2	2	3
Staff	Unable to deploy more than 50% of personnel	1	2	2	2	3	3	3
Accessibil ity	Loss of safe accessibility and vehicles	2	2	2	3	3	3	3

Table 5. 12 Khon Kaen hospital (Tertiary care level): Level of effects that occurred to public health care service working systems after emergency or disruption begins *(average value)*

Note: The level of effect refers to the Annex 24 (d): 1 = Very low ; 2 = Low ; 3 = Medium ; 4 = High

	Operational Hours After Emergency Begins	Day 1				Day 2	Day 3-4	Day 4+
		0-1 hr.	2-4 hr.	5-12 hr.	13 -24 hr.	25-48 hr.	49-96 hrs	> 96 hrs
Power	Disruption of electricity (grid power)	2	3	3	4	4	4	4
Water	Intermittent of pipe water & no water storage	1	1	1	1	2	3	4
Fuel	Loss of fuels (gasoline)	1	1	1	1	3	3	3
Communi cation	Disruption/failure of computer system or server	3	4	4	4	4	4	4
	Disruption/failure internet	2	3	3	4	4	4	4
	Disruption/failure of landline, cell phone, satellite phone/radio	3	4	4	4	4	4	4
Waste managem ent	Disruption of solid waste management system (including infectious waste, hazardous waste, etc.)	1	1	2	3	3	4	4
	Disruption of wastewater management system	1	1	1	2	2	3	3
Supplies	Shortage of food supplies, nutrients, and drinking water	2	3	4	4	4	4	4
	Shortage of medicine and medical supplies	2	3	4	4	4	4	4
	Shortage of linen	1	2	3	4	4	4	4
	Shortage of office supplies	1	1	1	2	2	3	3
Staff	Unable to deploy more than 50% of personnel	2	3	3	3	3	4	4
Accessibil ity	Loss of safe accessibility and vehicles	2	3	3	3	4	4	4

2) Expert review and prioritization

The identified Hazard and Vulnerability indicators were reviewed and assigned weighting values by the six health care experts through the expert survey (see Annex 21, 35). The survey result showed all experts (6) had no objection to the proposed indicators. Although one expert suggested including “coordinating and asking for external help during the crisis” as an indicator. However, the issue was already reflected as a sub-indicator under Integration and Coordination (V11) of the Vulnerability pillar. Hence, this study concluded that the proposed indicators are appropriate for the potential impact assessment in the context of this research. A summary of the experts weighing values can be found in Table 5.13.

17 Vulnerability related indicators were grouped into three components in order to facilitate the experts in dealing with a number of the proposed indicators, i.e. sensitivity (V1-V5), coping capacity(V6-V11), and adaptive capacity (V12-V17), respectively. Experts assigned weighting values for vulnerability indicators through ascending order prioritization within the same group, e.g. 1st order is the highest weighing value, and 5th is the least weighting value. The survey explicitly stated that the experts could give equal prioritization rank to more than one indicator. At the same time, the budgeting allocation approach was used by the expert to assign weighting values to the Hazard-related indicators. Since neither the experts nor technical standards were available for weighting the Exposure-related indicators; therefore, equal weight was applied.

The survey result showed that the experts assigned weighting values on Vulnerability indicators are highly heterogeneous, which can be observed through the Standard Deviation (SD) value of the dataset (Annex 21). As a result, the average weighting values among the vulnerability indicators are not widely distinct and cannot genuinely reflect the influence of a particular indicator on overall potential impact outcomes.

Among the three components of the Vulnerability-related indicators, adaptive capacity-related components received a more homogeneous prioritization score compared to sensitivity and coping capacity-related indicators. Particularly, coping capacity-related indicators revealed the most diverse opinions among the experts, especially, Diversity (V7), Integration and Coordination (V11), in which the value falls outside of the ±2SD range.

It is important to note that the survey also included “Experience in hazard/emergencies” as the proposed coping capacity-related indicators in the survey. However, with later consideration of public health care management in Thai’s context (high rotation of personnel and uncertainty of learning curve), the survey can not capture whether the experience will be internalized or encapsulated within the organization in the long term. Therefore, this proposed indicator was excluded from the potential impact assessment.

From the Hazard-related indicators perspective, 50 % of experts (3 out of 6) gave higher priority to managing water supply scarcity than floods management in a ratio of 60:40.

In contrast, about 33 % of experts (2 out of 6) allocated 50:50 of their tokens to both hazards. Only one expert prefered to distribute the resources to manage water stress less than floods with a ratio of 40:60. Thus, the weighting values of flooding (regardless of flood types) and water scarcity used for the weight normalization in this study are 0.32, 0.32, and 0.36.

In addition to the experts-weighted normalization scheme, this study also provides comparative configurations in which all indicators operated through equal-weighted normalization at the end of section 5.3.3.2.

Table 5.13 List of composite indicators and experts weighting value for potential impact assessment of Khon Kaen city's public health care service

Pillar	Indicators	Weighting value	Sub-indicators
Hazards	H1: Fluvial Flood	0.32	H1.0: Fluvial Flood
	H2: Pluvial Flood	0.32	H2.0: Pluvial Flood
	H3: Water scarcity	0.36	H3.0: Water scarcity
Exposure	E1: Exposure of public health facility's building(s)	0.5	E1.1: Exposure of public health facility's building(s) to fluvial flood
			E1.2: Exposure of public health facility's building(s) to pluvial flood
			E1.3: Exposure of public health facility's building(s) to water scarcity
	E2: Exposure of Working systems	0.5	E2.1 Exposure of primary working systems
			E2.2 Exposure of secondary working systems
Vulnerability	V1: Over carrying capacity	0.20	V1.0: Balance between service capacity and service demand
	V2: Variety of vulnerable patients	0.27	V2.0: Variety of vulnerable patient types
	V3: Resource insufficiency	0.20	V3.1: Insufficiency of financial resources for BaU operation
			V3.2: Insufficiency of healthcare personnel for BaU operation
	V4: Poor system conditions and maintenance of working systems	0.20	V4.1: System conditions
			V4.2: System monitoring and reporting
			V4.3: Availability of trained staff/technician for system maintenance and reparation
			V4.4: Availability of maintenance resources
	V5: Downtime of essential working systems	0.13	V5.0: Maximum downtime of essential working systems
	V6: Lack of flexibility & modularity	0.18	V6.1: Flexibility and modularity of key working systems
			V6.2: Connectivity (-ability) of sensitive working system with external devices/systems
			V6.3: One-stop service area with the highest protective level, in the case of hazards or high level of emergency
	V7: Lack of diversity of suppliers	0.11	V7.0: Diversity of suppliers of key working systems
	V8: Lack of redundancy	0.18	V8.1: Availability and capacity of primary backup systems
			V8.2: Procurement of special vehicle type (e.g. boat, amphibian, helicopter, drone) for carrying

Pillar	Indicators	Weighting value	Sub-indicators
			goods and passengers during emergencies or hazards
			V8.3: Alternate safe accessible route(s
			V8.4: Procurement of a secondary backup system
			V8.5: Standard procedure for recording a patient medical data in the case of no computer service
			V8.6: Using of runners (courier) as a backup for getting help from outside in the case of communication systems failure
			V8.7: On-campus shelter(s) for staff and family in the case of hazards
			V8.8: Assignment of alternate care site(s)
	V9: Lack of responsiveness	0.21	V9.1: Resources conservation plan implementation
			V9.2: Responsive plan for slow-onset climate-related hazards
			V9.3: Business continuity plan implementation
			V9.4: Contingency plan implementation
			V9.5: Surge personnel capacity plan implementation
			V9.6: Evacuation plan implementation (both partial and full evacuation)
			V9.7: Self-help
	V10: Lack of resource mobilization	0.18	V10.1: Availability and accessibility of financial resources for disaster risk preparation
			V10.2: Volunteer and external help management plan implementation
			V10.3: Availability of resources for reconstruction /reparations and lag time for resuming to full operation
	V11: Lack of integration and coordination	0.14	V11.1: Existence and efficiency of internal Board of committee/working group on disaster risk management
			V11.2: Specific coordinator on disaster risk management
			V11.3: Patient referral and transfer agreement with other hospitals
			V11.4: Agreement and exercise on partial or full patient evacuation to other hospitals/facilities in the case of emergency or hazards
			V11.5: Availability of automatically channels or systems for communicating and coordinating with utilities and key suppliers
	V12: Lack of Information	0.17	V12.1: Availability and accessibility of local hazard map and climate-related disaster risk database
			V12.2: Availability and accessibility of local future population and development projection dataset for long-term service planning
			V12.3: Availability and accessibility of information on local future climate-related disaster risks (floods and water supply scarcity)

Pillar	Indicators	Weighting value	Sub-indicators
	V13: Lack of preparedness and risk transfer	0.21	V13.1: Availability plan and long-term investment for increasing climate-related hazards resilience
			V13.2: Climate-related hazards risk insurance
			V13.3: Build Back Better plan implementation
	V14: Lack of participation and inclusiveness	0.21	V14.1: Community participation in disaster risk management planning
			V14.2: Disaster risk management planning and exercise with utilities, suppliers and other relevant agencies
	V15: Lack of capacity development	0.21	V15.1: In-house capacity building and awareness-raising on the importance of future climate-related disaster risk and resilience
			V15.2: Training on working with no-electricity or limited resources
	V16: Lack of mainstreaming climate-risk in planning process	0.13	V16.1: Mainstreaming disaster risk management in an action plan/budget plan
			V16.2: Integration of the future climate-risk/potential impact information with a system maintenance plan and reparation budget
	V17: Lack of monitoring &evaluation	0.08	V17.0: Monitoring and evaluation

5.3.3.2 Potential impact assessment

This section reports the result of the potential impact assessment of both “Trend scenario” and “Desirable scenario”. The first part of this section presents an overall process of a questionnaire survey of the local public health care facilities. The second part describes questionnaire survey data processing for composite indicators operationalization. The final part manifests the potential impact outcomes of the two scenarios, in area-based, service network, and service level aspects of the local public health service.

1) Questionnaire survey

From December 2019 – February 2020, the questionnaires were sent out to all 36 public health care facilities under MoPH in Mueang Khon Kaen district. By 16 March 2020, 25 completed questionnaires were received, or about 69 %. The responded public health facilities consist of 1 tertiary care hospital, 21 primary care units (PCUs), and three specialized facilities. Among these, 1 tertiary care is Khon Kaen Hospital CUP host, and 19 PCUs are members of the Khon Kaen Hospital CUP network. Meanwhile, two PCU (Thara SHPH and Don Hun SHPH) are members of Sirindhorn Hospital CUP network of Ban Haet district, although they are located in Khon Kaen city. It is important to note that the 3 specialized facilities are independently operated under MoPH. Figure 5.29 and Annex 13 illustrates the detail of MoPH’s public health facilities in the study area and their questionnaire respondent status.

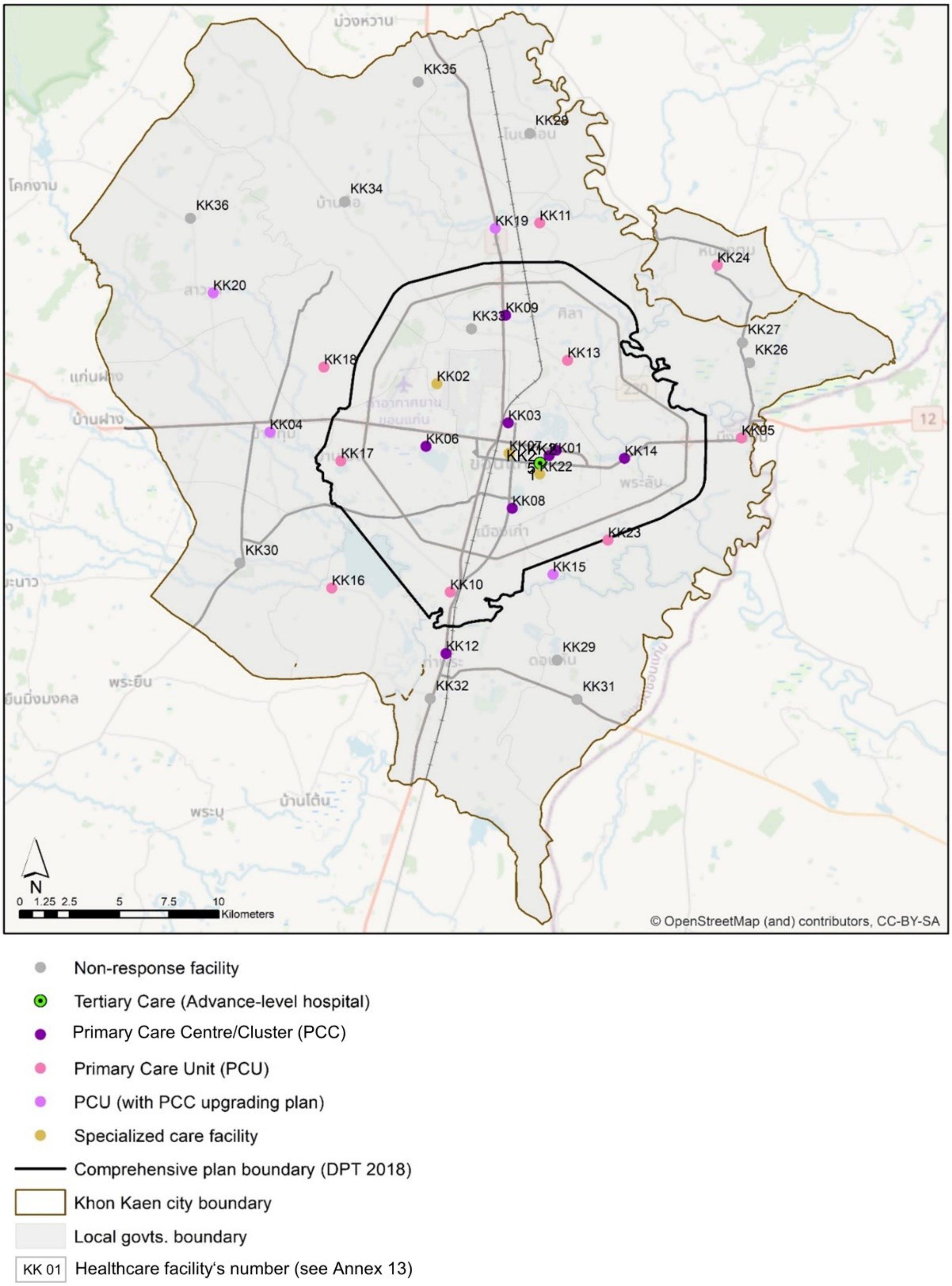
The responders consist of 7 males and 18 females. 84 % of responders have a bachelor degree, followed by a master degree and a doctoral degree with 12% and 4 %, respectively. Among these, 7 responders have experience in natural hazards or disaster risk management; meanwhile, 2 responders have experience or are responsible for overall emergency or risk management of a health care facility. The questionnaire input data and key features of the two scenario storylines were encoded and transferred to a Microsoft Excel spreadsheet based on the composite indicators configuration, aggregation and normalization schemes. Details of alteration in composite indicators values with respect to "Trend scenario" and “Desirable scenario” can be found in Annex 22. 5 interviews[53] with the local public health care facilities managers/executives (Annex 14) were conducted to contextualize the understanding and interpretation of the questionnaire survey inputs.

2) Data Aggregation and Normalization

Distance to target normalization was applied for unifying scales and units of the input dataset. Every sub-indicator was calculated with equal-weighted arithmetic (additive) aggregation in order to represent their respective indicator. At the indicator level, an indicator represents a value of at least one sub-indicator or an average value of many sub-indicators. The indicators' values were then arithmetic (additive) aggregated with proportionate normalization to represent pillar values. According to equation 1(Potential impact = Hazard*Exposure*Vulnerability (section 2.2)), the potential impact is a multiplication result of the Hazards, Exposure and Vulnerability pillars. The absence of one of these pillars or defined as 0 in one of the terms, meant no potential impact occurred. Therefore, the geometric (multiplicative) aggregation with proportionate normalization was calculated for this non-compensability interaction among potential impact pillars. The potential impact values were derived from the composite indicators operationalization presented in absolute terms between 0 to 1. 0 means a possibility of no potential impact, and 1 is a possibility of the highest potential impact outcome. It is important to remind that algorithm of multiplying numbers/decimals by a decimal (less than one); the multiplication product will be smaller than the number being multiplied. This study classified the potential impact outcomes in 4 equal intervals, very low (0.000 - 0.016), low (>0.016 - 0.125), medium (> 0.125 - 0.422), and high (>0.422 - 1.000). Further details of the possible range of potential impact outcome values (according to equation 1) can be found in Annex 23.

[53] Variety in terms of locations (zone) and service levels

Figure 5. 29 MoPH's public health facilities in the study area and their survey respondent status



3) Potential impact analysis

The result of the potential impact assessment of "Trend scenario" and "Desirable scenario" was illustrated in area-based, service network, and service hierarchy aspects (see Table 5.15, 5.21, 5.22). The analysis result presents in the range of *very low* to *high*, according to the classification schemes shown in Annex 23-24. Under "Trend scenario", the potential impact of the local public health services is at *medium level*, from the area-based perspective. The local public health units in Zone 1 were estimated as the highest potential impact value, followed by Zone 3, Zone 2 and Zone 4, respectively. On average, in terms of service hierarchy, the potential impact value of the primary care service level is the highest, followed by the specialized service and tertiary service. Focusing on a network-based perspective, the Khon Kaen Hospital, CUP host, shared service loading 75% (CUP-host); meanwhile, PCUs under the network (CUP-units) shared 25% of the workload. Although the CUP host and CUP units (on average) revealed a slightly distinct Hazard pillar value, the CUP host obviously showed lower exposure and vulnerability than its CUP units (on average). As a result, a network operation of public health service could theoretically influence the potential impact of climate-related hazards in Khon Kaen city. It is important to emphasise that this analytical result was based only on the survey responded public health facility; therefore, about 93% of the Khon Kaen Hospital CUP network was illustrated through this research result.

The purpose of the "Desirable scenario" aims to manifest efforts of the local public health care in minimizing the potential impact in response to the target (s) bandwidth, *low* to *very low* level (see section 5.3.1.2) through multiple measures implemented directly by the public health sector and indirectly outcomes of city-wide spatial planning-based measures (see section 5.3.2.3). The potential impact assessment of the "Desirable scenario" showed that direct implementation of the public health care sector could reduce the potential impact level from a *medium* level (under the "Trend scenario") to a *low* level. Hence, if the local public health service wants to achieve a "very low" level of potential impact minimization target, more efforts should be put into exposure and sensitivity reduction. Although the preferred city-wide spatial planning-based measures were implemented, neither successful nor effective outcomes of the measures can be guaranteed, especially hazard mitigation measures. Thus, this research highlights a conservative assumption that the local public health service would deal with the potential impacts through self-reliance orientation. From service network and service level analysis shows that there is a big room for implementing climate-resilient actions in primary care units or CUP units which could increase the climate-resilient of the service network as a whole. Therefore, in Khon Kaen city, more priority in addressing climate-resilient at the primary care level shall be emphasized. Detailed configurations of the potential impact operationalization under "Trend scenario" and "Desirable scenario" of individual public health facilities are shown in Annex 25 as well as presented in area-based, service network, and service hierarchy perspectives as follows.

3.1) Area-based perspective: (rethink about the structure again)

From an area-based perspective, the public health service of the study area was assessed as *medium* level of the potential impact of climate-related hazards under “Trend scenario”. According to the composite indicator pillars, the study area was classified as having a *high* level of Hazard, *medium* level of Exposure and *low* level of Vulnerability. The public health care units in Zone 1 revealed the highest potential impact value, followed by Zone 3, Zone 2 and Zone 4, respectively. Due to being located in fluvial flood-prone areas, Zone 1 might suffer the most from climate-related hazards in the future compared to other areas. Even though Zone 2 is also defined as a flood-prone area, the low vulnerability value pushes Zone 2 to the third place of potential impact value. Contrary to Zone 4, the area is situated in the safer zone (safer from the fluvial flood), but with the highest vulnerability score leading the Zone 4 was categorized as a *medium* level of potential impact as same as other zones.

As aforementioned, the city-wide stakeholders expressed their desire to implement the proposed spatial planning-based measures (see section 5.3.2). Nonetheless, outcomes in reducing hazards cannot be assured. Therefore, this study assumes that the Hazard pillar under the “Desirable scenario” has the same figure as the “Trend scenario”. However, the alteration between the two scenarios can be seen in the Exposure pillar and Vulnerability pillar. Under the “Desirable scenario”, exposure and vulnerability are varied according to the scenario storylines and assumably maximum internal efforts on climate-resilience of the public health sector. Hence, the overall potential impact outcome of the “Desirable scenario” was assessed as “*low level*”. Area-based analysis of the potential impact assessment under both scenarios shows in Table 5.14 -5.15 and Figure 5.30 with extensive explanations as follows.

Table 5. 14 Zonal average of potential impact profile of Khon Kaen city

Pillars	Trend scenario				Desirable scenario			
	Zone 1	**Zone 2**	**Zone 3**	**Zone 4**	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 4**
Normalized Hazard (H)	0.92	0.88	0.86	0.68	0.92	0.88	0.86	0.68
Normalized Exposure (E)	0.72	0.67	0.67	0.59	0.34	0.34	0.36	0.26
Normalized Vulnerability (V)	0.44	0.42	0.46	0.50	0.06	0.07	0.13	0.13
Potential impact = H*E*V *** Equal interval classification of potential impact value* Very low (0.000 - 0.016) Low (>0.016 - 0.125) Medium (> 0.125 - 0.422) High (>0.422 - 1.000)	**0.29**	**0.24**	**0.26**	**0.20**	**0.02**	**0.02**	**0.04**	**0.02**

Table 5. 15 Potential impact assessment of Khon Kaen city in area-based and service network perspectives[54]

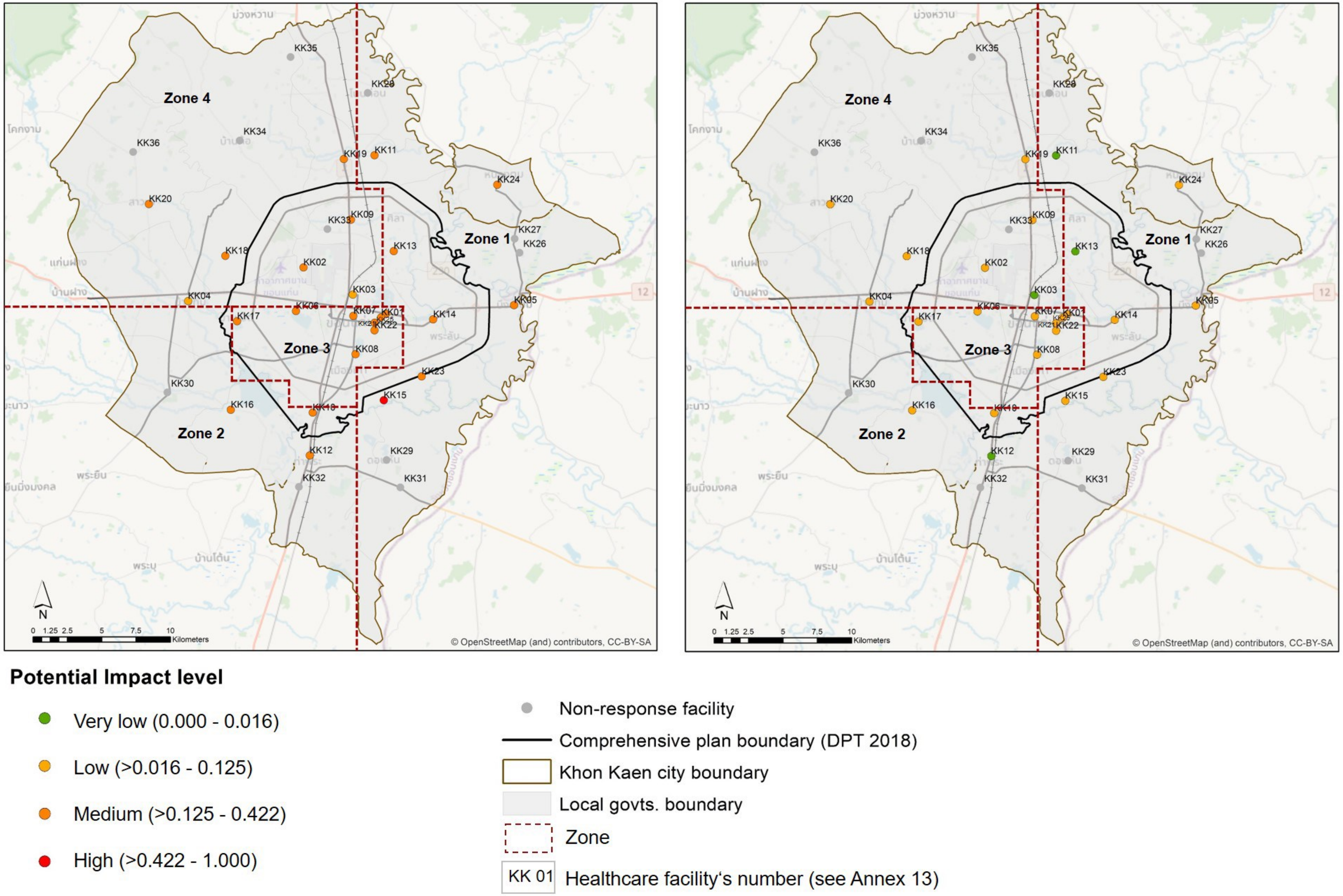
Indicators	Trend scenario		Desired scenario	
	Area-based	Service network	Area-based	Service network
H1: Fluvial flood	0.588	0.639	0.588	0.639
H2: Pluvial flood	1.279	1.279	1.279	1.279
H3: Water scarcity	1.442	1.442	1.442	1.442
Weighted normalized Hazard	**0.827**	**0.840**	**0.827**	**0.840**
E1: Exposure of public health facility's building(s)	1.040	1.017	1.040	1.017
E2: Exposure of working systems	1.594	1.178	0.263	0.279
Weighted normalized Exposure	**0.659**	**0.549**	**0.326**	**0.324**
V1: Over carrying capacity	0.800	0.800	0.480	0.710
V2: Variety of vulnerable patients	0.683	0.778	0.683	0.778
V3: Resource insufficiency	0.624	0.608	0.440	0.555
V4: Poor system conditions and maintenance of essential working systems	0.064	0.033	0.000	0.000
V5: Downtime of essential working systems	0.053	0.045	0.053	0.045
V6: Lack of flexibility & modularity	0.456	0.480	0.000	0.000
V7: Lack of diversity of suppliers	0.217	0.122	0.047	0.031
V8: Lack of redundancy	0.416	0.397	0.081	0.097
V9: Lack of responsiveness	0.626	0.559	0.000	0.000
V10: Lack of resource mobilization	0.359	0.535	0.000	0.000
V11: Lack of integration and coordination	0.300	0.084	0.000	0.000
V12: Lack of Information	0.388	0.424	0.000	0.000
V13: Lack of preparedness and risk transfer	0.720	0.594	0.000	0.000
V14: Lack of participation and inclusiveness	0.742	0.808	0.000	0.000
V15: Lack of capacity development	0.642	0.167	0.000	0.000
V16: Lack of mainstreaming climate-risk in planning process	0.440	0.487	0.000	0.000
V17: Lack of monitoring and evaluation	0.300	0.323	0.000	0.000
Weighted normalized Vulnerability	**0.461**	**0.426**	**0.105**	**0.130**
Potential impact = H*E*V *** Equal interval classification of potential impact value* Very low (0.000 - 0.016) Low (>0.016 - 0.125) Medium (> 0.125 - 0.422) High (>0.422 - 1.000)	**0.251**	**0.196**	**0.028**	**0.035**

[54] Details of data classification of potential impact value and indicator value can be found in Annex 23-24

Figure 5. 30 Potential impact assessment of (Area-based) Trend scenario and Desirable scenario *(see the list of hospitals and potential impact classification details in Annex 13 and 23, respectively)*

a) Trend scenario

b) Desirable scenario



3.1.1) Hazard Pillar

Even though structural and non-structural hazard mitigation measures would possibly be undertaken by relevant agencies outside the public health sector or micro-engineering & architectural solutions invested by a public health facility, neither successful nor effective outcomes of the measures can be guaranteed. Thus, “Trend scenario” and “Desirable scenario” share the same climate-related hazard bandwidth but differ in urban development and land use features and public health’s risk management. Based on the scenario storylines, fluvial flood is the only factor that contrasts the local hazard profile; meanwhile, pluvial flood and water scarcity were generalized as possible to occur regardless of spatial differences. According to the assessment result, Zone 1 revealed the highest hazard score, followed by Zone 2, 3 and 4, respectively. All zones are categorized as a *high* hazard level, except Zone 4, which is considered a safer zone classified as a *medium*-level under the Hazard pillar. Zone 1 and 2, are also known as flood-prone areas. Thereby, all SHPH in this zone may be underwater due to fluvial floods in the future. However, the fluvial flood scenario showed that Sila SHPH (KK13) and Thapra SHPH (KK12) might stay dry from the maximum fluvial flood level (155 m MSL). In the dense urban area (Zone 3), Pracha Samosorn Medical Center (KK25) is the only place that may suffer the most from a fluvial flood, although the exceeded water level is lower than 155 m MSL, in contrast to other health care facilities in the same zone, which might stay dry until the fluvial flood eventually crossed the 155 MSL contour line. As located in a higher ground area, all public health care facilities in Zone 4 might not deal with fluvial floods under the maximum climate bandwidth. The Hazard level of the local public health service is exhibited in Figure 5.31 and Table 5.16.

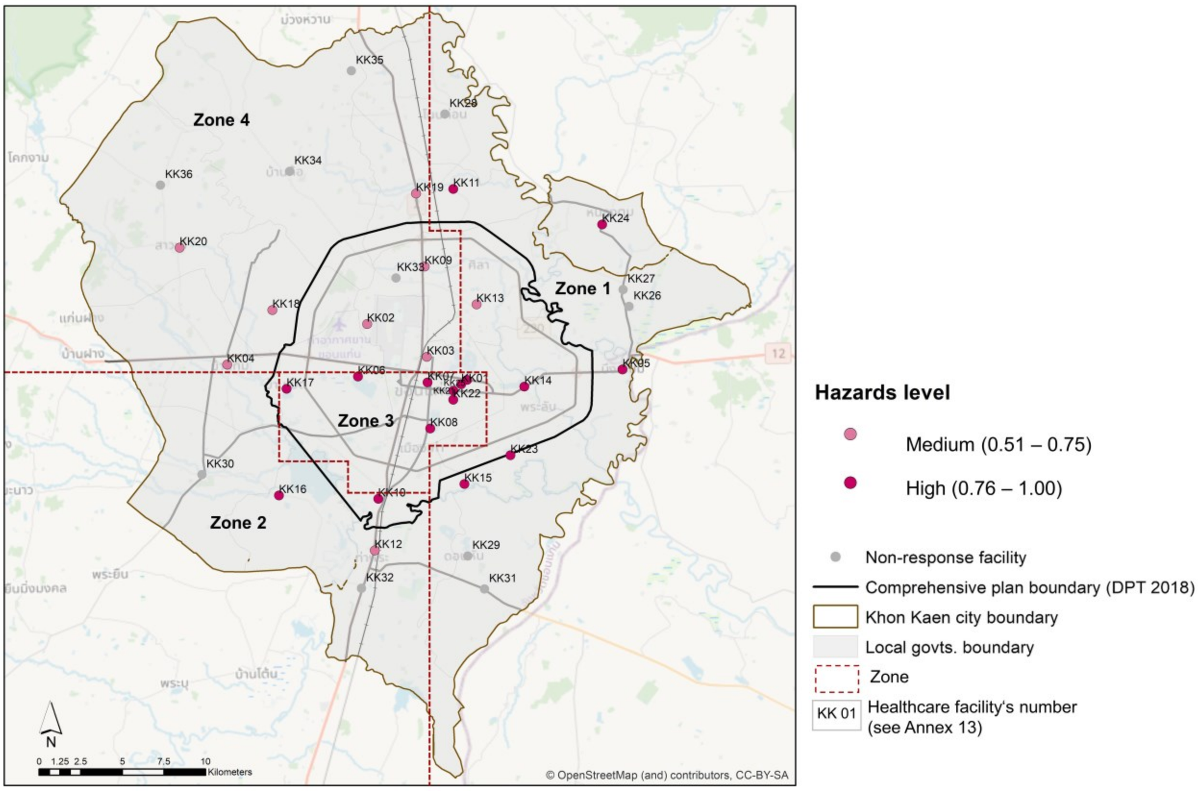
Table 5. 16 Zonal average value of Hazard pillar

Remark: Details of data classification of potential impact value and indicator value can be found in Annex 24

Hazards	Trend scenario				Desirable scenario			
	Zone 1	Zone 2	Zone 3	Zone 4	Zone 1	Zone 2	Zone 3	Zone 4
H1: Fluvial flood	0.96	0.80	0.72	0.00	0.96	0.80	0.72	0.00
H2: Pluvial flood	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28
H3: Water scarcity	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44

Figure 5. 31 Level of hazards of Trend scenario and Desirable scenario

Remark: See the list of hospitals and indicators classification details in Annex 13 and 24



3.1.2) Exposure

Under the "Trend scenario", no local public health facilities expressed their intention or plan to relocate or construct new buildings outside or far from their existing locations in the future. Therefore, this assessment assumed that the exposure of health care buildings remains at the current status. Hence, the assessment showed that all zones were classified as having a *medium* level of exposure. Zone 1 received the highest score on the Exposure pillar, followed by Zone 2, 3 and 4. At the indicator level, the working systems' location (E2) exhibited a higher contribution to an overall exposure value than the location of building(s) (E1). Every zone was categorized as having a *medium* level exposure of building(s) (E1), except Zone 4, which was assessed as *low* level. Meanwhile, other zones were classified as having a *high* level exposure of the working systems (E2), but Zone 3 received a score of *medium* level for this indicator.

Interestingly, the analysis showed that 14 (out of 25) public health care units exhibited *low* exposure value of their buildings, but only 2 (out of 25) public health care units showed *low* exposure value of their working systems. Therefore, it is fair to conclude that most public health care units in the study area have their working systems highly exposed to inundations even though their buildings are possibly safe from the fluvial flood. However, special attention should be paid to Zone 1, where the working systems of every public health care unit have high exposure to fluvial floods. Nevertheless, among all the public health care units in the study area, the highest priority should be Hua Thung Primary Care Centre, which was categorized as having a *high* level of exposure in both buildings and working systems aspects.

Under the “Desirable scenario”, even though the stakeholders did not highly prefer managed retreat strategies and the KKPHO can not express a concrete view of the possible intervention. Therefore, the figure of public health care buildings' exposure was assumed to be the same as “Trend scenario”. In contrast, the resilient (physical) upgrading option was embraced by KKPHO to minimize public health care units' working systems. In this respect, all internal essential primary and secondary (backup) working systems were assigned to be located in safer positions/locations. However, a few essential working systems that are technically neither possible nor practical to adjust their position/location to the safer areas were assumed to remain in their current location(s), i.e. drainage system, wastewater treatment facility, and parking lots. Hence, under the “Desirable scenario”, public health care units in the study area revealed a *low* level of exposure on average, which can be subtracted as *medium* exposure of buildings and a *very low* level of exposure of internal essential working systems. Zone 4 showed the lowest exposure value in the zonal perspective, followed by Zone 3, Zone 2 and Zone 1, respectively. Table 5.17 and Figure 5.32 illustrate the level of exposure under the scenarios.

Table 5. 17 Zonal average of Exposure pillar

Remark: Details of data classification of potential impact value and indicator value can be found in Annex 24

Exposure	Trend scenario				Desirable scenario			
	Zone 1	**Zone 2**	**Zone 3**	**Zone 4**	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 4**
E1: Exposure of public health facility’s building(s)	1.11	1.08	1.17	0.81	1.11	1.08	1.17	0.81
E2: Exposure of Working systems	1.77	1.60	1.50	1.54	0.25	0.27	0.28	0.25

3.1.3) Vulnerability

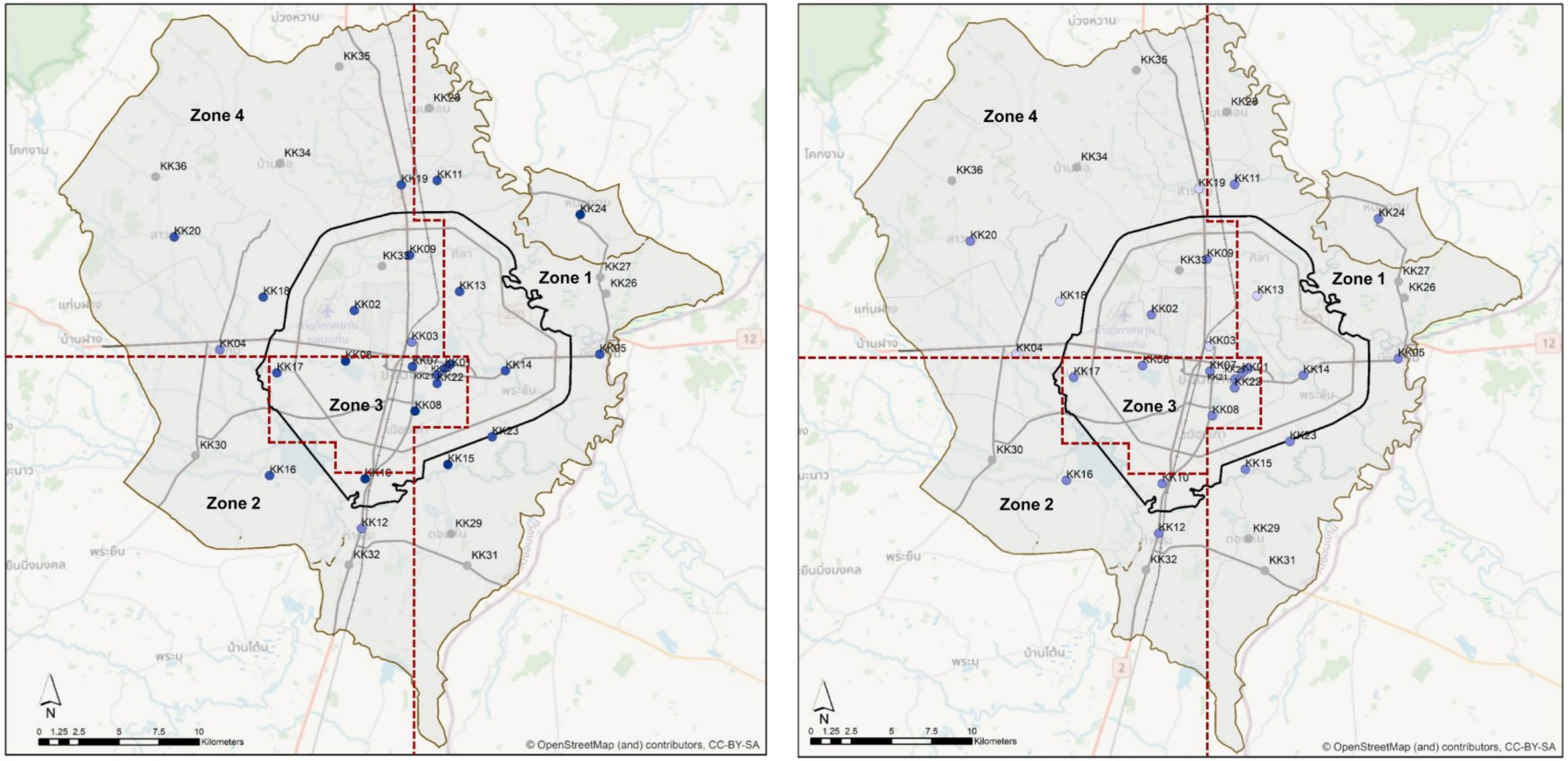
All zones exhibited a *low* level of vulnerability (0.46 on average) under the “Trend scenario” conditions. The highest vulnerability score was estimated in Zone 4, followed by Zone 3, Zone 1, and Zone 2, respectively. Even though the average figure of the Vulnerability pillar of Khon Kaen city is rather *low*, but there are primary care units classified as *medium* vulnerability level. Those should be considered as hotspots in the vulnerability perspective, such as Ban Phue SHPH (KK23), Ban Donbom SHPH (KK15) (Zone 1), Thapra SHPH (KK12) (Zone 2), Nong Wang Medical Center, Chatapadung Medical Center (KK08) (Zone 3), Ban Thum SHPH (KK04), Sumran SHPH (KK19), and Dang-yai SHPH (KK18) (Zone 4). In response to the targets, all necessary measures and actions that reduce sensitivity and strengthen coping and adaptive capacity were assumed to be executed under the “Desirable scenario”. Hence the local public health care service showed a *very low* level of vulnerability

(0.10 on average) under this scenario. However, no substantial differences in zonal vulnerability value, especially in coping capacity and adaptive capacity related indicators, spatially differences can be noticed in sensitivity-related indicators. Although all zone showed *low* sensitivity on average, the assessment revealed that many of health care units classified as having a *medium* level of sensitivity in Zone 3 (Chatapadung Medical Center (KK01), Nong Wang Medical Center (KK08), Ban Ped SHPH (KK17), Hua Thung Primary Care Center (KK06), Khon Kaen Hospital (KK21) and Zone 4 (Mittrapap Medical Center (KK03), Ban Thum SHPH (KK09), Sumran SHPH (KK19), Dang-yai SHPH (KK18)). Figure 5.33 illustrates the level of Vulnerability of the participating public health facilities under “Trend scenario” and “Desirable scenario”, while detailed explanations of each vulnerability component provide as follows.

Figure 5. 32 Level of exposure of Trend scenario and Desirable scenario

Remark: See the list of hospitals and indicators classification details in Annex 13 and 24

a)Trend scenario b) Desirable scenario



Exposure level

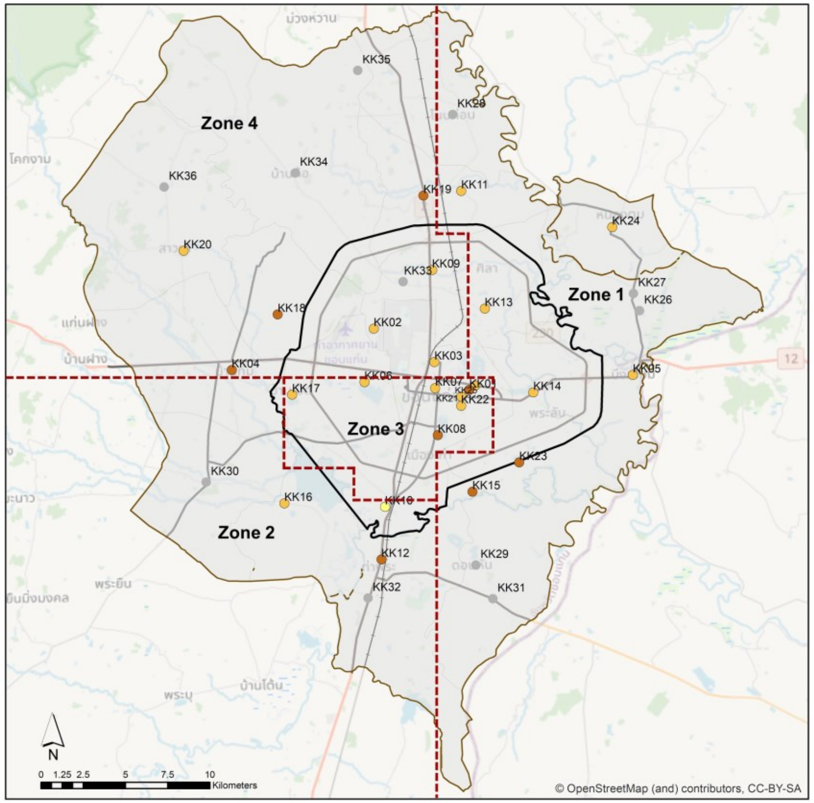
- Very low (0.00 - 0.25)
- Low (0.26 - 0.50)
- Medium (0.51 – 0.75)
- High (0.76 – 1.00)

- Non-response facility
- Comprehensive plan boundary (DPT 2018)
- Khon Kaen city boundary
- Local govts. boundary
- Zone
- KK 01 Healthcare facility's number (see Annex 13)

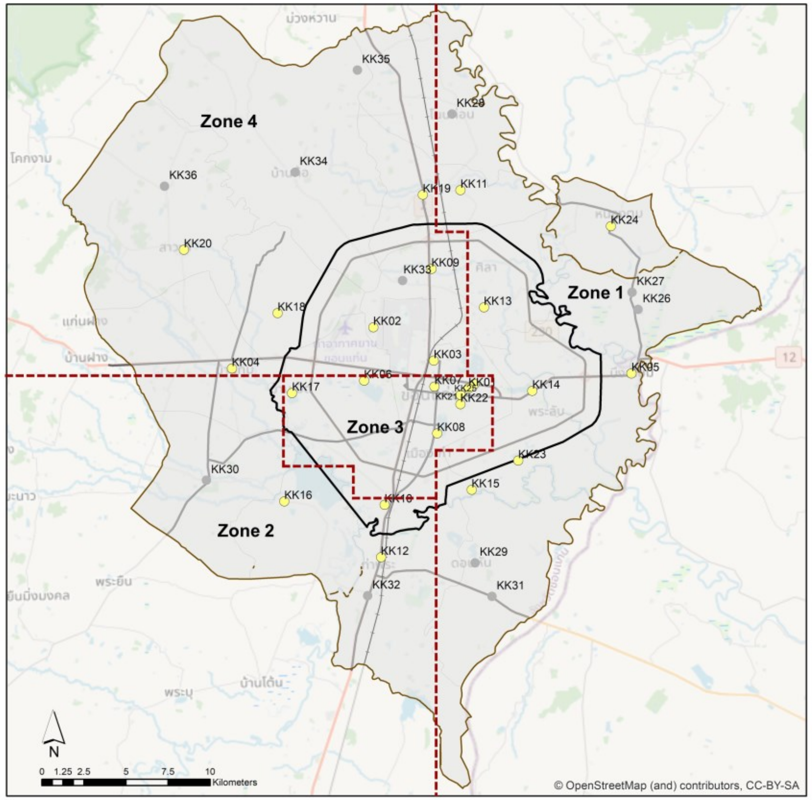
Figure 5. 33 Vulnerability level of Khon Kaen city public health service under Trend scenario and Desirable scenario

Remark: See the list of hospitals and indicators classification details in Annex 13 and 24

a)Trend scenario



b) Desirable scenario



Vulnerability level

- Very low (0.00 - 0.25)
- Low (0.26 - 0.50)
- Medium (0.51 – 0.75)
- High (0.76 – 1.00)

- Non-response facility
- Comprehensive plan boundary (DPT 2018)
- Khon Kaen city boundary
- Local govts. boundary
- Zone
- KK 01 Healthcare facility's number (see Annex 13)

3.1.3.1) Sensitivity-related vulnerability

Under the "Trend scenario", urbanization leads to increasing population in all zones of the city, which contradicts the zero-growth policy (service capacity and personnel resources) of the public health sector. All public health care facilities were revealed as *a high* score for Over carrying capacity indicator(V1). Most public health care units in Khon Kaen city were assumed to accommodate complex and varieties of vulnerable patients in the future, depending on service hierarchy. However, 3 health care units were declared as having less variation in vulnerable patient profiles, such as Sila SHPH (KK13) (Zone 1), Khon Kaen Rajanagarindra Psychiatric Hospital (Zone 3) (KK22), and Sawathee SHPH (KK20) (Zone 4). It is important to note that the Khon Kaen Rajanagarindra Psychiatric Hospital (KK22) is a specialized health care facility receiving only certain types of patients, especially mental disorder patients. Therefore, from the area-based perspective, a variety of vulnerable patients (V2) indicator was scored as *medium*.

