Framework for collaborative local climate adaptation scenario development- nexus between climate resilience, public health service and spatial planning

International Journal of Climate Change Strategies and Management

311

Received 11 September 2023
Revised 27 December 2023
3 May 2024
Accepted 23 September 2024

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Abstract

Purpose – The interaction between urban development and climate change significantly impacts local public health services. Unfortunately, cities and involved institutions often fail to prioritize and integrate spatial planning when dealing with these unprecedented future challenges. This study aims to offer Health Integrative Climate Resilience and Adaptation Future (HICRAF), an innovative planning framework that systematically operationalizes future climate risks and their impact on local public health services.

Design/methodology/approach – HICRAF is developed based on the intermix of explorative and normative scenario planning approaches. Mixed methods of quantitative and qualitative techniques were applied to develop and operationalize the local climate adaptation scenarios through stakeholder participation. The framework demonstrates how different methods and scales (spatial and temporal) can be linked to exhibit climate risk outcomes of different future pathways.

Findings – The practicality of HICRAF was demonstrated in Khon Kaen city, where it bridged the gaps between global climate trajectories and local climate adaptation scenarios. It also highlights the need to consider intertwining spatial and systemic risks in local infrastructure operations. Although HICRAF has gained political buy-in and fostered the establishment of stakeholder discourse on climate-resilient futures, further research is needed to enhance its robustness and replicability.

Originality/value – This paper proposes a novel planning framework, HICRAF, that can systematically operationalize the future challenges of unprecedented climate change and urban development changes for the

Our sincere thanks go to Mr. Surapong Khamtanit, Dr. Benjawan Tawatsupa, Khon Kaen city stakeholders and experts, Thai government agencies, as well as colleagues & friends who contributed their time and input to this research. The authors declare no conflict of interest. Ethics approval for this research was obtained from the Human Research Ethics Committee of Khon Kaen Hospital (Reference: KH 0032.002/259).

Funding: This study has received funding from Deutsche Forschungsgemeinschaft; Open Access Publication Costs.

International Journal of Climate Change Strategies and Management
Vol. 17 No. 1, 2025
pp. 311-332
Emerald Publishing Limited
1756-8692
DOI 10.1108/IJCCSM-09-2023-0110

local public health service. The demonstration of HICRAF in Khon Kaen city provides empirical evidence of its implementability and upscaling potential.

Keywords Climate risk, Local climate adaptation scenario, Climate resilience, Public health, Spatial planning

Paper type Research paper

1. Introduction

Compounding climate-related hazards and urbanization trends could raise service demands, disrupt service quality and influence poorer health outcomes of the local public health service (WHO, 2015; Ebi *et al.*, 2018; Murray *et al.*, 2022), particularly in growing medium-sized cities, where resources and infrastructure are often not prioritized in tandem with development. These challenges underscore the urgent need for future-oriented risk-informed planning at a local level, taking infrastructure operation and functionality into account. Despite research and analytical tools covering this urgency seems limited, scenario planning is a transcendent instrument for exploring the potential consequences of a variety of responsive and adaptive actions and interactions among physical, environmental and societal systems by considering the uncertainties and complexities of climate change (Moss *et al.*, 2010: 747–748; O'Neill *et al.*, 2014; Kebede *et al.*, 2018; Kok *et al.*, 2019: 643–645). Scenarios encompass 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). In climate vulnerability/risk studies, projecting socio-economic changes alongside climatic changes is necessary to assess future climate risk (Greiving *et al.*, 2018; O'Neill *et al.*, 2020). However, there are a few studies that encompassed a bottom-up approach involving stakeholders in linking global and subnational (i.e. regional, delta regions, city, neighborhood) shared socioeconomic pathways (SSPs) (e.g., Nilsson *et al.*, 2017; Kebede *et al.*, 2018; Lino *et al.*, 2019; Cradock-Henry *et al.*, 2021). Yet, there is a need to link global climate trajectories and local climate adaptation scenarios that consider local stakeholders and experts knowledge of the impact of land use-related decisions (Puntub *et al.*, 2022). Moreover, climate vulnerability/risk assessment studies are often dominated by a purely place-based concept, which has a clear constraint when looking at spatially and functionally interconnected infrastructures whose services provision is essential for urban systems in reality (Katina and Hester, 2013; Pescaroli and Alexander, 2015; Greiving *et al.*, 2021). Climate impacts may question a continuous service provision in and for areas which are not directly affected by extreme events but indirectly affected by service disruptions they are functionally dependent on (Etzold and Sakdapolrak, 2016; Puntub and Greiving, 2022). For example, a hospital may not be exposed to a hazard. But the hospital's function could be affected by disruption or loss of its dependent lifeline infrastructure located elsewhere outside the region/territory, which is exposed to the hazard. Thus, a strongly established purely place-based concept (Wisner *et al.*, 2004: 49; Cutter *et al.*, 2008) may not be sufficient to explain and manage climate vulnerability/risk of urban infrastructure where, in reality, place and systemic aspects are reciprocally bonded and bounded (Kruse *et al.*, 2021; Monstadt and Schmidt, 2019). Yet, an application of the mixed-methods approach is still a minority (Opdyke *et al.*, 2017) and sufficiently addressing cross-scale interactions influencing risk outcomes (Fekete *et al.*, 2010) is still a great challenge in this field of research.