The assessment exhibited an overall Resource insufficiency (V3) of the public health care units in the study area as *high* level. In the survey, most PCUs indicated having no financial insufficiency issues in business as usual situation. However, many PCUs reported struggling with human resources, such as Pralub SHPH (KK14), Ban Phue SHPH (KK23) (Zone 1), Muengkao SHPH (KK10), Ban Donbom SHPH (KK15) (Zone 2), Nong Wang Medical Center (KK08), Ban Ped SHPS (KK17), Khon Kaen Hospital (KK21) (Zone 3), Ban Thum SHPH (KK04), Ban Nong Kung Community Health Center (KK09), Dang-yai SHPH (KK18), and Sawathee SHPH (KK20) (Zone 4). Among the 25 public health care units, only Ban Phue SHPH (KK23) (Zone 1) declared itself as a *high* insufficiency of both financial and human resources.

For the working systems conditions and maintenance indicator (V4), the analysis showed that most of the essential working systems of public health care facilities range from good to fair conditions. However, there were indications for improvement needs, especially water supply and pumping system, computers and communication system, backup power generation, etc. Nevertheless, the "Trend scenario" analysis clearly pointed out that system monitoring and reporting, availability of trained staff/technicians for system maintenance, and reparation and availability of maintenance resources are urgently needed to be strengthened, particularly trained staff/technicians to regularly take care of power supply, water supply and drainage system, and communication system.

Although the average maximum downtime of essential working systems in the past five years (2014-2019) was less than 1 hour, the top 3 working systems which reported as the longest maximum downtime are internet (>2-4 days)[55], water supply (>2-4 days), and grid power system (4-12 hr), see more information in Table 5.10-5.12. Therefore, an overall score

[55] Some public health care facilities also reported occurrence of maximum downtime, >2-4 days, in computer and servers system, telephone and/or communication radio.

of this indicator was assessed as *very low* level under the Trend scenario. This study is aware of the fact that historical downtime could not directly determine future situations, but it could be used as a baseline for risk management. Hence, from an overview standpoint, it can be concluded that the local public health units could show a *medium* sensitivity level under the "Trend scenario".

According to the "Desired scenario", limiting development in flood-prone areas could stabilize or slow down population growth in Zone 1 and Zone 2. Under this scenario, the urban development strategy adheres to the public health sector's human resource management (zero-growth policy) and disaster risk reduction. On the contrary, promoting development and urbanization in Zone 3 and 4 could lead to a higher number of inhabitants with denser degrees. However, no plan and no wish to extend service capacity according to the zero-growth policy could cause insufficient service capacity to respond to the increased demands in Zone 3 and 4. In other words, mismatching between urban development strategy and public health resource management under the "Desirable scenario" could raise more sensitivity concerns in Zone 3 and Zone 4 (*high* level) than Zone 1 and Zone 2.

To maximize sectoral efforts in combating climate-related hazards, physical upgrading for all essential working systems will ensure to be in good condition with sufficient maintenance resources and regular inspections by experts (V4). However, downtime of the essential working systems (V5) was assumed to maintain the present figures since these measurable indicators are highly dependent on management rules and technological aspects of infrastructure, controlled by utilities and suppliers rather than the public health care unit itself. Plus, this study cannot provide a quantitative /forecast analysis of the techno-sociological aspect of the critical infrastructures due to limited research scope and resources. In these regards, the local public health units were evaluated as having a *low* sensitivity level under the "Desirable scenario", from an overall area-based perspective.

Table 5.18 and Figure 5.34 illustrate the level of sensitivity-related elements under the "Trend scenario" and "Desirable scenario" of the survey participating public health facilities.

Table 5. 18 Zonal average of Sensitivity-related indicators

Remark: Details of data classification of potential impact value and indicator value can be found in Annex 24

Sensitivity-related indicators	Trend scenario				Desirable scenario			
	Zone 1	Zone 2	Zone 3	Zone 4	Zone 1	Zone 2	Zone 3	Zone 4
V1: Over carrying capacity	0.80	0.80	0.80	0.80	0.00	0.00	0.80	0.80
V2: Variety of vulnerable patients	0.64	0.87	0.68	0.61	0.64	0.87	0.68	0.61
V3: Resource insufficiency	0.63	0.60	0.63	0.63	0.20	0.20	0.60	0.60
V4: Poor system conditions and maintenance of working systems	0.04	0.07	0.08	0.05	0.00	0.00	0.00	0.00
V5: Downtime of critical or sensitive working systems	0.05	0.07	0.03	0.08	0.05	0.07	0.03	0.08

3.1.3.2) Lacking coping capacity

Continuation of the current management presented the coping capacity-related indicators under the "Trend scenario". Thus, the local public health service was assessed as *medium* level in lack of coping capacity, especially in the aspect of lacking flexibility and modularity(V6), lacking diversity of suppliers (V7), lacking redundancy(V8), lacking responsiveness (V9) and lacking integration & coordination (V11). Meanwhile, lacking resource mobilization (V10) was apprised as *low* level. In the zonal aspect, the analysis exhibited that Zone 4 has the highest score in lacking coping capacity, especially Ban Thum SHPH (KK04). To minimize the potential impact of climate-related hazards, the "Desirable scenario" suggested fulfilling all actions that enhance and reinforce coping capacity under the direct management of the public health sector. As a result, the score of all indicators under (lack of) coping capacity-related elements was assigned to *very low* level under the "Desirable scenario". A summary of the zonal average score of the coping capacity-related component can be found in Table 5.19. Meanwhile, the extensive description of the lacking coping capacity aspect of both scenarios, from the area-based perspective, is as follows.

The "Trend scenario" assessment showed "*medium*" level of ***lacking flexibility and modularity* (V6)**. The working systems that significantly lack flexibility and modularity property include primary and backup power supply systems, water supply systems, water pumping and drainage systems, wastewater management, information and communication systems, and solid waste management. On the contrary, the analysis revealed that public health service in Khon Kaen city has quite high flexibility and modularity in medical and non-medical supply management, personnel management, and vehicles and accessibility. In the case of dysfunction of essential working systems, it is clear that most public health care units do not prepare or have necessary structure/equipment to ensure connectivity and compatibility between their in-house working stations and external devices/systems in order to secure continuity of operation in the case of hazards. Furthermore, in the case of health care buildings treated by hazards or dangers, most public health care facilities do not become aware of the needs or have no implementation in assigning one-stop service area(s) with the highest protective level as part of risk minimization and ensuring service continuity.

Hotspots of ***lacking diversity of suppliers* (V7)** can be found in every zone of the city, namely Bungniam SHPS, Pralub SHPS (KK14) (Zone 1), Ban Donbom SHPS (KK15) (Zone 2), Chatapadung Medical Center (KK01), Pracha Samosorn Medical Center (KK25) (Zone 3), and Dang-yai SHPS (KK18) (Zone 4). Among the focused 19 essential working systems, the following were assessed as highly lacking in supplier diversification: underground water source, grid power system, dispensable medical supplies, off-grid power system, internet system, and water supply-related systems. Contrary, multiple suppliers are possible for office supplies, food and nutrition, telephone and communication, human resources and vehicles.

Interestingly, the analytical result araising concerns about the government procurement system. The public health care units must follow the government procurement procedures that often do not allow them to have multiple suppliers in both businesses as usual and the case of emergency, especially public utilities, which are typically state-run enterprises (quasi-monopoly). Moreover, there are constraints in ministerial-level contracts binding with a particular supplier. Thus alternative contractors of lifeline infrastructures are hardly possible. Yet, all local public health care units do not have a contractual arrangement procedure and/or supportive technical structure/management installed available for more than one supplier in advance, particularly sophisticated immobility working systems. In contrast with food & nutrition and communication (mobile phone), individual staff or a public health unit can freely buy or choose service providers, usually paying from their pockets. Although a local public health facility can have high suppliers diversity in non-medical supplies, the PCUs must rely on CUP host to procure and distribute medical supplies, and dispatch a family doctor team for a CUP unit's operation.

Public health units of Khon Kaen city were assessed as *medium* level in ***lacking redundancy*** **(V8)**. Zone 4 exhibited the highest score in this indicator, followed by Zone 1, Zone 3 and 2. Except Zone 2, hotspots on this issue can be observed in every zone, such as Ban Kok SHPH (KK11), Pralub SHPH (KK14) (Zone1), Chatapadung Medical Center(KK01), Ban Nong Kung Community Health Center (KK09) (Zone 3), Dang-Yai SHPH (KK18), and Sawathee SHPH (KK20) (Zone 4). In the angle of sub-indicators, almost all of the public health units lack redundancy in terms of provision of secondary backup resources/systems, special vehicle types (e.g. boat, amphibian, helicopter, drone) for carrying goods and passengers during emergency/disasters, as well as no assignment of alternate care site. Moreover, only 5 (out of 25) of health care units allow staff and their family members to shelter on campus with designed locations and facilities ready in advance.

Nonetheless, most of the local public health care units have a management system for patient tracking and documentation in the case of electronic systems failure and use runners (couriers) as a backup option for getting help from outside during communication systems breakdown. In the temporal dimension, on average, the survey revealed the survey participating public health care units have a *low* level of lacking redundancy of primary backup systems/resources in relation to their effects after disruption begins. The local public health facilities have sufficient reserved water supply for 2-4 days on average (not the case for Khon Kean Hospital), but other working systems can continue working only for a very short period after the emergency begins, such as 1-4 hours for reserved power capacity, 1-4 hours for information systems, and 4-12 hours for communication systems approximately. However, linen is the only resource that most healthcare facilities do not have to worry much about its redundancy. It is important to keep in mind that different service hierarchies require different quantities and reliability of resources/systems (see Table 5.10-5.12).

Under the “Trend scenario”, the local public health care units showed a *medium* level of ***lacking responsiveness*** **(V9)**. All areas were categorized as having a *medium* level for this indicator, except Zone 4 (*high* level). Zone 4 obtained the highest score on lacking the ability to organize, rearrange, and give responding actions on time, followed by Zone 3, Zone 1 and Zone 2. The survey [56] stated that most local public health care units do not have responsiveness-related plans and are never aware of them, especially the evacuation plan, business continuity plan, and surge personnel capacity plan. However, some of the plans are available but limited in implementation, especially on resources conservation, slow-onset natural disasters response, self-help capacity, and contingency plan.

Under the composite indicators framework, the survey also showed that 13 of the public health care facilities (out of 25) have very limited responsiveness to climate-related hazards. Plus, 4 of them have none of the mentioned plans, which represented their responsiveness to climate-related hazards. Since the study cannot measure the responsiveness of the local public health care units directly but indirectly through responsiveness-related plan availability, it is important to note that, even though a public health care facility received the highest score in this indicator, it does not mean they have absolutely zero responsiveness.

“Trend scenario” assessment illustrated that public health facilities in the study area as *low* level in ***lacking resource mobilization*** **(V10)**. Zone 4 received the highest score for this indicator and was the only one classified as *medium* level, followed by Zone 3, Zone 1, and Zone 2, respectively. Except Zone 2, concerns of lacking resource mobilization revealed hotspots in almost every zone, such as Sila SHPH (KK13) (Zone 1), Chatapadung Medical Center (KK01), Nong Wang Medical Center (KK08), Khon Kaen Hospital (KK21) (Zone 3), Dang-yai SHPH (KK18), and Sumran SHPH (KK19) (Zone 4). From an overall sub-indicators perspective, even though most local public health care units have insufficient financial resources available for disaster risk preparation, it is not difficult for them to access monetary resources from external sources or donations. Among the participating public health care facilities, only Chatapadung Medical Center (KK01) and Nong Wang Medical Center (KK08) (Zone 3) reported difficulties in the availability and accessibility of financial resources. However, more than 60 % of public health care units have financial resources for reconstruction /reparations with less than six months to a year of lag time for resuming full operation. About 40 % of surveyed health care units (including Khon Kaen Hospital) have no financial resources for reconstruction or have to wait more than a year for financial resources to have arrived. Furthermore, the survey shows that 60 % (15 out of 25) of the facilities have no management plan for a possible influx of volunteer and external help.

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[56] The survey was conducted before the 2nd wave of COVID-19 in Thailand.

In an overview of ***lacking integration and coordination** indicator* (V11), the local public health care service was assessed as *medium* level. However, only Zone 1 and Zone 4 scored as *medium* level, while Zone 2 and Zone 3 were classified as *low* level in this indicator. Hotspots of this indicator can be observed in almost every zone, such as Ban Kok SHPH (KK11) (Zone 1), Chatapadung Medical Center (KK01) (Zone 3) and Mittrapap Medical Center (KK03), Ban Thum SHPH (KK04), Sumran SHPH (KK19), and Sawathee SHPH (KK20) (Zone 4). Only 4 (out of 25) public health facilities in the study area declared having an internal board of committee/working group specific to disaster risk management with regular meetings and sufficient resources and coordination. Plus, only 3 (out of 25) reported having designated coordinator (s) whose disaster risk management is his/her/their main task. Moreover, 28 % of the public health facilities have channels or systems for automatically communicating and coordinating with lifeline utilities and key suppliers. Furthermore, 72 % of the local public health facilities have no agreement and joint exercise on partial/full patient evacuation to other hospitals in emergency or disaster situations. In contradiction to other indicators specified on disaster risk management, the Thai public health care operation has a referral and transfer agreement among hospitals both within and outside the CUP network as a standard protocol, even though the CUP host solely commands the coordination.

With aims to reduce potential impact to a *low* and *very low* level, all possible measures defined in the coping capacity-related composite indicators were fulfilled under the "Desirable scenario" Hence, under the **"Desirable scenario"** potential impact assessment, all public health care units showed a *very low* level of lacking coping capacity in every aspect. However, exceptions for an indicator and a sub-indicator remain status quo defined by the "Trend scenario". First, lack of diversity of suppliers (V7); 2 working systems indicated otherwise due to the working systems' operation practices/rules (medicine & medical supplies and grid electricity). Second is the assignment of alternate care site(s) (V8.8) sub-indicator; KKPHO indicated no intention to assign and implement this measure in the future. Even though the result configurations present in terms of lacking coping capacity, but to enhance a better communication of the result, Figure 5.35 mirrors its interpretation by showing the level of coping capacity of the health care units.

Table 5. 19 Zonal average of Coping capacity-related indicators

Remark: Details of data classification of potential impact value and indicator value can be found in Annex 24

Coping capacity-related indicators	Trend scenario				Desirable scenario			
	Zone 1	Zone 2	Zone 3	Zone 4	Zone 1	Zone 2	Zone 3	Zone 4
V6: Lack of flexibility & modularity	0.44	0.46	0.45	0.47	0.00	0.00	0.00	0.00
V7: Lack of diversity of suppliers	0.24	0.22	0.22	0.19	0.05	0.04	0.04	0.05
V8: Lack of redundancy	0.42	0.33	0.39	0.49	0.06	0.08	0.08	0.09
V9: Lack of responsiveness	0.58	0.53	0.60	0.74	0.00	0.00	0.00	0.00
V10: Lack of resource mobilization	0.34	0.28	0.36	0.42	0.00	0.00	0.00	0.00
V11: Lack of integration and coordination	0.31	0.25	0.26	0.36	0.00	0.00	0.00	0.00

3.1.3.3) Lack of adaptive capacity

Under “Trend scenario”, the composite indicators framework assessed the local public health service as having a *high* level of lacking adaptive capacity attributions in all aspects. Zone 4 revealed the highest score in adaptive capacity deficits, followed by Zone 3, Zone 1, and Zone 2, respectively. Meanwhile, the “Desirable scenario” aims to strengthen adaptive capacity in every aspect; therefore, the local public health care services gained a *very low* level of lacking adaptive capacity. A summary of the zonal average score on the adaptive capacity-related component can be found in Table 5.20. A detailed explanation from the indicators standpoint of the two scenarios is as follows.

Under “Trend scenario”, ***lacking information for disaster risk managemen*t (V12)** was evaluated as *medium* level. Zone 4 showed the highest score in lacking information for disaster risk management, followed by Zone 2 and Zone 3. Zone 1 is the only area where the average score was categorized as a *low* level for this indicator. Nevertheless, hotspots in this regard can be seen in all areas, i.e. Bungniam SHPH (KK05), Ban Phue SHPH (KK23) (Zone 1), Thapra SHPH, Ban Donbom SHPH (KK15) (Zone 2), Chatapadung Medical Center (KK01), Hua Thung Primary Care Center (KK06), Khon Kaen Rajanagarindra Psychiatric Hospital (KK22) (Zone 3), Thanyarak Khon Kaen Hospital (KK02), Ban Thum SHPH (KK04), Dang-Yai SHPH (KK18), and Sawathee SHPH (KK20) (Zon4). The sub-indicators level showed that, on average, the local public health units are aware of and can access the information related to the future demographic trend. However, interview inputs (with hospital managers/executives) clarified that their data is not a high resolution and long time-span and they do not use it for long-term service planning. Nonetheless, it is important to note that they usually do not have a service plan which longer than a typical government plan cycle, 4-5 years. Moreover, most of them are neither aware of nor have access to the local hazard map and climate-related disaster risk database as well as the future-oriented climate-related hazards (flood and water scarcity) information/maps.

Lacking preparedness and risk transfer (V13) indicator received the second-highest score under the Vulnerability pillar under the “Trend scenario”. All areas gained a *high* level score for this indicator, except Zone 2, classified as *medium* level. All public health care units in Zone 4 were defined as a hotspot of lacking preparedness and risk transfer, followed by Zone 1 and Zone 3. Meanwhile, 80 % of the local public health facilities reported no availability and were never aware of a plan and long-term investment to increase climate-related disaster resilience, climate-related disaster risk insurance provision, and Build Back Better plan development.

Lacking participation and inclusiveness (V14) obtained the highest score compared to other indicators under the Vulnerability pillar. The "Trend scenario" assessment showed a *high* level score of this indicator in almost every zone, except Zone 2, where the only area was categorized as *medium* level. 80 % of the local public health units stated neither consideration of having disaster risk management planning and exercise with key stakeholders, especially utilities, suppliers and other relevant agencies, nor including a community in their disaster risk planning process. Similar to other indicators under the adaptive capacity-related component, the assessment showed that the public health facilities of Khon Kaen city ***lack capacity development on disaster risk management*** **(V15)** at a *high* level. Particularly Zone 4, where every public health care facility in the area lacks capacity development activities. Moreover, about 80 % of the local public health facilities reported no training on working under limited resources or lifeline infrastructure failure. Nevertheless, Khon Kaen Hospital and the other 2 PCUs organize this capacity-building activity with sufficient resources and coordination at least once a year.

About 72 % of the public health care units in the study area have no in-house capacity building and awareness-raising activities on the importance of future climate-related disaster risk and resilience. Furthermore, the "Trend scenario" assessment exhibited that the local public health care units in almost all zones are at *high* level of ***lacking mainstreaming risk-informed planning (V16)***, except zone 2. Again, Zone 4 was ranked as the highest value in this aspect, followed by Zone 3, Zone 1, and Zone 2. At the sub-indicators level, the survey illustrated that most of Khon Kaen city's public health units are not aware of the importance of mainstreaming disaster risk management in their action plan or budget plan. In addition, about 76 % of local public health units do not consider integrating the future climate-disaster risk impact information in the system maintenance plan and reparation budget at the working systems level.

A classical pitfall of all administrative levels in Thailand, no exception for the local public health care, is ***lacking monitoring and evaluation (M&E)*** **(V17)**. "Trend scenario" assessment showed that only 2 out of 25 survey participating public health facilities declared themselves to have a regular review of disaster risk management plan and sufficient resources and coordination for M&E implementation. Therefore, a *high* score level of lacking monitoring and evaluation was assigned for all zones under this scenario.

All possible implementations to improve the public health care units' adaptive capacity were orchestrated under the **"Desirable scenario"**. Therefore, all adaptive capacity-related measures reflected in the composite indicators were assumed to be implemented and accomplished to strengthen every health care unit's ability to adapt to the possible future conditions of climate-related hazards and urban development change. Thus, the local public health services were assessed as having a *very low* level of lacking adaptive capacity under this scenario.

Even though the indicators were operated in the aspect of lacking adaptive capacity, to communicate the result better, Figure 5.36 rotate the angle of the result interpretation by showing the level of adaptive capacity of the participating public health facilities.

Table 5. 20 Zonal average of Adaptive capacity-related indicators

Remark: Details of data classification of potential impact value and indicator value can be found in Annex 24

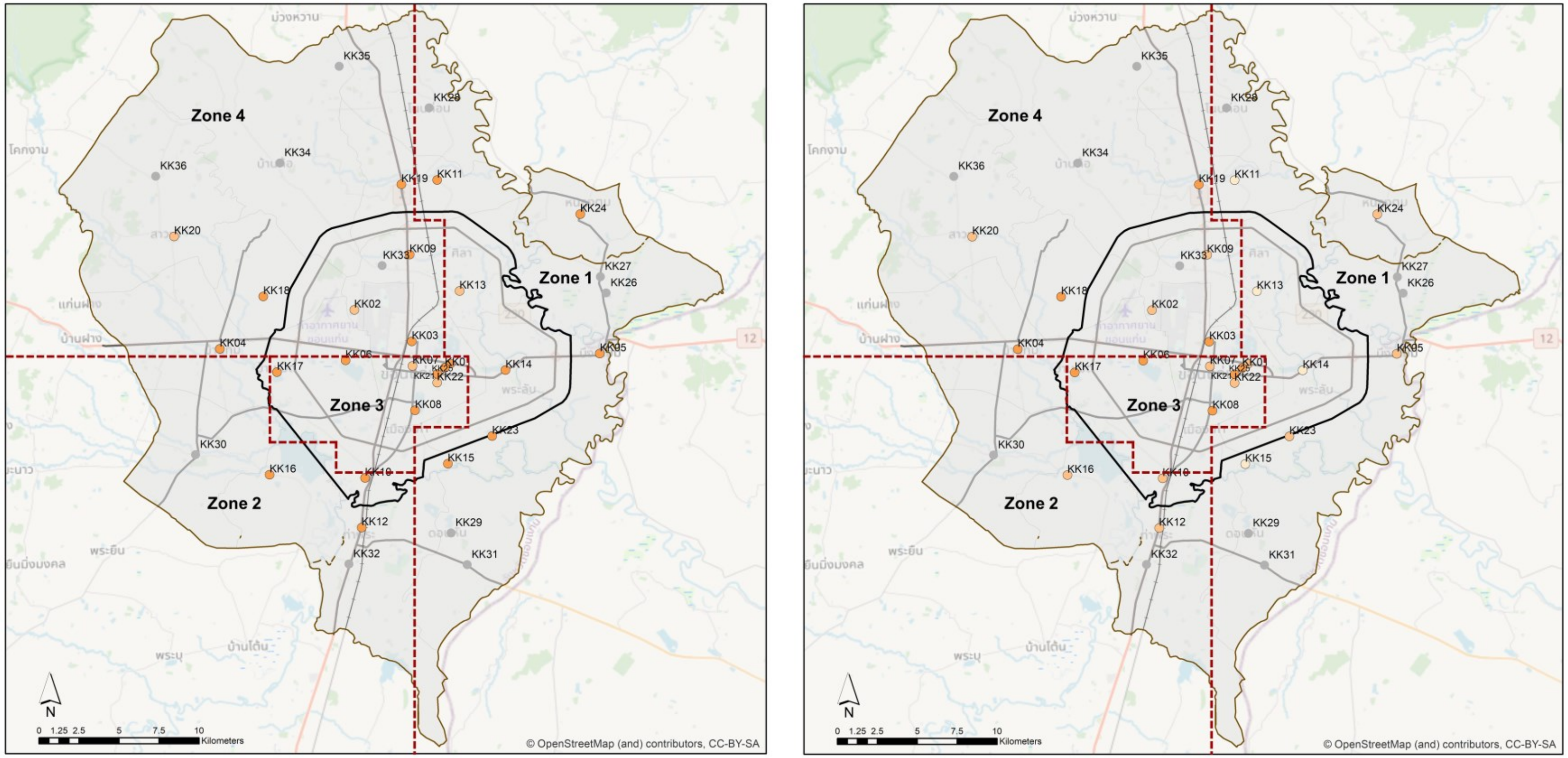
Adaptive capacity-related indicators	Trend scenario				Desirable scenario			
	Zone 1	Zone 2	Zone 3	Zone 4	Zone 1	Zone 2	Zone 3	Zone 4
V12: Lack of Information	0.32	0.37	0.40	0.44	0.00	0.00	0.00	0.00
V13: Lack of preparedness and risk transfer	0.73	0.58	0.72	0.79	0.00	0.00	0.00	0.00
V14: Lack of participation and Inclusion	0.76	0.55	0.75	0.83	0.00	0.00	0.00	0.00
V15: Lack of capacity development	0.57	0.55	0.60	0.80	0.00	0.00	0.00	0.00
V16: Lack of mainstreaming climate-risk in planning process	0.43	0.36	0.46	0.48	0.00	0.00	0.00	0.00
V17: Lack of monitoring and evaluation	0.25	0.25	0.33	0.33	0.00	0.00	0.00	0.00

Figure 5. 34 Level of sensitivity-related component of Khon Kaen public health service under Trend scenario and Desirable scenario

Remark: See the list of hospitals and indicators classification details in Annex 13 and 24)

a)Trend scenario

b) Desirable scenario



Sensitivity level

- Very low (0.00 – 1.00)
- Low (1.01 – 2.00)
- Medium (2.01 – 3.00)

- Non-response facility
- Comprehensive plan boundary (DPT 2018)
- Khon Kaen city boundary
- Local govts. boundary
- Zone
- KK 01 Healthcare facility's number (see Annex 13)

Figure 5. 35 Level of the coping capacity of Khon Kaen city's public health service

Remark: See the list of hospitals and indicators classification details in Annex 13 and 24

a)Trend scenario b) Desirable scenario

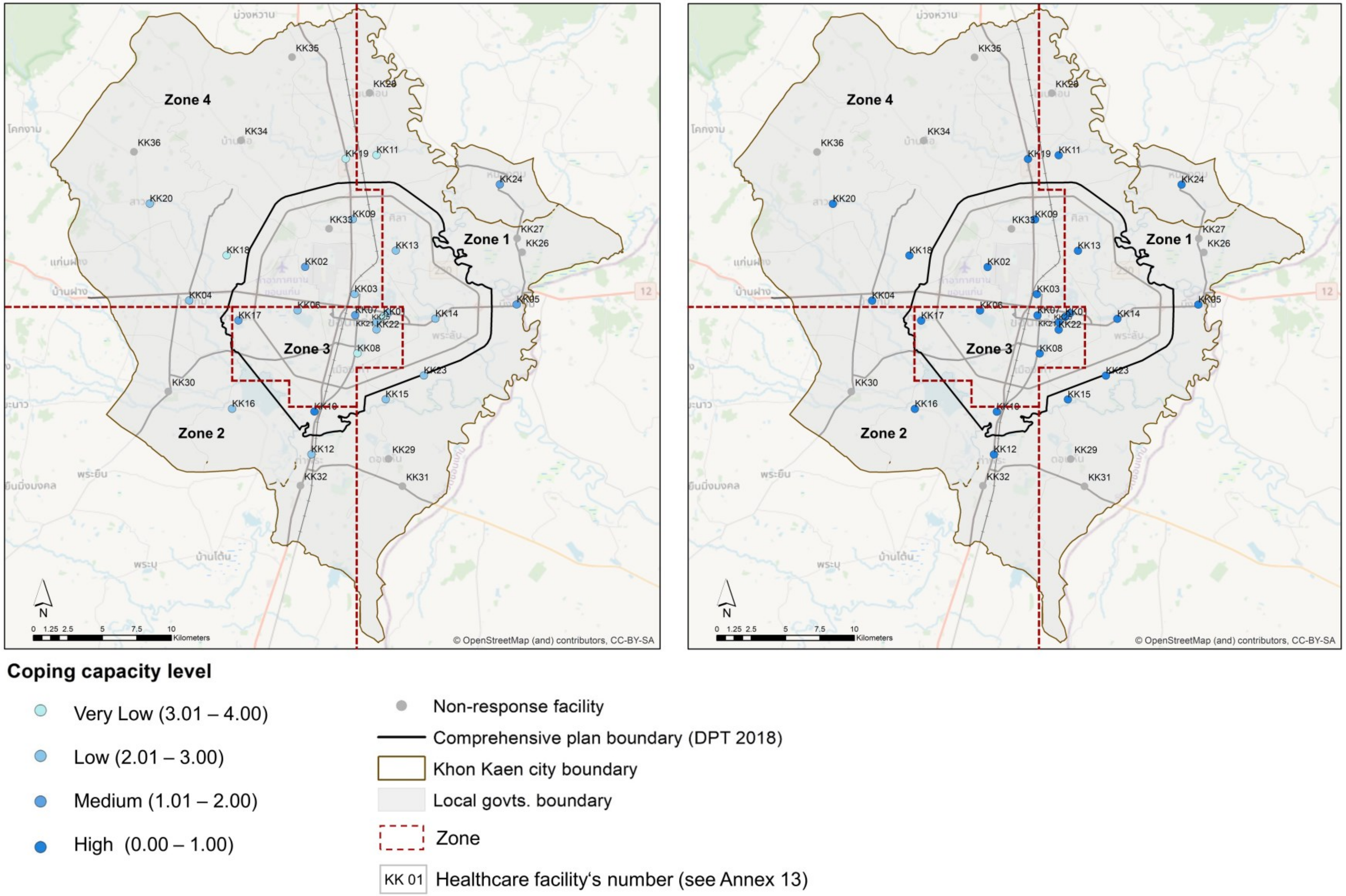
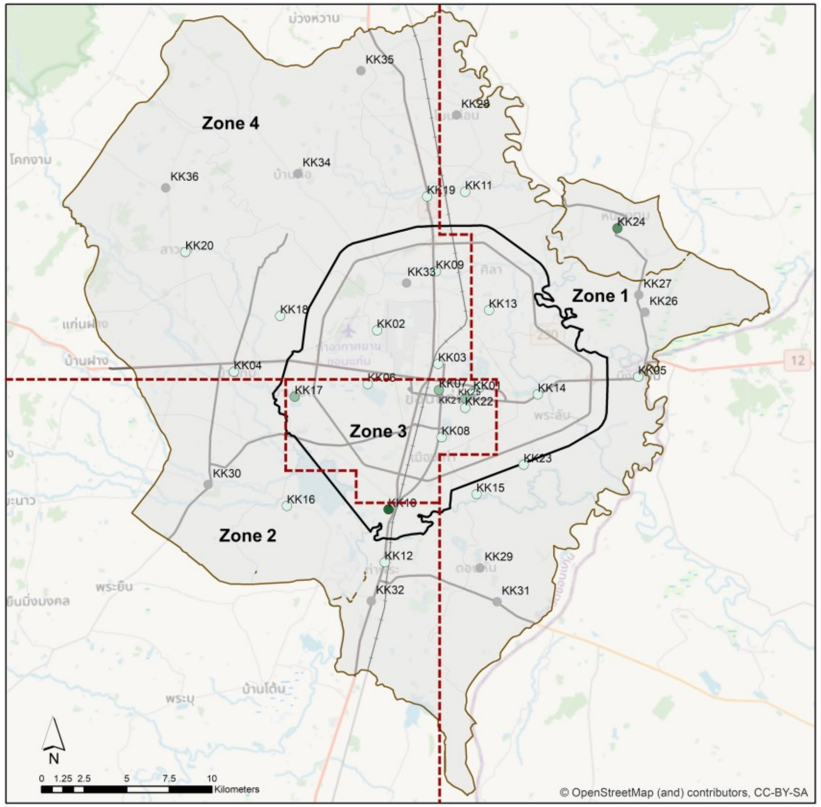


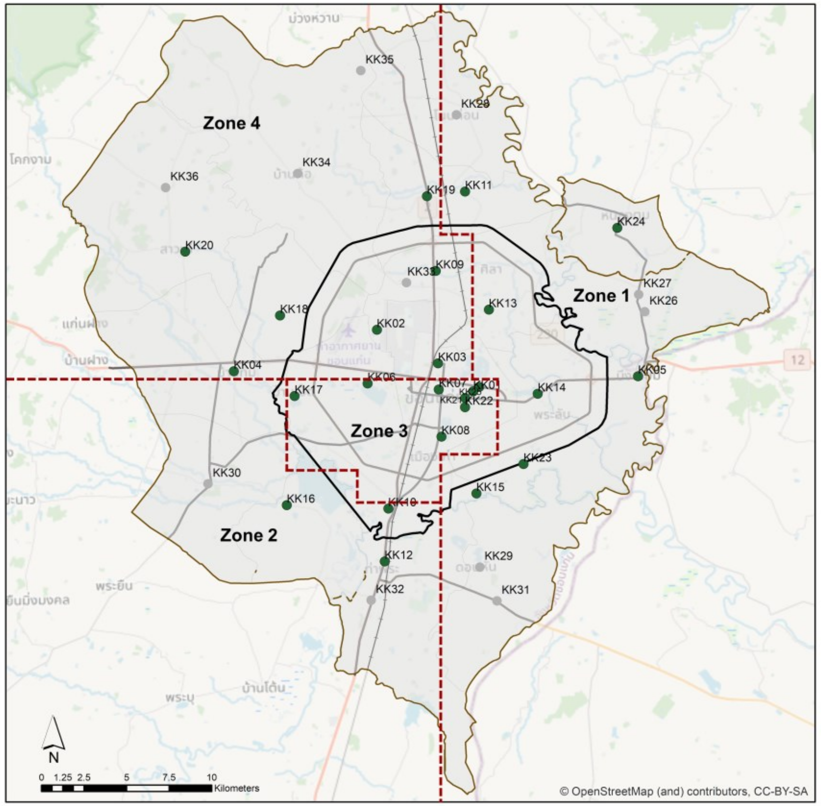
Figure 5. 36 Level of adaptive capacity of Khon Kaen city's public health service

Remark: See the list of hospitals and indicators classification details in Annex 13 and 24

a)Trend scenario



b) Desirable scenario



Adaptive capacity level

- Very Low (3.01 – 4.00)
- Low (2.01 – 3.00)
- Medium (1.01 – 2.00)
- High (0.00 – 1.00)

- Non-response facility
- Comprehensive plan boundary (DPT 2018)
- Khon Kaen city boundary
- Local govts. boundary
- Zone
- KK 01 Healthcare facility's number (see Annex 13)

3.2) Service network perspective

In the scope of Khon Kaen Hospital CUP network, Don Hun SHPH (KK29), Thapra SHPH (KK10)[57] and the three specialized health care units[58] were excluded from the analysis. Within the CUP network, 75 % of service capacity is allocated to CUP host - Khon Kaen Hospital (KKH), and another 25 % is distributed to CUP units - PCUs (primary care units & medical centers). Hence this potential impact assessment took this ratio into account. Under the "Trend scenario", Khon Kaen Hospital-CUP network was assessed as *medium* level of potential impact outcome. Even though the CUP host and its units exhibited the same Hazard pillar value, the CUP host manifested a lower degree of Exposure and Vulnerability. In other words, under the "Trend scenario", the CUP host revealed less potential impact value than its units. Nevertheless, among vulnerability elements, the CUP units showed less sensitivity score to climate-related hazards than the CUP host. In the "Desirable scenario" perspective, the CUP network showed *low* level of the potential impact assessment outcome. However, the improvement mainly resulted from avoiding the exposure of internal working systems and increasing coping capacity and adaptive capacity. The detail of the network-based potential impact assessment results is examined below and shown in Table 5.14 -5.21.

Under the "Trend scenario", on average CUP units gain a slightly higher score on the exposure of public health facility's building(s) and a significantly higher score on the exposure of internal working systems than their host. In the vulnerability point of view of the CUP network, there were 5 sensitivity and adaptive-related indicators defined as *high* level; *Over carrying capacity* (V1), *Resource insufficiency* (V3), *Lack of participation and inclusiveness* (V14), *Lack of mainstreaming climate-risk in planning process* (V15), *Lack of monitoring and evaluation* (V17). The analysis showed that the CUP network has no indicators highlighted as *high* in coping capacity-related indicators. Moreover, it also exhibited a *very low* sensitivity on *system conditions & maintenance of essential working systems* (V4) and *downtime of sensitive working systems* (V5). The CUP network also showed positive attributions on *integration and coordination* (V11) as well as *capacity development* (V15), even though mainly contributed by the CUP host.

In comparison between the CUP host and its CUP units, the CUP host showed a lower Vulnerability score than its units, except for the following indicators, *over carrying capacity* (V1), *variety of vulnerable patients* (V2), *lack of flexibility & modularity* (V6), *lack of resources mobilization* (V10), *lack of participation and inclusiveness* (V14), *lack of mainstreaming climate-risk in planning process, lack of monitoring and evaluation* (V17). Nevertheless, their score differentiations were very small, except *over carrying capacity* (V1) and *lack of resources mobilization* (V10).

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[57] Thara SHPH and Don Hun SHPH are members of Sirindhorn Hospital CUP network of Ban Haet district (although they are located in Mueang Khon Kaen district)

[58] Khon Kaen Rajanagarindra Psychiatric Hospital; Health Promotion Center 7 Khon Kaen; Thanyarak Khon Kaen Hospital

Under the "**Desirable scenario**", in which all preferred measures will be implemented, the CUP network showed *low* level of the potential impact outcome. Even though the hazard pillar remained the same as what is determined under "Trend scenario", avoidance of internal working system exposure and strengthening coping capacity and adaptive capacity help reduce the potential impact outcomes. In the "Desirable scenario" context, the CUP units revealed lower vulnerability values than the CUP host in all elements. Thereby, contrary to the "Trend scenario" where the CUP units seem to be a burden of the service network, under the "Desired scenario", the CUP units help remediate the network's potential impact outcome.

Table 5. 21 Service network perspectives of the potential impact assessment[59]

Indicators	Trend scenario			Desirable scenario		
	CUP Host	**CUP Units**	**CUP Network**	**CUP Host**	**CUP Units**	**CUP Network**
H1: Fluvial flood	0.639	0.639	0.639	0.639	0.639	0.639
H2: Pluvial flood	1.279	1.279	1.279	1.279	1.279	1.279
H3: Water scarcity	1.442	1.442	1.442	1.442	1.442	1.442
Weighted Normalized Hazard	**0.840**	**0.840**	**0.840**	**0.840**	**0.840**	**0.840**
E1: Exposure of public health facility's building(s)	1.000	1.067	1.017	1.000	1.067	1.017
E2: Exposure of working systems	1.024	1.639	1.178	0.290	0.244	0.279
Weighted Normalized Exposure	**0.506**	**0.677**	**0.549**	**0.323**	**0.328**	**0.324**
V1: Over carrying capacity	0.800	0.800	0.800	0.800	0.440	0.710
V2: Variety of vulnerable patients	0.800	0.713	0.778	0.800	0.713	0.778
V3: Resource insufficiency	0.600	0.630	0.608	0.600	0.420	0.555
V4: Poor system conditions and maintenance of working systems	0.021	0.072	0.033	0.000	0.000	0.000
V5: Downtime of essential working systems	0.040	0.059	0.045	0.040	0.059	0.045
V6: Lack of flexibility & modularity	0.486	0.462	0.480	0.000	0.000	0.000
V7: Lack of diversity of suppliers	0.087	0.228	0.122	0.024	0.052	0.031
V8: Lack of redundancy	0.388	0.425	0.397	0.103	0.079	0.097
V9: Lack of responsiveness	0.531	0.644	0.559	0.000	0.000	0.000
V10: Lack of resource mobilization	0.595	0.356	0.535	0.000	0.000	0.000
V11: Lack of integration and coordination	0.000	0.337	0.084	0.000	0.000	0.000
V12: Lack of Information	0.444	0.363	0.424	0.000	0.000	0.000
V13: Lack of preparedness and risk transfer	0.556	0.710	0.594	0.000	0.000	0.000
V14: Lack of participation and inclusiveness	0.833	0.733	0.808	0.000	0.000	0.000
V15: Lack of capacity development	0.000	0.667	0.167	0.000	0.000	0.000
V16: Lack of mainstreaming climate-risk in planning process	0.500	0.447	0.487	0.000	0.000	0.000
V17: Lack of monitoring and evaluation	0.333	0.292	0.323	0.000	0.000	0.000
Weighted Normalized Vulnerability	**0.413**	**0.467**	**0.426**	**0.139**	**0.104**	**0.130**
Potential impact = H*E*V *** Equal interval classification of potential impact value* Very low (0.000 - 0.016) Low (>0.016 - 0.125) Medium (> 0.125 - 0.422) High (>0.422 - 1.000)	**0.175**	**0.264**	**0.196**	**0.038**	**0.028**	**0.035**

[59] Details of data classification of potential impact value and indicator value can be found in Annex 23-24

3.3) Service level perspective

From the service level perspective, the primary care service level exhibited the highest potential impact value under “Trend scenario” followed by specialized care and tertiary care, respectively. However, a different pattern can be observed under the context of the “Desirable scenario” in which tertiary care showed the highest potential impact value, followed by specialized care and primary care service levels. More details of the potential impact assessment of different care levels are in Table 5.22 and the following elaborations.

Under the “Trend scenario”, primary care service gained the highest score for Exposure and Vulnerability pillars compared to other service types, especially on ***exposure of public health care’s buildings*** **(E1)** and ***lacking responsiveness*** **(V9)**. Meanwhile, the tertiary care level exhibited the highest sensitivity-related indicators value, particularly on a ***variety of vulnerable patients*** **(V2)**; the specialized care service was reckoned as having the lowest capacity to adapt, especially ***lacking preparedness and risk transfer*** **(V13)**.

Under the “Desirable scenario”, introducing exposure reduction of internal working systems helps generalize an overall exposure score of all care levels to be almost even. Strengthening coping capacity and adaptive capacity could heavily reduce the vulnerability of all care levels, especially the primary care service level. However, the measures taken under the “Desirable scenario” could significantly minimize the potential impact of climate-related hazards on all care levels; the primary care service level showed the best response to the measures, followed by specialized care and tertiary care.

Table 5. 22 Potential impact assessment of the 3 care levels under Trend scenario and Desirable scenario[60]

Indicators	Trend scenario			Desirable scenario		
	Tertiary care	Primary care	Specialized care	Tertiary care	Primary care	Specialized care
H1: Fluvial flood	0.639	0.609	0.426	0.639	0.609	0.426
H2: Pluvial flood	1.279	1.279	1.279	1.279	1.279	1.279
H3: Water scarcity	1.442	1.442	1.442	1.442	1.442	1.442
Weighted Normalized Hazard	**0.840**	**0.833**	**0.787**	**0.840**	**0.833**	**0.787**
E1: Exposure of public health facility’s building(s)	1.000	1.048	1.000	1.000	1.048	1.000
E2: Exposure of working systems	1.024	1.619	1.615	0.290	0.253	0.323
Weighted Normalized Exposure	**0.506**	**0.667**	**0.654**	**0.323**	**0.325**	**0.331**
V1: Over carrying capacity	0.800	0.800	0.800	0.800	0.419	0.800
V2: Variety of vulnerable patients	0.800	0.724	0.356	0.800	0.724	0.356
V3: Resource insufficiency	0.600	0.629	0.600	0.600	0.410	0.600
V4: Poor system conditions and maintenance of working systems	0.021	0.074	0.010	0.000	0.000	0.000
V5: Downtime of essential working systems	0.040	0.058	0.028	0.040	0.058	0.028
V6: Lack of flexibility & modularity	0.486	0.466	0.370	0.000	0.000	0.000

[60] Details of data classification of potential impact value and indicator value can be found in Annex 23-24

Indicators	Trend scenario			Desirable scenario		
	Tertiary care	Primary care	Speciali zed care	Tertiary care	Primary care	Speciali zed care
V7: Lack of diversity of suppliers	0.087	0.225	0.206	0.024	0.051	0.026
V8: Lack of redundancy	0.388	0.429	0.337	0.103	0.080	0.078
V9: Lack of responsiveness	0.531	0.655	0.456	0.000	0.000	0.000
V10: Lack of resource mobilization	0.595	0.362	0.258	0.000	0.000	0.000
V11: Lack of integration and coordination	0.000	0.337	0.140	0.000	0.000	0.000
V12: Lack of Information	0.444	0.377	0.445	0.000	0.000	0.000
V13: Lack of preparedness and risk transfer	0.556	0.715	0.810	0.000	0.000	0.000
V14: Lack of participation and inclusiveness	0.833	0.724	0.833	0.000	0.000	0.000
V15: Lack of capacity development	0.000	0.675	0.625	0.000	0.000	0.000
V16: Lack of mainstreaming climate-risk in planning process	0.500	0.449	0.354	0.000	0.000	0.000
V17: Lack of monitoring and evaluation	0.333	0.294	0.333	0.000	0.000	0.000
Weighted Normalized Vulnerability	**0.413**	**0.470**	**0.409**	**0.139**	**0.102**	**0.111**
Potential impact = H*E*V *** Equal interval classification of potential impact value* Very low (0.000 - 0.016) Low (>0.016 - 0.125) Medium (> 0.125 - 0.422) High (>0.422 - 1.000)	**0.175**	**0.259**	**0.210**	**0.038**	**0.027**	**0.029**

4) Comparative views between experts and equal-weighted normalization schemes

In addition to the experts-weighted normalization scheme, this study also provides a comparative configuration of the composite indicator-based potential impact assessment, in which all indicators operated through equal-weighted normalization. It is important to remark that under the experts-weighted normalization, even though the majority of indicators were weighted based on the experts' judgement, the Exposure pillar was assigned as equal weighting due to a lack of expertise and official standards for giving different weighing values. The results of equal-weighted normalization of the two scenarios are shown in Annex 25 (c,d).

Table 5.23 illustrates that the experts-weighted normalization showed less than 1% higher than the equal-weighted normalization value of the Hazard pillar. On the contrary, the equal-weighted normalization contributed to a higher degree of Potential Impact and Vulnerability pillar values by about 28%-29% under the “Trend scenario” and 14%-16% under the “Desirable scenario, in both cases area-based and service network perspectives. Although the equal-weighted normalization contributed to a higher Potential impact value than the experts' judgment weighting scheme, the classification of the Potential Impact level of both weighting schemes fell into the same category, *medium level*. However, significant distinctions can be observed under the “Trend scenario”, in which the result of equal-weighted normalization classified the Vulnerability pillar value as *medium level*; meanwhile, the experts-weighted normalization resulted in a *low* level. This comparative perspective illustrated that the equal-weighted normalization provided slightly more conservative potential impact outcomes for potential impact mitigation planning.

Nonetheless, it is crucial to recognize the heterogeneity weighting value given by the experts (see section 5.3.3.1 (2)). Therefore, this study suggested that experts workshop or focus groups shall be organized to discuss the composite indicators' weighting values in order to confirm the comparative implication of the two weighting schemes presented in this research. Moreover, this study also acknowledged using Principle Component Analysis (PCA) loading factor and Pearson correlation values as a weighting scheme. Chapter 6 will provide pragmatic limitations of these composite indicators and sample size concerns that prevent this data-driven weight normalization option.

Table 5. 23 Comparision of composite indicators-based potential impact assessment configurations between equal-weighted and experts-weighted normalization schemes

Components	Trend scenario			Desirable scenario		
	Equal-weighted	Experts-weighted	% Different	Equal-weighted	Experts-weighted	% Different
Area-based aspect						
Hazard	0.820	0.827	-0.9%	0.820	0.827	-0.9%
*Exposure**	*0.659*	*0.659*	*0.0%*	*0.326*	*0.326*	*0.0%*
Vulnerability	0.645	0.461	28.6%	0.124	0.105	15.6%
Potential impact	0.349	0.251	28.0%	0.033	0.028	14.8%
Service network aspect						
Hazard	0.833	0.840	-0.8%	0.833	0.840	-0.8%
*Exposure**	*0.549*	*0.549*	*0.0%*	*0.324*	*0.324*	*0.0%*
Vulnerability	0.596	0.426	28.5%	0.153	0.130	14.9%
Potential impact	0.273	0.196	28.0%	0.041	0.035	14.2%

*Note * Since neither the experts nor technical standard is available for justifying the weighting value of Exposure-related indicators; therefore, equal-weight was assigned instead of experts' judgement.*

5.3.3.3 Sensitivity analysis

Principle Component Analysis (PCA) was applied to appraise the robustness of the composite indicators. PCA serves as a data-driven approach for seeking interpretation of the dataset meaningfully while maintaining most of the variation in the dataset, despite a very small sample size. The PCA technique was applied for the Vulnerability pillar based on the composite indicator structure, which consists of 17 indicators or variables. According to the questionnaire responses, the sample size for this statistical analysis is 25N. The vulnerability pillar's overall mean value is 0.42, and the standard deviation is 0.16 (see Annex 26). Average Cronbach' alpha values = 0.852 considers as good internal consistency (>0.7). Boxplot visualization and histogram of the dataset revealed outliers based on Hoaglin & Iglewicz's (1987) definition as Annex 27. Only a few were classified as outliers analysis. However, the dataset is very small; therefore, no outliers were eliminated from this analysis.

According to Pearson correlation analysis (Annex 32), the result shows that all the indicators (independent variables) are positively correlated with the Vulnerability pillar score (dependent variable). In contrast to coping and adaptive capacity-related indicators, which obtained strong to very strong[61] positive correlation, sensitivity-related indicators show weak (to negligible) positive correlation to the dependent variable. However, only V4 (Poor system conditions and maintenance of working systems) does obtain a strong positive correlation compared to other indicators in the same component. Furthermore, most of the independent variables post moderate to very strong positive correlations among each other, except V1, V2, V3, V5, and V7.

PCA was performed using the "Dimension Reduction" option under the "Analysis" function of SPSS software. Inspection of sampling adequacy based on the Kaiser-Meyer-Olkin (KMO) was checked. According to the rule of thumb suggested Kaiser (1974) (Annex 28) that the dataset of this study, 0.524 is miserable but still acceptable for PCA execution (Table 5.24). Thus, the sample size at N = 25 was low satisfactory for PCA. Even though more sample size is needed to improve data adequacy, but marked here that the total sample size within the study area is also small (36 public health facilities in Khon Kaen city). Bartlett's Test of Sphericity, Chi-square approximation is 268.26, $P < 0.001$. Criteria for selecting the optimal number of PCs are either the PC has eigenvalues greater than 1 or 70-80% of total variance explained by all components (see Table 5.25). The result showed that 5 PCs represented 75.781% of the total variation and obtained Eigenvalues greater than 1. Scree Plot (Figure 5.37) also confirmed the choice of 5 PCs total variance explained (which eigenvalue are great than 1). This calculation indicated that the correlation between items was well defined for a PCA. Communalities value was estimated the variance in each variable accounted for by the PCs. Table 5.26 exhibited that the average extract commonalities of 5 PCs is 0.758. Most of the individual indicators showed high communalities value. Only V3 (Resource insufficiency) and V6 (Lack of flexibility & modularity) have communities value less than 0.7. Based on Oblimin with Kaiser Normalization rotation method, the 5 PCs were permitted to be correlated

[61] (The Political Science Department at Quinnipiac University cited in Akoglu, 2018)

with one another, presenting in the form of Pattern matrix (rotated factor loading) and Structure matrix (correlations). For an interpretive reason, a pattern matrix is preferable because it contains information about the unique contribution of a variable to a factor (Field, 2018: 816). Stevens (2002 as cited in Field, 2018) recommended interpreting factor loading with an absolute value greater than |0.4| (meaning ≥ +.4 or ≤ –.4) onto one of the PCs. Figure 5.38 and Table 5.27 illustrate the pattern matrix that most adaptive capacity-related indicators were grouped together.

PC1 showed a good representation of all adaptive capacity-related indicators. Only 2 coping capacity-related indicators, V8 (Lack of redundancy) and V9 (Lack of responsiveness), revealed fair representation through the PC1. PC2 mainly represented the sensitivity aspect of the Vulnerability pillar, specifically, Over carrying capacity (V1) and Resource insufficiency (V3). Meanwhile, PC3, PC4, and PC5 revealed their strong loading factors to the rest of the sensitivity and coping capacity-related indicators. Considering reducing variables, the indicators that have factor loading less than |0.4| onto one of PC1 and PC2 should be dropped out. In this regard, the PCA suggested excluding V2, V4, V5, V6, V7, and V10 from the analysis; the result still holds a meaningful interpretation. Nevertheless, these indicators still show strong factor loading in other PCs (PC3, PC4, and PC5), which shared about 25 % variable explained the result.

Regarding the correlation between the variables and factors, the structure matrix (Table 5.28) presented that most coping capacity and adaptive capacity-related indicators showed a strong positive correlation between PC1 and PC5, except V17, V14, and V12. Besides, there were 2 adaptive capacity-related indicators, V11 and V15, which also exhibited negative correlations with PC2. Meanwhile, V12 was the only adaptive capacity-related indicator that showed correlations with both PC 1 and PC3. Furthermore, most of the sensitivity-related indicators showed strong positive correlations with PC2, PC3 and PC4, but only V4 manifested correlations with PC4 and PC5. According to Oblimin with the Kaiser normalization rotation method, the component correlation matrix (Table 5.29) revealed that PC1 is fairly correlated with PC5. Meanwhile, other PCs do not show a strong correlation with each other. Especially, PC2 produced a negative correlation value with almost all other PCs, except a very weak positive sign of correlation with PC3. This study also conducted a reliability analysis to ensure that the measure consistently reflects the construct that its measuring (Field, 2018:821). Therefore, Cronbach's alpha coefficient was used to check internal consistency within each vulnerability component. An overall figure of the reliability test of vulnerability indicators is shown in Annex 29-31.

The PCA analysis indicated questionable internal consistency of sensitivity-related indicators. Besides their Cronbach's alpha coefficient being lower than the 0.3, the inter-item correlation matrix showed several negative values. Even though there is no universal rule of thumb for corrected item-total correlation values, below 0.3 (Ferketich, 1991) or 0.2 are undesirable. Discard small sample size; this data-driven analysis strongly suggested that the set of sensitivity-related indicators shall be improved to ensure better distribution of the dataset. Coping capacity and adaptive capacity-related indicators showed a good Cronbach's alpha coefficient value (0.80 and 0.85, respectively). Moreover, all coping capacity-related indicators presented a good positive inter-item correlation value and no suggestion to delete items for better internal consistency, except V7 (Lack of diversity of suppliers) which exhibited low and negative inter-item correlation value. In this regard, PCA suggested improving the reliability and internal consistency of the coping capacity aspect of the Vulnerability pillar by removing V7 (Lack of diversity of suppliers). Meanwhile, adaptive capacity-related indicators illustrated good inter-item correlation values; every item obtains an inter-item correlation greater than +0.3. Nonetheless, V12 (Lack of Information) showed a relative small corrected item-total correlation, but the difference between item Cronbach's Alpha and an overall Cronbach's Alpha is negligible (+0.003). Therefore, it is fair to conclude that adaptive capacity-related indicators are internally consistent.

In Chapter 6, the application of data-driven analysis in composite indicator-based potential impact assessment will be deeply discussed. Key challenges and recommendations will be specified for improving the robustness of the result and upscaling the application of this composite indicator framework.

Table 5. 24 KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.524
Bartlett's Test of Sphericity	Approx. Chi-Square	268.260
	df	136
	Sig.	0.000

Figure 5. 37 Scree Plot

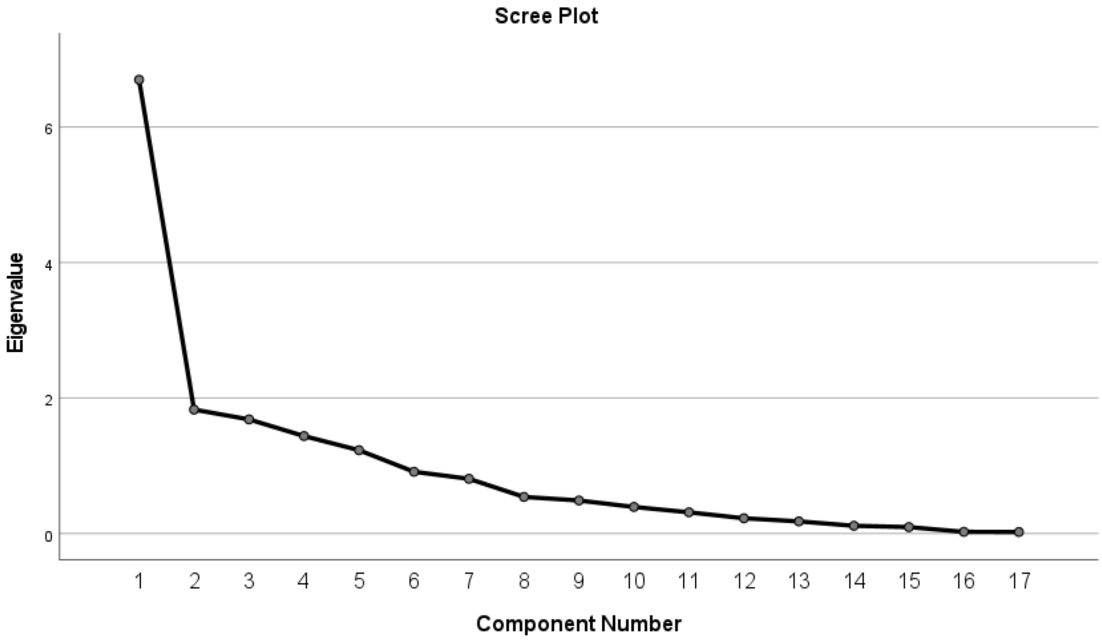

Table 5. 25 Total variance explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings[a]
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total
1	6.699	39.406	39.406	6.699	39.406	39.406	6.009
2	1.830	10.763	50.169	1.830	10.763	50.169	1.860
3	1.685	9.910	60.079	1.685	9.910	60.079	1.611
4	1.439	8.465	68.544	1.439	8.465	68.544	1.379
5	1.230	7.237	75.781	1.230	7.237	75.781	3.812
6	.912	5.365	81.146				
7	.808	4.753	85.899				
8	.541	3.180	89.079				
9	.488	2.870	91.949				
10	.393	2.310	94.259				
11	.314	1.844	96.103				
12	.225	1.326	97.429				
13	.179	1.056	98.485				
14	.115	.675	99.159				
15	.095	.559	99.719				
16	.025	.147	99.866				
17	.023	.134	100.000				
Extraction Method: Principal Component Analysis.							
a. When components are correlated, sums of squared loadings cannot be added to obtain a total variance.							

Table 5. 26 Communalities value

Indicators	Initial	Extraction
V1: Over carrying capacity	1.000	0.751
V2: Variety of vulnerable patients	1.000	0.838
V3: Resource insufficiency	1.000	0.507
V4: Poor system conditions and maintenance of working systems	1.000	0.822
V5: Downtime of sensitive working systems	1.000	0.841
V6: Lack of flexibility & modularity	1.000	0.753
V7: Lack of diversity of suppliers	1.000	0.752
V8: Lack of redundancy	1.000	0.701
V9: Lack of responsiveness	1.000	0.883
V10: Lack of resource mobilization	1.000	0.705
V11: Lack of integration and coordination	1.000	0.688
V12: Lack of Information	1.000	0.717
V13: Lack of preparedness and risk transfer	1.000	0.862
V14: Lack of participation and Inclusiveness	1.000	0.717
V15: Lack of capacity development	1.000	0.836
V16: Lack of mainstreaming climate-risk in planning process	1.000	0.785
V17: Lack of monitoring and evaluation	1.000	0.725
Extraction Method: Principal Component Analysis.		

Table 5. 27 Pattern Matrix

Indicators (variables)	Component				
	1	2	3	4	5
V14	.880				
V17	.849				
V13	.796				
V16	.730				
V15	.725				
V12	.711				
V8	.694				
V9	.625				.467
V11	.524				
V1		.829			
V3		.705			
V7			.809		
V2			.743		
V5				.914	
V10					.808
V6					.801
V4					.800
Extraction Method: Principal Component Analysis. Rotation Method: Oblimin with Kaiser Normalization.					
a. Rotation converged in 13 iterations.					

Figure 5. 38 Scatterplot of rotated loading factors (Pattern Matrix)

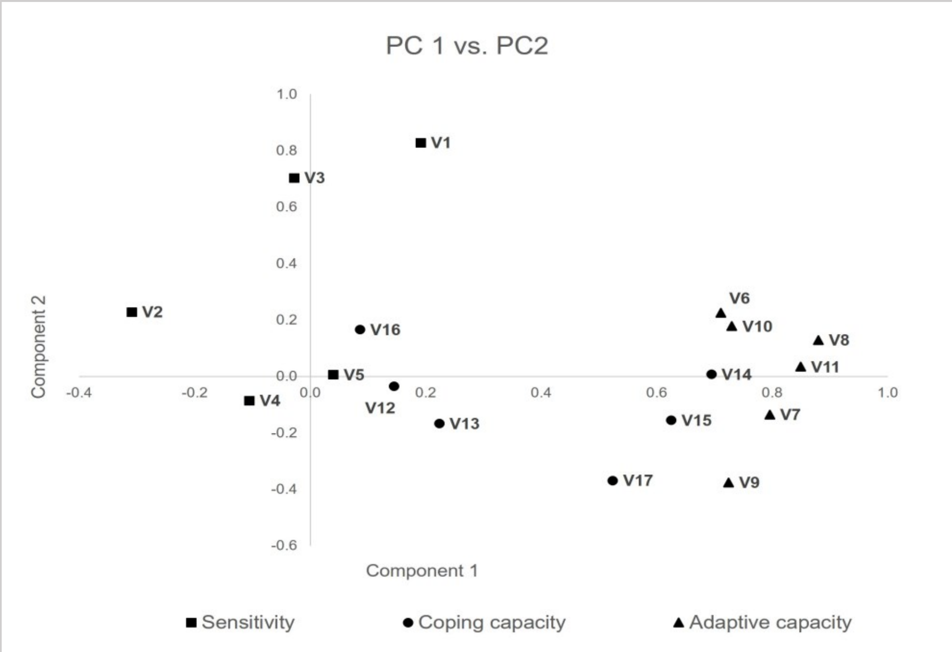

Table 5. 28 Structure Matrix

Indicators (variables)	Component				
	1	2	3	4	5
V13	.861				.480
V17	.849				
V16	.819				.506
V14	.813				
V15	.803	-.440			.448
V9	.797				.701
V8	.791				.526
V12	.664		.404		
V11	.617	-.432			.409
V1		.829			
V3		.686			
V7			.811		
V2			.744		
V5				.914	
V6	.425				.856
V10					.802
V4			.435		.802

Extraction Method: Principal Component Analysis.
Rotation Method: Oblimin with Kaiser Normalization.

Table 5. 29 Component Correlation Matrix

Component	1	2	3	4	5
1	1.000	-.062	.046	.025	.347
2	-.062	1.000	.038	-.028	-.133
3	.046	.038	1.000	.005	.073
4	.025	-.028	.005	1.000	.006
5	.347	-.133	.073	.006	1.000

Extraction Method: Principal Component Analysis.
Rotation Method: Oblimin with Kaiser Normalization.

5.4 Implementation

The last phase of this research process suggests roadmaps for realizing the stakeholders' desirable potential impact minimization targets. Based on the potential impact assessment outcomes, gaps were captured, and key implementation requirements were suggested for not only transition from "Trend scenario" to the "Desirable scenario" but also from the "Desirable scenario" to the “Targets”. In addition, residue potential impacts and how to minimize them were pointed out. This research also suggested timeframe and sequences in executing the required measures/actions in both city-wide and public health-specific aspects. From 2022 towards the end of the scenario (2037), the potential actions were organized in three timeslices, according to the 5-year planning cycle (2022-2026, 2027-2031, 2032-2037), and four phases of implementations (preparation & planning phase, execution phase, review & evaluation phase, and improvement & sustaining phase). The time duration for implementing the proposed actions/measures varies depending on the baseline, urgency, resources, institutional settings, and legality conditionalities that open further discourse among responsible agencies. However, it is important to note that some actions/measures might require the outcomes evaluation beyond the 2037 timeframe.

The objective of the roadmaps is to pursue Khon Kaen City Climate-resilient Public Health Service in 2037. The ultimate goal of the roadmap is to minimize the potential impact of climate-related hazards on the local public health service from *medium* to *very low* level. Therefore, the roadmap is organized into two core elements; 1) Climate-resilient Public Health Service (Table 5.30) and 2) Climate-resilient Urban Development (Table 5.31). The public health-specific road map was structured into five key strategies, hazard mitigation, exposure reduction, minimizing sensitivity, strengthening coping capacity, and reinforcing adaptive capacity. It suggested the level of implementation which adhere to the direct responsibility of the proposed measures, such as facility-based, service network, sectoral levels. It is noteworthy that even though the proposed measures suggested to be implemented by facilities and service networks, sectoral policy and resource allocation are crucial prerequisites. Nevertheless, the public health sector does not stand alone but highly depends on urban system management and spatial development orientation. Thus, this research aligned a city-wide spatial planning-based roadmap, which consists of four key strategies, hazard mitigation, exposure avoidance, capacity enhancement, and cross-cutting, to ensure integration between urban development and the local public health service, which enhance the climate-resilient future of the study area.

5.4.1 Roadmaps validation

In May 2021, the draft Khon Kaen climate-resilient public health service roadmap was submitted to MoPH (assigned DOH and HPC 7 to respond) and KKPHO; meanwhile, the Khon Kaen climate-resilient (spatial) development was sent to DPT and KKDPT for their comments and suggestions on the appropriateness of the propositions. The feedback/clarifications of these key responsible agencies on the draft roadmaps are shown in Annex 33. The validation feedback showed that the key responsible agencies in public health care and spatial planning agreed on the proposed roadmaps in terms of an overall perspective and the proposed strategies. A few suggestions from the agencies were that the roadmap should provide clear outputs, a target for each phase, and figures of required budgets for each measure. However, it is important to state that this roadmap serves as a guideline/planning framework for the relevant agencies rather than a ready to use document for a formal planning process, which requires detailed discussions within the planning & implementing institutions, feasibility studies for particular proposed measures, sufficient public participation, and budgeting framework of governments. Nevertheless, the validation process informs supplementary statements and clarifications on a certain action, summarized as follows.

5.4.1.1 Public health service perspective

The national (DOH) and local public health responsible agencies (KKPHO and HPC 7) strongly supported the application of HICRAF in climate-resilient public health service planning and implementation. However, the execution of the proposed roadmap requires a high level of integration among public health domains and health determining sectors, as well as overcoming the existing structural problem in Thai’s public health care, particularly resources (personal, equipment, finance) management under the universal health coverage scheme, as prerequisites. From a strategy-wise point of view, the public health agencies addressed several underlying challenges in undertaking the proposed measures as follows.

Strategy 1 Exposure reduction:

- Concern the contradiction between the proposed measures (No. 1,2,3) in limiting service capacity in the hazard-prone area and the existing service plan, which aims to upgrade the service capacity of several public health units, including those located in hazard-prone areas
- Emphasize the importance of environmental health in the detail of the evacuation plan and secondary working system provision and exposition in order to assure safety standards and to prevent cascading events caused by hospital operation system failure, e.g. spreading of infectious waste

- Propose a detailed climate change impact analysis as a crucial mandatory element for the Environmental Impact Assessment (EIA) of a new hospital/health care facility building

Strategy 2 Hazard mitigation:

- Emphasize the importance of the Design and construction division (Department of Health service support, MoPH) in oversight and implementing the proposed measures
- Highlight co-benefits of increasing permeability landscape and green space in air pollution and heat stress reduction
- Conduct buildings inspection and structural measures for flood protection (e.g. dike, watergates, drainage system) as well as external support coordination plan (for equipment and staff provision in an emergency) for a hospital/ public health care facility in high-risk areas, particularly

Strategy 3 Minimize sensitivity:

- Emphasize the importance of human resources management in Thai's Public health sector
- Underline a necessity of personal capacity building on climate-related hazard risks appraisal in order to minimize climate-related health risks of medical and medical support staff
- Prioritize resources provision reformation as key performance indicators at all levels

Strategy 4 Strengthen coping capacity:

- Address limitations of the Government Procurement and Supplies Management Act, B.E. 2560, which prevents the local public health care from adjusting their procurement regulations to adhere to climate-resilient and adaptation
- Emphasize the importance of environmental health, not only power supply system but also clean water and solid waste & wastewater management have to be under proper control and treatment according to standards
- Strengthen the coping capacity of hospital working systems in an emergency, especially clean water, waste management, and hygiene

Strategy 5 Reinforce adaptive capacity:

- Refer to the current mechanism and practice of public health emergency and disaster management at the provincial and district level
- Promote integrated climate-related health risk surveillance & warning and communication system & network at all levels through IT system and social media (precise, rapid and inclusive).
- Strengthen cooperation on climate-related risk information integration with relevant agencies

- Extract best practices and develop policy recommendations on climate resilience management

5.4.1.2 Spatial planning perspective

Local and central planning agencies (KKDPT and DPT) strongly supported the proposed roadmap (element 2). They found the proposed Khon Kaen climate-resilient (spatial) development appropriate. Nevertheless, broader technological and social change challenges aspects shall be emphasized in the roadmap, particularly regarding Smart city & Intelligent Operation Center (IOC) and other possible hazards (besides focusing on climate-related hazards) that might affect the overall development of Khon Kaen city in the future. From a more detailed perspective, the planning agencies addressed several key concerns, clarifications, and suggestions on the proposed measures as follows.

Strategy 1 Exposure avoidance

- Strongly agree with developing a legally binding and public accepted hazard map(s) developed based on scientific evidence and a thorough participation process
- Emphasize the importance of a greater detailed hazard map indicating both hazard level and appropriate and cost-effective management measures
- Emphasize the improvement of hazard map communication (It is crucial to note that in the current practice of a draft comprehensive plan, flood areas are not designated as a hazard-prone zone but as a rural and agricultural conservation zone. This practice has been causing inefficient/miscommunication with relevant agencies and the general public in using land use zoning as a key instrument for disaster risk management)

Strategy 2 Hazard mitigation

- Clarify the definition of “wetland” and strongly agree on increasing permeable surface & drainage capacity and promoting LID-related measures
- Emphasize the crucial importance of integrative wastewater management infrastructure and systems
- Emphasize the necessity of structural flood protection measures, especially for economic and historical/cultural significant areas

Strategy 3 Capacity enhancement

- Highlight new agricultural practices that may create co-benefit with disaster risk management
- Shed light on ageing society challenges and urban health service

Strategy 4 Cross-cutting

- Strongly agree with extending the comprehensive plan boundary to the district level and, establishing a working group at the district level and capacity & knowledge development
- Emphasize the importance of awareness-raising and capacity development to the general public in disaster risk preparation and readiness
- Strongly support the integration of a collaborative scenario planning approach to the existing disaster risk management plan and practice
- Suggest to mainstream the proposed measures in other comprehensive plan elements, besides land use plan, such as public utilities & services plan, open space, natural resources and environment protection plan, and transportation projects and traffic plan

5.4.1.3 Khon Kaen City Climate-resilient Public Health Service Roadmap 2022 – 2037

After consolidating feedback and recommendations from the key responsible agencies, the draft roadmap, Khon Kaen City Climate-resilient Public Health Service Roadmap 2022 – 2037, is presented as the following:

Title: Khon Kaen City Climate-resilient Public Health Service Roadmap 2022 – 2037
Objective: Khon Kaen city public health services are resilient to climate-related hazards and urban development change in 2037
Goals: Potential impact of climate-related hazards on the local public health service is minimized from *medium* to *very low* level in 2037

- Short-term: Profound policies, plans, legal framework, cooperation and financial mechanisms, participatory process, and capacity building for strengthening integrated climate-resilient public health care futures of Khon Kaen city will be established and initially implemented by 2026.
- Medium-term: Khon Kaen city's integrated climate-resilient public health care futures will be mainstreamed and implemented at all levels by 2031.
- Long-term: The implementation of integrated climate-resilient public health care futures of Khon Kaen city will be reviewed and extracted lessons learned for further improvement and transferring knowledge to other sectors, and being a role model on integrated climate-resilient public health service by 2037

Elements: This roadmap consists of 2 elements:1) Climate-resilient Public Health Service (Table 5.30) and 2) Climate-resilient Urban Development (Table 5.31) as follows.

Table 5.30 Element 1: Khon Kaen Climate-resilient Public Health Service 2037

Remarks:

1) ** = measures contributing to minimization of residue potential impacts of the Desirable scenario (from *low* to *very low potential impact level*);

2) *I (italic)* = adjusted points in accordance with the feedback from key responsible agencies;

3) Execution phases:

Planning & preparation | Implementation | Review & evalutation | Improvement & sustaining

Aspect	Strategy	Level (responsible)	Measures/Actions	2022-2026	2027-2031	2032-2037
1. Exposure reduction	1.1 Safer location	Sectoral level and Service network (*in cooperation with DPT and ONEP)*	1. Conduct feasibility study and implement relocation strategy of public health facilities in hazard-prone areas (fluvial flood) to safer areas			
			2. Conduct feasibility study and implement on limiting service capacity or advancement of Khon Kaen Hospital 2 are located in a flood-prone area			
			3. Conduct feasibility study and implement on limiting further extension/service capacity of public health facilities in a flood-prone area or potentially be isolated by flood			
			4. Require future-oriented climate-risk impact analysis as a mandatory element of a new health care buildings EIA report			
	1.2 Safer position	Facility and Sectoral level (led by Design and	5. Conduct feasibility studies and ensure all primary working systems are located on 2nd floor or higher (3 m from the ground) *with*			

Aspect	Strategy	Level (responsible)	Measures/Actions	2022-2026	2027-2031	2032-2037
		construction division)	*consideration of environmental health concerns and standards*			
			6. Conduct feasibility studies and ensure all secondary working systems are located on 2nd floor or higher (3 m from the ground) *with consideration of environmental health concerns and standards*			
2. Hazard mitigation	2.1 Spong Hospital	Facility, Service Network and *Sectoral level (led by Design and construction division)*	7. Integrate Low Impact Development concept in landscape and building designs with highlighted climate-resilient features and *co-benefits with other environmental concerns*			
	2.2 Risk-informed structural measures	Facility, Service Network and *Sectoral level (led by Design and construction division)*	8. Integrate future-oriented climate-related hazards information in drainage system design & improvement as well as other micro-level *structural flood protection measures*			
3. Minimize sensitivity	3.1 Service balance	Service network and Sectoral	9. **Develop future-oriented service planning by considering urban development dynamics and climate-related hazards in order to spatially balance service capacity and service demands, especially in the safer zone (Zone 4)			

Aspect	Strategy	Level (responsible)	Measures/Actions	2022-2026	2027-2031	2032-2037
	3.2 Resources for BaU operation		10. Ensure financial resources sufficiency for BaU operation			
			11.**Reform health care personnel management policy and strategy			
	3.3 Good working system conditions	Facility and service network	12. Ensure resilient upgrading and *inspections* of health care facilities' *buildings* and working systems, including system conditions, system monitoring and reporting, trained staff/technician for system maintenance and reparation, and maintenance resources			
	3.4 Minimize downtime		13. Minimize maximum downtime of essential working systems through (to be developed) sectoral benchmarking schemes and cooperation with relevant CIs			
4. Strengthen coping capacity	4.1 Flexibility and modularity	Facility	14. Increase flexibility and modularity of public health facilities' essential working systems			
			15. Ensure connectivity(-ability) of essential working systems with external devices/systems to ensure operation continuity, e.g. mobile power generator, clean water, waste management			
			16. Establish a one-stop service area with the highest protective level in the case of a disaster or high level of emergency			

Aspect	Strategy	Level (responsible)	Measures/Actions	2022-2026	2027-2031	2032-2037
	4.2 Diversity of Suppliers	*Sectoral level with work closely with Ministry of finance*	17. Render diversity of suppliers of essential working systems such as improving procurement regulation (s) in order to allow a public health facility to arrange contracts or install the supportive technical structure of multiple suppliers in advanced, in both BaU and hazard situations			
	4.3 Redundancy	Facility and service network	18. Ensure availability and capacity of primary backup systems according to 96 hours sustainability rule			
		Sectoral level with work closely with Ministry of finance	19. Improve procurement regulation(s) which allow a public health facility to purchase or rent special vehicles (e.g. boat, amphibian, helicopter, drone) for carrying goods and passengers in advance or during emergencies			
		Facility and service network	20. Survey/assign and maintain alternate safe and accessible routes			
		Sectoral level with work closely with Ministry of finance	21. Improve procurement regulation(s) in order to allow a public health facility to acquire and maintain secondary backup systems			
		Facility and service network	22. Conform standard procedure for recording a patient medical record in the case of no computer service			

Aspect	**Strategy**	**Level (responsible)**	**Measures/Actions**	**2022-2026**	**2027-2031**	**2032-2037**
			23. Assign runners (couriers) as a backup for getting help from outside during communication systems failures			
			24. Provide (on-campus) shelters for staff and their family member in the case of hazards			
			25. ** Conduct feasibility studies and assign alternate care site (s) in the safer areas			
			26. Conduct feasibility study and assign supernode(s) of the CUP network as secondary service centre/unit or supply warehouse outside hazard (flood)-prone area (in order to increase redundancy of the CUP host in both BaU and hazard emergencies)			
	4.4 Responsiveness	Facility and service network	27. Ensure resources conservation plan implementation			
			28. Develop and implement a responsive plan of essential working systems under both rapid & slow-onset climate-related hazards situations, especially clean water, waste management and sanitation			
			29. Develop and implement a Business Continuity Plan with detailed elaboration on climate-related risk evaluation and management			

Aspect	Strategy	Level (responsible)	Measures/Actions	2022-2026	2027-2031	2032-2037
			30. Develop and implement a contingency plan with a detailed elaboration on future-oriented climate-related risk evaluation and management			
			31. Develop and implement a surge personnel capacity plan			
			32. Develop and implement an evacuation plan (both partial and full evacuation) *with taking environmental health concerns into account*			
			33. Strengthen self-help capacity			
	4.5 Resources mobilization	Facility and service network	34. Develop and implement volunteer and external help management plan			
		Sectoral-based and service network	35. Ensure accessibility of financial resources for disaster risk preparation			
			36. Ensure availability of resources for reconstruction /reparations in order to assure that a public health facility can resume its full operation within 1 month and 6 months for low and high damage levels, respectively			
	4.6 Integration and coordination	Facility and service network	37. Assign specific coordinator on disaster risk management			
			38. Acquire agreements (e.g. MoU) in advance on patient referral and transfer agreement with other health care facilities both within and outside service network.			

Aspect	Strategy	Level (responsible)	Measures/Actions	2022-2026	2027-2031	2032-2037
			39. Acquire agreements (e.g. MoU) in advance on partial or full patient evacuation to other hospitals/facilities in the case of emergency or disaster			
			40. Establish real-time (almost real-time) channels or systems for communicating and coordinating with lifeline utilities and key suppliers			
5. Reinforce adaptive capacity	5.1 Information	All levels (led by sectoral policy)	41. Ensure availability, accessibility and integration of local hazard map and climate-related disaster risk database into long-term service plans			
			42. Ensure availability, accessibility and integration of future trends of demographic change, land use change and socio-economic development projection for long-term service planning			
		Sectoral	43. Acquire collaboration agreements with relevant agencies on the development and harmonization of future-oriented climate-related hazard database, hazard maps and spatial planning dataset			

Aspect	Strategy	Level (responsible)	Measures/Actions	2022-2026	2027-2031	2032-2037
		All levels (led by sectoral policy)	*44. Promote integrated climate-related health risk surveillance & warning and communication system & network at all levels through IT system and social media (precise, rapid and inclusive).*			
	5.2 Preparedness and Risk transfer	All levels (led by sectoral policy)	45. Develop a long-term action plan and investment plan for strengthening preparedness for climate-related disaster resilience			
			46. Ensure close collaboration among MoPH domains and relevant domestic & international agencies to mobilize resources and knowledge for strengthening climate resilience and adaption capacity of the local public health service			
			47. Develop and implement Build Back Better plan			
			48. Improve procurement process, which allows a public health facility/service network to render climate-related disaster risk insurance			
	5.3 Participation and inclusiveness	Facility and service network	49. Ensure community participation in disaster risk management planning			
			50. Conduct a disaster risk management plan and exercise with utilities, suppliers and other relevant agencies			

Aspect	Strategy	Level (responsible)	Measures/Actions	2022-2026	2027-2031	2032-2037
	5.4 Capacity building and awareness-raising	Facility and service network	51. Conduct in-house capacity building and awareness-raising on the importance of future climate-related hazards and climate-resilience			
			52. *Conduct capacity building on climate-related hazard risks appraisal, which may have a health impact on medical and medical support staff (both physical and mental health)*			
			53. Conduct training on working with no electricity or limited resources (at least 1 time/year)			
			54. Collectively *extract good practices* and transfer knowledge on HICRAF to other sectors and Asian countries			
	5.5 Mainstreaming	All levels (led by sectoral policy)	55. Ensure mainstreaming future-oriented risk-informed planning (considering both urban development change and climate change) in an action plan or budget plan process			
			56. Ensure integration of the future climate-disaster risk impact information in the system maintenance plan and reparation budget			
			57. Establish working group(s) to facilitate and build on the capacity of the local public health facilities and service network in a climate-resilient mainstreaming process			

Aspect	Strategy	Level (responsible)	Measures/Actions	2022-2026				2027-2031				2032-2037			
	5.6 Monitoring and Evaluation (M&E)	All levels (led by sectoral policy)	58. *Prioritize resources provision reformation as key performance indicators at all levels*												
			59. Establish technical working group(s) to review /improve the HICRAF's composite indicators in order to upscale its application to regional or national levels, as well as outside the health care sector												
			60. Integrate HICRAF's collaborative scenario planning framework and composite indicator into the MoPH's existing M&E system and platform												

Table 5.31 Element 2: Khon Kaen Climate-resilient Urban Development 2037

Remarks:

1) *I (italic)* = adjusted points in accordance with the feedback from key responsible agencies;
2) Execution phases:

Planning & preparation | Implementation | Review & evalutation | Improvement & sustaining

	Aspect	Potential spatial planning-related measurements	Zones				Now		Later		Later on		Responsible agencies/groups
			1	2	3	4	2022-2026		2027-2031		2032-2037		
Exposure avoidance	1.1 Formal planning instruments	1. Reinforce enforcement capacity and accountability of the land use zoning and relevant regulation (s)	✓	✓	✓								LGAs, DPT, KKDPT, Khon Kaen Provincial Planning Committee, KKLRO
	1.2 Hazard map	2. Develop publicly accepted *high-resolution* hazard map(s) which *tailor-made based on the combination of risk level and cost-effectiveness of risk mitigation interventions* (on the basis of a thorough scientific-evidence & public participation process), as well as promote public communication and awareness-raising on the hazard map	✓	✓	✓								KKDPM, Academia, KKDPT, CSO
	1.3 Reduce attractiveness for future development in hazard-prone areas	3. No LRT service (LRT yellow and green lines) in the flood-prone areas	✓	✓									LGAs, KKTT, Private sector, MoT, Academia

	Aspect	Potential spatial planning-related measurements	Zones 1	Zones 2	Zones 3	Zones 4	Now 2022-2026	Later 2027-2031	Later on 2032-2037	Responsible agencies/groups
	1.4 Impact sharing agreement	4. Discussion with relevant stakeholders on impact (burden) sharing agreement in order to promote fair compensation and reduce rural-urban conflicts	✓	✓	✓					All stakeholders (led by LGAs, KKDPM, KKDPT. RID, Private sector, Academia, CSO)
	1.5 Managed retreat	5. Conduct feasibility study and encourage flood-prone area inhabitants to relocate to safer-zone, e.g. throughout the existing affordable housing scheme or buyout programme	✓	✓	✓	✓				All stakeholders (led by LGAs, KKDPM, KKDPT, CSO, Academia, KKSDW/CODI)
		6. Conduct feasibility study and introduce selective retreat/stabilize the service capacity of critical infrastructures	✓	✓	✓					All stakeholders (led by LGAs, KKDPT, KKDPM, Public utilities)
Hazard mitigation	2.1 Vegetated floodplain (s) conservation	7. Promote vegetated floodplain conservation, e.g. natural protection zone, biodiversity promotion/education centre	✓	✓	✓					LGAs, KKNRE, REO10 KKDPT, Private sector, CSO, Academia
	2.2 Increase water retention capacity	8. Obtain more flood retention areas (e.g. civil contract)	✓	✓	✓					All stakeholders (led by RID, KKDPM, KKNRE, KKDPT, LGAs, Private sector)
		9. Link (small) water retention networks	✓	✓	✓					All stakeholders (led by RID, KKDPM, KKNRE, KKDPT, LGAs, Private sector)
	2.3 Promotion of eco-agro tourism	10. Promote water sports recreation activities and investments	✓	✓						LGAs, Private sector, KKOTS

Aspect	Potential spatial planning-related measurements	Zones				Now	Later	Later on	Responsible agencies/groups
		1	2	3	4	2022-2026	2027-2031	2032-2037	
	11. Promote eco-agricultural tourism	✓	✓						LGAs, Private sector, KKOAP, KKNRE, KKOTS
2.4 Blue-Green infrastructure	12. Conduct feasibility study and develop Green & Healthy corridor, in order to preserve flood retention areas, local balance environment & heat budget, promote health and well-being of local inhabitants	✓	✓	✓	✓				LGAs, Private sector, KKDPT, KKDPM, KKNRE, Academia, KKPHO, CSO
	13. Promote the integration of blue-green infrastructure development with economic investment projects	✓	✓	✓	✓				LGAs, Private sector, KKDPT, KKDPM, KKNRE, Academia
2.5 Surface permeability	14. Promote Low Impact Development (LID) integration with built environments and urban landscape design & development projects, *especially a large development project* (e.g. Blue TOD, Spong district, Green roof)			✓					LGAs, Private sector, KKDPT, KKDPM, KKNRE, Academia
2.6 Drainage system improvement	15. Reinforce municipal regulation in withdrawal right of building in vegetated floodplain & waterway areas and integrate future-oriented climate-related hazards dataset with drainage system			✓	✓				All stakeholders (led by LGAs, Private sector, KKDPT, KKDPM, Academia)

	Aspect	Potential spatial planning-related measurements	Zones				Now	Later	Later on	Responsible agencies/groups
			1	2	3	4	2022-2026	2027-2031	2032-2037	
		design & improvement as well as *other structural flood protection measures*								
		16. Conduct study and revise land excavation and land reclamation law(s)/regulation(s) which consider flood impacts into account	✓	✓	✓	✓				All stakeholders (led by LGAs, Private sector, KKDPT, KKDPM)
	2.7 Water pollution elimination	17. Conduct feasibility study and improve municipal regulation and local governments' cooperation on integrated wastewater management	✓							All stakeholders (led by LGAs, Private sector, KKNRE, Academia)
Enhance capacity	3.1 Water supply capacity	18. Improve water supply infrastructure and delivery network and system efficiency	✓	✓	✓	✓				LGAs, Public utilities
		19. Increase capacity and link in-city small water supply reservoirs				✓				LGAs, RID, KKDPM, KKNRE, KKDPT, Academia
	3.2 Safer-zone development incentivisation	20. Promote housing (real estate) development projects				✓				LGAs, Private sector, KKDPT
		21. Extend coverage of the LRT yellow line and LRT green line services				✓				LGAs,KKTS, Private sector, KKDPT, MoT, Academia
		22. Increase LRT connectivities among city centre, periurban areas, satellite cities				✓				LGAs, KKTS, Private sector, KKDPT, MoT
		23. Promote new business centres and hypermarkets development				✓				LGAs, Private sector, KKDPT

	Aspect	Potential spatial planning-related measurements	Zones 1	Zones 2	Zones 3	Zones 4	Now 2022-2026	Later 2027-2031	Later on 2032-2037	Responsible agencies/groups
	3.3 Public service decentralization	24. Decentralize and enhance service capacity of public institutions and utilities				✓				All stakeholders (led by LGAs, KKGO, Private sector, KKDPT, Khon Kaen Provincial Planning Committee, Public utilities, Academia, KKPHO)
Cross-Cutting	4.1 Overlapping and duplications reduction	25. Extend the comprehensive plan boundary to cover the whole Muaeng Khon Kaen district	✓	✓	✓	✓				Khon Kaen Provincial Planning Committee, KK DPT
		26. Establish a district-level working group under the provincial planning committee	✓	✓	✓	✓				Khon Kaen Provincial Planning Committee, KK DPT
		27. Conduct matrix analysis considers interactions among spatial planning, climate change and vital development sectors in both issue-based and area-based in order to identify possible policies and plans divergences and convergences	✓	✓	✓	✓				All stakeholders (led by KKGO, KKDPT, KKNRE, KKPHO, KKDPM)
	4.2 Building capacity & knowledge	28. Establish a working group that develops and considers scientific-based evidence and data harmonization in order to support future-oriented climate risk-informed decision making *and continuity of its implementation*	✓	✓	✓	✓				Khon Kaen Provincial Planning Committee, DPT, ONEP, Academia
		29. Promote capacity building development for relevant local institutions,	✓	✓	✓	✓				ONEP, KKDPT, LGAs, ONEP, Academia, Private sector

Aspect	Potential spatial planning-related measurements	Zones				Now	Later	Later on	Responsible agencies/groups
		1	2	3	4	2022-2026	2027-2031	2032-2037	
	governments and the *general public*, as well as mobilize financial resources and technology transfer to enhance climate-proof urban development								
4.3 Planing process	30. Adopt a collaborative scenario planning into the comprehensive plan development/revision process that considers urban development dynamics and future climate change into account, *with remarks on relevant technological and societal change aspects*	✓	✓	✓	✓				Khon Kaen Provincial Planning Committee, KKDPT, LGAs, DPT, ONEP, Academia
	31. Address the proposed measures (Strategy 1-3) in all relevant elements of the comprehensive plan, such as land use plan, public utility & service plan, open space plan, natural resources and environment plan, and transportation project and traffic plan	✓	✓	✓	✓				
4.4 Participation	32. Organize public discourse/dialogue (space/platform) to discuss local development direction and how to address possible future challenges	✓	✓	✓	✓				KKDPT, LGAs, Academia, CSO, Private sector

In summary, this chapter demonstrates the application of collaborative future-oriented scenario planning for climate-resilience public health service of a growing medium-sized city. Throughout the research process of a single case study in Khon Kaen city, this study conceptualizes the potential impact assessment of local public health care services considering future urban development change and climate-related hazards and their interaction. This research developed an operationalization framework for the potential impacts assessment and encompassing climate-resilient targets collaboratively and strategically, highlighting the combination between backcasting approach and composite indicators, so-called Health Integrative Climate Resilience Adaptation Future (HICRAF). HICRAF helps Khon Kaen city explore four key questions, What are possible and plausible bandwidth of future conditions of urban development change and climate change?; What is a desirable future, and how to realize them?; What are the potential impact outcomes of the alternative futures?; How to realize climate-resilient targets and a desirable future?