Although the scenario approach is dominant in climate change adaptation studies (van der Voorn *et al.*, 2017), backcasting has been first integrated with IPCC climate change mitigation storylines (Carlsson-Kanyama *et al.*, 2013). Robinson *et al.* (2011) demonstrated early attempts to integrate participatory interactive backcasting in climate change adaption, yet the application of backcasting in climate change impact analysis and adaptation at the local level is still not mainstream (Carlsson-Kanyama *et al.*, 2013). Manifestation of backcasting in climate change adaption is prominently revealed in e.g. van der Voorn *et al.* (2012), Carlsson-Kanyama *et al.* (2013), VA der Voorn *et al.* (2017) and Iwaniec *et al.* (2020). Particularly, Iwaniec *et al.* (2020) highlighted a connection between future climate change and urban development change through cycling between explorative and normative perspectives. However, using composite indicators to assess the future climate risk of urban infrastructure with spatial planning integration is rather uncommon. In health sector, scenario planning (including the backcasting approach) has been recognized by WHO since the early 1990s (Taket, 1993); however, health-care service is still unfamiliar with long-term future scenario planning. Insufficient understanding of uncertainties of climate projections and shared socio-economic pathways (Berry *et al.*, 2018:10–14; Ebi *et al.*, 2018), addressing the future climate risk to health-care service operation is challenging and hindered by short-term needs and urgencies (Ebi *et al.*, 2018). There are guidelines on climate resilience for public health facilities, such as WHO (2015, 2020, 2021a, 2021b, 2022), WHO&PAHO (2015), HHS (2018) and CCGHC (2021). Some address the need to consider the future trends of climatic and non-climatic changes as well as the linkage of health-care facilities with other lifeline infrastructures, e.g. WHO (2020, 2021a, 2022), HHS (2018) and CCGHC (2021). However, these climate resiliency tools are often in checklist format for an individual facility instead of indices that track risk reduction from the perspective of a single facility, area-based and service network. Furthermore, they often fail to systematically consider health determinant sectors beyond a health-care facility boundary. Hence, a city-region perspective is essential for health-care provision, as it contributes to the functionality of interconnected infrastructure sectors that drive economic and social activities (Puntub and Greiving, 2022). To fill these gaps, a concrete and comprehensive planning framework is needed to guide how different methods, scales (spatial and temporal) and stakeholders can be linked and articulated for future climate risk outcomes.

This study offers a climate resilience operationalization framework for urban public health services considering the interaction between urban development change and climate change across scales, the so-called Health Integrative Climate Resilience and Adaptation Future (HICRAF). The framework combines explorative and normative scenario planning using a mixed-methods approach of quantitative and qualitative techniques. This research aims to demonstrate how different methods and scales (spatial and temporal) can be linked and articulate the future climate risk outcomes of Khon Kaen city, a medium-sized city in Thailand. This paper consists of five sections. Sections 2 and 3 present the HICRAF's architecture and implementation in the case study. Section 4 discusses the results and their transferability, and Section 5 concludes with a summary and an invitation for further research.