To project possible future versions of Khon Kaen city, this study heavily involved stakeholders in the future envisioning exercise and validation of urban development change, as well as closing the gaps between global climate trajectories and local climate adaptation scenarios. Based on the multiple possible futures, “Trend scenario” (stakeholder selected plausible scenario) was selected to enable intensive focus on minimizing the potential impact. Stakeholders participated in target setting and designed potential measures to minimize the potential impact and fulfil the desirable future. Matrix analysis was used to identify matches and mismatches among urban development, climate-related hazards, and public health care in order to formulate “Trend Scenario” storyline as well as to explore robust policies and actions in mitigating the potential impact of the “Desirable scenario”. Both scenarios were assessed by using composite indicators tailored for the local public health care service. The potential impact assessment of the two scenarios showed that Khon Kaen city could minimize the potential impact from *medium* (Trend scenario) to *low* (Desirable scenario) level by 2037. However, if the local public health care would like to reach their ultimate goal of minimizing the potential impact level to a *very low* level, additional (least preferred) exposure reduction and sensitivity mitigation measures are needed to be implemented, altogether with the successful outcomes of the city-wide level key measures. Nevertheless, the robustness of the composite indicators cannot be clearly concluded through data-driven analysis, PCA, due to limited sample size and the composite architecture. The end of this chapter portrays the proposition of roadmaps for the realization of the desirable targets.

The next chapter will reflect findings and lessons learned from Khon Kaen city and what could be transferred to other cities and urban domains. Furthermore, limitations and invitation for further research will be addressed in the following chapters.

Chapter 6
Discussion

This chapter aims to share reflections from the study area, emphasize the contributions of this research to the body of knowledge, and present the potential application and limitations of this study. The first section illustrates key findings of how future-oriented climate-resilient scenario planning can be advanced and integrated through stakeholder collaborative scenario planning considering interaction among urban development, disaster risk, and public health. Hence this study originates a novel framework of collaborative future-oriented climate-resilient scenario planning for local public health services, the so-called Health Integrative Climate Resilient & Adaptation Future (HICRAF). The second part of this chapter discusses lessons learned from the development and application of HICRAF in Khon Kaen city and how it can be replicated and upscaled in other cities and sectors. Moreover, this section also addresses key reasons why further efforts and political engagement on HICRAF at the local and sectoral levels are crucial to bringing a new planning paradigm to climate-resilient public health service operationalization.

6.1 Key findings

The followings discuss five key research findings. The first finding illustrates the development and application of HICRAF in Khon Kaen city. The debate mainly focuses on supportive augmentations of how HICRAF could revitalize climate-risk/vulnerability assessment practices. On top of that, it particularly helps the public health sector to think beyond their sectoral scope when dealing with urbanization and climate change in the future. Secondly, the discussion turns the spotlight to understanding the interactions between urban development change and climate change and how it affects the local public health services. This finding underlines the awareness of vertical and horizontal casual effect relationships between local urbanization and multiple climatic layers, as well as the climate change mitigation and adaptation synergies of the study area. The third finding shows how this research results and approach encompass robust policy design and decision-making on climate resilience from city-wide and sectoral perspectives. The fourth finding underscores interlinkages of spatial and network dimensions in operationalizing future-oriented climate potential impact assessment, particularly in the intertwined local public health service and its urban development. The last finding disputes the utilization of composite indicators as a tool for coupling backcasting and potential impact assessment to operationalize the local public health care's desirable climate-resilient future in a long-term planning timeframe.

6.1.1 Contesting HICRAF – Does it bring a new frontier of advanced future-oriented local climate impact analysis?

Revitalization or a new generation of climate vulnerability/risk assessment practice is needed (Ford et al., 2018) to ensure integrative participatory future-oriented planning at a local level. The existing studies pay more attention to the parallel changes of both development change and climate change; however, the linkage between spatial and network operation of critical urban is still neglected. These gaps are not only occurred in vulnerability studies but in actual policy implementations. Particularly in public health services, attributable of climate change impact on urban public health is growing. However, scenario planning is still not explicitly applied in elaborating and assessing the potential impact of climate-related hazards on the local public health service. These gaps underscore the urgent need for strategic future-oriented risk-informed public health planning, which embodies uncertainties and complexities of climate change and future development choices through a participatory and political buy-in process.

What is HICRAF? - HICRAF is an advanced collaborative future-oriented scenario-planning framework for climate-resilient public health care, which was tailored and tested in Khon Kaen city under the context of this research. HICRAF framework was outlined based on the collaborative scenario planning approach, which intermixed the explorative and normative scenario planning methods and composite indicators technique. The framework addresses the interactions between the future development changes and climate changes and their potential impact on the local public health service. It offers a new architecture of composite indicators that helps the local public health service to operationalize the potential impact and backcasting their desirable climate resilience future (s). The HICRAF framework draws into 4 phases, 1) create shared understanding, 2) define the bandwidth of plausible climate trajectories and urban development scenarios, 3) set target and desirable future, and assess potential impact assessment of both plausible and desirable scenarios focusing on the local public health service, 4) layout implementation roadmap with detailed steps how the target (s) could be realized in a given time horizon. Each step involved multiple planning instruments and a wide range of stakeholders' participation.

This study found six key pragmatic issues dispute the application of HICRAF in Khon Kaen city as followings: 1) bandwidth of what is possible and what is desirable, 2) trade-off between process quality and planning under dissensus, 3) emergence of temporal dimension, 4) riddle of possibility - plausibility, 5) gap closure between global climate trajectories and local climate adaption scenarios, and 6) participatory scenario planning dilemmas.

1) Bandwidth of what is possible and what is desirable

With a parallel modelling concept, the possibilities of future climate change and urban development change were illustrated in a spectrum of possible changes. To explore what the future would bring, the bandwidth of urban development changes was built on existing plans and strategies combined with stakeholders' envisions on the future local development and land use changes. Meanwhile, the bandwidth of possible climate-related hazards resulted from the combination of downscaling climate data, sub-watershed water management practices, and local experts consultations. Overlay of the two bandwidths represents what is possible to happen in the future, bringing the stakeholders to debate which one should be the plausible one. Therefore, with the potential impact mitigation objective, the plausible future scenario was implied as a *reasonable worst-case*. The reasonable worst-case scenario reflects stakeholders' perception and informs their risk acceptability and preferred protective target(s). This study observed that the bandwidths of scenario formation stimulated stakeholders' learning process and incentivized buy-in on planning under uncertainties.

A conventional way of target setting is often a sole state of desire. In fact, the target(s) can also be spread out as a spectrum or tiers. Based on collaborative scenario planning, the stakeholders collectively agreed to minimize the potential impact in the range of "*low*" to "*very low*" levels. Bandwidth formation of the targets enhances cohesion among stakeholders groups and fields of responsibility, especially urban development and the public health sector, which often have distinct interests and viewpoints on climate-related hazards. Furthermore, the bandwidth of future conditions and targets also supports a composite indicator-based potential impact assessment. Distance to targets and proportional normalization schemes reflect linkages between targets and composite indicators, creating an opportunity to explore a continuum of the plausible future version to different tiers of desirable futures.

2) Process quality and planning under dissensus

Many studies criticize stakeholder participatory scenario planning, mostly in a workshop format, as time-consuming, complicated preparation, distressing in keeping stakeholders motivated throughout the iterative processes (Shaw et al., 2009; Robinson et al., 2011; Oteros-Rozas et al., 2015:13). However, this study found that bilateral discussion through in-depth interviews is also a practical choice for stakeholder engagement and unexpectedly gains informal political buy-in. Although this research recognizes and values stakeholder participatory workshop benefits where face-to-face interaction and group works could emerge a new set of ideas and consensus, individual discussion enables stakeholders to address their concerns, interests or criticize particular issues or a third party freely. Moreover, bilateral talks reduce pressures from their peers or his/her superiors whose presence might make a stakeholder compromise his/her expression of ideas and opinions, especially inter/intra institutions conflicts or controversial issues. Another key distinction between workshop/focus group format and individual discussions is that workshop-style often asks stakeholders to seek consensus on a particular issue. In contrast, individual talks conserve the diversity of thoughts, promoting the bandwidth of scenarios and planning with dissensus. Nevertheless, this study recommends conducting a validation process to close the gaps in individual sessions. The validation process helps transform the inputs from individuals into collective stakeholders' inputs. In addition to supplementary information or commentaries, the validation process also unexpectedly created informal buy-in from stakeholders, especially those presences in all individual talks sessions. This buy-in reflects through the local stakeholders-led workshop organization to discuss these initial research findings on 1st March 2020 as well as a well acceptance of the draft roadmaps from responsible agencies of both public health care and spatial planning. It is important to note that besides the informal buy-in, the draft roadmap (spatial planning element) was also gained political buy-in in a formal planning processs. The draft Khon Kaen Climate-resilient City roadmap 2037 (element 2) was presented to the Khon Kaen Provincial Planning Committee on the 14th July 2021 and received full acceptance and support from the committee. Additional, this research found that the individual discussion format is appropriate and practical for minimal capacity research settings. This technique is particularly helpful for a young research profession in developing countries that often have a limited resources and started at a marginal level of political engagement to initiate a long and iterative participatory process.

3) The emergence of a temporal dimension

Local stakeholders often find difficulties conceptualizing spatio-temporal dynamics among contradicting scenarios (Bradfield et al., 2005; Birkmann et al., 2015:64). With recognizing this intuitive logic limitation of the human brain (McKiernan, 2017), HICRAF facilitates local stakeholders envisioning the long-term future by breaking the forecasting timeframe into four smaller snapshots (e.g. 2022, 2027, 2032 and 2037). In each snapshot, the stakeholders are asked to provide a figure of possible minimum and maximum levels of urban development changes. This way helps stakeholders have a smooth transition in envisioning the future from today's perspective. Although this study found that stakeholders seem to have a crystal vision of Khon Kaen city's future in 2022, 2027, and 2032, the pictures of Khon Kaen city in 2037 were ambiguous. Most stakeholders only pointed out some small changes or said; the development in 2037 is the continuity of the development in 2032. Thus, the development dynamic in 2037 is rather flat and stable after the full operation of urban mass transit development. Therefore it is fair to confirm the observation of McKiernan (2017) that people often clearly specify the detail in the early period of the projection horizon than later/distant future ones, which usually contain generalities.

Interestingly, the distinction between the minimum and the maximum urban development spectrum of each snapshot is not dramatic, but it reflects the pacing of infrastructure development and major investments in the study area. In most cases, stakeholders simply assigned the figure of the maximum development level of the previous snapshot to be the minimum development level of the following one. For example, the maximum development figure in 2022 was seen as a continuum to the minimum development level in 2027, and the same logic applied to the following time spots. This observation signifies the importance of the temporal dimension in articulating urban development change scenarios. For example, agriculture and rural land use in flood-prone areas (Zone 1 and 2) were assigned as no further development in a minimum development bandwidth in 2037. However, beyond 2037, the areas will eventually convert to low residential areas. Therefore, the distinctions between the minimum and maximum development scenarios of Khon Kaen city are not only a spatial dimension of development but their temporal dimension in terms of development pace and dynamic.

4) Riddle of possibility - plausibility

In the explorative scenario planning component, the future envisioning exercise facilitated the stakeholders to have a systematic and smooth transition from the present urban development to what would be possible in 2037. This study used the current draft comprehensive plan and upcoming investments as a precursor for future visioning. On the one hand, urban development scenarios illustrated linkages between reality and future uncertainties from the stakeholders' standpoints. On the other hand, this approach still not be able to unbind stakeholders from their cognitive bias (e.g. present knowledge, paradigms, interests, and values) and departure for a more systematic exploration and looking for transformation (Robinson et al., 2011; Vergragt & Quist, 2011:750; Höjer et al., 2011: 820-821; Butler et al., 2020). Therefore, in this study, wildcard, extreme utopia or dystopia, and trend breaking scenarios have not emerged in the urban development scenario bandwidth. Thus, it is fair to imply that this study may portray the (stakeholders) selected plausible scenario rather than a full array of possible urban development futures. The experience from Khon Kaen city shows that even though the bandwidth of future urban development did not mention hyperloop or flying cars, discussing plausible futures addressed a certain level of uncertainty and fostered stakeholders' buy-in and self-knowledge of the importance of scenario planning.

The scenarios validation outcome shows that all stakeholders well accepted the bandwidth of urban development futures. No objections were mentioned during the validation process; rather, confirming and adding further details elaboration of the scenarios. Moreover, this informal political buy-in was expressed in both the validation process and local stakeholders-organized workshops, as well as in the formal planning platform, where most participants had not participated in the future envisioning exercise.

5) **Closing gaps between global climate trajectories to local climate adaptation scenarios**

The impact of local climate-related hazards is a result of climatic and non-climatic related factors beyond the city boundary. Climatic parameters and water management practices within the relevant sub-watersheds play a crucial role in determining the magnitude and frequency of climate-related hazards. Tangang et al. (2019) show that generally, the ensemble means precipitation agrees reasonably well with observations. However, projected rainfall changes of some individual models can be more than 40% larger than the ensemble means, yet distinct contrast among regions. Nevertheless, this study does not apply ensemble mean value but rather illustrates the figure from bias-corrected inputs from the Global Circulation Model dataset under the European community Earth-System Model (EC-EARTH). Although the climatic trajectories were derived from a single model, its application to Khon Kaen city underlines the importance of expert consultations and stakeholder participation in climate scenario development. Even though the climate model downscaling these days is significantly more advanced than in the last decade, direct application of the model result still opens many questions, at least for Khon Kaen city disaster risk management. For example, the RCP 8.5 showed the future average rainfall would be more than twice the present trend, and half of them exclusively poured in September. With this amount and distribution of rainfall, Khon Kaen city may find it impossible to face a water scarcity crisis in the future because the city is situated right below Ubonrattana Dam. However, it is an example of how this sounds malarkey if one solely relies on and communicates these global climate trajectories to people who live in the mid of drought when their reservoir reaches below its dead storage (March 2018-2020). Another example occurred in an initial phase of the local climate scenarios exploration process. Without integrating expert consultation in identifying the local climate-related hazard scenario, the maximum climate bandwidth derived directly from the climate model showed the potential fluvial flood level could cause the whole eastern half of the city to be underwater, including the CBD and public institutions quarters. Thus, one of the stakeholders even stated during the interview that:

> "Oh, it might theoretically be possible but indeed unbelievable".

When stakeholders do not feel making sense, the study might lose stakeholder motivation and buy-in to participate in the lengthy collaborative scenario planning process. Thus, this research adjusted the climate trajectories by considering uncertainties, local water management practices, and local expert opinions.

Furthermore, this study also demonstrated a combination of deterministic and probabilistic methods in climate-related hazard scenario exploration, especially fluvial flood hazards. The minimum fluvial flood level of climate scenario bandwidth was defined based on the current worst flood level, informally adopted as the local fluvial flood management benchmark. Meanwhile, the climate trajectories dataset determined the maximum level of climate scenario bandwidth. As a result of these combinations, the stakeholders have well-accepted the proposed future climate-related hazards bandwidth as their *reasonable worst-case scenario* (the selected plausible scenario) rather than the surreal one directly derived from the model. In addition, the stakeholders were in favour of the scenarios bandwidth visualization in particular. Visualizing future climate-related hazards bandwidth created awareness of potential spatial extension of affected areas and critical infrastructures and encouraged further debates on risk acceptance and protective targets. It is important to remark that due to lacking high geospatial resolution data set this research applied simple 2D geo-spatial analysis to present the future climate-related hazard bandwidth under the assumption of failure of the existing and planned structured flood protection measures, e.g. flood barriers, dikes along Phong river, etc.

6) Participatory scenario planning dilemma - Collaborative ≠ Inclusive

This study demonstrates collaborative scenario planning for local public health services in dealing with the potential impact of future urbanization and climate-related hazards. Stakeholders involvement played a crucial role throughout the HICRAF process. Stakeholder participation is reflected in various elements of this study, such as shared understanding articulation, urban development and climate-related hazards scenarios exploration and validations, target(s) setting, and desirable future formulation. Throughout three years of field research, political-buy in scenario planning practice has gradually increased, especially among the local urban development-related stakeholders who organized a workshop for discourse on this research findings. Plus later on, the researcher[62] was invited to present the research result and the draft roadmap to the Khon Kaen Provincial Planning Committee (14.07.2021).

This study identified key stakeholders based on their legitimacy roles and relevance in both vertical layers (i.e. central, provincial and local levels) and horizontal points of view (i.e.

[62] Wiriya Puntub

public (government), private, academic, and civil society). In the local context, it is unclear about an organization representing civil society or NGOs. Civil society's view was mainly reflected through a professor (academia) who advocates for urban poor and disadvantaged groups. In an attempt to reach an agency that represents the general public perspective, the local media (journalist), Esan-Biz, only emerged and was involved in research in 2020 (2 years after the first stakeholder interviews). Even though Esan-Biz's role is not typical and radical civil society but rather acts as a coordinator in bridging different parties and interest groups to discuss the future development of Khon Kaen under the umbrella of Khon Kaen's work Community for the Future Foundation[63].

During the scenario development process, the Khon Kaen City Municipality was the only local government participating in the future envisioning exercise. In contrast, other local government representatives were only involved in apprising preferred measures for mitigating potential impact in the backcasting process. Nevertheless, they were informed about scenarios and had no further comments on the proposed plausible future scenario. However, if they could join the process from the beginning, their views on urban development and climate-related hazards may alter the scenarios corridor, such as encounter-trend scenarios or a wider spectrum of future urban development bandwidth. For example, the Pralub Sub-district municipality representative was miserable with withdrawing LRT yellow line investment from their administrative boundary in Zone 1 (flood-prone area) and promoting socio-economic in Zone 4 (safer zone) instead. On the other hand, the mayor of Sila Town municipality perceived his area to become a new CDB in the future and disagreed with preventing the flood-prone area from further development. Therefore, this study suggests that in a bigger research setting, participation of all local government representatives from the beginning of the research should be emphasized in order to improve the quality of the scenario exploratory and backcasting process. Thus, this improvement helps to increase the process quality of scenario planning and political buy-in for roadmap implementation.

Remarkably, this research conducted extensive discussions about the future, but the young generation who will live long enough to see the changes or developments was rarely involved or invisible in the discourses. The view of the future urban development changes presented in this research was exclusively derived from a circle of key stakeholders who are actively involved in formal planning and decision-making, usually senior officials or experts. Hence, it is fair to state that even though this research promotes multi-stakeholders collaborative scenario planning, but still risks capturing the interests of certain groups of society and generations. Nonetheless, three additional young generation representatives (see Annex

[63] Khon Kaen Community for the Future Foundation platform is a space where local government leaders, private sectors, academia, and local activists could discuss and have a common understanding of the situation and problem and find a way to drive forward.

34) were interviewed to express their interests and concerns about the city's future development. The issues of basic safety, inequality, and public participation adequacy were arisen by young generations interviewees, while these issues were not strongly addressed by the core stakeholders groups, except the academia whom radical movement inclined. In this respect, this study strongly recommends further investigations by conducting public surveys or focus group discussions to discourse on Khon Kaen city's future, with equal representation of all social groups and generations.

Notwithstanding, a collaborative planning process seems ideal for creating a shared vision, communicating risks, collectively future envisioning, and political buy-in. However, Versteeg & Hajer (2010) warned that collaborative processes might provide a space for discourse and settle consensus, but participating stakeholders might have to swallow a decision they disagree with, but they can not be against it because they were involved in the process. Therefore, sincerity, appropriateness, and representational adequacy must be secured to gain trust and resolve conflicts rather than exclusively fulfil the legitimacy of the participation process.

6.1.2 Addressing vertical and horizontal interaction between future urban development change and changing climate-related hazards

Interactions between urban and regional & global climate are still relatively primitive and insufficiently understood (Romero Lankao & Qin, 2011; Cardona et al. 2012: 76; Zhao, 2018); however, physical interactions of urban heat studies might be more extensively understood in comparing to other climate-related hazards. However, this study attempts to conceptualize these interactions through casual relationships using Khon Kaen city as an example for other medium-sized growing cities in Thailand. This research found that both horizontal interactions among local systems and vertical relationships between local and regional & global climate layers shape the potential impact at the local level.

In the vertical aspect, regional and global climate change triggers local temperature and precipitation changes, positively affecting climate-related hazards such as floods, drought, heat stress and Urban Heat Island (UHI). These hazards may conceptually discourage human settlements in the exposed areas. At the same time, urbanization shows positive feedback loops to regional & global climate layers by increasing local anthropogenic greenhouse gases (GHG) emissions and albedo reduction. The direct GHG emission is a consequence of natural resource consumption altered by urbanization. Meanwhile, losing vegetation and increasing built-up areas dampen the local albedo effect, thus creating a warmer environment. Thus, the effect of local albedo may theoretically accumulate in the regional and global climate layers. This notion yet mentions that fewer agricultural activities in the study area may reduce its direct GHG emission to the atmosphere. Vice versa, reducing vegetation in urban and rural settlements could lead to a decline in the local long-term and seasonal carbon stock. Nevertheless, negative feedback from urbanization may conceptually occur due to improved public transport networks and decreased agricultural activities, reducing GHG emissions. But it is important to mark that huge GHG emissions occur somewhere outside the city boundary (scope 2 and 3 emissions) where the city imports electricity, food products, and essential resources to meet the demands of the increasing population under growing urbanization.

From a horizontal point of view, positive feedback can be observed from the deep linkages between increasing urbanization, population density and natural resources consumption. It is important to note that the number of populations is not always a direct variable of resource consumption. However, air conditioning usage, fuel combustion, increased build-up areas, and losing vegetation could amplify the local air pollution, human heat stress, and urban heat island. Meanwhile, increased sealed/impermeable surface and losing green space and agricultural land could conceptually intensify the magnitude of local floods and drought through human-induced factors. Moreover, without an integrative wastewater management system, urbanization could soar water pollution, cascading water scarcity concerns to the locals. Decreased agricultural activities could lead to declining N-fertilizers usage, which plunges agricultural-related water pollution, thus more qualified raw water for water supply production. However, increasing sealed land cover could negatively affect the underground water table level, which reduces the redundancy of the local water supply.

This articulation of interactions between local urbanization and local, regional & global climate illustrates linkages between the global Shared Socio-economic Pathways (SSPs) and local urbanization vertically. Yet, it sheds light on how the local climate and urban development interact horizontally. Indeed, this interaction analysis informs the local stakeholders on how urban development and climate-related hazards are connected and interrelated. This apprehension reveals opportunities to signify and visualize the co-benefits of synergies between climate change mitigation and adaptation actions at the city level.

6.1.3 Enabling robust policy design and decision-making through internal and inter-sectoral convergence and divergent scrutiny

Different sectors and agencies often work or intervene in the same space and time with diverse/contradicting overarching purposes, goals, characteristics, and interests. Lack of area-based integration and coordination are common causes of overlapping, completing, and mismatching in terms of policies and strategies among sectors, thus preventing the city from reaching its ultimate goal. This study demonstrates a way to promote integrative and collaborative future-oriented scenario planning through matrix analysis. The application of matrix analysis in the case study cogitated the local policies, strategies, and investment projects in three different aspects, urban development, climate-related hazards, and public health service. This research found that identifying internal and intersectoral convergences and divergences among disaster risk management, city planning, and local public health care operation is vital and encompasses integrating climate-resilient future both city-wide and sector-specific. For example, city planning aims to promote compact city development and prevent new development in flood-prone areas. However, the flagship investment in a mass transit system, LRT yellow line, promotes urban expansion to flood-prone areas. This mismatch also conveys a question to the local public health sector whether their zero-growth policy, which limits service and personal capacity, is still valid in an area with a growing population and fluvial flood-prone.

Different groups of stakeholders diversely articulated the proposed potential spatial planning-based measures derived from the matrix analysis. Even though no regret measures on hazard mitigation were well welcome by most stakeholders, the local governments in a flood-prone areas showed the least preference for climate-related hazards exposure avoidance measures, such as redirecting the development out of the area and relocation. In contradiction, the stakeholders who focus on the city-wide development strongly agreed to keep the areas free from development or maintain the lowest development degree as much as possible, despite recognizing possible difficulties and constraints in implementing such measures. However, the stakeholders strongly required detailed scientific evidence to understand human settlement dynamics, risk communication, discourse for decision-making, and relevant law enforcement concerns. In this regard, open debate on the climate-risk scenarios and the right to be developed shall be initiated and publicly taken place as part of climate justice discussion based on supporting scientific evidence.

Internal and inter-sectoral convergence and divergence scrutiny allow robust spatial planning-based measures that conceptually contribute to the desired scenario achievement. The case of Khon Kaen city shows that, even though the measures might be well accepted from a city-wide perspective, they may not be the case for the local public health sector. With obligation in ensuring accessibility of health care service, relocation or establishing alternate care sites outside the service areas might not be variable because their patients still live there. Public health does not mean against the measures, but they can only follow if their patients were moved out from the hazard-prone areas too. Thereby, policy choices of the local public health sector are highly dependent on the city-wide level implementation. Resilient upgrading of public healthcare units and limiting service advancement expansion in hazard-prone areas are preferable in comparison to other measures. However, the sector was strongly hesitant to expand and increase service capacity and redundancy according to city-wide development redirection (to Zone 4). These options required higher spatial resolutions of demographic projection analysis (in individual care unit's service catchment area) to ensure cost-effectiveness between the number of potential patients and investment of health care service per capita under the limited resources of the national universal healthcare coverage. This trade-off somehow bound their view with a short-term planning perspective rather than strategically taking long-term uncertainty of urban development and climate-related hazards into account.

Besides cost-effective analysis, in reality, damages of catastrophes are usually much greater than expected and even far beyond the local impacts. Therefore a conventional function of risk assessment (Risk = Probability of occurrence x Consequence) or conventional cost-estimation may not enable adequately and efficiently decisions on risk preventive measures. Risk aversion is the concept that gives an additional over-proportional weight factor (so-called aversion factor φ) in the risk assessment function. This quantitative risk operation includes consequences of possible events deriving from the sum of direct and indirect follow-up consequential costs of infrequent events with large consequences (e.g. black swan event) corresponding to the statistical expected value of damages (Enander & Lajksjö, 2003; Schneider, 2006). Based on the experience of Swiss authorities, although Risk-aversion is a risk estimation tool with conservative assumptions, practical problem in terms of gathering relevant data, entails value judgements, inevitably subjective valuations still raise major concerns in this risk operational technique (Bohnenblust et al., 2008). Yet, the concept of Risk-aversion is based on past events; therefore, its applicability with future-oriented potential impact assessment shall be further investigated.

6.1.4 Operationalizing future-oriented climate-resilient scenario planning and linking spatial-network potential impact assessment in local public healthcare

The architecture of HICRAF's composite indicators is based on the IPCC AR5 climate risk concept. The composite indicators signify interlinkages among local urban development, climate-related hazards, and public health care operation. This integration breaks two crucial limitations of disaster risk management in the local public health service.

First is shifting from conventional health care planning and monitoring and evaluation (M&E), which often focuses on facility-based emergency response, to address projections of climate change health impacts under different climate and socio-economic futures of the whole service network. The composite indicators enable the local public health service to overcome a number of challenges in addressing climate resilience, such as lacking awareness and recognition of climate change impact on public health services, lacking long-term scenario planning, insufficient understanding of climate uncertainties and interactions with health determinants sectors, lacking institution learning management, and lacking mainstreaming adaptation processes and outcomes. The indices are characterized on the basis of the local public health service settings and their dependency and interdependency with other critical infrastructures and health determining sectors. Moreover, the potential impact assessment outcomes inform risk management and service planning from multiple perspectives, such as facility-based, area-based, network-based, and service levels. These help the public health sector link its reality with future scenario planning. Hence, this study strongly emphasizes that without integration of the criticality concept and network-based perspective in vulnerability assessment is insufficient for reflecting the reality of the local public health operation under the potential impact of urban development and climate-related hazards in the future. Therefore, the co-existing paradox of place-based and network-based concepts should be further investigated in climate vulnerability and climate risk assessment studies.

The second is shifting the local public health service from Business as Usual to a desirable climate-resilient future through combining the collaborative scenario planning framework and composite indicators instrument. This combination allows operationalization of the potential impact by including projected climate conditions, changes in health system demands (such as population growth, demographic changes) and anticipated health services capacity in order to build climate resilience public health services. Moreover, it also encompasses the local public health service to strategically identify actions, layout transition steps, and track the achievement over time.

The case of Khon Kaen city proved that it is possible to put minimal resources and technical expertise in conducting the potential impact assessment for the local public health care. Contrary to other healthcare-related disaster risk management guidelines, which require engineers or experts specialising in a particular hazard or system operation, HICRAF is simple enough for the local public health care facility manager or personnel to minister this self-assessment. However, direct input from an individual public health care unit is limited only to (internal) exposure and vulnerability components. Therefore, firm cooperation among spatial planning, disaster risk management, and public health is a prerequisite for deriving future scenarios of city-wide hazards, and exposure determined health population and (inter)dependency profile of critical infrastructures. Importantly, HICRAF can be embedded with the existing online reporting platform of the Thai public health ministry/sector. Thus the assessment result shall enable the local public health service to be proactive and more strategic in confronting changes in urban development and climate change in the future.

6.1.5 Sectoral benchmarking in needs

In this research, expert involvements in composite indicators development exhibit a high deviation of expert opinions on the composite indicator weighing value. Although all the experts are working in the health sector, they are diverse in a specific field of expertise and experience dealing with climate-related hazards. Thus, it is fair to assume that these differences in personal background and experiences influenced their assignment on the indicators weighting values. The data showed that the experts who work closely with patients and day-to-day hospital operations are more familiar with typical routine problems of Thai's public health services, such as over carrying capacity and resource deficits. It is assumably explained why they gave low weight value to the related indicators they have to deal with daily. Another high contrast case is the expert who had experience managing the hospital during hazards, e.g. the Bangkok flood 2011, gave an outstanding score for a diversity of suppliers indicators (V7) compared to other experts.

Moreover, the indicator weighing values profile also reflects the experts' field of interest or needs. For example, experts in engineering and architectural aspects of public health care gave a highly weighted on system conditions and maintenance of working systems; downtime of essential working systems; and flexibility & modularity of working systems. Furthermore, it is not surprising that most experts gave low weighing value to future-oriented planning indicators except those with engineering and architectural backgrounds whose expertise usually deals with a long life span of construction and design. Although this study involved a small group of experts in identifying the composite indicator weight scheme, they are national/sectoral significant responsible agencies. Thereby, the result reveals a vital reflection that future-oriented planning is not yet well aware and mainstream in the planning practice in Thai's public health sector.

In addition, it is an important remark that the current situation's perception may also affect how experts assign weighting value to an indicator, especially hazard-related indicators. The survey was launched from late October to December 2020. At that moment, Thailand was experiencing a prolonged drought. There were reports on severely water supply scarcity in many areas where tertiary hospitals are located. These facts may affect the experts' awareness while giving the weighting values to different climate-related hazards. Furthermore, it is crucial to mention that the survey does not ask the expert to distinguish between flood types such as fluvial and pluvial floods but rather floods as general hazard phenomena. This gap should be closed by giving an extensive explanation of the climate change aspect/implication of each indicator, which is assumably less relevant to their field of expertise (medical/healthcare) or routine work.

Nonetheless, the experts' opinions on indicators prioritization were rather varied and diverse; however, it unmasked the experts' mutual view on indicators which important to climate-related hazards/disaster risk reduction, such as Variety of vulnerable patients (V2), Redundancy (V8), Responsiveness (V9), Capacity development (V15), and Preparedness and risk transfer (V13). However, the study cannot jump to a certain conclusion of why the experts weighted the indicators in the way the result is presented. However, besides basic individual variations (e.g. gender, age, education level), it can be generalised that key factors that could affect the experts' judgment are expertise background, experience in handling situations/problems, and recent perception of particular climate-related hazards. In this regard, this study points out that it is essential to organize experts workshops or focus groups to discuss potential impact assessment composite indicators to justify or consensus on appropriate definitions, characteristics and weighting schemes of individual indicators as well as their sub-indicators in order to derive sectoral or national benchmarking which could upscale to be a national/universal guideline. Especially, sectoral expert discourses on the composite indicators weighting schemes and a wider contest of HICRAF composite indicators with a larger sample size would allow comparison among various weighting techniques such as expert-weighted, equal-weighted, data-driven weighted-normalization (e.g. PCA). Hence, this comparison will enable the public health sector to derive the most appropriate weighted normalization schemes for the potential climate-resilience benchmark.

6.1.6 Composite indicator-based potential impact assessment and data-driven approach constraints

This study demonstrates fundamental challenges in performing composite indicators-based potential impact assessment on the basis of the IPCC AR5 climate risk concept. Balancing composite indicator structure, statistical and theoretical coincide, and the quality of input data reflects the robustness of the composite indicators and the reliability of the potential impact outcomes. The following provides an argumentation of the key challenges and recommendations for further improving the application of composite indicator-based potential impact assessment.

1) Balancing the number of indicators

To comprehensively encapsulate all essential attributions of public health service and its climate-related vulnerability is not the only challenge in identifying non-observable variations, but balancing a number of indicators representing each dimension/pillar of the composite indicators adhered with the IPCC climate risk concept. The indices applied in this potential impact assessment were fitted for the purpose. Therefore, the number of indicators and sub-indicators depends on the local climate-related hazard profile, urban development context, and public health service characteristics. Hence, the set of composite indicators consists of 3:2:17 indicators for hazards, exposure, and vulnerability. Imbalance is clear for the vulnerability pillar. The pillar requires 49 sub-indicators derived from 223 input data which are hidden behind a single number. Although this study applied *distance to target* and *proportionate* normalization schemes to conserve the complexity of the crucial properties of the system as well as promote M&E of the potential impact mitigation target (s), communication of the result should be very mindful of blinding visibility of the local public health efforts on climate resilience. Because even though the public health actors might ideally undertake and invest in reducing vulnerability and exposure of public health working systems/operations, the outcomes in potential impact mitigation might do little if there is no change in city-level or health determinants sectors on the aspect of city-wide hazard mitigation and exposure avoidance.

2) Statistical and theoretical coincide

Although statistical dimensions do not necessarily represent or coincide with the theoretical influence of the indicators or sub-indicators on the phenomenon being assessed, a revision of composite indicators or sub-indicators might be considered, especially the vulnerability indicators. In this study, Principle Component Analysis (PCA) technique was used to inform the robustness of the composite indicators. The technique helps to reduce the dimension of variables by encapsulating a minimum number of variables that provide a meaningful output based on the correlation among data points. Despite a sample size concern, the data-driven analysis suggested that 50 % of the Vulnerability indicators hold a meaningful explanation without three sensitivity and three coping capacity-related indicators representing vulnerability. However, in reality, those six indicators[64] are key determinations of a public health care unit's vulnerability, even without considering climate change concerns. Yet, the PCA reflected that most of the Vulnerability could be explained exclusively by adaptive capacity-related indicators, which is questionable.

The nature of input data may play a major role in this statistical and theoretical dissonant. The majority of input data representing adaptive capacity-related indicators are homogenous in the form of checking of availability and implementation status of relevant plans and policies, which enable transformation change and enhance capacity in a long-term perspective. Since climate/disaster risk management is not yet well mainstream in local public health policy and operation in Thailand, most participating hospitals fed almost the same figure of input data. In contrast, sensitivity and coping capacity-related indicators are highly

[64] V2: Variety of vulnerable patients; V4: Poor system conditions and maintenance of working systems; V5: Downtime of critical or sensitive working systems; V6: Lack of flexibility & modularity; V7: Lack of diversity of suppliers; V10: Lack of resource mobilization

heterogeneous based on the day-to-day operation of the local public health units. These contradictions reflect low reliability and internal consistency of sensitivity and coping capacity-related indicators compared to adaptive capacity-related indicators. It is important to mark that sensitivity and coping capacity-related indicators usually require more diverse input data characteristics and complex aggregation schemes than adaptive capacity-related indicators in which the input data were arranged in a similar ordinal scale. These statistical concerns do not only matter in verifying the composite indicators but also prevent the utilization of PCA input as an alternative for indicators weighting, besides expert judgment and equal weight schemes.

Another argumentation that could address the challenges in finding statistical coincide with the theoretical influence of composite indicators is through the lens of linear regression analysis (Pearson correlation). Very low or no variance of the dataset may affect the correlation between the indicator (independent variable) and the vulnerability outcome (dependent variable). For example, the "Trend scenario" condition assumed that all hospitals might deal with an imbalance between service demand and supply. Therefore, all of them exhibited the identical figure of this sensitivity. Thus, the input data polarization caused by lacking dataset variation in responding to the scenario storyline prevents statistical robustness verification of the indicators.

3) Quality of input data

Besides the complexity of the survey structure, the responders' understanding of the questions and their knowledge and awareness of socio-economic development and disaster risk management is crucial to ensure the input data's consistency, especially on the issues beyond their day-to-day routine or area of responsibility. For example, some public health units declared that they utilize a hazard map or climate projection data for long-term planning, contrary to the fact that Khon Kaen city does not have this piece of information available at the local level. Another contradictory example is that the MoPH promotes a Business Continuity Plan development, but most local public health facilities have none. Only Khon Kaen Hospital has the plan and implementing it in responding to COVID-19 outbreaks in November 2020[65] (KKH, 2020). Regarding the respondents' eligibility, even though the survey addressed the director/the head of an organization, a few primary care units assigned a professional nurse to answer the questionnaire. It is no doubt that nurses are the right person who can provide input data regarding day-to-day operation issues, but in terms of policy and long-term planning are often beyond their eligibility to answer. Therefore, a few primary care units left these items blank (excluded from the analysis). Moreover, answering the questionnaire is more challenging at a higher health care service level. For example, in tertiary care or specialized care, works

[65] Khon Kaen Hospital BCP gives a low priority to flooding issue and does not identify water scarcity as treats

are more complex and allocated to different departments. Thereby coordination or meeting among relevant departments is essential for completing the survey. In addition to the survey, this study also conducted interviews with selected five public healthcare facilities located in different parts of the city in order to collect additional inputs, which the questionnaires may not be able to capture. For example, human resource management and procurement regulation issues were deeply emphasized and highlighted during the interviews. Therefore, this research recommends conducting interviews with the local public health facilities to complement the survey inputs and better understand realities.

Concerning the data-driven perspective, this study reveals that a limited number of samples, nature and distribution structure of input data, and a vague understanding of the issues substantially affect the robustness and reliability of potential impact assessment. Even though almost 70 % of the questionnaires received are considered a high rate, only 25 sample sizes are truly challenging for applying data-driven analysis. A larger sample size is preferable to enhance the statistical robustness of the result (Björklund, 2019), especially for the PCA technique. Although the analysis result shows an acceptable ratio of sampling adequacy, plus there is no certain critical ratio between the number of variables (indicators) and sample size, more is always better. In general, a sample size of 50N to 400N is recommended by many studies on factor analysis, such as Barrett & Kline (1981) and Aleamoni (1976) (as cited in Osborne & Costello, 2004). Expanding the study areas to provincial or national levels is recommended to improve the robustness of vulnerability indicators. Furthermore, the study suggests organizing an orientation workshop with the target public health care units to minimise input data bias and inconsistency. The workshop could enhance input data quality and reinforce knowledge and awareness of the potential impact of the future climate change and development change on the local public health care network.

As abovementioned, relevant experts have reviewed the structure of composite indicators. However, further and deepening discussions are required to improve the indicators' reliability and internal consistency, especially sensitivity and coping capacity-related indicators. In addition, some input data requires a debate on a certain benchmark among public health domains, for instance, critical downtime of essential working systems, level of redundancy, a ratio of vulnerable patients, etc. This improvement shall benefit upscaling and developing this set of composite indicators as a national or international standard. Furthermore, to mainstream HICRAF in the existing public health planning and M&E system, an online interface self-potential impact assessment functions should be established and integrated with the existing public health information platform. Hence, these figures/profiles of the potential impact outcomes enhance the local public health managers and relevant policy decision-makers at all levels in making robust decisions under uncertainties of urban development changes and climate change in the long-term future.

6.2 From Khon Kaen to other cities and beyond

This section extracts lessons learned from collaborative scenario planning of Khon Kaen city's public health service. The lessons learned reflect what is unique about the application of HICRAF in Khon Kaen city and what is worth spreading to other cities and global communities. The following text portrays four major aspects of the case study as follows.

6.2.1 Single story: Mutual understanding or framed understanding?

Generating a shared understanding of the local development and power relations among key players provides a firm ground for scenario planning. In the process of TOWS analysis (in 2018), multiple groups of stakeholders actively involved in urban development expressed mutual understanding of the city's roles, state of development, prospect direction, power relations, and challenges. The stakeholders told a similar set of facts and perceptions of Khon Kaen city, especially internal and external factors influent the local being. The study found that the stakeholders were excellent at defining their internal and domestic push-pull factors but less recognizing the influence of prominent global trends such as the AI revolution and global pandemic. From a climate-related hazards perspective, although the stakeholders somehow discern global climate change, unplanned development and local infrastructures' mismanagement are more to blame as a cause of loss and damages than climatic factors.

This mutual understanding of Khon Kaen city development may derive from their uniques and strong coalition among the three main local actors 1) municipal government, 2) private sector, 3) scholar community. This coalition is perceived as Khon Kaen Model, which profounds city development where other cities in Thailand are still struggling. It is important to note that the Khon Kaen model might imply Khon Kaen City Municipality Model rather than the whole Meaung Khon Kaen district, where all local governments shall involve in the process. Although mutual understanding or single storytelling is helpful for scenario development and validation, conducting the same research strategy in a city with a high disparity of self-perceptions among stakeholders may lead to difficulties in capturing diversities or bonding fragmentations. Moreover, from a downside perspective, a single story may prevent "expect the unexpected" during the exploration of scenario bandwidth, such as hindrance wildcard, the emergence of encounter trend scenarios and so on.

From a city-wide perspective, the existing firm collaborations and strong awareness of the local development are key factors that enable political buy-in on future-oriented risk-informed planning from the local stakeholders. But, a district level forum, where all local governments and all public citizens are equally represented in the discourse, is still missing in the context of this research and the real world. Physical and virtual spaces are essential for discussing urban development change and future challenges on climate-related hazards, as well as initiating political engagement and investment in the proposed roadmaps. Furthermore, requirements for solid scientific evidence were emphasized as a crucial vehicle for encompassing the discourse, technical benchmark and law enforcement on disaster risk management. In this regard, this study strongly suggests establishing a Khon Kaen city's technical working group that explores and develops scientific-based evidence to support future-oriented risk inform planning and decision making and promote capacity building of relevant actors and the general public on climate resilience actions.

However, it can be difficult to apply the collaborative scenario planning approach in a city where stakeholders are inactive and lack strong cooperation in combination with low awareness of climate-related hazards (either low hazards risk profile or never have (recently) experienced a high magnitude of hazards) and a mild degree of an urban setting. A low degree of these challenges might cause hardship to motivate stakeholders to participate in the lengthy planning exercise and gain political buy-in on what they think is insignificant or unforeseen.

6.2.2 Mismatches

The mismatches between scale and boundary of the land use planning, public administration, and sectoral operation prevent coordination across local governments on spatial development, disaster risk management, and public health care operation. Therefore, the scope of Khon Kaen city comprehensive plan should cover the whole district administrative boundary rather than be limited to the urbanized characteristics of the area. This boundary adjustment could enhance spatial-network integration among political bodies and mainstream sustainable development and climate resilience in both area-based and sectoral-based perspectives.

Matrix analysis is a useful instrument for identifying sectoral and intersectoral matches and mismatches in terms of plans, policies, and responsible areas. Recognition of possible convergences and divergences is crucial for creating robust policy design and decision-making at a local level. In this regard, Khon Kaen city needs to establish a district-level coordination body rather than the provincial body. Return coordination power and forum to the district level could signify the alignment of all local governments and sectoral institutions' interests and needs, thus being able to determine an overall district development strategy in the future. The district-level platform shall enable and empower stakeholders from flood-prone areas, safer zone, and CBD to have an open dialogue about their version(s) of plausible and desirable futures, as well as how much risk or the potential impact they are willing to embrace and how to set the target which everyone can be reached in their own speed and capacity. Hence, from a spatial planning perspective, this study strongly suggests establishing a district-level working group under the provincial planning committee. However, this formal process might be ideal for reaching this transformation or have to wait until the next round of plan revision. An informal process can be deployed through an existing development collaboration network. In addition to these suggestions, there are crucial entry points encompassing the city to grab their low hanging fruits together, such as improving the database, legislation, and technical benchmarks for avoiding exposure, mitigating hazards, and enhancing adaptive capacity. On top of that, interaction analysis between the local urban system and higher climate layers points out explicit opportunities for climate change mitigation and adaption synergies of Khon Kaen city, which could tap external funding.

6.2.3 Climate-related hazard scenarios

The lessons learned from Khon Kaen city show that mixed methods between deterministic and climate projection analysis gained well acceptance and buy-in from stakeholders throughout the subsequent scenario planning steps, especially target setting and designing spatial planning-based potential impact reduction measures. Including the local water management practices and stakeholders' opinions in developing future climate scenarios turned "possible but unbelievable" to "plausible and reasonable". However, expecting the unexpected is necessary, especially in a society where everyone sees things in a similar direction. Therefore, scenarios beyond the (stakeholders selected) maximum level of future climate bandwidth should be analyzed and considered to ensure the city has a plan for the future which might be beyond their reasonable worst-case. Regarding climate scenario bandwidth identification, the methods used for Khon Kaen city are relatively empirical and require minimal data in setting up climate scenarios. Therefore, this method can be applied without obstacles in a country where downscaling climate data is available. Nonetheless, a higher spatial resolution analysis could capture greater details of elements and populations at risk and possible cascading events. Hence, this study recommends conducting further detailed and high-resolution analysis of pluvial flood and the extension of fluvial flood in a building block level, as well as projecting water scarcity by considering technological and social changes factors into account when a high spatial resolution of current and future land use datasets is available.

Climate-related hazards scenarios generated based on a collaborative scenario planning approach shall be the center of disaster risk management, enabling public discourse and acceptance on the local hazard map. Thus, it is clear that the application of collaborative scenario planning should be integrated with the existing disaster risk management planning and practices. In the spatial planning aspect, this approach not only spotlights mainstreaming climate resilience in land use elements but also other components of a comprehensive plan, such as open space plan, transportation and traffic plan, public utilities and public services plan, and M&E mechanism.

6.2.4 Public healthcare

Although the future potential impact of the local public health care units mainly depends on city-wide hazard mitigation in both structure and non-structural measures. However, if all sectoral efforts in reducing vulnerability can be realized according to the desirable scenario, the local public health care service can still maintain its function with certain residue impacts, even though there are no actions implemented at the city-wide level. In other words, under the reasonable worse-case, Khon Kaen city public health service may fail safely through sectoral exposure avoidance and vulnerability reduction. However, to minimize the potential impact to a negligible level as the upper-tier target (*very low level*), besides waiting for city-wide level implementation, immense sectoral change in unlashing structural deadlocks in terms of personal and resources management is a prerequisite, on the one hand. On the other hand, the planning paradigm needs to be shifted *from* considering a relatively short-term demographical change and emergency response *to* longer scenarios planning considering future-oriented changes of demo-socioeconomic, urban development and climate-related hazards. In addition to planning orientation, when coming to climate-related hazards, the mindset of public health care service needs to be reshaped *from* helping other people first *to* the hospital has to be safe first, because a hospital shall be able to continue its operation and be a community lighthouse in the crisis. These *shifts and changes* have to mainstream throughout public health domains and local public health care networks. In addition, considering the criticality of public health service dependent lifeline infrastructures is also very important to understand and operationalize possible cascading effects on local public health services. Thus, it is pivotal for local public health services to cooperate with health determining sectors, particularly other critical infrastructures and local governments, in managing and investing in climate resilience. To serve these necessities, a vast area of research to refine and upgrade the HICRAF to a more advanced version is needed.

In a country where public health care has to operate at the margin of resources, investment in potential impact mitigation with a long-term perspective is a great challenge and hindered by short-term problems and emergency constraints. Only visualization and presentation of scenarios may be insufficient. Detailed cost-benefit analysis or risk-aversion estimation, as well as a feasible study on implementation options, are highly required. Nevertheless, fulfilling the desirable climate-resilient targets demands enormous efforts that obviously exacerbate the underlying illness of Thai's public health care system, especially understaffing and overloading capacity in a public health care unit, especially a tertiary care hospital. Yet emphasis that the central procurement system oversight by the Ministry of Finance hinders public health services from being prepared and ready for future development and climate change challenges. Therefore, this study echoes a call for more integrative planning on public health services and critically revisiting conventional cost-benefit assessments and investments in public health infrastructure.

Climate change coordination units under the MoPH and local universities could play a vital role in setting up the reporting system and capacity building activities, facilitating and keeping potential impact assessment in check. Hence, HICRAF can be well consolidated with the existing safety standard and monitoring & reporting system in order to avoid overwhelming a local health care unit with the additional burden from their routine work. With a clear roadmap, Khon Kaen city's public health sector shall acquire external cooperation in technical and financial support to implement climate resilience initiatives, especially international funding and collaborations.

The application of HICRAF in Khon Kaen city and well acceptance of the proposed roadmaps exhibit clear opportunities for upscaling and conforming to the framework as a standard self-assessment and benchmarking scheme. It is important to note that HICRAF is unlimited. It can be applied to both a standalone health care facility and network-based operations, such as the CUP network in Thailand. It is advisable to highlight that these findings and lessons learned from Khon Kaen city ignite the revitalization of climate vulnerability and risk assessment practice and enable public health care to operationalize spatial-network potential impact assessment of the urban public health service that genuinely fulfils the gaps HNAP and the existing WHO guidelines.

Chapter 7
Conclusions

To deal with the future changes, public health care demands to shift their planning and operation paradigms, on the one hand -- from reactive, responsive and short-term planning -- to proactive future-oriented and long-term planning. On the other hand -- from too narrow in sectoral and facility-based focus -- to linking city-wide spatial planning and network operation perspective. It is vital to urge public health care to balance their mindset -- from helping others first -- to ensuring the safety of public health care facilities is a primary concern. Unfortunately, the existing attempts in health sectors are still inadequate to obtain these necessities. Despite growing awareness of climate resilience health care, the existing guidelines or toolkits are exclusive within a hospital area; and only broadly address urgent needs for future-oriented climate risk-inform planning rather than endowing solidity and tailor-made operationalization framework and processes, particularly for the local public health service.

To prepare the local public health services to be ready for possible unpleasant futures, this research offers a collaborative future-oriented scenarios planning framework tailored for urban public health service, the so-called Health Integrative Climate Resilience and Adaptation Future (HICRAF). The HICRAF combines a collaborative scenario planning approach and composite indicators to help local public health care achieve three key essentials in addressing climate resiliency. First, *a collaborative scenario planning framework* enables the public health and relevant stakeholders in urban domains to understand the interaction between development change and climate change and their potential impact on the local public health service. Second, a *composite indicators-based operationalization framework* encompasses the local public health service to strategically and collaboratively meet their targets to minimise the potential impacts and enhance climate resilience. Thirdly, *roadmaps* to escort how the local health care could transit from today's conditions to desirable futures despite confronting climate change and urban development dynamics constraints. The findings of this research reveal that HICRAF breaks a new frontier of climate change impact assessment by not only performing collaborative scenario planning to address the potential impact of climate-related hazards at a local level; but also operationalizing the potential impact and climate resilience targets by linking spatial and network operation of the urban public health service.

The explorative scenario phase of HICRAF exhibits how the gaps between global climate trajectories and local climate scenarios can be closed and gain buy-in by taking local water management practices and the local risk threshold into account. Future urban envisioning exercise enabled key stakeholders to be aware of and debate on multiple possible futures, thus deriving a mutual understanding of the plausible bandwidth of future conditions and uncertainties. Throughout the collaborative planning processes, this study illustrated what could be vertical and horizontal interactions between future urban development changes and changing climate-related hazards from both city-wide and public health sector-specific perspectives. Unrolling internal and intersectoral matches and mismatches helps streamline spatio-temporal boundaries, needs, goals, and interests among the three domains (urban development, climate change, public health service). The revelation of these interactions leads to a robust policy design, inclusive planning, and strategic decision-making in order to achieve climate resilience and sustainable development. The composite indicators element of HICRAF allows local public health care services to operationalize their potential impact in different future versions and targets, especially exposure and vulnerability components. The composite indicators provide a broader and deeper perspective of potential impact and promote spatial-network integration with other health determining realms than the existing checklists and practices. Moreover, configurations of the potential impact outcomes can be manifested to fit the needs of different policy decision-making levels, such as individual health care facility, area-based, service network, and service levels. Furthermore, the application of HICRAF in Khon Kaen city shows a huge potential for mainstreaming the process of climate resilience and adaption to the existing reporting and budgeting of the public health care sector and spatial planning practice in Thailand.

Khon Kaen city's experience divulges both technical and pragmatic concerns of this collaborative scenario planning framework and its composite indicators. However, the scenario development process of HICRAF facilitates the stakeholders to depart from today's reality to future possibilities in a smaller fraction of time (several snapshots). Conceptualizing spatio-temporal dynamics among contradicting scenarios is still challenging and needs complementary from experts or the researcher to consummate the future canvas. Although scenario planning helps simplify complexity while conserving diversities of contrast futures, a dilemma between what is possible and what is reasonable or believable may frame the stakeholders' (cognitive) thinking process of future envisioning towards the continuum of present rather than trend breaking or extreme changes. This study also confirms that process quality often needs compromisation in order to assure stakeholders buy-in and long-term engagement throughout iterative backcasting steps. Full-scale collaborative scenario planning demands more time, resources, and political support, which this minimal research setting may not fully cover. Thus, the future scenarios generated in this research can not be claimed to represent as the envisioning of Khon Kaen city’s futures from the perspective of all local governments, social groups, and generations, but merely the relevant stakeholders who participated in the research process. The visualization of the scenarios received complements from stakeholders as a good medium in communicating a variety of futures and potential impacts; however, more technical or engineering model simulations with high spatial resolution shall be further research such as future urban water scarcity and pluvial flooding, which often sensitive to network infrastructure settings and micro-level of urban landscape alteration.

Notwithstanding, the application of HICRAF in this study covers both spatial and network aspects of public health service under the Ministry of Public Health. In reality, Khon Kaen city's health care system comprises many health care providers that often interlink through referral systems, such as private hospitals, university medical school, military hospital(s), local governments' health care facilities, private clinics and pharmacies, etc. Even though HICRAF can be adjusted and utilized for all types of health care facilities regardless of service level or affiliations, it needs to be cautious in interpreting and communicating the potential impact outcomes resulting from composite indicator operationalization. In theory, only healthcare facilities with similar service capacity and management practices can compare their performance and potential impact outcomes. However, it is possible to include the potential impact outcomes of different service operators/levels to manifest the whole figure of the local health care network system by considering the service capacity and workload proportion of the service network for support bird-eye view policy-decision making.

The composite indicators framework reflects a great detail of the local public health care characteristics and fastens the day-to-day operation and long-term planning aspect. Still, there is a vast room for composite indicators improvement which need further explorations, such as high-resolution population projection, dynamic of human settlements and population health of each catchment area, projection of vulnerable population and its relation to climate-related health risk, projection of local health care personnel resources, mental health aspect of health care workers, technological and social changes trajectories, etc. In addition, the application of HICRAF emphasizes the necessity of specific technical debate on several indicators such as technical benchmarks of internal working systems' exposure, downtime of essential working systems, redundancy threshold, and so on. These benchmarks could be scalable as the national standard serving differences in regional or local levels in terms of health population, social and environmental health determinants, interdependency critical infrastructures, etc. Plus, assessing the public health service's interdependency on critical infrastructures, especially power, water supply, communications, and fuels, is essential for the local public health care to proactively prepare and coordinate for unexpected disruption in a certain time window. Importantly, HICRAF sheds light on a broad overview of public health care working systems having a clear interface with climate-related hazards and urban development dynamic, rather than engineering aspects of hospital working systems or taking technology forecast into account. Thereby, to develop a higher tier or advanced version of HICRAF in the future, it is vital to include criticality and technological-engineering aspects of the essential working systems of both health care service networks and relevant lifeline infrastructures into account. The case of Khon Kaen confirmed the need to integrate the criticality concept and network-based perspective in vulnerability assessment to reflect the realities of the local public health operation under urban development change and changing climate-related hazards in the future. Hence, the co-existing paradox of place-based and network-based concepts should be widely explored in climate vulnerability /risk assessment studies with a great extension to health determining sectors, especially in urban settings.

With a focus on the composite indicator technique, HICRAF shows composite indicators approach is appropriate in operationalizing the complexity of the potential impact of climate-related hazards on public health services in Khon Kaen city. However, it is to be careful in communicating the result of potential impact outcomes. A composite indicator is a tool for simplifying complex phenomena to something manageable. Therefore, it is important to be aware that behind a single number is a myriad of input data representing phenomena. Hence, composite indicators should be transparent and proportionately conserve the complexity of input data in order to enhance climate resilience policy tracking. Through the lens of the composite indicators framework, this study found that despite the public health care actors in the case study area might take immense efforts in changing and transforming their working systems or operations, the outcomes in mitigating potential impact may so little if there is no change in city-level or health determining sectors on the aspect of hazard and urban exposure. Therefore, this study genuinely wishes for integrative planning between the local public health care sector and other urban domains in executing climate resilience intervention. Still, the robustness of the composite indicators is needed to be further explored with more sample size and diversity of healthcare settings, geographical and cultural contexts, and climate-related hazards profile to ensure statistical and theoretical coincide and its universality. Despite the composite indicators element of the HICRAF is simple enough for a public health facility's manager or eligible staff to conduct this self-assessment without extensive technical support requirements, a short orientation workshop for responders is highly recommended to ensure the input data quality and implication of the assessment. Besides the survey, this study suggests that it is crucial to conduct complementary interviews with the local public health facilities managers to collect possible emerging issues, local context, or cultural matters that the survey could not capture.

This research encapsulates unique lessons from Khon Kaen city on applying HICRAF's collaborative scenario planning and potential impact assessment of the local public health service. The profound capital of Khon Kaen city is not its economic development but a strong coalition among key stakeholders who have a shared understanding of local development and prospects. These strong collaborations and active stakeholders/actors are the key factors that enable political buy-in on future-oriented risk-informed planning. However, a public forum at the district level, where all local governments and citizens are equally represented in the discourse, is still missing in this research context and in reality.

Khon Kaen city 's experience on HICRAF shows that gaining stakeholders' buy-in on climate scenarios is equally important as urban development change scenarios. Although the climate trajectories involved rigorous data analysis of downscaling climate analysis and expert consultations, stakeholders were the key actors who shaped the bandwidth of future climate scenarios to adhere to their risk perceptions. Even though the climate model provides what is “possible” from regional and global viewpoints but at the local level, people need what so-called “reasonable worst-case” in linking what they experienced in the past and what they could expect in the future. This way encompasses the stakeholders seeing the potential impact on the same page and informs their level of risk perceptions and protective targets. Co-existing between strong collaboration and fraction & mismatches occur in the scope of land use planning, climate-risk management, and public health service operation. Therefore, this study recommends that Khon Kaen city re-define the scope of the Khon Kaen city comprehensive plan, covering the whole district administrative boundary rather than being limited within urbanized areas and their green buffer. This boundary adjustment shall enhance coordination among political bodies and allow policy integration among relevant actors and sectors on mainstreaming sustainable development and climate resilience. Moreover, identifying internal and intersectoral matches and mismatches in plans, policies, and responsible areas is crucial for creating robust policy design and decision-making. Therefore, this study emphasizes the importance of policy interactions analysis (matrix analysis), particularly among spatial planning, climate change and urban development domains (such as the public health sector), to promote the design of policies and measures that are beneficial and effective for all parties in both Business as Usual and unusual situations. Exploration of no-regret measures/policies should be prioritized in order to encompass robust decision making and reduce overlapping and inconsistencies of relevant agencies and local governments, usually working in the same space and time. In these regards, Khon Kaen city shall establish a district-level coordination body/working group to align all local governments and sectoral institutions' interests and needs, thus then be able to determine an overall future-oriented district development strategy under the Khoon Kaen Provincial Planning Committee. This setting may include a foundation of a technical working body that provides relevant scientific evidence and facilitates collaborative scenario planning to support public participation and scientific sound decision-making. A district-level platform shall be formulated for empowering stakeholders to have an open dialogue on their version of plausible and desirable futures, as well as how much risk or the potential impact they are willing to embrace and how to set the target(s) which all parties, local governments, and generations can be reached in their own pace and tiers. Although city-wide stakeholders found visualization of the future climate scenario and urban development changes is helpful, but still not enough for the public health sector. Cost-benefits analysis or risk aversion estimation of the spatial planning-based measures to minimize the potential impact is required to support decision-making and investment in climate resilience and adaptation, particularly in a developing country where public health care resources are at the margin. Even though Thailand's local public health care network operation promotes climate resilience, exposure and redundancy of the host of service network (CUP-host) should be highly prioritized. Fulfilling the desirable climate-resilient targets demands immense efforts that obviously exacerbate the underlying chronic symptoms of the Thai public health care system, understaffing and overloading capacity, particularly in tertiary care hospitals. Thereby mainstreaming the HICRAF in the existing reporting and monitoring systems with minimum burden to local public health services is an immense challenge.

The case of Khon Kaen city demonstrates that integrative and collaborative future-oriented scenario planning considering climate change and development change at the local critical infrastructure operation level is possible and gained stakeholder buy-in. Hence, this study is confident that HICRAF is not only revitalizing climate risk assessment practices but helping the public health sector understand and operationalize climate resilience with a solidity pathway. Furthermore, backcasting element of the HICRAF reinforces paradigm shifts in the local public health care operation, planning, investing and M&E process. Nonetheless, many research domains are needed to be fulfilled in order to strengthen the robustness of the HICRAF or replicate/modify HICRAF to other critical infrastructure sectors, such as developing sectoral or local benchmark of the relevant indicators, cost-benefits analysis (or risk aversion) in risk mitigation measures, high resolutions of climate-related hazards analysis, inclusiveness and intergeneration justice in future-oriented scenario planning. In terms of public health policy implications, besides the well-accepted proposed roadmaps and planning framework (HICRAF), this research also fills the gaps in the existing WHO guidelines and the Thai HNAP in addressing integrative climate resilience planning and calling for revisiting investment practices in public health infrastructure and services. From a spatial planning perspective, this study underscores the need for collaborative scenario planning among local development domains at the district and inter-sectoral levels in order to align development agendas, interests, social groups, and generations to enhance robust decision-making for a resilient climate future.

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- Figure 5.20a https://bit.ly/2Q6SgAw (accessed 20.01.2020)
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- Figure 5.20f Own photo
- Figure 5.20g Suhyeon Choi https://unsplash.com/photos/ka0v56vwwnw(accessed 19.10.2021)
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- Figure 5.22c Zachary Olson https://unsplash.com/photos/iPjAS-aTBdE (accessed 19.10.2021)
- Figure 5.22d https://bit.ly/3he2xpA (accessed 01.01.2020)
- Figure 5.22e Own photo;
- Figure 5.22f Mostafa Meraji https://unsplash.com/photos/X0yKdR_F9rM (accessed 19.10.2021)
- Figure 5.22g https://bit.ly/2RApYPh(accessed 01.01.2020)

Annex

Annex 1 Climate risk key terms and definition based on IPCC AR5 (2014a)

Risk - The potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. Risk results of the interaction among vulnerability, exposure, and hazard. In this study, the term risk is used primarily to refer to the risks of climate change impacts.

Hazard - The potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources. The term hazard usually refers to climate-related physical events or trends or their physical impacts in this report.

Exposure - The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected.

Vulnerability - The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

- **Contextual vulnerability (Starting-point vulnerability)**
  A present inability to cope with external pressures or changes, such as changing climate conditions. Contextual vulnerability is a characteristic of social and ecological systems generated by multiple factors and processes (O'Brien et al., 2007).
- **Outcome vulnerability (End-point vulnerability)**
  Vulnerability as the end point of a sequence of analyses beginning with projections of future emission trends, moving on to the development of climate scenarios, and concluding with biophysical impact studies and the identification of adaptive options. Any residual consequences that remain after adaptation has taken place, define the levels of vulnerability (Kelly and Adger, 2000; O'Brien et al., 2007).

Sensitivity: The degree to which a system or person, or community is affected, either adversely or beneficially, by climate variability or change. The effect may be direct or indirect.

Coping capacity - The ability of people, institutions, organizations, and systems, using available skills, values, beliefs, resources, and opportunities, to address, manage, and overcome adverse conditions in the short to medium term.

Adaptive capacity - The ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences.

Impacts (Consequences, Outcomes) - Effects on natural and human systems. In this report, the term impacts is used primarily to refer to the effects on natural and human systems of extreme weather and climate events and of climate change. Impacts generally refer to effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services, and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific time period and the vulnerability of an exposed society or system. Impacts are also referred to as consequences and outcomes. The impacts of climate change on geophysical systems, including floods, droughts, and sea level rise, are a subset of impacts called physical impacts.

Annex 2 Landuse ratio of the draft comprehensive plan of Khon Kaen city (DPT,2018: 5-6)

Land-use type	Percentage
Low-density residential area	22.07
Medium-density residential area	5.50
Commercial and high-density residential area	3.09
Rural and agriculture	21.63
Rural and agriculture conservation	24.35
Open space, recreation and environmental quality preservation	1.96
Educational institutions	4.04
Open space and environmental quality preservation	2.19
Cultural promotion and heritage conservation	0.10
Religion institutions	0.61
Government, public utilities and infrastructures	2.71
Others	11.75

Annex 3 List of stakeholders participating in diagnosing the current context & shortcoming development during May-July 2018

Group of stakeholders	Agencies/Institutes	Name and designation
National government	Department of Public Works and Town & Country Planning (DPT)	Mrs. Nantana Jamjod, Chief of the 3rd Comprehensive Plan Group Mr.Sukot Rattanawan, Planner – Practioner level
	Department of Public Works and Town & Country Planning	Dr.Arkarlat Kunvitaya, Director of Urban Planning Engineer
	Office of Transport and Traffic Policy and planning	Mr.Nirand Ketkaew, Director of regional transport and traffic promotion office
Provincial government	Khon Kaen Provincial Strategy Office	Mr.Thanakorn Toso, Representative of Khon Kaen provincial strategy office
	Office of Public Works and Town & Country Planning, Khon Kaen	Mr.Surapong Khamtanit, Planner
	Office of Disaster Prevention and Mitigation, Khon Kaen Province	Mr.Chatnarong Siriporn Na Ratchasrima, Chief
	Office of Natural Resources and Environment, Khon Kaen Province	Mr.Pichit Sombatmak, Director
Local government	Khon Kaen City Municipality	Mr.Thirasak Thikhayuphan, Mayor
Private sector	The Khon Kaen Chamber of Commerce	Mr.Khemchart Somjaiwong, Chairman (2018)
	Khon Kaen Real Estate Association (KKREA)	Mr.Channarong Buristrakul, President *(2018)*
Academia	Faculty of engineer, Department of civil engineering, Khon Kaen University (Transportation engineer expert - LRT project consultant)	Assoc. Prof. Pongrid Klungboonkrong, Deputy Director for Administrative Affairs, SIRDC - Sustainable Infrastructure Research and Development Centre
	Faculty of Architecture, Urban planning department, Khon Kaen University	Assoc. Prof. Rawee Hanpachern, Lecturer & Co-founder of Khon Kaen City Development (KKTT) Co., LTD
	Faculty of Humanities and Social Sciences, Khon Kaen University	Asst.Prof.Dr.Thanapauge Chamaratana, Lecturer

Annex 4 List of local primary infrastructure operators/managers

Critical infrastructure	Agencies/Institutes	Name and designation
(grid) Electricity	Provincial Electricity Authority Khon Kaen 2 (Mailwan Branch)	3 Representatives
Waterwork and water resources management	Regional 6 Waterwork Office	Mr.Serm Huekkhuntod, Director
	Nong Wai Operation and Maintenance Office, Khon Kean, Royal Irrigation Department	Mr.Songwut Kitworawut,Chief of Nong Wai Operation and Maintenance Office
	Faculty of Engineer, Khon Kaen University	Asst. Prof. Dr. Kittiwet Kuntiyawichai, Lecturer
Communication	TOT Khon Kaen	Mr. Kowith Sermdamrongsak, Manager
	Telecommunication expert (Private company)	Mr.Jaruwat Charoenlapkit

Annex 5 List of stakeholders participating in the process of scenarios formulation & validation, plausible scenario selection, target setting and spatial planning-based measures preference appraisal

Group of stakeholders	Agencies/Institutes	Name and designation	Scenario formulation (Step 3)[66]	Possible scenarios validation & Trend scenario selection(Step 4)[67]	Target setting and proposed measures identification (Step 5)[68]	Trend scenarios storylines validation (Step 4) [69]	Preference measures appraisal (Step 6)
National government	Department of Public Works and Town & Country Planning	Mrs. Nantana Jamjod, Chief of the 3rd Comprehensive Plan Group	■			■	■
		Mr.Sukot Rattanawan, Planner - Profressional level, Officer, 3rd Comprehensive Plan Group	■	■	■		
		Mrs. Pochanie Kajonpredanon, Senior Advisor		■	■		
Provincial government	Khon Kaen Provincial Strategy Office	Mr.Thanakorn Toso, Officer	■				

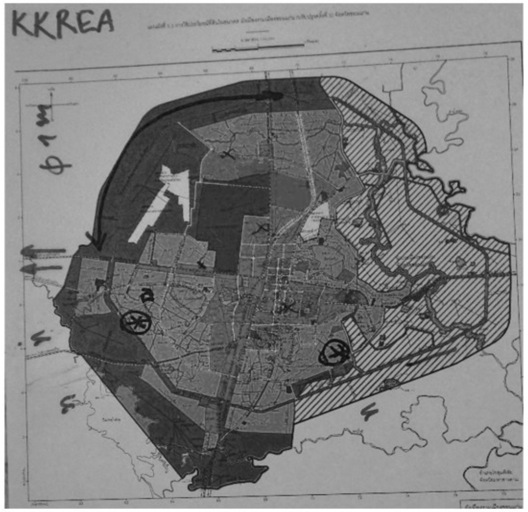
[66] In May 2018
[67] During 4-18 March 2019
[68] Target setting discussion (4-18 March 2019)
[69] Validation discussion during 5-13 February 2020 and focus group workshop on 1 March 2020

Group of stakeholders	Agencies/Institutes	Name and designation	Scenario formulation (Step 3)[66]	Possible scenarios validation & Trend scenario selection(Step 4)[67]	Target setting and proposed measures identification (Step 5)[68]	Trend scenarios storylines validation (Step 4)[69]	Preference measures appraisal (Step 6)
	Khon Kaen Province	Dr. Somsak Changtragul, Khon Kaen Province Governor					
	Provincial Administration Organization	Mrs.Pattanawadee Viriyaphiya, Chief of Administrative Office					
	Office of Public Works and Town & Country Planning, Khon Kaen	Mr.Surapong Khamtanit, Planner					
	Office of Disaster Prevention and Mitigation, Khon Kaen Province	Mr.Chatnarong Siriporn Na Ratchasrima, Chief					
		Mr.Chanwit Pradubwong, Senior Engineer, Chief of disaster prevention and operation					
	Office of Natural Resources and Environment, Khon Kaen Province	Mr.Pichit Sombatmak, Director					
	Khon Kaen Office of Provincial Public Health	Ms.Tewaruck Phukrongnak, Officer					
		2 Representatives					
	Khon Kaen Hospital	Dr.Chanchai Chanworachaikul, M.D., Director					
Local government	Khon Kaen City Municipality	Mr.Thirasak Thikhayuphan, Mayor					
		Mr.Julnop Thongsopit, Deputy Mayor of Khon Kaen City					
	Sila Town Municipality	Dr. Yodying Chantanapimp, Mayor					
	Ban Thum Town Municipality	Mr. Thammarat Chaita, Director of engineering division					
	Ban Ped Subdistrict Municipality	Dr.Chakarin Akkhasetthan, Director of engineering division					
	Pralub Subdistrict Municipality	Mr.Chalermchai Keawkrachang, Director of engineering division					

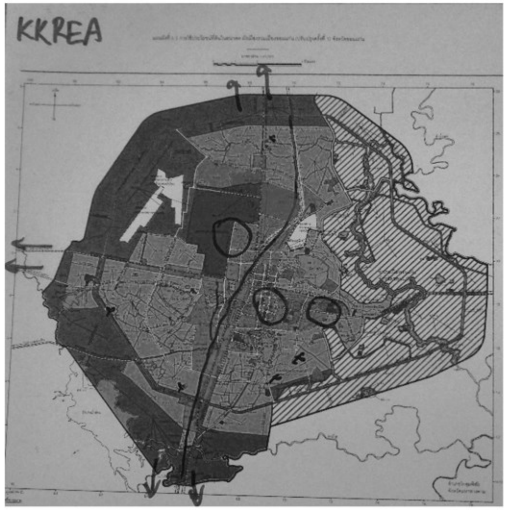
Group of stakeholders	Agencies/Institutes	Name and designation	Scenario formulation (Step 3)[66]	Possible scenarios validation & Trend scenario selection(Step 4)[67]	Target setting and proposed measures identification (Step 5)[68]	Trend scenarios storylines validation (Step 4) [69]	Preference measures appraisal (Step 6)
	Muengkao Subdistrict Municipality	Mr.Wichan Srilawan, Chief of Disaster Prevention				■	■
Private sector	The Khon Kaen Chamber of Commerce	Mr.Khemchart Somjaiwong, Chairman (2018)	■	■	■	■	■
	Khon Kaen Real Estate Association (KKREA)	Mr.Channarong Buristrakul, President	■				
Academia	Faculty of engineer, Department of civil engineering (LRT project consultant), Khon Kaen University	Assoc. Prof. Pongrid Klungboonkrong (Transportation engineering) Deputy Director for Administrative Affairs, SIRDC - Sustainable Infrastructure Research and Development Centre	■				
	Faculty of Humanities and Social Sciences, Khon Kaen University	Asst.Prof.Dr.Thanapauge Chamaratana[70]		■	■	■	■
Journalist/Civil society	Khon Kaen Community for the Future Foundation	Mr.Jachoernluk Pradubpetch, Secretatriat and Chief editor of Esan-Biz				■	■

[70] civil society incline

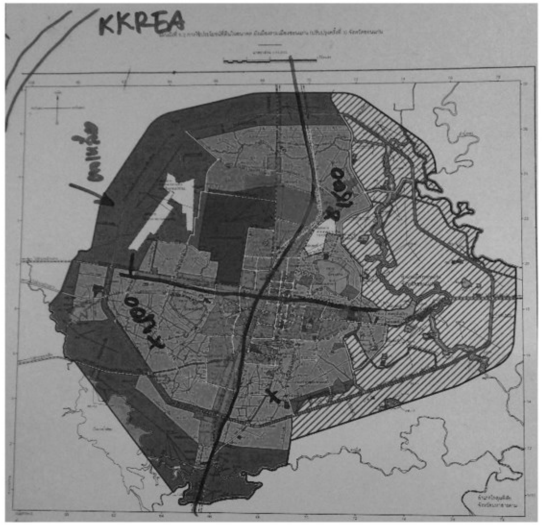
Annex 6 A sample of stakeholder land-use change envisioning



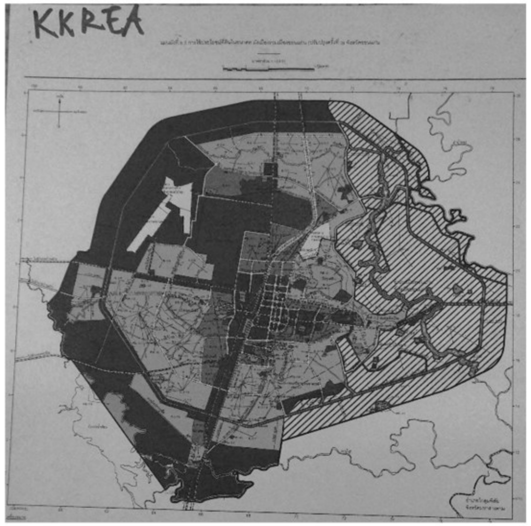
Snap shot 1



Snap shot 2



Snap shot 3



Snap shot 4

Annex 7 List of advisory experts involved in local climate scenarios development process

Group of stakeholders	Agencies/Institutes	Name and designation
National level	Department of Disaster Prevention and Mitigation	Deputy Director-General
	Hydro – Informatics Institute (HII)	Dr.Winai Chaowiwat, Water resources informatics division, researcher
Regional & Provincial level	Nong Wai Operation and Maintenance Office, Khon Kean, Royal Irrigation Department	Mr.Songwut Kitworawut Chief of Nong Wai Operation and Maintenance Office
	Regional Irrigation Office 6	Mr. Wanlop Kannika Chief of Water Resource Management Group, Water management and maintenance section
	Regional underground water 4	Mrs.Anchalee Pongsatitpat Director of operation section, Regional underground water 4

Annex 8 Dimensionless unit hydrograph calculation based on Hydrology Division (2009:2,11)

$$Tp = a\,(LLc/\sqrt{s}\,)^{b}$$

$$Qp/A = c\,(Tp)^{d}$$

when

Tp = Time from beginning of rise to the peak (Peak time)

Qp = Peak discharge (m^3/s/mm)

a = Catchment area (sq.km)

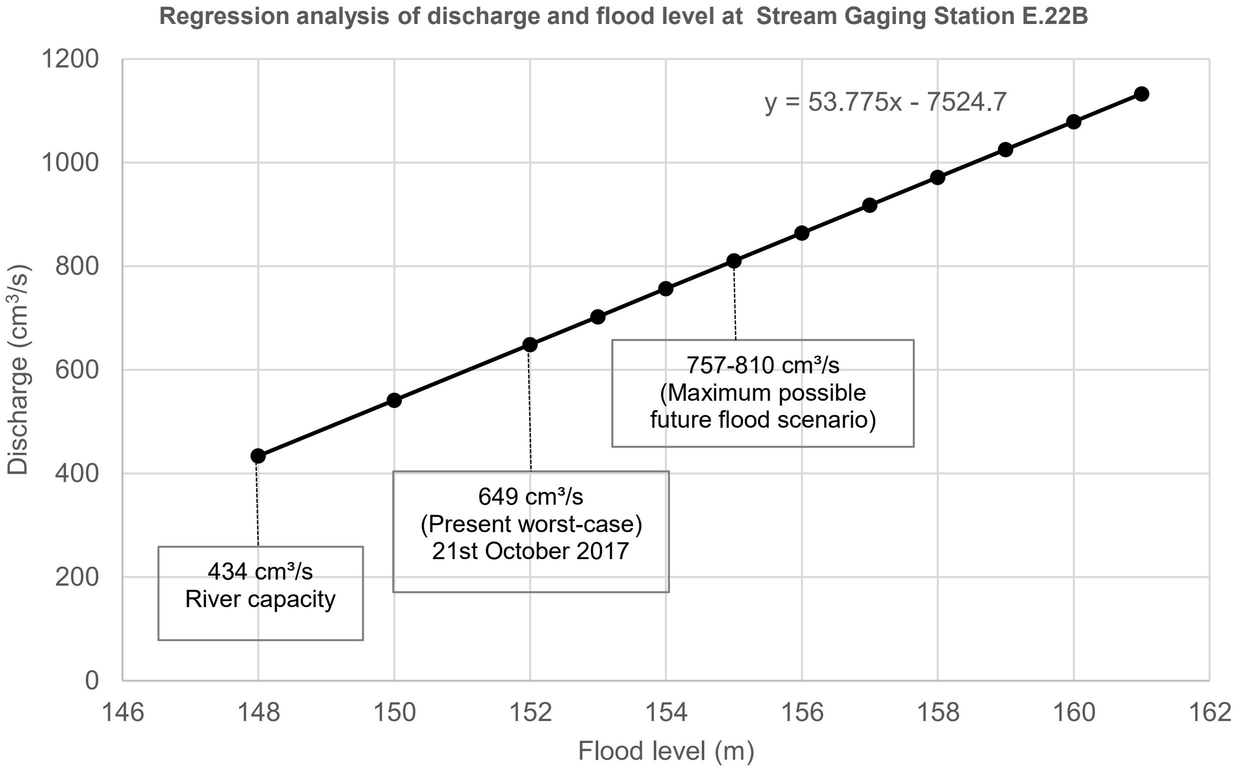
L = Main channel length (km)

Lc = Distance from basin centroid to mouth (km)

S = Main channel slop

a, b, c, d is regression coefficient of each watershed

Annex 9 Regression analysis of discharge and flood level at stream gaging station E.22B based on Unit Hydrograph calculation



Annex 10 List of experts/practitioners interviews for composite indicators identification

Expert groups	Institutions/agencies	Name/ Designation
National public health	Ministry of Public Health	Mr. Watchai Charunwatthana Director of Health Economics and Security
	Design and construction division, Department of Health service support, Ministry of Public health	Mr.Watthana Suthiranart, Special professional architect
Provincial public health	Khon Kaen Office of Provincial Public Health	Ms.Tewaruck Phukongnak, Officer
Local public health facility	Khon Kaen Hospital	Dr.Chanchai Chanworachaikul., M.D., Director
	Pralub Sub-district Health Promotion Hospital	Director
	Beungnium Sub-district Health Promotion Hospital	Director
Local academia	Faculty of Public Health, Khon Kaen University	Assoc. Prof. Dr. Uraiwan Inmuong
University hospital - Bangkok flood 2011 affected hospital	Thammasart Hospital	Dr.Pharuhat Tor-udom, M.D:, Director

Annex 11 List of health experts participating in the draft composite indicator review and indicators weighting scheme

Expert groups	Institutions/agencies	Name/ Designation
National government	Public Health Emergency Division, Ministry of Public Health	Deputy of Public Health Emergency Division, Ministry of Public health
	Office of the Expert Committee, Department of Health	Ms.Siriwan Chandanachulaka, Acting public health expert, environmental health
	Design and Construction Division, Department of Health Service Support, Ministry of Public Health	Mr.Watthana Suthiranart, *Special professional architect*
Regional and provincial government	Office of Health Service Support 7, Khon Kaen Province	Mr.Boonpeng Yodboonma, Director
Bangkok flood 2011 experience	Thammasart Hospital	Dr.Pharuhat Tor-udom, M.D., Director
	Golden Jubilee Medical Center, Faculty of Medicine Siriraj Hospital of Mahidol University	Yingyos Padchimpetch, Chief of engineering service section

Annex 12 Selected normalization schemes for the potential impact assessment

Normalization scheme	Formula	Explanation
Distance to target (Talukder et al.,2017)	$N_{ias} = \frac{X_{ias}}{Target\ X_{ias}}$	Where N_{ias} = normalized value of indicator *i* for a potential impact pillar, X_{ias} = variable *X* for indicator *i* for a potential impact pillar
Proportionate (Talukder et al.,2017)	$\frac{I_i}{\sum_i I_i}\ 0 < N_{ias} < 1$	Where N_{ias} = normalized value of indicator *i* for a potential impact pillar, I_i = indicator value, $\sum_i I_i$ = sum of the indicators

Annex 13 List of MoPH's public health care facilities in the study area and their questionnaire respondent status

Location	Code	Public Healthcare Facility	Service Hierarchy	KKH CUP network	Questionnaire respondent
Zone 1	KK05	Beungniam Sub-district Health Promotion Hospital	Primary Care Unit	Yes	Yes
Zone 1	KK11	Ban Kok Sub-district Health Promotion Hospital	Primary Care Unit	Yes	Yes
Zone 1	KK13	Sila Sub-district Health Promotion Hospital	Primary Care Unit	Yes	Yes
Zone 1	KK14	Pralub Sub-district Health Promotion Hospital	Primary Care Unit	Yes	Yes
Zone 1	KK23	Ban Phue Sub-district Health Promotion Hospital	Primary Care Unit	Yes	Yes
Zone 1	KK24	Nong Toom Sub-district Health Promotion Hospital	Primary Care Unit	Yes	Yes
Zone 1	KK26	Khon Kaen Hospital 2 (Sirithammikawat Temple Branch)	Primary Care Unit	Yes	**No**
Zone 1	KK27	Koksi Sub-district Health Promotion Hospital	Primary Care Unit	Yes	No
Zone 1	KK28	Non Thon Sub-district Health Promotion Hospital	Primary Care Unit	Yes	**No**
Zone 2	KK10	Muengkao Sub-district Health Promotion Hospital	Primary Care Unit	Yes	Yes
Zone 2	KK12	Thapra Sub-district Health Promotion Hospital	Primary Care Unit	**No**	Yes
Zone 2	KK15	Ban Donbom Sub-district Health Promotion Hospital	Primary Care Unit	Yes	Yes
Zone 2	KK16	Don Chang Sub-district Health Promotion Hospital	Primary Care Unit	Yes	Yes
Zone 2	KK29	Don Hun Sub-district Health Promotion Hospital	Primary Care Unit	**No**	**No**
Zone 2	KK30	Banwa Sub-district Health Promotion Hospital	Primary Care Unit	Yes	**No**
Zone 2	KK31	Ban Nong Ya Preak Sub-district Health Promotion Hospital	Primary Care Unit	**No**	**No**
Zone 2	KK32	Ban Nong Bua Di Mi Sub-district Health Promotion Hospital	Primary Care Unit	**No**	**No**
Zone 3	KK01	Chatapadung Medical Center (Khon Kaen Hospital)	Primary Care Unit	Yes	Yes
Zone 3	KK06	Hua Thung Primary Care Center	Primary Care Unit	Yes	Yes
Zone 3	KK07	Health Promotion Center 7, Khon Kaen	Specialized Care	**No**	Yes
Zone 3	KK08	Nong Wang Medical Center (Khon Kaen Hospital)	Primary Care Unit	Yes	Yes
Zone 3	KK17	Ban Ped Sub-district Health Promotion Hospital	Primary Care Unit	Yes	Yes
Zone 3	KK21	Khon Kaen Hospital	Tertiary	Yes	Yes
Zone 3	KK22	Khon Kaen Rajanagarindra Psychiatric Hospital	Specialized Care	**No**	Yes
Zone 3	KK25	Pracha Samosorn Medical Center (Khon Kaen Hospital)	Primary Care Unit	Yes	Yes
Zone 4	KK02	Thanyarak Khon Kaen Hospital	Specialized Care	**No**	Yes
Zone 4	KK03	Mittrapap Medical Center (Khon Kaen Hospital)	Primary Care Unit	Yes	Yes
Zone 4	KK04	Ban Thum Sub-district Health Promotion Hospital	Primary Care Unit	Yes	Yes
Zone 4	KK09	Ban Nong Kung Community Health Center	Primary Care Unit	Yes	Yes

Location	Code	Public Healthcare Facility	Service Hierarchy	KKH CUP network	Questionnaire respondent
Zone 4	KK18	Dang-yai Sub-district Health Promotion Hospital	Primary Care Unit	Yes	Yes
Zone 4	KK19	Sumran Sub-district Health Promotion Hospital	Primary Care Unit	Yes	Yes
Zone 4	KK20	Sawathee Sub-district Health Promotion Hospital	Primary Care Unit	Yes	Yes
Zone 4	KK33	Non Moung Sub-district Health Promotion Hospital	Primary Care Unit	Yes	No
Zone 4	KK34	Ban Kho Sub-district Health Promotion Hospital	Primary Care Unit	Yes	**No**
Zone 4	KK35	Ban Sum Chan Sub-district Health Promotion Hospital	Primary Care Unit	Yes	**No**
Zone 4	KK36	Non Rang Sub-district Health Promotion Hospital	Primary Care Unit	Yes	**No**

Annex 14 List of in-depth interview participating public health care facilities

Rational	Public health facilities	Informants
Location: Zone 1 Service level: Primary care unit	Beungnium Sub-district Health Promotion Hospital	Mrs. Usaneepan Sudsaeng, Nurse (Special Professional level)
Location: Zone 2 Service level: Primary care unit – Node of service network	Muengkao Sub-district Health Promotion Hospital	Mr.Adul Kongsaten, Director
Location: Zone 3 Service level: Tertiary care, Advance hospital – CUP Host	Khon Kaen Hospital	Dr. Seksan Suwanpang, M.D., Deputy Director - Medical
Location: Zone 3 Service level: Specialized care, Health promotion unit	Regional Health Promotion Center 7 Khon Kaen	Ms. Watinee Chancharoen, Senior public health technical officer
Location: Zone 3 Service level: Primary care unit – Node of service network	Hua Tung Primary Care Unit	Mrs. Waranee Charoentrap, Director
Location: Zone 4 Service level: Primary care unit – Node of service network	Nongkung Town Community Health Center	Mrs. Napaporn Pinnok, Director
Location: Zone 4 Service level: Primary care unit	Ban Thum Sub-district Health Promotion Hospital	Mrs.Pattarapon Sornpunya, Nurse (professional level)

Annex 15: List of participants of the local experts dialogue on future-oriented risk-informed planning of Khon Kaen city: Reflection on planning approach and proposed spatial planning based measurement (organized by Khon Kaen Community for the Future Foundation and College of Local Administration, Khon Kaen University (COLA) on the 1st of March 2020 at COLA)

Group of Experts	Agencies/Institutes	Name and designation
Local government	Khon Kaen City Municipality	Mr.Julnop Thongsopit, Deputy Mayor of Khon Kaen City
		Mr. Tawatchai Wanapitakkul, Director of Engineer division
Private sector	Khon Kaen Real Estate Association (KKREA)	Mr.Channarong Buristrakul, President (he is also KKTT Board of committee Vice-chairman of The Khon Kaen Chamber of Commerce)
	Khon Kaen Industry Association	Mr.Wuttikrai Suwanvanit
	Tourism Council, Khon Kaen	Mr.Chakkrit Siripanitch
	The Khon Kaen Chamber of Commerce	Mr.Khemchart Somjaiwong, Former chairman
	Khon Kaen Transit System Co.,LTD (KKTS)	Mr.Panya Kerdsak Na Wangnoy
Private sector + Academia	KhonKaen City Development Company Limited: KKTT*)* and College of Local Administration, Khon Kaen University	Mr. Suradech Taweesangsakulthai, associate dean and Chairman of KhonKaen City Development Company Limited: *KKTT*)
Academia	College of Local Administration, Khon Kaen University	Assoc. Prof. Supawatanakorn Wongthanavasu
	Sirindhorn College of Public Health Khon Kaen	Mrs. Jiranan Parkpien
Civil society	Senior social activist and independent researcher	Mr.Sompop Boonnak
	Khon Kaen Community for the Future Foundation	Mr.Jachoernluk Pradubpetch, Secretatriat (Journalist)
		Dr.Suvit Laohasiriwong, Chairman (Academia)

Dialogue on future-oriented risk-informed planning of Khon Kaen city: Reflection on planning approach and proposed spatial planning based measurement, 1st of March 2020 at COLA

Source: Khon Kaen Community for the Future Foundation

Annex 16 List of plan and policy review[71]

Level	Plan and Policy documents
National	Thailand's 20-Year National Strategy (Public health) (2018-2037)
	12th National Economic and Social Development Plan (2017- 2021)
	Guideline for cascading the strategy on regional urban and economic area development under the 12th NESDP into action (2019)
	Thailand National Spatial Development Plan 2057 • Regional Spatial Plan • Sub-regional Spatial Plan
	National Master Plan on Disaster Prevention and Mitigation 2015
	National Climate Change Master Plan (2015-2050)
Regional	Regional Development Plan 2017-2022 (review version)
	Strategic Plan for the Northeastern Province Roi Et - Khon Kaen - Mahasarakham - Kalasin
Provincial	Khon Kaen Provincial Development Plan 2018 – 2022
	Provincial Health Strategy 2020-2022
	Khon Kaen Smart City Strategy
	KhonKaen Smart City Master Plan 2029
	Direction of Khon Kaen Province, 2022: Infrastructure, personnel management, transportation and traffic (under the infrastructure development strategy of Thailand 2015 – 2022 (Transport section))
	Provincial Local Development Plan (2017-2022), Khon Kaen Provincial Administrative Organization
Local	Strategic plan on the development of local administrative organizations in Khon Kaen province (2018-2022)
	3rd Revision of Khon Kaen City Comprehensive Plan (2018)
	Khon Kaen City Municipality Development Strategy (2017 – 2020)
	Muengkao Sub-district Local Development Plan (2018 – 2021)
	Ban Ped Sub-district Municipality Development Strategy (2017 – 2020)
	Sila Town Municipality Development Strategy (2017 – 2019)
	Pralub Sub-district Municipality Development Strategy (2017 – 2019)
	Don Chang Sub-district Local Administrative Organization Local Development Plan (2017 – 2021)
	Sumran Sub-district Municipality Local Development Plan (2017 – 2022)
	Tha Pra Sub-district Municipality Local Development Plan (2017 – 2022)
	Sawathi Sub-district Municipality Local Development Plan (2017 – 2021)
	Don Hun Sub-district Municipality Local Development Plan (2017 – 2022)
	Non Thon Sub-district Local Development Plan (2017 – 2022)
	Ban Kho Sub-district Local Development Plan (2015 – 2017)
	Kok Si Sub-district Local Administrative Organization Local Development Plan (2017 – 2019)
	Nong Toom Sub-district municipality Vision and Misssion on Local development
Sectoral	Thailand's 20-Year National Strategy (Public health)
	National Strategy on Adaptation in the Health Sector 2017-2030 (HNAP)
	Ministry of Public Health Strategy, Budget year 2017
	Service plan 2017- 2021

[71] Remark: The following documents can not be accessed online: Banwa Sub-district Local Administrative Organization Local Development Plan (2017 – 2019); Dangyai Sub-district Local Administrative Organization; Tha Pra Sub-district Local Administrative Organization Local Development Plan (2017 – 2022); Tha Pra Sub-district Local Administrative Organization Local Development Plan (2017 – 2022); Ban Thum Town Municipality Local Development Plan (2017 – 2022)

Annex 17 Future possible bandwidth of the local water supply scarcity
a) Local drought index adapted from RID standard value based on annual rainfall (mm/year).