2. Methodology

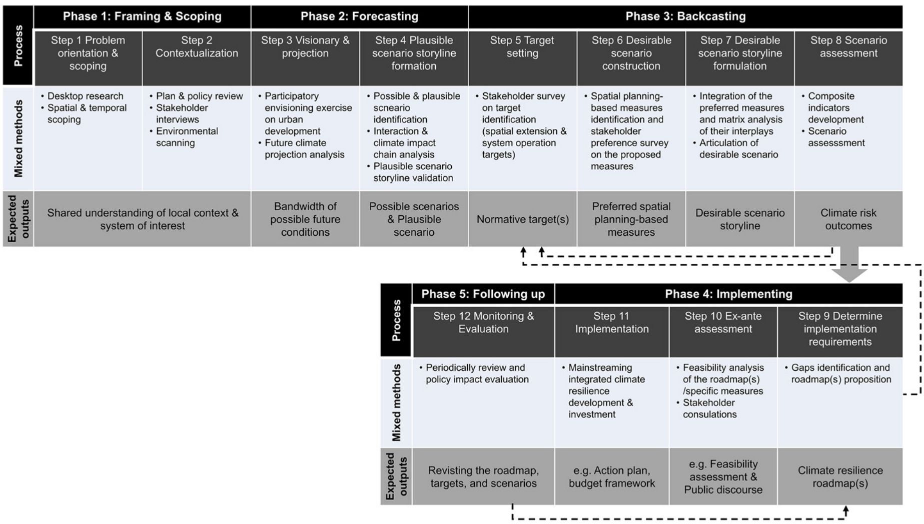
HICRAF is a comprehensive planning approach that combines explorative and normative scenario planning methods with a plug-in of composite indicators. It involves 5 phases and 12 steps that require multistakeholder participation and various planning instruments. *Phase 1 Framing and scoping* determines the objectives and problem orientation of the study area. It also identifies the spatial and temporal scope of scenarios, including the system of interest and key stakeholders. *Phase 2 Forecasting* combines stakeholders' aspirations toward future urban development and climate scenario analysis. This step helps in sketching a range (bandwidth) of possible future conditions. *Phase 3 Backcasting* enables the identification of targets and preferred climate risk mitigation strategies that inform desirable scenario formulation. This step also involves developing composite indicators and scenario assessments tailored to the local public health service. *Phase 4 Implementing* outlines roadmaps guiding a transition from current conditions to the desired climate-resilient future (s). Completing the full cycle of HICRAF requires real-world implementation of the proposed roadmaps by responsible agencies; therefore, steps of ex ante assessment and execution of the proposed actions in Phase 4, as well as monitoring and evaluation (M&E) in Phase 5, are not reported in this paper. Figure 1 and the following subsections give details on each phase and its outputs. This article features HICRAF as a planning tool and its application in a case study. For more information on composite indicators and scenario assessment, see Puntub and Greiving, 2022.

2.1 Phase 1 − framing and scoping

In scenario planning, it is crucial to establish a clear understanding of the scope, system of interest, planning objectives and problem orientation. HICRAF achieves this by conducting policy reviews and stakeholder interviews in two main steps.

Step 1 identifies the objective(s) and the system(s) of interest (i.e. urban development, climate-related hazards and public health service). In a temporal aspect, the future scenario timespan can be determined by taking into account significant national/local development policies and targets. From a spatial perspective, the study area's scope can be defined using a shared boundary of the systems of interest, such as physical setting (e.g. watershed, sub-watershed), administration (e.g. municipality, city, district, province) and service operation (e.g. service area, network, service levels).

Step 2 involves diagnosing the current situation, dynamics and future trends of the systems of interest through policy reviews and stakeholder interviews. These inputs can be analyzed using qualitative environmental scanning instruments, e.g. SWOT or TOWS analysis.