Index	Annual rainfall (mm/yr)
Extreme drought	871.4
Drought	924.2
Quite drought	977.0 – 1,029.8
O.K. level	1,082.6 -1,135.3
Average	1,188.1
Good rain	1,240.9-1,346.5
Very good	1,399.3 -1,452.0

b) 90th percentile average annual rainfall data of RCP 4.5 and RCP 8.5 climate projection datasets during 2021-2050

Year	Maximum	Minimum
2021	717.2	823.2
2022	828.8	830.6
2023	895.5	1000.7
2024	838.8	960.1
2025	934.8	945.1
2026	896.4	921.2
2027	983.7	987.1
2028	782.0	802.7
2029	844.5	882.3
2030	707.5	962.3
2031	757.7	990.1
2032	981.6	982.1
2033	1024.0	1042.0
2034	897.4	975.1
2035	742.8	953.0
2036	940.1	1015.3
2037	907.5	920.2
2038	816.5	1005.5
2039	685.9	994.1
2040	897.0	1067.5
2041	1021.7	1026.8
2042	993.8	1220.0
2043	764.7	830.5
2044	1007.5	1066.4
2045	885.5	1017.3
2046	825.1	1043.8
2047	966.6	994.9
2048	944.1	959.2

Year	Maximum	Minimum
2049	926.9	947.9
2050	924.0	950.6

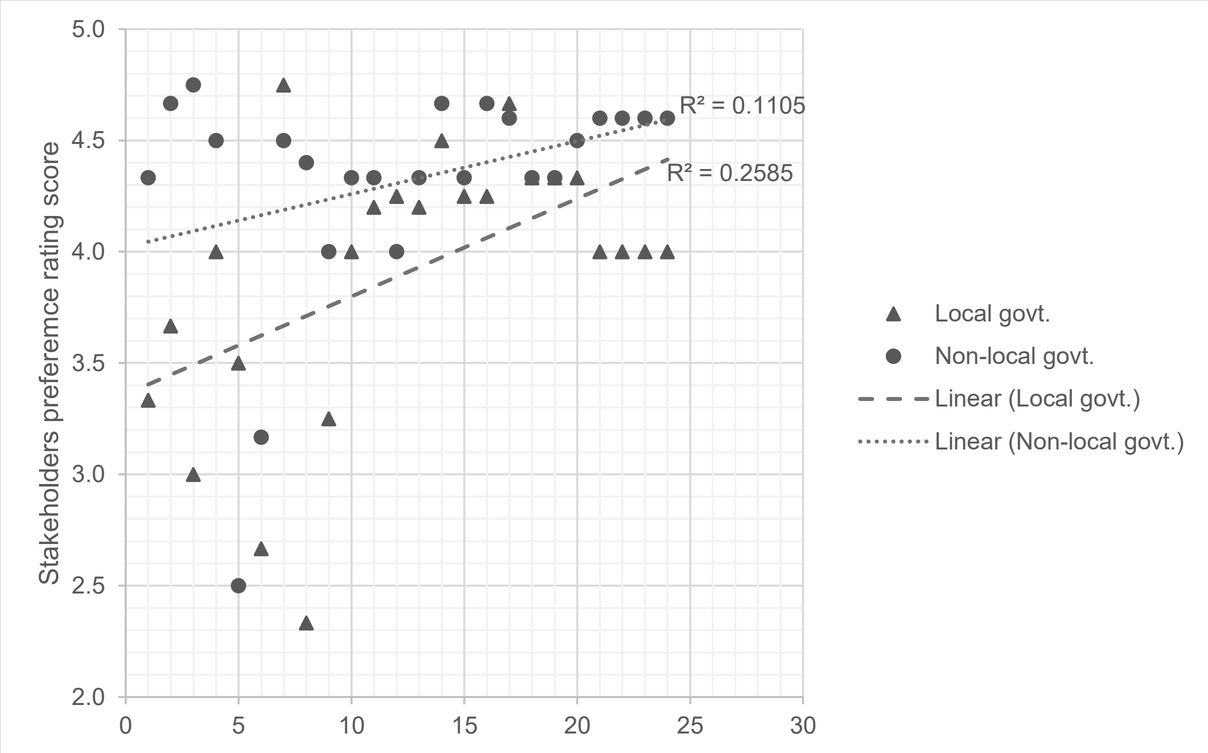
Annex 18 Stakeholders' preference on the proposed city-wide potential spatial planning-based *measures*

Aspects	List of spatial planning based measures	Preferred level
Exposure avoidance	1. Reinforce enforcement capacity and accountability of the land use zoning and relevant regulation (s)	4.0
	2. Develop publicly accepted hazard map and promote public communication and awareness-raising on the hazard map	4.3
	3. No LRT service (LRT yellow and green lines) in the flood-prone areas	4.0
	4. Initiate impact (burden) sharing agreement on flood management	4.4
	5. Encourage flood-prone area's inhabitants to relocate to safer-zone, e.g. throughout the existing affordable housing scheme or buyout programme	2.9
	6. Introduce selective retreat/stabilize the service capacity of critical infrastructures	3.0
Hazard mitigation	7. Promote vegetated floodplain conservation, e.g. natural protection zone, biodiversity promotion/education centre	4.6
	8. Obtain more flood retention area (e.g. civil contract)	3.6
	9. Link (small) water retention networks	3.6
	10. Promote water sport activities and investment	4.2
	11. Promote eco-agricultural tourism	4.3
	12. Promote blue-green infrastructure development and integration	4.1
	13. Promote Low impact development (LID) integration on development projects, e.g. Blue TOD or Spong district	4.3
	14. Reinforce municipal regulation in withdrawal right of building in vegetated floodplain and waterway areas	4.6
	15. Revise land excavation and land reclamation law(s)/regulation(s)	4.3
	16. Improve municipal regulation and local governments' cooperation on integrated wastewater management	4.5
Capacity enhancement	17. Improve water supply system and delivery network accessibility and efficiency	4.6
	18. Increase capacity of in-city small water supply reservoirs	4.3
	19. Link (small) water reservoirs network	4.3
	20. Promote housing (real estate) development projects	4.4
	21. Increase connectivity between the safer-zone and inner-city by extending the LRT yellow line and LRT green line	4.4
	22. Link Khon Kaen city with surrounding satellite cities	4.4
	23. Promote new business centres and hypermarkets	4.4
	24. Decentralize and enhance service capacity of public institutions and utilities	4.4

Annex 19 Local governments and non-local government perspective on the preference of the proposed city-wide potential spatial planning-based measures

Aspects	List of spatial planning-based measures	Preferred level	
		Local govt.	Non-local govt.
Exposure avoidance	1. Reinforce enforcement capacity and accountability of the land use zoning and relevant regulation (s)	3.3	4.3
	2. Develop publicly accepted hazard map and promote public communication and awareness-raising on the hazard map	3.7	4.7
	3. No LRT service (LRT yellow and green lines) in the flood-prone areas	3.0	4.8
	4. Initiate impact (burden) sharing agreement on flood management	4.0	4.5
	5. Encourage flood-prone area's inhabitants to relocate to safer-zone, e.g. throughout the existing affordable housing scheme or buyout programme	3.5	2.5
	6. Introduce selective retreat/stabilize the service capacity of critical infrastructures	2.7	3.2
Hazard mitigation	7. Promote vegetated floodplain conservation, e.g. natural protection zone, biodiversity promotion/education centre	4.8	4.5
	8. Obtain more flood retention area (e.g. civil contract)	2.3	4.4
	9. Link (small) water retention networks	3.3	4.0
	10. Promote water sport activities and investment	4.0	4.3
	11. Promote eco-agricultural tourism	4.2	4.3
	12. Promote blue-green infrastructure development and integration	4.3	4.0
	13. Promote Low impact development (LID) integration on development projects, e.g. Blue TOD or Spong district	4.2	4.3
	14. Reinforce municipal regulation in withdrawal right of building in vegetated floodplain and waterway areas	4.5	4.7
	15. Revise land excavation and land reclamation law(s)/regulation(s)	4.3	4.3
	16. Improve municipal regulation and local governments' cooperation on integrated wastewater management	4.3	4.7
Capacity enhancement	17. Improve water supply system and delivery network accessibility and efficiency	4.7	4.6
	18. Increase capacity of in-city small water supply reservoirs	4.3	4.3
	19. Link (small) water reservoirs network	4.3	4.3
	20. Promote housing (real estate) development projects	4.3	4.5
	21. Increase connectivity between the safer-zone and inner-city by extending the LRT yellow line and LRT green line	4.0	4.6
	22. Link Khon Kaen city with surrounding satellite cities	4.0	4.6
	23. Promote new business centres and hypermarkets	4.0	4.6
	24. Decentralize and enhance service capacity of public institutions and utilities	4.0	4.6

a) Regression analysis stakeholders preference rating score on the city-wide spatial planning-based measures



Annex 20 KKPHO's preference on the public healthcare-specific proposed potential spatial planning-based measures

Aspects	Spatial planning-based measurements	Preference rating score
Exposure reduction	1. Limit the extension of services of the supernode in a flood-prone area	4.0
	2. Introduce selective retreat for high-risk public health facilities	2.0
	3. Limit further provision of service capacity in flood-prone areas	5.0
Capacity enhancement	4. Introduce resilient upgrading of health facility building and working system operation	4.0
	5. Increase service capacity and advancement of primary care units outside flood-prone areas (safer areas)	NA
	6. Assign supernode of the CUP-host as secondary service centre/unit or supply warehouse outside the flood-prone areas	3.0
	7. Assign alternate care sites outside flood-prone areas	1.0

Annex 21 Result of experts prioritization survey for composite indicators weighting (October – December 2020)

Vulnerability Indicators		Prioritization		Weighting value
		Average	SD	
Sensitivity	Over carrying capacity	3	1.7	0.20
	Variety of vulnerable patients	3	0.9	0.27
	Resource insufficiency	2	1.2	0.20
	Poor system conditions and maintenance of working systems	3	1.4	0.20
	Downtime of essential working systems	4	1.1	0.13
Coping capacity	Lack of flexibility & modularity	3	1.2	0.18
	Lack of diversity of suppliers	4	2.3	0.11
	Lack of redundancy	3	0.5	0.18
	Lack of responsiveness	2	0.5	0.21
	Lack of resource mobilization	3	1.6	0.18
	Lack of integration and coordination	4	2.1	0.14
Adaptive capacity	Lack of information	3	1.5	0.17
	Lack of preparedness and risk transfer	2	0.8	0.21
	Lack of participation and inclusiveness	2	1.0	0.21
	Lack of capacity development	2	0.7	0.21
	Lack of mainstreaming climate-risk in planning process	4	1.5	0.13
	Lack of monitoring &evaluation	5	1.1	0.08
Hazard indicators (budget allocation approach)		**Total budget 100 Million THB**		**Weighting value**
	Fluvial flood	47 Mio		0.32
	Pluvial flood			0.32
	Water supply scarcity	53 Mio		0.36

Annex 22 Reflection of scenario storylines in composite indicators assessment

Measures	Indicators	Sub-indicators	Assumptions/Rating score variations	
			Trend scenario	Desirable scenario
Trend & Desirable scenarios Hazard mitigation measures would possibly be undertaken by relevant agencies outside the public health care sector. Even though all measures were implemented, but outcomes could not guarantee hazards mitigation outcomes	H1: Fluvial Flood	H1.0: Fluvial Flood	Based on storyline	Based on storyline
	H2: Pluvial Flood	H2.0: Pluvial Flood	Based on storyline	Based on storyline
	H3: Water scarcity	H3.0: Water scarcity	Based on storyline	Based on storyline
Trend & Desirable scenarios A potential extension of health care facilities and advancement of service will be located in the existing (almost the same) location	E1: Exposure of public health facility's building(s)	E1.1: Exposure of public health facility's building(s) to fluvial flood	Remain status quo	Remain status quo
		E1.2: Exposure of public health facility's building(s) to pluvial flood	Remain status quo	Remain status quo
		E1.3: Exposure of public health facility's building(s) to water scarcity	Remain status quo	Remain status quo
Trend scenario: Remain status quo **Desirable scenario:** Physical upgrading of all health care facilities and working systems	E2: Exposure of Working systems	E2.1 Exposure of primary working systems	Remain status quo	Most of the internal working systems are located on the 2nd floor or higher
		E2.2 Exposure of secondary working systems	Remain status quo	Most of the internal working systems are located on the 2nd floor or higher
Trend scenarios: Urbanization and increasing population in all zones **Desirable scenarios:** • Limit development in Zone 1 and 2	V1: Over carrying capacity	V1.0: Balance between service capacity and service demand	Insufficient service capacity occurs in all area	Insufficient service capacity occurs in Zone 3 and 4, while Zone 1 and 2 have sufficient service capacity

Measures	Indicators	Sub-indicators	Assumptions/Rating score variations	
			Trend scenario	Desirable scenario
• Promote development in zone 3 and 4				
Trend and Desirable scenarios: • Conservative assumption	V2: Variety of vulnerable patients	V2.0: Variety of vulnerable patient types[72]	High level	High level
Trend and Desirable scenarios: Zero growth policy **Desirable scenario:** Improvement of financial and procurement management	V3: Resource insufficiency	V3.1: Insufficiency of financial resources for BaU operation	Remain status quo	Low level
		V3.2: Insufficiency of healthcare personnel for BaU operation	Insufficient service capacity occurs in all area	Insufficient service capacity occurs in Zone 3 and 4, while Zone 1 and 2 have sufficient service capacity
Trend scenario: Status quo **Desirable scenario:** Physical upgrading of health care facilities and working systems	V4: Poor system conditions and maintenance of working systems	V4.1: System conditions	Remain status quo	Very low level
		V4.2: System monitoring and reporting	Remain status quo	Very low level
		V4.3: Availability of trained staff/technician for system maintenance and reparation	Remain status quo	Very low level
		V4.4: Availability of maintenance resources	Remain status quo	Very low level
Trend and Desirable scenarios Status quo	V5: Downtime of or sensitive working systems	V5.0: Maximum downtime of sensitive working systems	Baseline level	Baseline level
Trend scenarios: Status quo **Desirable scenario:** Increase coping and adaptive capacity to minimize potential impact to a very low level, indicating a target by a representative of KKPHO. However, there are a few sub-indicators stated otherwise according to KKPHO	V6: Lack of flexibility & modularity	V6.1: Flexibility and modularity of key working systems	Remain status quo	Very low level
		V6.2: Connectivity (-ability) of sensitive working system with external devices/systems	Remain status quo	Very low level
		V6.3: One-stop service area with the highest protective level, in the case of hazards or high level of emergency	Remain status quo	Very low level
	V7: Lack of diversity of suppliers	V7.0: Diversity of suppliers of key working systems	Remain status quo	Very low level for all working system except,

[72] Respiratory ventilator/Oxygen-dependent or Dialysis dependency; Disability and self-movement difficulty; Elderly; Infant/Toddlers (0-5 year-old); Pregnancy women; Continuity medication treatment dependency; Local language proficiency; Mental illness; Others

Measures	Indicators	Sub-indicators	Assumptions/Rating score variations	
			Trend scenario	Desirable scenario
preference appraisal e.g.V7 and V8.8 (see section 5.3.2.2 (2)).				1) High level for medicine & medical supplies for primary care unit in all areas (because Khon Kaen Hospital centralizes it), for others remain the same, 2) Remain status quo for in grid electricity due to monopoly operation of state utility
	V8: Lack of redundancy	V8.1: Availability and capacity of (15) primary backup systems	Remain status quo	Very low level
		V8.2: Procurement of special vehicle type (e.g. Boat, amphibian, helicopter, drone) for carrying goods and passenger during emergency or hazards	Remain status quo	Very low level
		V8.3: Alternate safe accessible route(s	Remain status quo	Very low level
		V8.4: Procurement of a secondary backup system	Remain status quo	Very low level
		V8.5: Standard procedure for recording a patient medical data in the case of IT service	Remain status quo	Very low level
		V8.6: Using of runners (courier) as a backup for getting help from outside during communication systems failures	Remain status quo	Very low level
		V8.7: Shelter(s) on-site for staff and family in the case of hazards	Remain status quo	Very low level
		V8.8: Assignment of alternate care site(s)	Remain status quo	High
	V9: Lack of responsiveness	V9.1: Resources conservation plan implementation	Remain status quo	Very low level
		V9.2: Responsive plan for slow-onset natural hazards	Remain status quo	Very low level

Measures	Indicators	Sub-indicators	Assumptions/Rating score variations	
			Trend scenario	Desirable scenario
		V9.3: Business continuity plan implementation	Remain status quo	Very low level
		V9.4: Contingency plan implementation	Remain status quo	Very low level
		V9.5: Surge personnel capacity plan implementation	Remain status quo	Very low level
		V9.6: Evacuation plan implementation (both partial and full evacuation)	Remain status quo	Very low level
		V9.7: Self-help	Remain status quo	Very low level
	V10: Lack of resource mobilization	V10.1: Availability and accessibility of financial resources for disaster risk preparation	Remain status quo	Very low level
		V10.2: Volunteer and external help management plan implementation	Remain status quo	Very low level
		V10.3: Availability of resources for reconstruction /reparations and lag time for resuming to full operation	Remain status quo	Very low level
	V11: Lack of integration and coordination	V11.1: Existence and efficiency of internal Board of committee/working group on disaster risk management	Remain status quo	Very low level
		V11.2: Specific coordinator on disaster risk management	Remain status quo	Very low level
		V11.3: Patient referral and transfer agreement with other hospitals	Remain status quo	Very low level
		V11.4: Agreement and exercise on partial or full patient evacuation to other hospitals/facilities in the case of emergency or hazards	Remain status quo	Very low level

Measures	Indicators	Sub-indicators	Assumptions/Rating score variations	
			Trend scenario	Desirable scenario
		V11.5: Availability of automatically channels or systems for communicating and coordinating with utilities and key suppliers	Remain status quo	Very low level
	V12: Lack of Information	V12.1: Availability and accessibility of local hazard map and climate-related disaster risk database	Remain status quo	Very low level
		V12.2: Availability and accessibility of local future population and development projection dataset for long-term service planning	Remain status quo	Very low level
		V12.3: Availability and accessibility of information on local future climate-related disaster risks (floods and water supply scarcity)	Remain status quo	Very low level
	V13: Lack of preparedness and risk transfer	V13.1: Availability plan and long-term investment for increasing climate-related hazards resilience	Remain status quo	Very low level
		V13.2: Climate-related hazards risk insurance	Remain status quo	Very low level
		V13.3: Build Back Better plan implementation	Remain status quo	Very low level
	V14: Lack of participation and inclusiveness	V14.1: Community participation in disaster risk management planning	Remain status quo	Very low level
		V14.2: Disaster risk management planning and exercise with utilities, suppliers and other relevant agencies	Remain status quo	Very low level
	V15: Lack of capacity development	V15.1: In-house capacity building and awareness-raising on the importance of future climate-related disaster risk and resilience	Remain status quo	Very low level

Measures	Indicators	Sub-indicators	Assumptions/Rating score variations	
			Trend scenario	**Desirable scenario**
		V15.2: Training on working with no-electricity or limited resources	Remain status quo	Very low level
	V16: Lack of mainstreaming climate-risk in planning process	V16.1: Mainstreaming disaster risk management in an action plan or budget plan	Remain status quo	Very low level
		V16.2: Integration of the future climate-disaster risk impact information in the system maintenance plan and reparation budget	Remain status quo	Very low level
	V17: Lack of monitoring and evaluation	V17.0: Monitoring and evaluation	Remain status quo	Very low level

Annex 23 Potential impact classification

Hazard	Exposure	Vulnerability	Potential Impact (= H*E*V)
1	1	1	1.000
0.99	0.99	0.99	0.970
0.98	0.98	0.98	0.941
0.97	0.97	0.97	0.913
0.96	0.96	0.96	0.885
0.95	0.95	0.95	0.857
0.94	0.94	0.94	0.831
0.93	0.93	0.93	0.804
0.92	0.92	0.92	0.779
0.91	0.91	0.91	0.754
0.9	0.9	0.9	0.729
0.89	0.89	0.89	0.705
0.88	0.88	0.88	0.681
0.87	0.87	0.87	0.659
0.86	0.86	0.86	0.636
0.85	0.85	0.85	0.614
0.84	0.84	0.84	0.593
0.83	0.83	0.83	0.572
0.82	0.82	0.82	0.551
0.81	0.81	0.81	0.531
0.8	0.8	0.8	0.512
0.79	0.79	0.79	0.493
0.78	0.78	0.78	0.475
0.77	0.77	0.77	0.457
0.76	0.76	0.76	0.439
0.75	0.75	0.75	0.422
0.74	0.74	0.74	0.405
0.73	0.73	0.73	0.389
0.72	0.72	0.72	0.373
0.71	0.71	0.71	0.358
0.7	0.7	0.7	0.343
0.69	0.69	0.69	0.329
0.68	0.68	0.68	0.314
0.67	0.67	0.67	0.301
0.66	0.66	0.66	0.287
0.65	0.65	0.65	0.275
0.64	0.64	0.64	0.262
0.63	0.63	0.63	0.250
0.62	0.62	0.62	0.238
0.61	0.61	0.61	0.227
0.6	0.6	0.6	0.216
0.59	0.59	0.59	0.205
0.58	0.58	0.58	0.195
0.57	0.57	0.57	0.185
0.56	0.56	0.56	0.176
0.55	0.55	0.55	0.166
0.54	0.54	0.54	0.157
0.53	0.53	0.53	0.149
0.52	0.52	0.52	0.141
0.51	0.51	0.51	0.133
0.5	0.5	0.5	0.125
0.49	0.49	0.49	0.118
0.48	0.48	0.48	0.111
0.47	0.47	0.47	0.104
0.46	0.46	0.46	0.097
0.45	0.45	0.45	0.091
0.44	0.44	0.44	0.085
0.43	0.43	0.43	0.080
0.42	0.42	0.42	0.074
0.41	0.41	0.41	0.069
0.4	0.4	0.4	0.064
0.39	0.39	0.39	0.059
0.38	0.38	0.38	0.055
0.37	0.37	0.37	0.051
0.36	0.36	0.36	0.047
0.35	0.35	0.35	0.043
0.34	0.34	0.34	0.039
0.33	0.33	0.33	0.036
0.32	0.32	0.32	0.033
0.31	0.31	0.31	0.030
0.3	0.3	0.3	0.027
0.29	0.29	0.29	0.024
0.28	0.28	0.28	0.022
0.27	0.27	0.27	0.020
0.26	0.26	0.26	0.018
0.25	0.25	0.25	0.016
0.24	0.24	0.24	0.014
0.23	0.23	0.23	0.012
0.22	0.22	0.22	0.011
0.21	0.21	0.21	0.009
0.2	0.2	0.2	0.008
0.19	0.19	0.19	0.007
0.18	0.18	0.18	0.006
0.17	0.17	0.17	0.005
0.16	0.16	0.16	0.004
0.15	0.15	0.15	0.003
0.14	0.14	0.14	0.003
0.13	0.13	0.13	0.002
0.12	0.12	0.12	0.002
0.11	0.11	0.11	0.001
0.1	0.1	0.1	0.001
0.09	0.09	0.09	0.001
0.08	0.08	0.08	0.001
0.07	0.07	0.07	0.000
0.06	0.06	0.06	0.000
0.05	0.05	0.05	0.000
0.04	0.04	0.04	0.000
0.03	0.03	0.03	0.000
0.02	0.02	0.02	0.000
0.01	0.01	0.01	0.000
0	0	0	0.000

Potential impact

Level	Value
High	>0.422 - 1.000
Medium	> 0.125 - 0.422
Low	>0.016 - 0.125
Very low	0.000 - 0.016

Annex 24 Indicator level (equal interval) classification in accordance with the weighted normalization schemes

a) Hazard indicators

Level	Value			
	Overall	H1: Fluvial Flood	H2: Pluvial Flood	H3: Water scarcity
High	0.76 – 1.00	0.97 - 1.28	0.97 - 1.28	1.09 - 1.44
Medium	0.51 – 0.75	0.65 - 0.96	0.65 - 0.96	0.73 - 1.08
Low	0.26 - 0.50	0.33 - 0.64	0.33 - 0.64	0.37 - 0.72
Very low	0.00 - 0.25	0.00 - 0.32	0.00 - 0.32	0.00 - 0.36

b) Exposure indicators

Level	Value		
	Overall	E1: Exposure of public health facility's building(s)	E2: Exposure of working systems
High	0.76 – 1.00	1.51 – 2.00	1.51 - 2.00
Medium	0.51 – 0.75	1.01 – 1.50	1.01 – 1.50
Low	0.26 - 0.50	0.51 – 1.00	0.51 - 1.00
Very low	0.00 - 0.25	0.00 – 0.50	0.00 – 0.05

c) Vulnerability indicators

- **Overall Vulnerability**

Level	Overall
High	0.76 – 1.00
Medium	0.51 – 0.75
Low	0.26 - 0.50
Very low	0.00 - 0.25

- **Sensitivity-related indicators**

Level	Value					
	Overall	V1: Over carrying capacity	V2: Variety of vulnerable patients	V3: Resource insufficiency	V4: Poor system conditions and maintenance of working systems	V5: Downtime of essential working systems
High	3.01 – 4.00	0.61 - 0.80	0.81 - 1.07	0.61 - 0.80	0.61 - 0.80	0.41 - 0.53
Medium	2.01 – 3.00	0.41 - 0.60	0.54 - 0.80	0.41 - 0.60	0.41 - 0.60	0.28 - 0.40
Low	1.01 – 2.00	0.21 - 0.40	0.28 - 0.53	0.21 - 0.40	0.21 - 0.40	0.14 - 0.27
Very low	0.00 – 1.00	0.00 - 0.20	0.00 - 0.27	0.00 - 0.20	0.00 - 0.20	0.00 - 0.13

- **Coping capacity-related indicators**

Level	Value						
	Overall	V6: Lack of flexibility & modularity	V7: Lack of diversity of suppliers	V8: Lack of redundancy	V9: Lack of responsiven ess	V10: Lack of resource mobilization	V11: Lack of integration &coordinati on
High	3.01 – 4.00	0.55 - 0.71	0.33 - 0.43	0.55 - 0.71	0.65 - 0.86	0.55 - 0.71	0.44 - 0.57
Medium	2.01 – 3.00	0.37 - 0.54	0.22 - 0.32	0.37 - 0.54	0.44 - 0.64	0.37 - 0.54	0.30 - 0.43
Low	1.01 – 2.00	0.19 - 0.36	0.12 - 0.21	0.19 - 0.36	0.22 - 0.43	0.19 - 0.36	0.15 - 0.29
Very low	0.00 – 1.00	0.00 - 0.18	0.00 - 0.11	0.00 - 0.18	0.00 - 0.21	0.00 - 0.18	0.00 - 0.14

- **Adaptive capacity-related indicators**

Level	Value						
	Overall	V12: Lack of Information	V13: Lack of preparedness and risk transfer	V14: Lack of participation & inclusiveness	V15: Lack of capacity development	V16: Lack of mainstreaming climate-risk in planning process	V17: Lack of monitoring and evaluation
High	3.01 – 4.00	0.51 - 0.67	0.65 - 0.86	0.65 - 0.86	0.65 - 0.86	0.39 - 0.50	0.26 - 0.33
Medium	2.01 – 3.00	0.34 - 0.50	0.44 - 0.64	0.44 - 0.64	0.44 - 0.64	0.26 - 0.38	0.18 - 0.25
Low	1.01 – 2.00	0.18 - 0.33	0.22 - 0.43	0.22 - 0.43	0.22 - 0.43	0.14 - 0.25	0.09 - 0.17
Very low	0.00 – 1.00	0.00 - 0.17	0.00 - 0.21	0.00 - 0.21	0.00 - 0.21	0.00 - 0.13	0.00 - 0.08

d) **Description of the level of impacts that occurred to public health care service working systems** (adapted from University of Rochester, 2021)

Effects level	Descriptions
Very low	All services can continue without any discernible impact or change
Low	• Some services may be reduced or suspended. • Some advanced or special services may be canceled • Services for non-priority clients/sections may be temporarily suspended.
Medium	• Shutdown of auxiliaries sections, but most critical service may continue. • Obtain needed resources/supports from outside • Full implementation of conservation measures in order to sustain essential services • Limit new inflow patients and maximize patient discharge. • Declare total diversion status or partial/total evacuation.
High	• Discontinued of service to most critical services. • No new patients' admission. • All patients will be transferred to others/nearby service facility • Declare total evacuation. • Only designed staff assigned to control and observe loss and damages allow staying on-site

Annex 25 Potential impact assessment of participating hospitals in the study area (see list of facilities as Annex 13)

a) Expert-weighted normalization - Trend scenario

Zone	3	4	4	4	1	3	3	3	4	2	1	2	1	1	2	2	3	4	4	4	3	3	1	1	3
Facilities / **Indicators**	**KK 01**	**KK 02**	**KK 03**	**KK 04**	**KK 05**	**KK 06**	**KK 07**	**KK 08**	**KK 09**	**KK 10**	**KK 11**	**KK 12**	**KK 13**	**KK 14**	**KK 15**	**KK 16**	**KK 17**	**KK 18**	**KK 19**	**KK 20**	**KK 21**	**KK 22**	**KK 23**	**KK 24**	**KK 25**
H1: Fluvial flood	0.64	0.00	0.00	0.00	1.28	0.64	0.64	0.64	0.00	1.28	0.64	0.00	0.00	1.28	1.28	0.64	0.64	0.00	0.00	0.00	0.64	0.64	1.28	1.28	1.28
H2: Pluvial flood	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28
H3: Water scarcity	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44
Normalized Hazard	**0.84**	**0.68**	**0.68**	**0.68**	**1.00**	**0.84**	**0.84**	**0.84**	**0.68**	**1.00**	**0.84**	**0.68**	**0.68**	**1.00**	**1.00**	**0.84**	**0.84**	**0.68**	**0.68**	**0.68**	**0.84**	**0.84**	**1.00**	**1.00**	**1.00**
E1: Exposure of public health facility's building(s)	1.00	1.00	0.67	0.67	1.33	1.67	1.00	1.33	1.00	1.33	0.67	0.67	0.67	1.33	1.33	1.00	1.33	0.67	0.67	1.00	1.00	1.00	1.33	1.33	1.00
E2: Exposure of working systems	1.73	2.00	0.52	0.76	1.67	1.68	1.28	2.00	1.49	1.89	2.00	1.20	2.00	1.50	2.00	1.32	1.65	2.00	2.00	2.00	1.02	1.56	1.66	1.80	1.11
Normalized Exposure	**0.68**	**0.75**	**0.30**	**0.36**	**0.75**	**0.84**	**0.57**	**0.83**	**0.62**	**0.81**	**0.67**	**0.47**	**0.67**	**0.71**	**0.83**	**0.58**	**0.75**	**0.67**	**0.67**	**0.75**	**0.51**	**0.64**	**0.75**	**0.78**	**0.53**
V1: Over carrying capacity	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
V2: Variety of vulnerable patients	0.93	0.53	0.53	0.93	1.07	1.07	0.13	0.67	0.53	0.93	0.53	0.93	0.13	0.53	0.67	0.93	0.93	0.80	0.80	0.13	0.80	0.40	0.80	0.80	0.53
V3: Resource insufficiency	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.80	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.80	0.60	0.60	0.60	0.60	0.80	0.60	0.60
V4: Poor system conditions and maintenance of working systems	0.31	0.02	0.00	0.02	0.01	0.00	0.00	0.12	0.11	0.02	0.01	0.11	0.06	0.10	0.05	0.10	0.10	0.12	0.10	0.00	0.02	0.01	0.09	0.00	0.12
V5: Downtime of essential working systems	0.02	0.04	0.22	0.10	0.04	0.06	0.00	0.01	0.01	0.04	0.08	0.02	0.02	0.03	0.10	0.11	0.05	0.09	0.08	0.00	0.04	0.04	0.06	0.04	0.01
V6: Lack of flexibility & modularity	0.63	0.38	0.56	0.21	0.28	0.20	0.19	0.62	0.46	0.24	0.56	0.56	0.49	0.50	0.61	0.45	0.40	0.71	0.48	0.48	0.49	0.54	0.56	0.25	0.56
V7: Lack of diversity of suppliers	0.37	0.25	0.06	0.26	0.34	0.27	0.15	0.21	0.05	0.16	0.24	0.16	0.02	0.50	0.40	0.18	0.04	0.43	0.23	0.02	0.09	0.22	0.30	0.04	0.41
V8: Lack of redundancy	0.56	0.23	0.40	0.45	0.35	0.35	0.34	0.34	0.66	0.00	0.60	0.51	0.33	0.55	0.45	0.37	0.30	0.60	0.45	0.65	0.39	0.44	0.46	0.22	0.40
V9: Lack of responsiveness	0.86	0.54	0.73	0.57	0.42	0.72	0.39	0.73	0.86	0.07	0.80	0.86	0.69	0.72	0.59	0.60	0.47	0.80	0.83	0.86	0.53	0.44	0.63	0.23	0.69
V10: Lack of resource mobilization	0.71	0.46	0.32	0.24	0.00	0.12	0.00	0.71	0.24	0.00	0.36	0.48	0.60	0.18	0.24	0.42	0.12	0.60	0.60	0.48	0.60	0.32	0.52	0.38	0.32
V11: Lack of integration and coordination	0.46	0.15	0.46	0.46	0.34	0.34	0.11	0.46	0.34	0.00	0.46	0.34	0.34	0.38	0.30	0.34	0.23	0.23	0.46	0.46	0.00	0.15	0.19	0.15	0.34
V12: Lack of Information	0.67	0.52	0.15	0.67	0.67	0.59	0.15	0.45	0.44	0.00	0.22	0.67	0.30	0.22	0.67	0.15	0.00	0.52	0.15	0.67	0.44	0.67	0.52	0.00	0.22
V13: Lack of preparedness and risk transfer	0.83	0.83	0.56	0.83	0.56	0.56	0.83	0.83	0.83	0.00	0.83	0.83	0.83	0.83	0.83	0.67	0.56	0.83	0.83	0.83	0.56	0.76	0.83	0.46	0.83
V14: Lack of participation and inclusiveness	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.10	0.73	0.56	0.73	0.83	0.83	0.69	0.56	0.83	0.83	0.83	0.83	0.83	0.83	0.59	0.42
V15: Lack of capacity development	0.83	0.73	0.83	0.83	0.42	0.83	0.52	0.83	0.83	0.00	0.83	0.83	0.73	0.63	0.63	0.73	0.42	0.83	0.73	0.83	0.00	0.63	0.83	0.00	0.73
V16: Lack of mainstreaming climate-risk in planning process	0.50	0.42	0.50	0.50	0.42	0.50	0.31	0.50	0.50	0.00	0.35	0.50	0.50	0.50	0.50	0.44	0.50	0.50	0.44	0.50	0.50	0.33	0.50	0.29	0.50
V17: Lack of monitoring &evaluation	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.00	0.25	0.33	0.33	0.25	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.00	0.33
Normalized Vulnerability	**0.60**	**0.45**	**0.46**	**0.51**	**0.44**	**0.48**	**0.34**	**0.54**	**0.50**	**0.18**	**0.49**	**0.53**	**0.44**	**0.48**	**0.51**	**0.47**	**0.38**	**0.58**	**0.51**	**0.50**	**0.41**	**0.44**	**0.53**	**0.29**	**0.46**
Potential impact = H*E*V	**0.346**	**0.230**	**0.093**	**0.124**	**0.329**	**0.338**	**0.161**	**0.381**	**0.210**	**0.141**	**0.272**	**0.170**	**0.200**	**0.340**	**0.422**	**0.227**	**0.237**	**0.262**	**0.233**	**0.254**	**0.175**	**0.238**	**0.399**	**0.224**	**0.242**

b) Expert-weighted normalization - Desirable scenario

Zone	3	4	4	4	1	3	3	3	4	2	1	2	1	1	2	2	3	4	4	4	3	3	1	1	3
Indicators / **Facilities**	**KK 01**	**KK 02**	**KK 03**	**KK 04**	**KK 05**	**KK 06**	**KK 07**	**KK 08**	**KK 09**	**KK 10**	**KK 11**	**KK 12**	**KK 13**	**KK 14**	**KK 15**	**KK 16**	**KK 17**	**KK 18**	**KK 19**	**KK 20**	**KK 21**	**KK 22**	**KK 23**	**KK 24**	**KK 25**
H1: Fluvial flood	0.64	0.00	0.00	0.00	1.28	0.64	0.64	0.64	0.00	1.28	0.64	0.00	0.00	1.28	1.28	0.64	0.64	0.00	0.00	0.00	0.64	0.64	1.28	1.28	1.28
H2: Pluvial flood	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28
H3: Water scarcity	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44
Normalized Hazard	**0.84**	**0.68**	**0.68**	**0.68**	**1.00**	**0.84**	**0.84**	**0.84**	**0.68**	**1.00**	**0.84**	**0.68**	**0.68**	**1.00**	**1.00**	**0.84**	**0.84**	**0.68**	**0.68**	**0.68**	**0.84**	**0.84**	**1.00**	**1.00**	**1.00**
E1: Exposure of public health facility's building(s)	1.00	1.00	0.67	0.67	1.33	1.67	1.00	1.33	1.00	1.33	0.67	0.67	0.67	1.33	1.33	1.00	1.33	0.67	0.67	1.00	1.00	1.00	1.33	1.33	1.00
E2: Exposure of working systems	0.33	0.32	0.00	0.18	0.19	0.19	0.34	0.24	0.23	0.26	0.40	0.43	0.26	0.23	0.14	0.26	0.42	0.35	0.14	0.50	0.29	0.31	0.23	0.20	0.13
Normalized Exposure	**0.33**	**0.33**	**0.17**	**0.21**	**0.38**	**0.46**	**0.33**	**0.39**	**0.31**	**0.40**	**0.27**	**0.27**	**0.23**	**0.39**	**0.37**	**0.32**	**0.44**	**0.25**	**0.20**	**0.38**	**0.32**	**0.33**	**0.39**	**0.38**	**0.28**
V1: Over carrying capacity	0.80	0.80	0.80	0.80	0.00	0.80	0.80	0.80	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.80	0.80	0.80	0.80	0.80	0.00	0.00	0.80
V2: Variety of vulnerable patients	0.93	0.53	0.53	0.93	1.07	1.07	0.13	0.67	0.53	0.93	0.53	0.93	0.13	0.53	0.67	0.93	0.93	0.80	0.80	0.13	0.80	0.40	0.80	0.80	0.53
V3: Resource insufficiency	0.60	0.60	0.60	0.60	0.20	0.60	0.60	0.60	0.60	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.60	0.60	0.60	0.60	0.60	0.60	0.20	0.20	0.60
V4: Poor system conditions and maintenance of working systems	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V5: Downtime of essential working systems	0.02	0.04	0.22	0.10	0.04	0.06	0.00	0.01	0.01	0.04	0.08	0.02	0.02	0.03	0.10	0.11	0.05	0.09	0.08	0.00	0.04	0.04	0.06	0.04	0.01
V6: Lack of flexibility & modularity	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V7: Lack of diversity of suppliers	0.05	0.02	0.03	0.05	0.04	0.07	0.03	0.03	0.03	0.03	0.06	0.03	0.02	0.11	0.07	0.03	0.04	0.14	0.08	0.02	0.02	0.02	0.05	0.03	0.06
V8: Lack of redundancy	0.11	0.08	0.10	0.08	0.00	0.05	0.05	0.10	0.10	0.00	0.10	0.10	0.10	0.08	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.05	0.05	0.03
V9: Lack of responsiveness	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V10: Lack of resource mobilization	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V11: Lack of integration and coordination	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V12: Lack of Information	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V13: Lack of preparedness and risk transfer	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V14: Lack of participation and inclusiveness	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V15: Lack of capacity development	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V16: Lack of mainstreaming climate-risk in planning process	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V17: Lack of monitoring &evaluation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Normalized Vulnerability	**0.15**	**0.12**	**0.13**	**0.15**	**0.08**	**0.16**	**0.10**	**0.13**	**0.12**	**0.07**	**0.06**	**0.08**	**0.03**	**0.06**	**0.07**	**0.08**	**0.15**	**0.15**	**0.14**	**0.10**	**0.14**	**0.12**	**0.07**	**0.07**	**0.12**
Potential impact = H*E*V	**0.041**	**0.027**	**0.015**	**0.022**	**0.030**	**0.061**	**0.027**	**0.043**	**0.026**	**0.028**	**0.013**	**0.014**	**0.004**	**0.022**	**0.025**	**0.021**	**0.055**	**0.026**	**0.020**	**0.025**	**0.038**	**0.032**	**0.027**	**0.025**	**0.034**

c)Equal-weighted normalization - Trend scenario

Zone	3	4	4	4	1	3	3	3	4	2	1	2	1	1	2	2	3	4	4	4	3	3	1	1	3
Facilities / Indicators	**KK 01**	**KK 02**	**KK 03**	**KK 04**	**KK 05**	**KK 06**	**KK 07**	**KK 08**	**KK 09**	**KK 10**	**KK 11**	**KK 12**	**KK 13**	**KK 14**	**KK 15**	**KK 16**	**KK 17**	**KK 18**	**KK 19**	**KK 20**	**KK 21**	**KK 22**	**KK 23**	**KK 24**	**KK 25**
H1: Fluvial flood	2.00	0.00	0.00	0.00	4.00	2.00	2.00	2.00	0.00	4.00	2.00	0.00	0.00	4.00	4.00	2.00	2.00	0.00	0.00	0.00	2.00	2.00	4.00	4.00	4.00
H2: Pluvial flood	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
H3: Water scarcity	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Normalized Hazard	**0.83**	**0.67**	**0.67**	**0.67**	**1.00**	**0.83**	**0.83**	**0.83**	**0.67**	**1.00**	**0.83**	**0.67**	**0.67**	**1.00**	**1.00**	**0.83**	**0.83**	**0.67**	**0.67**	**0.67**	**0.83**	**0.83**	**1.00**	**1.00**	**1.00**
E1: Exposure of public health facility's building(s)	2.00	2.00	1.33	1.33	2.67	3.33	2.00	2.67	2.00	2.67	1.33	1.33	1.33	2.67	2.67	2.00	2.67	1.33	1.33	2.00	2.00	2.00	2.67	2.67	2.00
E2: Exposure of working systems	3.46	4.00	1.04	1.53	3.33	3.35	2.57	4.00	2.99	3.78	4.00	2.41	4.00	3.00	4.00	2.65	3.31	4.00	4.00	4.00	2.05	3.12	3.32	3.61	2.21
Normalized Exposure	**0.68**	**0.75**	**0.30**	**0.36**	**0.75**	**0.84**	**0.57**	**0.83**	**0.62**	**0.81**	**0.67**	**0.47**	**0.67**	**0.71**	**0.83**	**0.58**	**0.75**	**0.67**	**0.67**	**0.75**	**0.51**	**0.64**	**0.75**	**0.78**	**0.53**
V1: Over carrying capacity	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
V2: Variety of vulnerable patients	3.50	2.00	2.00	3.50	4.00	4.00	0.50	2.50	2.00	3.50	2.00	3.50	0.50	2.00	2.50	3.50	3.50	3.00	3.00	0.50	3.00	1.50	3.00	3.00	2.00
V3: Resource insufficiency	3.00	3.00	3.00	3.00	3.00	3.00	3.00	4.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	4.00	3.00	3.00	3.00	3.00	4.00	3.00	3.00
V4: Poor system conditions and maintenance of working systems	1.57	0.09	0.00	0.10	0.03	0.00	0.00	0.60	0.55	0.12	0.03	0.57	0.30	0.52	0.24	0.49	0.49	0.62	0.52	0.00	0.10	0.06	0.45	0.00	0.58
V5: Downtime of essential working systems	0.15	0.30	1.67	0.73	0.27	0.44	0.00	0.09	0.10	0.33	0.57	0.18	0.15	0.24	0.78	0.83	0.41	0.67	0.57	0.00	0.30	0.33	0.48	0.33	0.09
V6: Lack of flexibility & modularity	3.50	2.12	3.11	1.20	1.56	1.13	1.08	3.48	2.56	1.33	3.15	3.11	2.72	2.78	3.42	2.52	2.26	4.00	2.70	2.67	2.72	3.01	3.15	1.37	3.15
V7: Lack of diversity of suppliers	3.48	2.30	0.57	2.44	3.17	2.56	1.41	1.93	0.47	1.48	2.29	1.48	0.22	4.67	3.78	1.66	0.40	4.00	2.18	0.22	0.81	2.07	2.82	0.37	3.81
V8: Lack of redundancy	3.14	1.29	2.26	2.49	1.98	1.98	1.92	1.90	3.67	0.02	3.38	2.84	1.83	3.06	2.54	2.08	1.70	3.38	2.54	3.66	2.17	2.45	2.56	1.24	2.21
V9: Lack of responsiveness	4.00	2.52	3.43	2.67	1.95	3.38	1.81	3.43	4.00	0.33	3.71	4.00	3.24	3.38	2.76	2.81	2.19	3.71	3.86	4.00	2.48	2.05	2.95	1.10	3.24
V10: Lack of resource mobilization	4.00	2.56	1.78	1.33	0.00	0.67	0.00	4.00	1.33	0.00	2.00	2.67	3.33	1.00	1.33	2.33	0.67	3.33	3.33	2.67	3.33	1.78	2.89	2.11	1.78
V11: Lack of integration and coordination	3.20	1.07	3.20	3.20	2.40	2.40	0.80	3.20	2.40	0.00	3.20	2.40	2.40	2.67	2.13	2.40	1.60	1.60	3.20	3.20	0.00	1.07	1.33	1.07	2.40
V12: Lack of Information	4.00	3.11	0.89	4.00	4.00	3.56	0.89	2.67	2.67	0.00	1.33	4.00	1.78	1.33	4.00	0.89	0.00	3.11	0.89	4.00	2.67	4.00	3.11	0.00	1.33
V13: Lack of preparedness and risk transfer	4.00	4.00	2.67	4.00	2.67	2.67	4.00	4.00	4.00	0.00	4.00	4.00	4.00	4.00	4.00	3.22	2.67	4.00	4.00	4.00	2.67	3.67	4.00	2.22	4.00
V14: Lack of participation and inclusiveness	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	0.50	3.50	2.67	3.50	4.00	4.00	3.34	2.67	4.00	4.00	4.00	4.00	4.00	4.00	2.84	2.00
V15: Lack of capacity development	4.00	3.50	4.00	4.00	2.00	4.00	2.50	4.00	4.00	0.00	4.00	4.00	3.50	3.00	3.00	3.50	2.00	4.00	3.50	4.00	0.00	3.00	4.00	0.00	3.50
V16: Lack of mainstreaming climate-risk in planning process	4.00	3.34	4.00	4.00	3.34	4.00	2.50	4.00	4.00	0.00	2.84	4.00	4.00	4.00	4.00	3.50	4.00	4.00	3.50	4.00	4.00	2.67	4.00	2.34	4.00
V17: Lack of monitoring &evaluation	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	0.00	3.00	4.00	4.00	3.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	0.00	4.00
Normalized Vulnerability	**0.85**	**0.64**	**0.66**	**0.72**	**0.62**	**0.67**	**0.48**	**0.76**	**0.69**	**0.21**	**0.68**	**0.74**	**0.62**	**0.69**	**0.73**	**0.65**	**0.52**	**0.82**	**0.72**	**0.70**	**0.58**	**0.63**	**0.75**	**0.37**	**0.66**
Potential impact = H*E*V	**0.481**	**0.318**	**0.129**	**0.171**	**0.467**	**0.469**	**0.227**	**0.529**	**0.286**	**0.173**	**0.376**	**0.231**	**0.278**	**0.486**	**0.606**	**0.314**	**0.325**	**0.362**	**0.319**	**0.352**	**0.243**	**0.335**	**0.559**	**0.288**	**0.349**

d) *Equal-weighted normalization - Desirable scenario*

Zone	**3**	**4**	**4**	**4**	**1**	**3**	**3**	**3**	**4**	**2**	**1**	**2**	**1**	**1**	**2**	**2**	**3**	**4**	**4**	**4**	**3**	**3**	**1**	**1**	**3**
Indicators / **Facilities**	**KK 01**	**KK 02**	**KK 03**	**KK 04**	**KK 05**	**KK 06**	**KK 07**	**KK 08**	**KK 09**	**KK 10**	**KK 11**	**KK 12**	**KK 13**	**KK 14**	**KK 15**	**KK 16**	**KK 17**	**KK 18**	**KK 19**	**KK 20**	**KK 21**	**KK 22**	**KK 23**	**KK 24**	**KK 25**
H1: Fluvial flood	2.00	0.00	0.00	0.00	4.00	2.00	2.00	2.00	0.00	4.00	2.00	0.00	0.00	4.00	4.00	2.00	2.00	0.00	0.00	0.00	2.00	2.00	4.00	4.00	4.00
H2: Pluvial flood	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
H3: Water scarcity	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Normalized Hazard	**0.83**	**0.67**	**0.67**	**0.67**	**1.00**	**0.83**	**0.83**	**0.83**	**0.67**	**1.00**	**0.83**	**0.67**	**0.67**	**1.00**	**1.00**	**0.83**	**0.83**	**0.67**	**0.67**	**0.67**	**0.83**	**0.83**	**1.00**	**1.00**	**1.00**
E1: Exposure of public health facility's building(s)	2.00	2.00	1.33	1.33	2.67	3.33	2.00	2.67	2.00	2.67	1.33	1.33	1.33	2.67	2.67	2.00	2.67	1.33	1.33	2.00	2.00	2.00	2.67	2.67	2.00
E2: Exposure of working systems	0.67	0.64	0.00	0.35	0.38	0.38	0.67	0.48	0.46	0.52	0.80	0.85	0.52	0.46	0.29	0.53	0.85	0.71	0.29	1.00	0.58	0.63	0.46	0.39	0.25
Normalized Exposure	**0.33**	**0.33**	**0.17**	**0.21**	**0.38**	**0.46**	**0.33**	**0.39**	**0.31**	**0.40**	**0.27**	**0.27**	**0.23**	**0.39**	**0.37**	**0.32**	**0.44**	**0.25**	**0.20**	**0.38**	**0.32**	**0.33**	**0.39**	**0.38**	**0.28**
V1: Over carrying capacity	4.00	4.00	4.00	4.00	0.00	4.00	4.00	4.00	4.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.00	4.00	4.00	4.00	4.00	4.00	0.00	0.00	4.00
V2: Variety of vulnerable patients	3.50	2.00	2.00	3.50	4.00	4.00	0.50	2.50	2.00	3.50	2.00	3.50	0.50	2.00	2.50	3.50	3.50	3.00	3.00	0.50	3.00	1.50	3.00	3.00	2.00
V3: Resource insufficiency	3.00	3.00	3.00	3.00	1.00	3.00	3.00	3.00	3.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	1.00	3.00
V4: Poor system conditions and maintenance of working systems	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V5: Downtime of essential working systems	0.15	0.30	1.67	0.73	0.27	0.44	0.00	0.09	0.10	0.33	0.57	0.18	0.15	0.24	0.78	0.83	0.41	0.67	0.57	0.00	0.30	0.33	0.48	0.33	0.09
V6: Lack of flexibility & modularity	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V7: Lack of diversity of suppliers	0.44	0.22	0.29	0.44	0.42	0.62	0.30	0.30	0.24	0.30	0.57	0.30	0.22	1.00	0.67	0.25	0.40	1.33	0.73	0.22	0.22	0.22	0.44	0.30	0.57
V8: Lack of redundancy	0.62	0.44	0.57	0.43	0.01	0.29	0.30	0.58	0.58	0.02	0.56	0.58	0.59	0.43	0.57	0.58	0.58	0.56	0.57	0.56	0.58	0.58	0.30	0.30	0.15
V9: Lack of responsiveness	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V10: Lack of resource mobilization	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V11: Lack of integration and coordination	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V12: Lack of Information	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V13: Lack of preparedness and risk transfer	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V14: Lack of participation and inclusiveness	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V15: Lack of capacity development	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V16: Lack of mainstreaming climate-risk in planning process	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V17: Lack of monitoring &evaluation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Normalized Vulnerability	**0.17**	**0.15**	**0.17**	**0.18**	**0.08**	**0.18**	**0.12**	**0.15**	**0.15**	**0.08**	**0.07**	**0.08**	**0.04**	**0.07**	**0.08**	**0.09**	**0.17**	**0.18**	**0.17**	**0.12**	**0.16**	**0.14**	**0.08**	**0.07**	**0.14**
Potential impact = H*E*V	**0.048**	**0.032**	**0.019**	**0.025**	**0.032**	**0.070**	**0.033**	**0.050**	**0.030**	**0.030**	**0.015**	**0.015**	**0.006**	**0.027**	**0.030**	**0.024**	**0.064**	**0.031**	**0.024**	**0.030**	**0.044**	**0.039**	**0.030**	**0.028**	**0.041**

e) Potential impact assessment of Khon Kaen city in area-based and service network perspectives, based on equal-weighted normalization scheme

Indicators	Trend scenario		Desired scenario	
	Area-based	**Service network**	**Area-based**	**Service network**
H1: Fluvial flood	1.840	2.000	1.840	2.000
H2: Pluvial flood	4.000	4.000	4.000	4.000
H3: Water scarcity	4.000	4.000	4.000	4.000
Weighted normalized Hazard value	**0.820**	**0.833**	**0.820**	**0.833**
E1: Exposure of public health facility's building(s)	2.080	2.033	2.080	2.033
E2: Exposure of working systems	3.189	2.356	0.525	0.557
Weighted normalized Exposure value	0.659	0.549	0.326	0.324
V1: Over carrying capacity	4.000	4.000	2.400	3.550
V2: Variety of vulnerable patients	2.560	2.919	2.560	2.919
V3: Resource insufficiency	3.120	3.038	2.200	2.775
V4: Poor system conditions and maintenance of essential working systems	0.321	0.167	0.000	0.000
V5: Downtime of essential working systems	0.400	0.336	0.400	0.336
V6: Lack of flexibility & modularity	2.552	2.686	0.000	0.000
V7: Lack of diversity of suppliers	2.024	1.142	0.440	0.000
V8: Lack of redundancy	2.332	2.224	0.452	0.288
V9: Lack of responsiveness	2.920	2.609	0.000	0.543
V10: Lack of resource mobilization	2.009	2.999	0.000	0.000
V11: Lack of integration and coordination	2.101	0.590	0.000	0.000
V12: Lack of Information	2.329	2.544	0.000	0.000
V13: Lack of preparedness and risk transfer	3.458	2.851	0.000	0.000
V14: Lack of participation and inclusiveness	3.560	3.879	0.000	0.000
V15: Lack of capacity development	3.080	0.800	0.000	0.000
V16: Lack of mainstreaming climate-risk in planning process	3.520	3.894	0.000	0.000
V17: Lack of monitoring and evaluation	3.600	3.875	0.000	0.000
Weighted normalized Vulnerability value	**0.645**	**0.596**	**0.124**	**0.153**
Potential impact = H*E*V	**0.349**	**0.273**	**0.033**	**0.041**

Annex 26 Descriptive statistics of all vulnerability's indicators

Indicators (variables)	Mean	Std. Deviation	Analysis N
V1	0.432	0.1108	25
V2	0.683	0.278	25
V3	0.368	0.206	25
V4	0.064	0.071	25
V5	0.053	0.047	25
V6	0.456	0.149	25
V7	0.207	0.136	25
V8	0.416	0.147	25
V9	0.626	0.205	25
V10	0.359	0.216	25
V11	0.300	0.144	25
V12	0.388	0.243	25
V13	0.720	0.197	25
V14	0.742	0.177	25
V15	0.642	0.273	25
V16	0.440	0.114	25
V17	0.300	0.093	25

Annex 27 Outlier detection of vulnerability indicators

Indicators	**Detected outliers** *(based on Hoaglin & Iglewicz (1987))*	**Screened outliers** *(based on data input characteristic and histogram)*	Remarks
V1: Over carrying capacity	KK004 KK 021		No data point is treated as outliers because it is in the range of day-to-day operation practice of different health care facilities
V14: Lack of participation and inclusiveness	KK 010 KK025	KK 010 KK025	
V15: Lack of capacity development	KK010 KK024	KK010 KK024	
V16: Lack of mainstreaming climate-risk in planning process	KK 010	KK 010	
V17: Lack of monitoring and evaluation	KK 010 KK 011 KK014 KK024	KK 010 KK0 24	KK011 and KK014 do not appear as outliers on histogram graph

Annex 28 Rule of thumb for Kaiser-Meyer-Olkin (KMO), Kaiser (1974)

≥ 0.9	marvelous
[0.8, 0.9)	meritorious
[0.7, 0.8)	middling
[0.6, 0.7)	mediocre
[0.5, 0.6)	miserable
<0.5	unacceptable

Annex 29 Reliability analysis of vulnerability and its elements

Vulnerability's elements	Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	Number of indicators (N)
Overall vulnerability	0.825	0.852	17
Sensitivity	0.318	0.292	5
Coping capacity	0.808	0.808	6
Adaptive capacity	0.854	0.899	6

Annex 30 Inter-item correlation matrix of vulnerability indicators

1) Sensitivity-related indicators

Indicators	V1	V2	V3	V4	V5
V1	1.000	0.199	0.340	-0.187	0.097
V2	0.199	1.000	0.068	0.248	0.243
V3	0.340	0.068	1.000	0.007	-0.051
V4	-0.187	0.248	0.007	1.000	-0.203
V5	0.097	0.243	-0.051	-0.203	1.000

2) Coping capacity -related indicators

Indicators	V6	V7	V8	V9	V10	V11
V6	1.000	0.287	0.560	0.626	0.670	0.308
V7	0.287	1.000	0.205	0.157	-0.011	0.143
V8	0.560	0.205	1.000	0.817	0.325	0.568
V9	0.626	0.157	0.817	1.000	0.544	0.737
V10	0.670	-0.011	0.325	0.544	1.000	0.251
V11	0.308	0.143	0.568	0.737	0.251	1.000

3) Adaptive-related indicators

Indicators	V12	V13	V14	V15	V16	V17
V12	1.000	0.445	0.521	0.440	0.443	0.527
V13	0.445	1.000	0.645	0.740	0.689	0.698
V14	0.521	0.645	1.000	0.479	0.626	0.648
V15	0.440	0.740	0.479	1.000	0.607	0.676
V16	0.443	0.689	0.626	0.607	1.000	0.781
V17	0.527	0.698	0.648	0.676	0.781	1.000

Annex 31 Item-total statistics of vulnerability indicators

1) Sensitivity-related indicators

Indicators	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
V1	1.168	0.149	0.302	0.204	0.195
V2	0.918	0.073	0.240	0.205	0.208
V3	1.232	0.122	0.156	0.126	0.275
V4	1.536	0.176	0.096	0.189	0.317
V5	1.547	0.180	0.127	0.138	0.316

2) Coping capacity -related indicators

Indicators	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
V6	1.909	0.373	0.719	0.640	0.748
V7	2.157	0.474	0.179	0.164	0.846
V8	1.948	0.378	0.701	0.716	0.753
V9	1.739	0.296	0.843	0.852	0.702
V10	2.006	0.352	0.495	0.582	0.806
V11	2.064	0.404	0.558	0.600	0.782

3) Adaptive capacity -related indicators

Indicators	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
V12	2.844	0.529	0.549	0.344	0.857
V13	2.511	0.520	0.788	0.686	0.801
V14	2.490	0.568	0.684	0.548	0.823
V15	2.590	0.451	0.699	0.611	0.832
V16	2.792	0.635	0.744	0.659	0.831
V17	2.932	0.652	0.810	0.713	0.834

Annex 32 Multivariate Correlation Analysis

Correlations																			
		Vulnerability	**V1**	**V2**	**V3**	**V4**	**V5**	**V6**	**V7**	**V8**	**V9**	**V10**	**V11**	**V12**	**V13**	**V14**	**V15**	**V16**	**V17**
Pearson Correlation	Vulnerability	1.000	0.122	0.067	0.122	0.504	0.104	0.635	0.412	0.786	0.851	0.562	0.632	0.659	0.762	0.651	0.776	0.822	0.730
	V1	0.122	1.000	0.199	0.340	-0.187	0.097	-0.214	-0.073	0.000	-0.110	0.081	-0.150	0.207	-0.040	0.156	-0.248	0.159	0.108
	V2	0.067	0.199	1.000	0.068	0.248	0.243	-0.157	0.301	-0.220	-0.151	-0.083	-0.035	0.081	-0.416	-0.212	-0.194	-0.027	-0.157
	V3	0.122	0.340	0.068	1.000	0.007	-0.051	0.058	-0.033	0.128	-0.072	-0.095	-0.199	0.098	-0.084	-0.021	-0.145	0.093	-0.058
	V4	0.504	-0.187	0.248	0.007	1.000	-0.203	0.547	0.350	0.332	0.468	0.496	0.308	0.118	0.329	0.007	0.327	0.347	0.230
	V5	0.104	0.097	0.243	-0.051	-0.203	1.000	0.138	0.039	-0.013	0.039	-0.043	0.199	-0.160	-0.169	0.135	0.150	0.096	0.058
	V6	0.635	-0.214	-0.157	0.058	0.547	0.138	1.000	0.287	0.560	0.626	0.670	0.308	0.231	0.500	0.218	0.452	0.473	0.390
	V7	0.412	-0.073	0.301	-0.033	0.350	0.039	0.287	1.000	0.205	0.157	-0.011	0.143	0.364	0.293	0.151	0.275	0.149	0.194
	V8	0.786	0.000	-0.220	0.128	0.332	-0.013	0.560	0.205	1.000	0.817	0.325	0.568	0.464	0.718	0.574	0.640	0.626	0.535
	V9	0.851	-0.110	-0.151	-0.072	0.468	0.039	0.626	0.157	0.817	1.000	0.544	0.737	0.384	0.717	0.493	0.815	0.758	0.640
	V10	0.562	0.081	-0.083	-0.095	0.496	-0.043	0.670	-0.011	0.325	0.544	1.000	0.251	0.232	0.454	0.301	0.323	0.430	0.266
	V11	0.632	-0.150	-0.035	-0.199	0.308	0.199	0.308	0.143	0.568	0.737	0.251	1.000	0.221	0.508	0.359	0.735	0.547	0.404
	V12	0.659	0.207	0.081	0.098	0.118	-0.160	0.231	0.364	0.464	0.384	0.232	0.221	1.000	0.445	0.521	0.440	0.443	0.527
	V13	0.762	-0.040	-0.416	-0.084	0.329	-0.169	0.500	0.293	0.718	0.717	0.454	0.508	0.445	1.000	0.645	0.740	0.689	0.698
	V14	0.651	0.156	-0.212	-0.021	0.007	0.135	0.218	0.151	0.574	0.493	0.301	0.359	0.521	0.645	1.000	0.479	0.626	0.648
	V15	0.776	-0.248	-0.194	-0.145	0.327	0.150	0.452	0.275	0.640	0.815	0.323	0.735	0.440	0.740	0.479	1.000	0.607	0.676
	V16	0.822	0.159	-0.027	0.093	0.347	0.096	0.473	0.149	0.626	0.758	0.430	0.547	0.443	0.689	0.626	0.607	1.000	0.781
	V17	0.730	0.108	-0.157	-0.058	0.230	0.058	0.390	0.194	0.535	0.640	0.266	0.404	0.527	0.698	0.648	0.676	0.781	1.000
Sig. (1-tailed)	Vulnerability		0.280	0.375	0.281	0.005	0.310	0.000	0.020	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	V1	0.280		0.170	0.048	0.186	0.322	0.152	0.365	0.500	0.301	0.351	0.237	0.160	0.425	0.228	0.116	0.224	0.304
	V2	0.375	0.170		0.374	0.116	0.121	0.227	0.072	0.146	0.235	0.347	0.434	0.351	0.019	0.154	0.177	0.449	0.227
	V3	0.281	0.048	0.374		0.486	0.405	0.391	0.437	0.271	0.366	0.325	0.171	0.320	0.346	0.461	0.245	0.330	0.391
	V4	0.005	0.186	0.116	0.486		0.165	0.002	0.043	0.052	0.009	0.006	0.067	0.288	0.054	0.487	0.055	0.045	0.134
	V5	0.310	0.322	0.121	0.405	0.165		0.256	0.427	0.475	0.426	0.418	0.171	0.223	0.209	0.260	0.237	0.324	0.392
	V6	0.000	0.152	0.227	0.391	0.002	0.256		0.082	0.002	0.000	0.000	0.067	0.134	0.005	0.148	0.012	0.009	0.027
	V7	0.020	0.365	0.072	0.437	0.043	0.427	0.082		0.163	0.227	0.479	0.248	0.037	0.077	0.235	0.091	0.239	0.177
	V8	0.000	0.500	0.146	0.271	0.052	0.475	0.002	0.163		0.000	0.057	0.002	0.010	0.000	0.001	0.000	0.000	0.003
	V9	0.000	0.301	0.235	0.366	0.009	0.426	0.000	0.227	0.000		0.002	0.000	0.029	0.000	0.006	0.000	0.000	0.000
	V10	0.002	0.351	0.347	0.325	0.006	0.418	0.000	0.479	0.057	0.002		0.113	0.132	0.011	0.072	0.058	0.016	0.099
	V11	0.000	0.237	0.434	0.171	0.067	0.171	0.067	0.248	0.002	0.000	0.113		0.144	0.005	0.039	0.000	0.002	0.023
	V12	0.000	0.160	0.351	0.320	0.288	0.223	0.134	0.037	0.010	0.029	0.132	0.144		0.013	0.004	0.014	0.013	0.003
	V13	0.000	0.425	0.019	0.346	0.054	0.209	0.005	0.077	0.000	0.000	0.011	0.005	0.013		0.000	0.000	0.000	0.000
	V14	0.000	0.228	0.154	0.461	0.487	0.260	0.148	0.235	0.001	0.006	0.072	0.039	0.004	0.000		0.008	0.000	0.000
	V15	0.000	0.116	0.177	0.245	0.055	0.237	0.012	0.091	0.000	0.000	0.058	0.000	0.014	0.000	0.008		0.001	0.000
	V16	0.000	0.224	0.449	0.330	0.045	0.324	0.009	0.239	0.000	0.000	0.016	0.002	0.013	0.000	0.000	0.001		0.000
	V17	0.000	0.304	0.227	0.391	0.134	0.392	0.027	0.177	0.003	0.000	0.099	0.023	0.003	0.000	0.000	0.000	0.000	

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000[a]	1.000	1.000	0.000000
a. Predictors: (Constant), V17, V5, V3, V7, V10, V1, V2, V11, V12, V14, V8, V4, V16, V15, V13, V6, V9				

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	0.200	17	0.012		.[b]
	Residual	0.000	7	0.000		
	Total	0.200	24			
a. Dependent Variable: Vulnerability						
b. Predictors: (Constant), V17, V5, V3, V7, V10, V1, V2, V11, V12, V14, V8, V4, V16, V15, V13, V6, V9						

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	8.016E-10	0.000				0.000	0.000
	V1	0.059	0.000	0.071			0.059	0.059
	V2	0.059	0.000	0.180			0.059	0.059
	V3	0.059	0.000	0.133			0.059	0.059
	V4	0.059	0.000	0.046			0.059	0.059
	V5	0.059	0.000	0.031			0.059	0.059
	V6	0.059	0.000	0.096			0.059	0.059
	V7	0.059	0.000	0.088			0.059	0.059
	V8	0.059	0.000	0.095			0.059	0.059
	V9	0.059	0.000	0.132			0.059	0.059
	V10	0.059	0.000	0.140			0.059	0.059
	V11	0.059	0.000	0.093			0.059	0.059
	V12	0.059	0.000	0.157			0.059	0.059
	V13	0.059	0.000	0.127			0.059	0.059
	V14	0.059	0.000	0.114			0.059	0.059
	V15	0.059	0.000	0.176			0.059	0.059
	V16	0.059	0.000	0.073			0.059	0.059
	V17	0.059	0.000	0.060			0.059	0.059
a. Dependent Variable: Vulnerability								

Annex 33 Feedback from responsible agencies on the proposed roadmaps

1) Khon Kaen City Climate Resilient Public Health Service

Strategies	Appropriateness	Feedback/Clarification/Suggestion
Overall	Yes	**KKPHO:** The roadmap is appropriate. HICRAF should be integrated with the work of other agencies and relevant public health domains under MoPH, such as Public Health Emergency Management (PHEM), Incidence Command System (ICS) and Emergency Operations Center (EOC), in order to solve the structural problem Thai's public health in a sustainable way. **DOH:** The roadmap is appropriate and comprehensive in various aspects, especially on risk mitigation, prevention and preparedness, emergency response, participation and monitoring and evaluation. However, the roadmap should emphasize the importance of environmental health in disaster risk management, which has a significant result on medical personnel and patients within the hospital and inhabitants and communities surrounding a public health care facility. **HPC 7:** (Khon Kaen): The roadmap should define a clear objective and goals (overall, short-term, medium-term and long-term)
Strategy 1 Exposure reduction	Yes	**KKPHO:** There are limitations in implementing the proposed measures No. 1, No. 2 and No.3. However, the implementation of these measures involves many relevant sectors, such as the SAOs, PAO, KKPHO. Yet the proposed measures No.2 and No.3 may contradict with the existing provincial public health service plan, which aims to enhance the capacity of the local public health service capacity through the long-term Primary Care Cluster (PCC) development plan (including management framework & investments (supplies and construction) **HPC 7 (Khon Kaen):** • EIA for a new hospital building shall require climate analysis. • Location of a working system shall not be located in the waterway or blocked waterway.
Strategy 2 Hazard mitigation	Yes	**KKPHO:** The implementation of this strategy requires integration with the Design and construction division, Department of Health service support, MoPH who is responsible for public health care facilities' buildings (in accordance with relevant standards, laws and regulations) **DOH:** Agreed in improving the permeability of a health care facility landscape. Nevertheless, the synergy between increasing green space and heat and pollution reduction shall be highlighted. Moreover, this measure (2.1) should be implemented at both the healthcare facility and network levels.

Strategies	Appropriateness	Feedback/Clarification/Suggestion
		HPC 7 (Khon Kaen): In a high-risk area, the local public health care shall inspect building conditions and conduct structural measures for flood protection (e.g. dike, Watergate, drainage system) as well as external support coordination plan (for equipment and staff provision in an emergency).
Strategy 3 Minimize sensitivity	Yes	**KKPHO:** Proposed measure No. 9, MoPH has managed manpower based on the workload and service plan according to the Need-based approach in order to determine frameworks for manpower management, recruitment, and human capacity development. However, the universal health insurance scheme set a policy that limits the number of government officials in the public health care sector, which contradicts the increased service volume of Outpatient services (OPD), about 120 -150 million times/year (only MoPH). This zero-growth policy limits no civil servant position (permanent contract). The temporary employment contract has discouraged health care personnel from working in the public health system, resulting in a shortage of human resources. Therefore, integration planning between local governments and educational institutions to promote public health personnel development through long-term binding scholarship is crucial. **DOH:** This strategy shall underline the necessity of personal capacity building in order to be able to appraise climate-related hazard risks for minimizing climate-related health risks of medical and medical support staff. **HPC 7 (Khon Kaen):** The reformation of resources provision shall be a priority for the ministry of public health, Health Area 7 and Khon Kaen province in order to drive its execution. M&E of this reformation shall be key performance indicators of the ministry and Health Area.
Strategy 4 Strengthen coping capacity	Yes	**KKPHO:** According to the proposed measures No. 15,17, and 19, the public health care units have no mandate to revise or improve the procurement regulation. All public agencies have to follow the Government Procurement and Supplies Management Act, B.E. 2560, under the supervision of the Comptroller General Department, Ministry of Finance. **DOH:** BesidesThis strategy shall emphasize the importance of environmental health, not only power supply system but also clean water and solid waste & wastewater management have to be under proper control and treatment according to standards. Special attention shall be paid to infectious waste management, ensuring its containment and minimizing potential impact on nearby communities. **HPC 7 (Khon Kaen):** • DDPM has already acquired these vehicle provisions. (note: they do not belong and are managed by a public health facility) • Survey accessible route shall be conducted • Strengthen the coping capacity of hospital working systems and infrastructure in an emergency, especially clean water, waste management, and hygiene.

Strategies	Appropriateness	Feedback/Clarification/Suggestion
Strategy 5 Reinforce adaptive capacity	Yes	**KKPHO:** • KKPHO has an integrated operation system for managing “public health emergency”, which is considered a “disaster” that causes public safety (in terms of life and injuries) with other relevant agencies. Under the KKPHO, Public Health Emergency Management (PHEM), Incidence Command System (ICS) and Emergency Operations Center (EOC) are the core units working under the umbrella of the provincial Business Continuity Plan (BCP). • KKPHO has developed an “Integrated Disaster Risk Mitigation and Prevention on Medical and Public health” in accordance with the National Disaster Prevention and Mitigation Plan. At the provincial level, there are Provincial Emergency Operation Center, chaired by the Governor; under this structure, there are Provincial and District Emergency Operation Centers. The operation of these centers covers the provision of public health emergency response plan, exercise, monitoring & evaluation, resources acquisition and execution of local public health service/units, as well as building human capacity on emergency preparedness, risk assessment (both natural and man-made hazards) and incident speculation with relevant agency network such as police, military, local government agencies within Khon Kaen province. **DOH:** This strategy should include a measure that promotes integrated climate-related health risk surveillance and communication system at all levels. Moreover, the public health sector shall seek climate-related risk information integration with relevant agencies that have a good body of knowledge and technology. **HPC 7 (Khon Kaen):** • Establish hospital information centre and communication network for hazard warning through IT system and social media (precise, rapid and inclusive). • Extract best practices and develop policy recommendations on climate resilience management

2) Khon Kaen City Climate-Resilient (spatial) Development

Strategies	Appropriateness	Feedback/Clarification/Suggestion
Overall	Yes	**KKDPT** • Future scenarios should cover technological and social change into account. With the Smart city development agenda, technology will play a crucial role in urban development, including health care services. Khon Kaen province is very active in technology applications such as Intelligent Operation Center (IOC), led by Digital Economy Promotion Agency (DEPA). • There might be other possible hazards that affect an overall city development. **DPT** • The roadmap shall define a clear output of each implementation phase
Strategy 1 Exposure avoidance	Yes	**KKDPT** • Hazard mapping is the most important part of Strategy 1. Relevant agencies are working separately to serve their own organizational purpose. This problem leads to lacking integration and cooperation among relevant agencies as well as challenges in conducting a genuinely public consultation process on this issue. • Hazard map shall classify the area into multiple zones according to impact level (loss and damages) in combination with a study on hazards mitigation and prevention. For example, high hazard risk area but cost ineffectiveness in investing in a protection system, while some area structural measures might substantially help mitigate risk. • However, process and acceptability are the uttermost important. Particularly insufficient (scientific) evidence supporting the designation of hazard zones may affect public acceptability because enforcement of the hazard map strongly affects the land market (land price), right on land ownership, and conflict of interests. • Hazard map shall be legally binding and ensure its effective enforcement. **DPT** • The research should provide a feasibility study on the introduction of Buy-out programm and Selective retreat measures. • DPT has been using the KKDPM district level hazard map (based on historical data) in land use zoning. However, the comprehensive plan does not call the flood zone a hazard-prone area but a Rural and agriculture conservation zone. This practice has been causing inefficient/miscommunication with relevant agencies and the general public in using land use zoning as a key instrument for disaster risk management.
Strategy 2 Hazard mitigation	Yes	**KKDPT** • The term “wetland” has a specific meaning determined by ONEP; however, there is no area designed as national or international importance “wetland” in Mueang Khon Kaen District. Therefore, this term shall be changed to flood retention areas or refer to areas receiving water during flooding season. • Strongly agree that water catchment areas and “waterway” areas should be designated according to the Hazard map to prevent trespassing, landownership possession, and landfilling blocking natural drainage channels. • It is advisable to promote sponge area development, especially for large built-up projects, such as a construction of a pond in the land allocation project, and provision of green roofs for large buildings. These measures will help slow down run-off to the city drainage system.

Strategies	Appropriateness	Feedback/Clarification/Suggestion
		• Wastewater treatment is the most neglected issue in Thailand. There are only two places in Khon Kaen province and a few main cities in Thailand with a wastewater treatment system. The urban wastewater treatment system should be prioritized and offered various options according to the capacity of the local governments or even at the household level. • The current Town planning act has begun to specify water-permeable areas in planning requirements. However, in practice, this matter has not been prioritized (and may be difficult to monitor). **DPT:** More emphasis shall be given to structural measures, especially for economic areas or historical/cultural heritage areas
Strategy 3 Capacity Enhancement	Yes	**KKDPT** • Heavy promotion of Khok Nong Na model[73] led by the Department of Community Development, Ministry of Interior may help promote rural and agricultural land to function as flood retention in the rainy season and increase water storage capacity in drought season. • There should be an emergency response plan in the case of hazards or pandemics, such as setting up field hospitals, and preparing for rehabilitation medicine and long-term care health facilities for the elderly population. The establishment of the new KKU Medical hub, probably the biggest medical facility in this region, may play an important role for elderly clients who would like to utilize the urban service and high quality of health care service (especially those who live alone).
Strategy 4 Cross-Cutting	Yes	**KKDPT & DPT** • Strongly agree with the expansion of the Khon Kaen City Plan to be a district-level plan as well as the establishment of a working group at the district level and capacity & knowledge development. However, a key concern regarding the working group is that the working group member is usually bound with individuals and not organizational level. Therefore, the classic problem is that when people rotate to other positions or departments, it typically causes discontinuity in implementation and direction change. • There is still a lack of addressing the issue of awareness-raising and capacity development to the general public in disaster risk preparation and readiness. **KKDPT:** The collaborative scenario planning approach shall be integrated with the existing provincial disaster risk management action plan. **DPT:** The integration of measures should be addressed as part of planning guidelines, not only the land use plan part of the comprehensive plan, but also in public utilities & services plan, open space plan, natural resources and environment, and transportation project and traffic plan.

[73] The Khok Nong Na model is a new agricultural concept based on the New Theory Agriculture and the Sufficiency Economy philosophy initiated by His Majesty King Bhumibol Adulyadej The Great. The model divides land into four parts: 30% for irrigation water storage, 30% for growing rice, 30% for growing a mixture of plants and the remaining 10% reserved for residential and livestock areas (Bangkokpost, 2020) https://www.bangkokpost.com/thailand/general/1992531/royal-farming-model-off-to-running-start Accessed: 12.06.2021

Annex 34 List of Khon Kaen young generation interviewees (born and raised in Khon Kaen city)

Name - Surname	Occupation/Expertise	Age
Dr. Pattamaporn Wongwiriya	Lecturer, Faculty of Architecture, Urban planning Department, Khon Kaen University (Transportation planning)	36
Mr. Nuttawut Krompukdee	NGO (Friends of Homeless Group)	32
Ms.Nuntanuch Jaemsuwan	Master student, Faculty of Architecture, Urban planning Department, Khon Kaen University	25

Remark: The interviews were conducted online during 11-13 August 2020

Annex 35 English translation version of the expert survey on the development of climate-related hazards potential impact composite indicators for urban public health care services

Expert survey on the development of climate-related hazards potential impact composite indicators for urban public health care services

55 % of the world's population living in urban areas today and projected to reach 68% by 2050 (UNDESA,2018)[74]. Cities expose to climate-related disasters such as flooding, water shortages or extreme weather conditions, imposing huge challenges to urban health facilities and services in the future. Besides ensuring service capabilities to meet growing demands driven by urbanization, the local public health care service must adapt to worsen climate change impacts. In this regard, it is crucial to strengthen climate-resilient urban public health care services by integrating spatial planning and service network operations among urban development domains, disaster risk management and the local health sector.

The purpose of this survey is to gather opinions from experts on the compositions and prioritization of the attributions determining the potential impact of climate-related hazards on urban public health care services. This survey will be used for developing composite indicators framework for potential impact assessment of Khon Kaen city public health care services.

The questionnaire consists of 5 parts as the following:

Part 1: General personal data of responders

Part 2: Sensitivity-related indicators prioritization

Part 3: Coping capacity-related indicators prioritization

Part 4: Adaptive capacity-related indicators prioritization

Part 5: Hazards budget allocation

[74] United Nations, Department of Economic and Social Affairs, Population Division (2018). World Urbanization Prospects: The 2018 Revision.

- Key Terminology –

Hazard: The potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources. In this report, the term hazard usually refers to climate-related physical events or trends or their physical impacts

Disaster: A serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources

Exposure: The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected.

Vulnerability: the propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

Sensitivity: the degree to which a system, person, or community is affected, either adversely or beneficially, by climate-related hazards. Sensitivity is related to physical, socio-economic, culture and environment tendency of a system, person, or community.

Coping capacity The ability of people, institutions, organizations, and systems, using available skills, values, beliefs, resources, and opportunities, to address, manage, and overcome adverse conditions in the short to medium term

Adaptive capacity The ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences

Resilience: The capacity of social, economic and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity and structure, while also maintaining the capacity for adaptation, learning and transformation

Sources;

IPCC, 2014: Annex II: Glossary [Mach, K.J., S. Planton and C. von Stechow (eds.)]. In: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, pp. 117-130.

UNISDR, 2009: UNISDR Terminology on Disaster Risk Reduction. United Nations International Strategy for Disaster Reduction, Geneva, Switzerland.

Part 1: General personal data of responders

1.1 Name-Surname of responder:………………………..……………………..……………………

1.2 Organization: ……………………………………………..…………………………..……………

1.3 Current designation: ………………………….……………………………………..……………

1.4 Address: …………………….………..……………………………………….…………………..…………

1.5 E-mail: ………………………….…….………… 1.6Telephone: ……………..…………………..…..

1.7 Gender ☐ Male ☐ Female ☐ Others

1.8 Age: …………………………………………...………

1.9 Education level

☐ High school graduate ☐ Bachelor degree or equivalent

☐ Bachelor degree or equivalent ☐ Doctoral degree or equivalent

1.10 Relevant experience/responsibility on risk managment or natural disaster risk (if any) management

Year	Description

1.11 Survey response date: ....

Part 2: Sensitivity-related indicators prioritization

Remarks:

- 1st order is the highest priority, and 5th is the lowest priority
- Equal prioritization for more than one indicator is possible
- Suggestion(s) additional sensitivity-related attributions is possible

Sensitivity-related attributions	Priority (1-5)
Over carrying capacity	
Resource insufficiency (financial, personnel, resources)	
Variety of vulnerable patients[75]	
Poor system conditions and maintenance of working systems	
Downtime of critical working systems	
Others (Please specify ....)	

Notes/Comments (If any)

....

....

Part 3: Coping capacity-related indicators prioritization

Remarks

[75] e.g.Respiratory ventilator/Oxygen-dependent or Dialysis dependent; Disability and self-movement difficulty; Elderly; Infant/Toddlers (0-5 year-old); Pregnancy women; Continuity medication treatment dependency; Local language proficiency; Mental illness

- 1st order is the highest priority, and 7th is the lowest priority
- Equal prioritization for more than one indicator is possible
- Suggestion(s) additional sensitivity-related attributions is possible

Coping capacity-related attributions	Priority (1-7)
Flexibility & modularity	
Diversity of suppliers	
Redundancy	
Responsiveness	
Resource mobilization	
Integration and coordination	
Experience in hazard/emergencies confrontation or management	
Others (Please specify ....)	

Notes/Comments (If any)

....

....

Part 4: Adaptive capacity-related indicators prioritization

Remarks

- 1st order is the highest priority, and 6th is the lowest priority
- Equal prioritization for more than one indicator is possible
- Suggestion(s) additional sensitivity-related attributions is possible

Adaptive capacity-related attributions	Priority (1-6)
Information (availability and accessibility of climate-related disaster risk database and future-oriented local demographical and socio-economic development and climate projection (15 – 30 years)	
Preparedness and risk transfer (Availability long-term and procurement of investment plan, build back better plan and insurance for the future-oriented potential impact of climate-related hazards)	
Participation and Inclusion (stakeholders & communities participation in disaster risk management planning)	
Capacity development (capacity building and awareness-raising on the importance of future climate-related disaster risk and adaptation)	
Mainstreaming climate risk in planning process (mainstreaming disaster risk management in an action plan or budget plan)	
Monitoring and evaluation (M&E) (Availability, coordination, and implementation of M&E on climate resilience plan)	
Others (Please specify ....)	

Notes/Comments (If any)

....

....

Part 5: Hazards budget allocation

In the case that you have 100 Mio baht, how would you allocate the budget for the preparation and protection of urban public healthcare facilities from the following hazards

Floods	Water scarcity
.... THB	.... THB
Total 100 Mio THB	

Notes/Comments (If any)

....

....

Please return the questionnaire in *.doc, *.pdf, or *.jpg format to below contact information

Email wiriya.puntub@tu-dortmund.de or wiriya.puntub@gmail.com

By 29 November 2019

Further information needed, please contact Ms. Wiriya Puntub, LINE ID: phalloha

Thank you very much for your kind cooperation

Wiriya Puntub

Researcher

Faculty of Spatial Planning, TU Dortmund University

Annex 36 English translation version of the survey on potential impact assessment of climate-related hazards on urban public health service, Khon Kaen city

Survey on potential impact assessment of climate-related hazards on urban public health service, Khon Kaen city

55 % of the world's population living in urban areas today and projected to reach 68% by 2050 (UNDESA,2018)[76]. Cities expose to climate-related disasters such as flooding, water shortages or extreme weather conditions, imposing huge challenges to urban health facilities and services in the future. Besides ensuring service capabilities to meet growing demands driven by urbanization, the local public health care service must adapt to worsen climate change impacts. In this regard, it is crucial to strengthen climate-resilient urban public health care services by integrating spatial planning and service network operations among urban development domains, disaster risk management and the local health sector.