Source: Authors own work

Figure 1. HICRAF process

2.2 Phase 2 − forecasting

This phase highlights the exploratory scenario planning aspect of HICRAF. Through stakeholders' participation and coproduction, qualitative and quantitative techniques are applied to project the potential changes of urban development and climate-related hazards in the future. This phase contains two main steps: envisioning future urban development and analysis of climate projections (Step 3) and the formulation of the locally validated scenario storylines (Step 4).

Step 3 includes two subsequent steps: formulating a bandwidth of future conditions for changing land use/urban development (Step 3.1) and climate-related hazards (Step 3.2). Step 3.1 combines statistical analysis of possible population changes and future envisioning exercises on land use changes to envisage future urban development. Future population estimates can be obtained from the existing studies or demographic consensus data sets. A local land use map can be used to help stakeholders envision possible land use change and development dynamics in the future. The stakeholders participating in the future envisioning exercise may include planning agencies, local governments, private sector, civil society and academia. In bilateral talk format, they are asked to envision potential urban development directions, prioritize investment projects and identify push-pull factors influencing land use changes over a given temporal snapshot (e.g. five-year time slide or adhered to policy cycle) leading up to a specific scenario endpoint (e.g. 2030, 2050). To create a bandwidth for future conditions of non-climatic change, stakeholders shall be asked to differentiate the degree of possible development change into low and high levels for each visionary snapshot. The inputs from stakeholders can be thematically analyzed to create a narrative and visualization of urban development changes for each temporal snapshot of a specific development zone in the study area. Step 3.2 involves formulating the bandwidth of possible climatic changes in the future. The climate projections from global climate models or regional climate models can be used to generate downscaled climate data for the city/regions (catchments/watershed area) under different representative concentration pathways (RCPs). For instance, RCP 4.5 and RCP 8.5 can be applied to portray emissions-dependent variability and evaluate a moderate scenario alongside the strongest scenario of future climate signals. Considering the deep uncertainty of climate projection, short- to medium-term (i.e. up to 2050) or long-term (i.e. up to 2100) are often selected as climate scenario time horizon. However, full implementation of a global framework at city level presents notable challenges, including increased complexity in capturing the diverse facets of change (i.e. climate, socio-economic factors and policy) as well as issues of scale (Kebede *et al.*, 2018; Cradock-Henry *et al.*, 2021). To bridge the gaps between global climate trajectories and local climate scenarios, a downscaling climate data set shall be integrated with a historical meteorological data set, local water management rules and local expert consultations. Then, the possible bandwidth of future conditions resulting from the coupled non-climatic and climatic changes shall be presented and validated with stakeholders. Although more sophisticated analysis tools considering the interaction of urban atmospheric boundary layers dynamics and urban structure and its surface characteristics are advisable, their application may emphasize mainly heat-related risks, such as urban climate model (e.g., PALM-4U) (Maronga *et al.*, 2019), urbisphere modeling (urbisphere, 2022) and urban-canopy model MORUSES (Hertwig *et al.*, 2020).

Step 4 aims to identify possible scenarios (all the conceivable or possible futures), and select a plausible scenario based on validation by local stakeholders (Walton *et al.*, 2019). The validated scenario will then be used to formulate a storyline that takes into account interactions among climate change, urban development changes and their potential impact on public health services. This step consists of two elements: Step 4.1 involves constructing possible scenarios and selecting a plausible scenario; Step 4.2 involves elaborating and validating the plausible scenario storyline. To begin Step 4.1, future scenarios of possible urban development changes and changing climate-related hazards are coupled and framed into 2 × 2 scenarios matrix (Puntub *et al.*, 2022). The scenarios matrix is then geo-spatially visualized and discussed with stakeholders. Stakeholders may select one of the scenarios representing plausible future conditions of the case study. Formulating the scenario storylines (Step 4.2) is centered around the articulation of the systems of interest (urban development, climate-related hazards and public health services). Additional analytical tools can be applied to conceptualize their relationships and interactions across scales, such as the cause−effect relationship approach and impact chain analysis. The cause−effect relationship approach is useful for contextualizing vertical and horizontal interactions and feedback loops between the urban environment and regional and global climate layers. Meanwhile, impact chain analysis (Zebisch *et al.*, 2021) helps narrow down how climate stimuli propagate through the system of interest, causing a direct and indirect impact on its operation and outcomes. Moreover, possible convergences and divergences of internal and interactional perspectives among the systems of interest (such as operation rules, sectoral interests, policy targets and management boundaries) that may emerge in each city zone or settlement typologies shall be defined and organized in matrix format (see Table 1). This match and mismatch analysis helps systematically determine the scenario storyline(s) and identify low-regret strategies in the later steps. It also raises awareness of integrated planning among the involved institutions and stakeholders.

2.3 Phase 3 − backcasting

HICRAF divides this phase into four steps: target setting (Step 5), desirable scenario construction (Step 6), desirable scenario storyline formulation (Step 7) and scenarios assessment (Step 8).

Step 5 focuses on setting target(s) considering stakeholders' perception of protection worthiness in both spatial extension and urban system operation. Stakeholders decide on spatial boundaries of protection worthiness, such as prioritized/protected areas (e.g. inner city), and discuss their anticipated and desired levels of potential impact on urban operation systems when dealing with the validated plausible scenario (see Table 2). It is essential to note that the identified operational impact levels are neither absolute nor empirically proven; they provide a normative sense of baseline and target(s) for a desirable scenario storyline formulation and scenario assessment in the later steps.

Step 6 constructs the desirable scenario that adheres to the target(s). This is achieved by identifying potential spatial planning-based climate resilience measures based on stakeholders' inputs. For each city zone or settlement typology, city-wide and public health-specific measures can be proposed through three strategic domains: hazard mitigation, exposure avoidance and capacity enhancement. The proposed interventions are visualized and discussed with stakeholders in bilateral discussions and/or a focus group format to validate their comprehensiveness and appropriateness. A stakeholder survey using a Likert scale, 1 (least preferred) to 5 (most preferred), is conducted to appraise the stakeholder preference for the proposed measures and to obtain their validation. The measures that received an average score of less than 2 (low preferred) can be excluded from the desirable scenario storyline in Step 7.

Step 7 involves constructing the desirable scenario by incorporating the preferred spatial planning based-interventions determined in Step 6 with the validated plausible scenario. Then, it reiterates Step 4.2 to define possible convergence and divergence in both internal and interactional perspectives of the proposed measures from both zonal and city-wide

Table 1. Example of matrix analysis − Northwestern part (zone 4) of Khon Kaen city

Key features (measures/actions/investments)			
Urban development	Climate-related hazards	Public health services	Possible interplay outcomes
• 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 • Prolonged water scarcity • Pluvial flood due to an inappropriate land cover change/landscape modification • Insufficient and inefficient water supply infrastructure provision	• Stable/almost no increase in service capacity and advancement • Overload of service demand • Under staff • Inefficient procurement process and budget use	*Convergence*: • High workload of primary health-care facilities • High dependency on tertiary health-care facility (Khon Kaen hospital) *Divergence* Internal divergence *Urban development:* • Car-oriented transportation • Insufficient service of public transport in response to the increasing population *Public health*: • Discrepancy between increasing service demand and capacity may negatively affect service quality Interactional divergence • Insufficient public health service capacity in response to growing development • Inadequate water supply for increased inhabitants and operation of public health services

Notes: Table 1 shows an example of matrix analysis among urban development, climate-related hazards and public health service in the Northwestern part (Zone 4) of Khon Kaen city. *Convergence* refers to matching between/among key features of the three systems of interests (urban development, climate-related hazards, public health service) which reinforces/amplifies/promotes the overarching targets and interests of each other; *Internal divergence* means mismatching of the key features of the system of interests which diminish/dampen/demotes the overarching targets and interests of its own sector; *Interactional divergence* refers to mismatching of the key features of the system of interests which diminish/dampen/demotes the overarching targets and interests of other systems (sector)
Source: Authors’ own work

perspectives. The proposed interventions are articulated in a matrix format (see Table 1) to create a desirable scenario storyline, which will then be validated with stakeholders.