The purpose of this survey is to assess the potential impact of climate-related hazards on the urban public health service of the Ministry of Public Health in Khon Kaen Province. The survey result will be used for potential impact assessment, and climate-resilient operationalization tailored for Khon Kaen city public health service and formulate policy recommendations for mainstreaming integrated climate-resilient and adaption to sectoral and local public health care operation. The responder of this survey should be a responsible person (s) for the environment and safety of the hospital who can coordinate information from various related departments such as management, finance department, maintenance & service support department, nursing, emergency service, and other relevant divisions.

The questionnaire consists of 5 parts as follows

Part 1: General information

Part 2: Status quo – Trend of potential service capacity

Part 3: Sensitivity-related elements

Part 4: Coping capacity-related elements

Part 5: Adaptive capacity-related elements

[76] United Nations, Department of Economic and Social Affairs, Population Division (2018). World Urbanization Prospects: The 2018 Revision.

- Key Terminology –

Hazard: The potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources. In this report, the term hazard usually refers to climate-related physical events or trends or their physical impacts

Disaster: A serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources

Exposure: The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected.

Vulnerability: the propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

Sensitivity: the degree to which a system, person, or community is affected, either adversely or beneficially, by climate-related hazards. Sensitivity is related to physical, socio-economic, culture and environment tendency of a system, person, or community.

Coping capacity The ability of people, institutions, organizations, and systems, using available skills, values, beliefs, resources, and opportunities, to address, manage, and overcome adverse conditions in the short to medium term

Adaptive capacity The ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences

Resilience: The capacity of social, economic and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity and structure, while also maintaining the capacity for adaptation, learning and transformation

Sources;

IPCC, 2014: Annex II: Glossary [Mach, K.J., S. Planton and C. von Stechow (eds.)]. In: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, pp. 117-130.

UNISDR, 2009: UNISDR Terminology on Disaster Risk Reduction. United Nations International Strategy for Disaster Reduction, Geneva, Switzerland.

Part 1: General information

1.1 Organization:……………………………………..……………………………………..…

1.2 Address:………………….……………..………………….……………….………….…..…

1.3 Name-Surname of responder:………..…………………..………….…..……………..………………

1.4 Current designation: …………..……………………..……………………………...……….……

1.5 Department/Bureau/Section: ……………………….…………………….……...……….……

1.6 E-mail: …………………….…..………… 1.7 Telephone: …………………………….…..

1.8 Gender ☐ Male ☐ Female ☐ Others 1.9 Age: ………………………………..….

1.10 Education level

☐ High school graduate ☐ Bachelor degree or equivalent

☐ Bachelor degree or equivalent ☐ Doctoral degree or equivalent

1.11 Relevant experience/responsibility on risk management or natural disaster risk (if any) management

Year	Description

1.12 Survey response date ....

Part 2: Status quo – Trend of potential service capacity

Note: Please fill in the information or mark ✓ in the box corresponding to characteristics / service potential of your organization.

***** Current operation status (Year 2019) *****

2.1 Please specify the number of patients admitted to your organization in the fiscal year 2019.
Number of emergency patients ………………… persons/day
Number of patients in ………………… persons/ day
Number of outpatients ………………… people /day
Number of patients receiving out-of-office services (eg. Service unit) …………… people/day
Others (Please specify ……………………………………………) ………………… People/day

2.2 Do you think that your agency will provide services according to the capacity to accommodate patients according to the health service standards or not?
☐ Yes, the number of patients using the service is equal to the capacity of the service.
☐ No number of patients exceeded the capacity for which the service was available. (Please provide details)
☐ No number of patients using the service is less than the capacity to accommodate. (Please provide details)
*** If you answered "No", please specify the number of patients you think is appropriate. According to the potential to accommodate patients according to the health service standards of your organization (Average estimate)
Number of emergency patients ………………… persons/day
Number of patients in ………………… persons/day
Number of outpatients ………………… people/day
Number of patients receiving out-of-the-box services (e.g. Service unit) ………… people/day
Others (Please specify …………………………………………………) ……… people / day

2.3 Does your organization have the following types of patients under your current (2019) care or area of care?

Vulnerable patients	No	Yes (Please specify the number of patients)	Remarks
Respiratory ventilator/Oxygen-dependent or Dialysis dependent			
Disability and self-movement difficulty			
Elderly			
Infant/Toddlers (0-5 year-old)			
Pregnancy women			
Continuity medication treatment dependency			
Local language proficiency			
Mental illness patient			
Others (please specify ……………………………)			

Notes/Comments (If any)

2.4 Please specify the minimum number of personnel. For providing service efficiently in accordance with the standards. In various situations Of your organization as follows

Service status	Minimum number of personnel (person/day) for operation (Average estimated value)			Remarks
	Medical staff [77]	Medical service staff [78]	Hospital service staff [79]	
Open for service in all departments				
Open part of the service (Only for the work that is necessary)				
Open only for the emergency department / basic laboratory.				
Closed				

Notes/Comments (If any)

2.5 Please specify locations of the following essential working systems (more than 1 option is possible)

Working systems	No/not relevant	Location of internal working systems					Off-site
		Outdoor	Indoor				
		<=1st fl.	Under ground	1st fl.	2nd fl.	>2nd fl.	
Electricity power control center	☐	☐	☐	☐	☐	☐	☐
Back up power source (s) (CHP, renewable energy)	☐	☐	☐	☐	☐	☐	☐
Liquid fuel (for backup generator, vehicle, water pumping, cooking etc.)	☐	☐	☐	☐	☐	☐	☐

[77] Staff who perform a job that provides medical examination and direct medical treatments, such as doctors, dentists, nurses, nursing assistants, nursing staff, midwives, and other nursing services

[78] Staff who perform medical services other than direct medical examinations, such as X-ray personnel, physical therapist, medical technicians, pharmacists, nutritionists and staff members in the medical service department, etc.

[79] Staff who perform work not related to medical care or medical services, such as finance and accounting staff, procurement officer, driver, cleaning staff, security guards, etc..

Working systems	No/not relevant	Location of internal working systems						Off-site
		Outdoor	Indoor					
		<=1st fl.	Under ground	1st fl.	2nd fl.	>2nd fl.		
Computer/Server control center	☐	☐	☐	☐	☐	☐		☐
Internet control center	☐	☐	☐	☐	☐	☐		☐
Telephone/Radio control center	☐	☐	☐	☐	☐	☐		☐
Document/Medical record archive	☐	☐	☐	☐	☐	☐		☐
Drinking/ Potable water storage	☐	☐	☐	☐	☐	☐		☐
Water filter or purication system	☐	☐	☐	☐	☐	☐		☐
Water supply (Tap water)	☐	☐	☐	☐	☐	☐		☐
Drainage system	☐	☐	☐	☐	☐	☐		☐
Pumping system	☐	☐	☐	☐	☐	☐		☐
Waste water treatment system	☐	☐	☐	☐	☐	☐		☐
Solid waste storage	☐	☐	☐	☐	☐	☐		☐
Infectious waste storage	☐	☐	☐	☐	☐	☐		☐
Hazardous waste storage	☐	☐	☐	☐	☐	☐		☐
Infectious waste incineration facility	☐	☐	☐	☐	☐	☐		☐
Medical radiology and imaginary system	☐	☐	☐	☐	☐	☐		☐
Morgue	☐	☐	☐	☐	☐	☐		☐
Food and nutriention storage	☐	☐	☐	☐	☐	☐		☐
Medicine and pharmaceutical storage	☐	☐	☐	☐	☐	☐		☐
Blood bank	☐	☐	☐	☐	☐	☐		☐
Medical gases and liquid oxygen supply storage/center	☐	☐	☐	☐	☐	☐		☐
Dispensible medical supplies storage	☐	☐	☐	☐	☐	☐		☐
Multipurpose space/spare room	☐	☐	☐	☐	☐	☐		☐
Parking lots	☐	☐	☐	☐	☐	☐		☐

Notes/Comments (If any)

2.6 The longest downtime/disruption/shortage of the following systems in the past 5 years (2014-2019).

Working systems	Downtime								Not relevant
	Never	<1 hr.	>1-4 hrs.	>4-12 hrs.	>12-24 hrs.	>1-2 days	>2-4 days	>4 days	
Grid power control center	☐	☐	☐	☐	☐	☐	☐	☐	☐
Backup power source (s) (e.g. diesel generator, CHP, renewable energy)	☐	☐	☐	☐	☐	☐	☐	☐	☐
Gasoline/Liquid fuel (for backup generator, vehicle, water pumping, cooking etc.)	☐	☐	☐	☐	☐	☐	☐	☐	☐
Computer/Server control center	☐	☐	☐	☐	☐	☐	☐	☐	☐

Working systems	Downtime								Not relevant
	Never	<1 hr.	>1-4 hrs.	>4-12 hrs.	>12-24 hrs.	>1-2 days	>2-4 days	>4 days	
Internet control center	☐	☐	☐	☐	☐	☐	☐	☐	☐
Telephone/Radio control center	☐	☐	☐	☐	☐	☐	☐	☐	☐
Drinking/ Potable water	☐	☐	☐	☐	☐	☐	☐	☐	☐
Tap water (water supply)	☐	☐	☐	☐	☐	☐	☐	☐	☐
Pumping system	☐	☐	☐	☐	☐	☐	☐	☐	☐
Wastewater treatment system	☐	☐	☐	☐	☐	☐	☐	☐	☐
Drainage system	☐	☐	☐	☐	☐	☐	☐	☐	☐
Waste management system (solid waste, infectious waste, hazardous waste)	☐	☐	☐	☐	☐	☐	☐	☐	☐
Medicine and dispensable medical supplies (incl. Medical gases, blood)	☐	☐	☐	☐	☐	☐	☐	☐	☐
Linin service	☐	☐	☐	☐	☐	☐	☐	☐	☐
Office stationery	☐	☐	☐	☐	☐	☐	☐	☐	☐
Food and nutrients	☐	☐	☐	☐	☐	☐	☐	☐	☐
Personnel (in charge less than 50 %)	☐	☐	☐	☐	☐	☐	☐	☐	☐
Vehicles	☐	☐	☐	☐	☐	☐	☐	☐	☐
Safe access route(s)	☐	☐	☐	☐	☐	☐	☐	☐	☐
Others (please specify………………..)	☐	☐	☐	☐	☐	☐	☐	☐	☐

Notes/Comments (If any)

2.7 How does your organization manage the working conditions and maintenance practice of the following systems?

Working system	System conditions and maintenance				Not relevant
	System condition	Examination & reporting	Trained staff/technician	Resources	
Grid power system (electricity)	☐ Disrepair ☐ Fair ☐ Good	☐ None ☐ Yes, but irregular ☐ Yes and regular	☐ None ☐ Yes	☐ None ☐ Yes, but insufficient ☐ Yes and sufficient	☐
Backup power source (s) (e.g. diesel generator, CHP, renewable energy)	☐ Disrepair ☐ Fair ☐ Good	☐ None ☐ Yes, but irregular ☐ Yes and regular	☐ None ☐ Yes	☐ None ☐ Yes, but insufficient ☐ Yes and sufficient	☐
Gasoline (liquid) storage	☐ Disrepair ☐ Fair ☐ Good	☐ None ☐ Yes, but irregular ☐ Yes and regular	☐ None ☐ Yes	☐ None ☐ Yes, but insufficient ☐ Yes and sufficient	☐
Computer/Server control center	☐ Disrepair ☐ Fair ☐ Good	☐ None ☐ Yes, but irregular ☐ Yes and regular	☐ None ☐ Yes	☐ None ☐ Yes, but insufficient ☐ Yes and sufficient	☐
Internet control center	☐ Disrepair	☐ None	☐ None	☐ None	☐

Working system	System conditions and maintenance				Not relevant
	System condition	Examination & reporting	Trained staff/technician	Resources	
	☐ Fair ☐ Good	☐ Yes, but irregular ☐ Yes and regular	☐ Yes	☐ Yes, but insufficient ☐ Yes and sufficient	
Telephone/Radio control center	☐ Disrepair ☐ Fair ☐ Good	☐ None ☐ Yes, but irregular ☐ Yes and regular	☐ None ☐ Yes	☐ None ☐ Yes, but insufficient ☐ Yes and sufficient	☐
Water filter or purication system	☐ Disrepair ☐ Fair ☐ Good	☐ None ☐ Yes, but irregular ☐ Yes and regular	☐ None ☐ Yes	☐ None ☐ Yes, but insufficient ☐ Yes and sufficient	☐
Water supply (Tap water)	☐ Disrepair ☐ Fair ☐ Good	☐ None ☐ Yes, but irregular ☐ Yes and regular	☐ None ☐ Yes	☐ None ☐ Yes, but insufficient ☐ Yes and sufficient	☐
Pumping system	☐ Disrepair ☐ Fair ☐ Good	☐ None ☐ Yes, but irregular ☐ Yes and regular	☐ None ☐ Yes	☐ None ☐ Yes, but insufficient ☐ Yes and sufficient	☐
Waste water treatment system	☐ Disrepair ☐ Fair ☐ Good	☐ None ☐ Yes, but irregular ☐ Yes and regular	☐ None ☐ Yes	☐ None ☐ Yes, but insufficient ☐ Yes and sufficient	☐
Drainage system	☐ Disrepair ☐ Fair ☐ Good	☐ None ☐ Yes, but irregular ☐ Yes and regular	☐ None ☐ Yes	☐ None ☐ Yes, but insufficient ☐ Yes and sufficient	☐
Waste management system (solid waste, infectious waste, hazardous waste)	☐ Disrepair ☐ Fair ☐ Good	☐ None ☐ Yes, but irregular ☐ Yes and regular	☐ None ☐ Yes	☐ None ☐ Yes, but insufficient ☐ Yes and sufficient	☐
Document/Medical record archive	☐ Disrepair ☐ Fair ☐ Good	☐ None ☐ Yes, but irregular ☐ Yes and regular	☐ None ☐ Yes	☐ None ☐ Yes, but insufficient ☐ Yes and sufficient	☐
Linin service	☐ Disrepair ☐ Fair ☐ Good	☐ None ☐ Yes, but irregular ☐ Yes and regular	☐ None ☐ Yes	☐ None ☐ Yes, but insufficient ☐ Yes and sufficient	☐
Office stationary	☐ Disrepair ☐ Fair ☐ Good	☐ None ☐ Yes, but irregular ☐ Yes and regular	☐ None ☐ Yes	☐ None ☐ Yes, but insufficient ☐ Yes and sufficient	☐
Vehicles	☐ Disrepair ☐ Fair	☐ None	☐ None ☐ Yes	☐ None	☐

Working system	System conditions and maintenance				Not relevant
	System condition	Examination & reporting	Trained staff/technician	Resources	
	☐ Good	☐ Yes, but irregular ☐ Yes and regular		☐ Yes, but insufficient ☐ Yes and sufficient	
Safe access route(s)	☐ Disrepair ☐ Fair ☐ Good	☐ None ☐ Yes, but irregular ☐ Yes and regular	☐ None ☐ Yes	☐ None ☐ Yes, but insufficient ☐ Yes and sufficient	☐
Others (please specify………………..)	☐ Disrepair ☐ Fair ☐ Good	☐ None ☐ Yes, but irregular ☐ Yes and regular	☐ None ☐ Yes	☐ None ☐ Yes, but insufficient ☐ Yes and sufficient	☐

Notes/Comments (If any)

2.8 Has your agency ever experienced an emergency or disaster in the past 5 years (2014-2019)? If yes, how has it affected to work systems and operations of your organization?

☐ Never

☐ Yes, but all systems can still work/perform continuously without significant impact.

☐ Yes, the hospital had to temporarily reduce/suspense some services for…… day(s).

☐ Yes, the hospital can only open critical service sections and announced partially evacuation of patients/staff or relocation of essential working systems to a safer location for ………. day(s).

☐ Yes, the hospital had shut down all work systems, announced full evacuation and relocation of essential working systems to a safer location for……. day(s)

If you answered "Yes", please provide a brief description of the incident (s)

....

....

2.9 Are there differences of patients with a particular type of illness or diseases during hazard events (especially, floods or water supply shortages (drought)) and business as usual situation?

☐ No

☐ Yes, please specify details in the table below.

Flooding	Water supply shortages (drought)

Notes/Comments (If any)

<u>Forecasting future conditions</u>

2.10 If in the next 18 years (2037) (by the end of the 20-year National Strategy's timeframe), there is an increasing number of health population/patients in your service areas by 60% compared to today situation (2019). Are there needs of your organization to expand or increase a service capacity or units in response to the increased number of patients or not?.and how?

☐ None, please specify the reason briefly

☐ Yes, in the same area / same location

- Please specify a number of beds / service units and / or buildings ………………
- Please specify characteristics /functions of the potential units/buildings

☐ Yes, in other locations

- Please specify a number of beds / service units and / or buildings ………………
- Please specify characteristics /functions of the potential units/buildings

- Please provide details the potential units/buildings locations (e.g. address, village, sub-district)

Part 3: Sensitivity-related elements

Please appraise the level of impact of working systems in your organization if confronting with the following situations without external helps or supports in accordance with the given potential downtime.

Table 3-1 Description of the level of impacts that occurred to public health care service working systems

Impact level	Descriptions
Very low	All services can continue without any discernible impact or change
Low	Some services may be reduced or suspended. Some advanced or special services may be canceled. Services for non-priority client/section may be temporarily suspended.
Medium	Shutdown of auxiliaries sections but most critical service may continue. Obtain needed resources/supports from outside Full implementation of conservation measures in order to sustain essential services. Limit new inflow patients and maximize patient discharge. Declare total diversion status or partial or total evacuation.
High	Discontinued of service to most critical services. No new patients' admission. All patients will be transferred to others/nearby service facility. Declare total evacuation. Only designed staff assigned to control and observe loss and damages allow staying on-site

3.1 Power system is outage or failure (both from the main power system and the backup system)

Potential downtime	Impact level (see table 3-1)				Not relevant (no system in place)
	Very low	Low	Medium	High	
< 1 hr.	☐	☐	☐	☐	☐
>1-4 hrs.	☐	☐	☐	☐	☐
>4-12 hrs.	☐	☐	☐	☐	☐
>12-24 hrs.	☐	☐	☐	☐	☐
>1-2 days	☐	☐	☐	☐	☐
> 2-4 days	☐	☐	☐	☐	☐
> 4 days	☐	☐	☐	☐	☐

3.2 Shortage of water supply (both tap water and reserved storage)

Potential downtime	Impact level (see table 3-1)				Not relevant (no system in place)
	Very low	Low	Medium	High	
< 1 hr.	☐	☐	☐	☐	☐
>1-4 hrs.	☐	☐	☐	☐	☐
>4-12 hrs.	☐	☐	☐	☐	☐
>12-24 hrs.	☐	☐	☐	☐	☐
>1-2 days	☐	☐	☐	☐	☐
> 2-4 days	☐	☐	☐	☐	☐
> 4 days	☐	☐	☐	☐	☐

3.3 S**hortage of Gasoline/Liquid fuel** (for backup generator, vehicle, water pumping, cooking, etc)

Potential downtime	Impact level (see table 3-1)				Not relevant (no system in place)
	Very low	Low	Medium	High	
< 1 hr.	☐	☐	☐	☐	☐
>1-4 hrs.	☐	☐	☐	☐	☐
>4-12 hrs.	☐	☐	☐	☐	☐
>12-24 hrs.	☐	☐	☐	☐	☐
>1-2 days	☐	☐	☐	☐	☐
> 2-4 days	☐	☐	☐	☐	☐
> 4 days	☐	☐	☐	☐	☐

3.4 Computer and server system disruption or failure

Potential downtime	Impact level (see table 3-1)				Not relevant (no system in place)
	Very low	Low	Medium	High	
< 1 hr.	☐	☐	☐	☐	☐
>1-4 hrs.	☐	☐	☐	☐	☐
>4-12 hrs.	☐	☐	☐	☐	☐
>12-24 hrs.	☐	☐	☐	☐	☐
>1-2 days	☐	☐	☐	☐	☐
> 2-4 days	☐	☐	☐	☐	☐
> 4 days	☐	☐	☐	☐	☐

3.5 Internet system disruption or failure

Potential downtime	Impact level (see table 3-1)				Not relevant (no system in place)
	Very low	Low	Medium	High	
< 1 hr.	☐	☐	☐	☐	☐

Potential downtime	Impact level (see table 3-1)				Not relevant (no system in place)
	Very low	Low	Medium	High	
>1-4 hrs.	☐	☐	☐	☐	☐
>4-12 hrs.	☐	☐	☐	☐	☐
>12-24 hrs.	☐	☐	☐	☐	☐
>1-2 days	☐	☐	☐	☐	☐
> 2-4 days	☐	☐	☐	☐	☐
> 4 days	☐	☐	☐	☐	☐

3.6 Telephone/radio system disruption or failure

Potential downtime	Impact level (see table 3-1)				Not relevant (no system in place)
	Very low	Low	Medium	High	
< 1 hr.	☐	☐	☐	☐	☐
>1-4 hrs.	☐	☐	☐	☐	☐
>4-12 hrs.	☐	☐	☐	☐	☐
>12-24 hrs.	☐	☐	☐	☐	☐
>1-2 days	☐	☐	☐	☐	☐
> 2-4 days	☐	☐	☐	☐	☐
> 4 days	☐	☐	☐	☐	☐

3.7 Waste management system (including solid waste, infectious waste, hazardous waste) disruption or failure

Potential downtime	Impact level (see table 3-1)				Not relevant (no system in place)
	Very low	Low	Medium	High	
< 1 hr.	☐	☐	☐	☐	☐
>1-4 hrs.	☐	☐	☐	☐	☐
>4-12 hrs.	☐	☐	☐	☐	☐
>12-24 hrs.	☐	☐	☐	☐	☐
>1-2 days	☐	☐	☐	☐	☐
> 2-4 days	☐	☐	☐	☐	☐
> 4 days	☐	☐	☐	☐	☐

3.8 Wastewater treatment system disruption or failure f

Potential downtime	Impact level (see table 3-1)				Not relevant (no system in place)
	Very low	Low	Medium	High	
< 1 hr.	☐	☐	☐	☐	☐
>1-4 hrs.	☐	☐	☐	☐	☐
>4-12 hrs.	☐	☐	☐	☐	☐
>12-24 hrs.	☐	☐	☐	☐	☐
>1-2 days	☐	☐	☐	☐	☐
> 2-4 days	☐	☐	☐	☐	☐
> 4 days	☐	☐	☐	☐	☐

3.9 Shortage of food, nutrients and drinking water

Potential downtime	Impact level (see table 3-1)				Not relevant (no system in place)
	Very low	Low	Medium	High	
< 1 hr.	☐	☐	☐	☐	☐
>1-4 hrs.	☐	☐	☐	☐	☐
>4-12 hrs.	☐	☐	☐	☐	☐
>12-24 hrs.	☐	☐	☐	☐	☐
>1-2 days	☐	☐	☐	☐	☐
> 2-4 days	☐	☐	☐	☐	☐
> 4 days	☐	☐	☐	☐	☐

3.10 Shortage of medicine and dispensable medical supplies (incl. medical gases, blood and etc.)

Potential downtime	Impact level (see table 3-1)				Not relevant (no system in place)
	Very low	Low	Medium	High	
< 1 hr.	☐	☐	☐	☐	☐
>1-4 hrs.	☐	☐	☐	☐	☐
>4-12 hrs.	☐	☐	☐	☐	☐
>12-24 hrs.	☐	☐	☐	☐	☐
>1-2 days	☐	☐	☐	☐	☐
> 2-4 days	☐	☐	☐	☐	☐
> 4 days	☐	☐	☐	☐	☐

3.11 Shortage of linin or disruption of linin service

Potential downtime	Impact level (see table 3-1)				Not relevant (no system in place)
	Very low	Low	Medium	High	
< 1 hr.	☐	☐	☐	☐	☐
>1-4 hrs.	☐	☐	☐	☐	☐
>4-12 hrs.	☐	☐	☐	☐	☐
>12-24 hrs.	☐	☐	☐	☐	☐
>1-2 days	☐	☐	☐	☐	☐
> 2-4 days	☐	☐	☐	☐	☐
> 4 days	☐	☐	☐	☐	☐

3.12 Shortage of office stationery

Potential downtime	Impact level (see table 3-1)				Not relevant (no system in place)
	Very low	Low	Medium	High	
< 1 hr.	☐	☐	☐	☐	☐
>1-4 hrs.	☐	☐	☐	☐	☐
>4-12 hrs.	☐	☐	☐	☐	☐
>12-24 hrs.	☐	☐	☐	☐	☐
>1-2 days	☐	☐	☐	☐	☐
> 2-4 days	☐	☐	☐	☐	☐
> 4 days	☐	☐	☐	☐	☐

3.13 Shortage of 50% of staff (compared to BaU)

Potential downtime	Impact level (see table 3-1)				Not relevant (no system in place)
	Very low	Low	Medium	High	
< 1 hr.	☐	☐	☐	☐	☐
>1-4 hrs.	☐	☐	☐	☐	☐
>4-12 hrs.	☐	☐	☐	☐	☐
>12-24 hrs.	☐	☐	☐	☐	☐

Potential downtime	Impact level (see table 3-1)				Not relevant (no system in place)
	Very low	Low	Medium	High	
>1-2 days	☐	☐	☐	☐	☐
> 2-4 days	☐	☐	☐	☐	☐
> 4 days	☐	☐	☐	☐	☐

3.14 No vehicles and safe accessible route (s)

Potential downtime	Impact level (see table 3-1)				Not relevant (no system in place)
	Very low	Low	Medium	High	
< 1 hr.	☐	☐	☐	☐	☐
>1-4 hrs.	☐	☐	☐	☐	☐
>4-12 hrs.	☐	☐	☐	☐	☐
>12-24 hrs.	☐	☐	☐	☐	☐
>1-2 days	☐	☐	☐	☐	☐
> 2-4 days	☐	☐	☐	☐	☐
> 4 days	☐	☐	☐	☐	☐

Notes/Comments (If any)

Part 4: Coping capacity element

4.1 (current) Level of flexibility and modularity of essential working systems

Table 4-1 Description of flexibility and modularity levels of essential working systems

Level	Descriptions
No/insignificant	The working system can NOT be moved, or adjusted, or modulated its elements or functions.
Low	The working system can be moved, or adjusted, or modulated its elements or functions by using special equipment/devices or done by specialist supervision or specialist supervision. Likely, the working system may have lower efficiency or productivity after moving, adjusting, or modulating its elements or functions.
Medium	The working system can be moved, or adjusted, or modulated its elements or functions by specialist supervision or specialist supervision and/or using special equipment/devices. Likely, the working system remains the same level of efficiency or productivity after moving, adjusting, or modulating its elements or functions.
High	The working system can be moved, or adjusted, or modulated its elements or functions by users and/or using typical available equipment/devices. Likely, the working system remains the same level of efficiency or productivity after moving, adjusting, or modulating its elements or functions.

Working systems	Level of flexibility and modularity *(see Table 4-1)*				Not relevant (no system in place)
	No	Low	Medium	High	
Grid (electricity) power control center	☐	☐	☐	☐	☐
Backup power source (s) (e.g. diesel generator, CHP, renewable energy)	☐	☐	☐	☐	☐
Computer/Server control center	☐	☐	☐	☐	☐
Internet control center	☐	☐	☐	☐	☐
Telephone/Radio control center	☐	☐	☐	☐	☐
Water filter/Purification	☐	☐	☐	☐	☐
Water supply (Tap water)	☐	☐	☐	☐	☐
Pumping system	☐	☐	☐	☐	☐

Working systems	Level of flexibility and modularity *(see Table 4-1)*				Not relevant (no system in place)
	No	Low	Medium	High	
Waste water treatment system	☐	☐	☐	☐	☐
Waste management system (incl. solid waste, infectious waste, hazardous waste)	☐	☐	☐	☐	☐
Medicine and dispensable medical supplies (incl. medical gases, blood, etc.)	☐	☐	☐	☐	☐
Linin service	☐	☐	☐	☐	☐
Office stationary	☐	☐	☐	☐	☐
Food and nutriention	☐	☐	☐	☐	☐
Multipurpose space/spare room	☐	☐	☐	☐	☐
Personnel management	☐	☐	☐	☐	☐
Vehicles	☐	☐	☐	☐	☐
Safe access route	☐	☐	☐	☐	☐
Personnel commuting service	☐	☐	☐	☐	☐
Others (please specify………………)	☐	☐	☐	☐	☐

Notes/Comments (If any)

4.2 (current) Level of diversity of suppliers which necessary for essential working systems

Table 4-2 Description of diversity of suppliers' levels

Level	Descriptions
No/insignificant	Single supplier or monopoly
Low	Two or multiple suppliers are available only in the case of an emergency/hazards or business as unusual. No contract and supportive technical structure/management system are agreed upon and installed in advance.
Medium	Two or multiple suppliers are available only in the case of emergency/hazards or business as unusual. Contract and supportive technical structure/management system are agreed upon and installed in advance.
High	Two or multiple suppliers are available in both emergency/hazards and business as usual. Contract and supportive technical structure/management system are agreed upon and installed in place.

Working systems	Level of diversity of suppliers *(see Table 4-2)*				Not relevant (no system in place)
	No	Low	No	Low	
Grid (electricity) power control center	☐	☐	☐	☐	☐
Backup power source (s) (diesel generator, CHP, renewable energy, etc.)	☐	☐	☐	☐	☐
Computer/Server control center	☐	☐	☐	☐	☐
Internet control center	☐	☐	☐	☐	☐
Telephone/Radio control center	☐	☐	☐	☐	☐
Water filter/Purification	☐	☐	☐	☐	☐
Water supply (Tap water)	☐	☐	☐	☐	☐
Underground water	☐	☐	☐	☐	☐
Pumping system	☐	☐	☐	☐	☐
Waste water treatment system	☐	☐	☐	☐	☐

Working systems	Level of diversity of suppliers *(see Table 4-2)*				Not relevant (no system in place)
	No	Low	No	Low	
Waste management system (solid waste, infectious waste, hazardous waste)	☐	☐	☐	☐	☐
Medicine and dispensable medical supplies (incl. Medical gases, blood)	☐	☐	☐	☐	☐
Linin service	☐	☐	☐	☐	☐
Office stationary	☐	☐	☐	☐	☐
Food and nutriention	☐	☐	☐	☐	☐
Multipurpose space/spare room	☐	☐	☐	☐	☐
Personnel management	☐	☐	☐	☐	☐
Vehicles	☐	☐	☐	☐	☐
Personnel commuting service	☐	☐	☐	☐	☐
Others (please specify………………)	☐	☐	☐	☐	☐

Notes/Comments (If any)

4.3 Potential redundancy of essential working systems in the case that primary systems/resources malfunction and no replenishment/replacement is possible

Working system	No	Reserved systems or resources which can be used after primary systems malfunction					
		0-1 hr	>1-4 hrs	>4-12 hrs	>1-2 days	>2-4 days	>4 days
Backup power source (s) (diesel generator, CHP, renewable energy, etc.)	☐	☐	☐	☐	☐	☐	☐
Fuel (for diesel generators, vehicles, pumping, and etct.)	☐	☐	☐	☐	☐	☐	☐
Computer/server (including reserved batteries)	☐	☐	☐	☐	☐	☐	☐
Internet	☐	☐	☐	☐	☐	☐	☐
Telephone/Radio (including reserved batteries)	☐	☐	☐	☐	☐	☐	☐
Water supply	☐	☐	☐	☐	☐	☐	☐
Drinking water	☐	☐	☐	☐	☐	☐	☐
Water filter/Purification	☐	☐	☐	☐	☐	☐	☐
Water storage system (e.g. pond, tank)	☐	☐	☐	☐	☐	☐	☐
Pumping system	☐	☐	☐	☐	☐	☐	☐
Waste water treatment system	☐	☐	☐	☐	☐	☐	☐
Waste management system (solid waste, infectious waste, hazardous waste)	☐	☐	☐	☐	☐	☐	☐
Medicine and dispensable medical supplies (incl. Medical gases, blood)	☐	☐	☐	☐	☐	☐	☐
Linin service	☐	☐	☐	☐	☐	☐	☐
Office stationary	☐	☐	☐	☐	☐	☐	☐
Food and nutrients	☐	☐	☐	☐	☐	☐	☐
Multipurpose space/spare room	☐	☐	☐	☐	☐	☐	☐
Surge/back up personnel	☐	☐	☐	☐	☐	☐	☐
Others (please specify………………)	☐	☐	☐	☐	☐	☐	☐

Notes/Comments (If any)

4.4 Positions/locatons of back-up working systems/resources

Working systems	No/not relevant	Location of internal working systems					Off-site
		Outdoor	Indoor				
		<=1st fl.	Under ground	1st fl.	2nd fl.	> 2nd fl.	
Backup power source (s) (diesel generator, CHP, renewable energy, etc.)	☐	☐	☐	☐	☐	☐	☐
Liquid fuel (for backup generator, vehicle, water pumping, cooking etc.)	☐	☐	☐	☐	☐	☐	☐
Computer/server (including reserved batteries)	☐	☐	☐	☐	☐	☐	☐
Telephone/Radio (including reserved batteries)	☐	☐	☐	☐	☐	☐	☐
Water supply	☐	☐	☐	☐	☐	☐	☐
Water filter/Purification	☐	☐	☐	☐	☐	☐	☐
Waste water treatment system	☐	☐	☐	☐	☐	☐	☐
Waste management system (solid waste, infectious waste, hazardous waste)	☐	☐	☐	☐	☐	☐	☐
Water storage system (e.g. pond, tank)	☐	☐	☐	☐	☐	☐	☐
Pumping system	☐	☐	☐	☐	☐	☐	☐
Medicine and dispensable medical supplies (incl. Medical gases, blood)	☐	☐	☐	☐	☐	☐	☐
Food and nutrients	☐	☐	☐	☐	☐	☐	☐
Document/Medical record archive	☐	☐	☐	☐	☐	☐	☐
Multipurpose space/spare room	☐	☐	☐	☐	☐	☐	☐
Morgue	☐	☐	☐	☐	☐	☐	☐
Parking lots	☐	☐	☐	☐	☐	☐	☐
Others (please specify………………)	☐	☐	☐	☐	☐	☐	☐

Notes/Comments (If any)

4.5 Procurement of special vehicle type (e.g. Boat, amphibian, helicopter, drone) for carrying goods and passengers during emergencies or hazards

☐ None and never aware of it

☐ No, but have a plan/under consideration)

☐ Yes, own purchased or contracted service providers but lack of regular technical checkup)

☐ Yes, own purchased or contracted service providers with regular technical checkup)

4.6 Alternate safe accessible route(s)

☐ None and never aware of it

☐ No, but have a plan/under consideration)

☐ Yes, surveyed and designed alternate safe accessible route(s) but lack of regular maintenance

☐ Yes, surveyed and designed alternate safe accessible route(s) and conducting regular maintenance

4.7 Connectivity(-ability) of sensitive working system with external devices/systems

☐ None and never aware of it

☐ No, but have a plan/under consideration

☐ Yes, only particular working systems

☐ Yes, all working system can connect with external devices or systems

4.8 Procurement of a secondary backup system

☐ None and never aware of it

☐ No, but have a plan/under consideration)

☐ Yes, own purchased or contracted service providers but lack of regular technical checkup

☐ Yes, own purchased or contracted service providers with regular technical checkup

4.9 Resources conservation plan implementation

☐ None and never aware of it

☐ No, but under discussion or drafting plan

☐ Yes, have a plan but no regular review and drills

☐ Yes, have a plan, regular review/drill(s), but no/insufficient resources for implementation

☐ Yes, have a plan, regular review/drill(s), and have sufficient resources for implementation

4.10 Shelter(s) for staff and family in the case of hazards

☐ No

☐ Yes, but no designated places and facilities in advance

☐ Yes with designated places and facilities in advance

4.11 Patient referral and transfer agreement with other hospitals

☐ No

☐ Yes

If yes, please identify the designated referral hospitals

1)
2)
3)

4.12 Agreement and exercise on partial or full patient evacuation to other hospitals/facilities in the case of emergency or hazards

☐ No

☐ Yes

If yes, please identify the designated referral hospitals

1)
2)
3)

4.13 Standard procedure for recording a patient medical data in the case of no computer service

☐ No

☐ Yes, manual (written) recording

4.14 Using of runners (courier) as a backup for getting help from outside during communication systems failures

☐ No

☐ Yes

4.15 Availability of automatically channels or systems for communicating and coordinating with utilities and key suppliers

☐ No

☐ Yes, partially/not all key utilities/suppliers

☐ Yes, all key utilities/suppliers

4.16 Responsive plan for slow-onset natural hazards

☐ None and never aware of it

☐ No, but under discussion or drafting plan

☐ Yes, have a plan but no regular review and drills

☐ Yes, have a plan, regular review/drill(s), but no/insufficient resources for implementation

☐ Yes, have a plan, regular review/drill(s), and have sufficient resources for implementation

4.17 Self-help capacity

☐ No plan, no necessary workforce and resources for self-help, only rely on external supports

☐ Yes, have necessary workforce and resources for initial self-help while waiting for external supports

☐ Yes, have necessary workforce and resources for protecting properties and working system with a little needs for external supports)

☐ Yes, have necessary workforce and resources for protecting properties and working system with no external supports needed)

4.18 Availability and accessibility financial resources for BaU operation

☐ Insufficient financial resource for BaU operation (deficit)

☐ Sufficient financial resource for BaU operation (but no surplus)

☐ Surplus financial resource for BaU operation

4.19 Availability and accessibility of financial resources for disaster risk preparation

☐ No/Insufficient and difficult to acquire the resources from external sources or donation

☐ Insufficient but not difficult to acquire the resources from external sources or donation

☐ Sufficient and no need to acquire the resources from external sources or donation

4.20 Availability and accessibility of BaU financial resources or other sources (e.g. donation, emergency budget from central, provincial, and local governments) for long-term investment on increasing climate-related hazards resilience

☐ No/Insufficient and difficult to acquire the resources from external sources or donation

☐ Insufficient but not difficult to acquire the resources from external sources or donation

☐ Sufficient and no need to acquire the resources from external sources or donation

Notes/Comments (If any)

Part 5 Adaptive capacity

5.1 Availability and accessibility of local future population and development for long-term service planning

☐ No and never aware of it

☐ Aware of the information but limited accessibility

☐ Aware of and access to the information but does not use it for service planning

☐ Aware of and access to the information and use it for service planning

5.2 Availability and accessibility of information on local future climate-related disaster risks (floods and water supply scarcity) in your area

☐ No and never aware of it

☐ Aware of the information but limited accessibility

☐ Aware of and access to the information but does not use it for risk management planning

☐ Aware of and access to the information and use it for risk management planning

5.3 Availability and accessibility of local hazard map and climate-related disaster risk database

☐ No and never aware of it

☐ Aware of the information but limited accessibility

☐ Aware of and access to the information but does not use it for risk communication with relevant stakeholders

☐ Aware of and access to the information and use it for risk communication with relevant stakeholders

5.4 In-house capacity building and awareness-raising on the importance of future climate-related disaster risk and resilience

☐ None and never aware of it
☐ No, but under discussion or drafting plan
☐ Yes, have a plan but no implementation
☐ Yes, have a plan, but no/insufficient resources and coordination for implementation
☐ Yes, have a plan, sufficient resources and coordination for implementation

5.5 Business continuity plan implementation

☐ None and never aware of it
☐ No, but under discussion or drafting plan
☐ Yes, have a plan but no regular review and drills
☐ Yes, have a plan, regular review/drill(s), but no/insufficient resources for implementation
☐ Yes, have a plan, regular review/drill(s), and have sufficient resources for implementation

5.6 Contingency plan implementation

☐ None and never aware of it
☐ No, but under discussion or drafting plan
☐ Yes, have a plan but no regular review and drills
☐ Yes, have a plan, regular review/drill(s), but no/insufficient resources for implementation
☐ Yes, have a plan, regular review/drill(s), and have sufficient resources for implementation

5.7 Existence and efficiency of internal Board of committee/working group on disaster risk management

☐ None and never aware of it
☐ No, but under discussion)
☐ Yes, have regular meetings but lack of resources and efficient coordination
☐ Yes; have regular meetings with sufficient resources and efficient coordination

5.8 Specific coordinator on disaster risk management

☐ None and never aware of it
☐ No, but under discussion

☐ Yes, have clear designed coordinator (s) but disaster risk management is not his/her main task
☐ Yes, have clear designed coordinator (s) who disaster risk management is his/her main task

5.9 Surge personnel capacity plan implementation
☐ None and never aware of it
☐ No, but under discussion or drafting plan
☐ Yes, have a plan but no regular review and drills
☐ Yes, have a plan, regular review/drill(s), but no/insufficient resources for implementation
☐ Yes, have a plan, regular review/drill(s), and have sufficient resources for implementation

5.10 Training on working with no-electricity or limited resources
☐ None and never aware of it
☐ No, but under discussion
☐ Yes, <1 time a year
☐ Yes, at least 1 time a year, but have insufficient resources and coordination
☐ Yes, at least 1 time a year and have sufficient resources and coordination

5.11 One-stop service area with the highest protective level, in the case of hazards or high level of emergency
☐ None and never aware of it
☐ No, but under discussion or drafting plan
☐ Yes, have a plan, but no implementation
☐ Yes, have a plan, conducting plan review/ drill(s), but no/insufficient resources for implementation
☐ Yes, have a plan, conducting plan review/ drill(s), have sufficient resources for implementation

5.12 Assignment of alternate care site(s)
☐ None and never aware of it
☐ No, but under discussion or drafting plan
☐ Yes, have a plan but no implementation
☐ Yes, have a plan, conducting plan review/ drill(s), but no/insufficient resources for implementation
☐ Yes, have a plan, conducting plan review/ drill(s), have sufficient resources for implementation)

5.13 Evacuation plan implementation (both partial and full evacuation)

☐ None and never aware of it

☐ No, but under discussion or drafting plan

☐ Yes, have a plan but no regular review and drills)

☐ Yes, have a plan, regular review/drill(s), but no/insufficient resources for implementation)

☐ Yes, have a plan, regular review/drill(s), and have sufficient resources for implementation)

5.14 Volunteer and external help management plan implementation

☐ None and never aware of it

☐ No, but under discussion or drafting plan)

☐ Yes, have a plan but no regular review and drills)

☐ Yes, have a plan, regular review/drill(s), but no/insufficient resources for implementation)

☐ Yes, have a plan, regular review/drill(s), and have sufficient resources for implementation)

5.15 Community participation in disaster risk management planning

☐ Internal process and not involve the community in planning and exercise process

☐ Involve the community in the plan exercise process

☐ Involve the community in the planning process but irregular exercise the plan with communities

☐ Involve the community in the planning process and exercise regularly

5.16 Disaster risk management planning and exercise with utilities, suppliers and other relevant agencies

☐ None and never aware of it

☐ No, but under discussion or drafting plan

☐ Yes, have a plan but no implementation

☐ Yes, have a plan, but no/insufficient resources and coordination for implementation

☐ Yes, have a plan, sufficient resources and coordination for implementation

5.17 Mainstreaming disaster risk management in an action plan or budget plan

☐ None and never aware of it

☐ No, but under discussion or drafting plan

☐ Yes, have a plan but no implementation

☐ Yes, have a plan, but no/insufficient resources and coordination for implementation

☐ Yes, have a plan, sufficient resources and coordination for implementation

5.18 Availability of climate-related hazards management integration on action plan and BaU budget plans

☐ None and never aware of it
☐ No, but under discussion or drafting plan
☐ Yes, have a plan but no implementation
☐ Yes, have a plan, but no/insufficient resources and coordination for implementation
☐ Yes, have a plan, sufficient resources and coordination for implementation

5.19 Build Back Better plan implementation
☐ None
☐ No, but under discussion or drafting plan
☐ Yes, have a plan and regular plan review, but no/insufficient resources and coordination for implementation)
☐ Yes, have a plan, regular plan review, sufficient resources and coordination for implementation)

5.20 Monitoring and evaluation
☐ None
☐ No, but under discussion or drafting plan
☐ Yes, have a plan and regular plan review, but no/insufficient resources and coordination for implementation
☐ Yes, have a plan, regular plan review, sufficient resources and coordination for implementation

5.21 Availability of BaU resources for reconstruction /reparations and lag time for resuming to full operation
☐ No financial resources
☐ Yes, have financial resources but >1 year of delay for reparation and resuming full operation
☐ Yes, have financial resources but <=6 months of delay for reparation and resuming full operation
☐ Yes, have financial resources but <=1 month of delay for reparation and resuming full operation

5.22 Integration of the future climate-disaster risk impact information in the system maintenance plan and reparation budget
☐ None and never aware of it
☐ No, but under discussion or drafting plan
☐ Yes, have a plan but no implementation

☐ Yes, have a plan, but no/insufficient resources and coordination for implementation

☐ Yes, have a plan, sufficient resources and coordination for implementation

5.23: Climate-related hazards risk insurance

☐ None

☐ Yes, but not cover all types of climate-related hazards

☐ Yes, cover all types of climate-related hazards

5.24 Shall MoPH's hospital be insured on climate-related hazards? Please justify your support argumentation

Please return the questionnaire in *.doc, *.pdf, or *.jpg format to below contact information

Email wiriya.puntub@tu-dortmund.de By 29 February 2019

Thank you very much for your kind cooperation

Wiriya Puntub