Step 8 focuses on scenario assessment. The composite indicators technique is used to evaluate the complex climate risk outcomes and operationalize the climate resilience targets of the local public health service. Composite indicators are developed based on the climate risk concept of IPCC (Oppenheimer *et al.*, 2014; Reisinger *et al.*, 2020), where the climate risk is the non-compensable aggregation of hazard, exposure and vulnerability. This step lays out the scenario assessment process into four key elements:

(1) composite indicators development;

(2) data collection;

Table 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 patient/client/section may be temporarily suspended
Medium	• Demand to obtain needed resources/supports from outside • Full implementation of conservation measures to sustain essential services • Shutdown of auxiliaries sections • Declare total diversion status or partial/total evacuation
High	• Discontinuity of essential services • All patients/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)

(3) data analysis and interpretation; and
(4) sensitivity analysis.

Detailed elaboration and discussion of the composite indicators development and operationalization can be found in Puntub and Greiving(2022).

2.4 Phase 4 − implementing and Phase 5 − following up

This backcasting process involves several steps, including determining implementation requirements or roadmap (Step 9), ex ante assessment (Step 10) and mainstreaming the climate resilience roadmap into implementation (Step 11). After roadmap implementation, Phase 5, M&E or ex post assessment (Step 12) shall be launched to track the policy's progress in responding to the targets. As aforementioned, within this research timeframe and capacity, only Step 9 is presented in this paper.

Step 9 outlines the implementation roadmap(s) to determine the transitional steps toward a climate-resilient future. Gaps between the validated plausible scenario and the desirable scenario, as well as between the desirable scenario and the desired target(s), shall be identified. The emergence of the gaps may trigger revisiting the preferred risk mitigation measures and iterating Steps 6–8 to meet the desired target(s). Potential climate resilience strategies with defined implementation timeframes shall be proposed for the transition from today's situation to the desired target(s) by the given scenario end point. Finally, the roadmaps shall be reviewed by relevant policy decision-making agencies as part of the validation process.

3. Results

Khon Kaen city, or Mueang Khon Kaen, a district of Khon Kaen province located in the Northeastern region of Thailand, was selected to demonstrate the application of HICRAF. With a size of approximately 953 sq. km, and a registered population of 416,285 (2019), Khon Kaen city is a secondary city that plays a significant role in provincial and regional development. The city's economic growth is attributed to its well-equipped infrastructure, education institutions, medical services and a good location for logistics and transportation. However, the city faces several challenges, including unplanned urbanization, an ageing society, environmental degradation and climate risk, which could hinder its future development. Khon Kaen's public health operation is under the national universal health-care coverage scheme. Khon Kaen Hospital's Contracting Unit of Primary care (CUP) network oversees the service network of the city consisting of 22 Sub-district Health Promotion Hospitals (SHPH), five Primary care centers and one tertiary hospital (Khon Kaen Hospital). Besides being overwhelmed with service demands, the public health services also face climate risk challenges, including frequent floods and water scarcity, that emphasize the need to address the nexus among urban development, climate risks and public health services.

3.1 Bandwidth of possible futures

District administrative boundary was defined as the shared spatial scope of urban development and public health service. This research has scoped the global climate projection data to relevant sub-watersheds for analyzing three hydro-meteorological hazards that are significant for urban development and public health service, i.e. fluvial flood, pluvial flood and water supply scarcity. The year 2037 was used as the scenario endpoint, aligned with Thailand's 20-year National Strategy. This study integrated local historical meteorological datasets (1969–2015), water management rules and downscaled global climate projections (2021–2050) to construct possible future scenarios of local climate-related hazards in 2037.

Based on the population projections [DPT (Department of Public Works and Town and Country Planning), 2018] and the demographic consensus data set extrapolation, the stakeholders selected 2.8% and 3.6% as low and high bandwidths of population growth toward the end of 2037. The city land use map served as a medium for the stakeholders' participatory future envisioning exercise in a bilateral discussion format. Eight representatives from seven local stakeholder agencies participated in the exercise, including government, private sector and academia. The stakeholders were requested to envisage possible urban development dynamics, flagship investments, key driving factors and land-use changes for each snapshot, 2022, 2027, 2032 and 2037, respectively. To create the urban development bandwidth, the stakeholders were asked to distinguish between low and high degrees of urban development (in terms of expansion of the urban fabric and population growth) for each snapshot. The stakeholders' inputs were thematically analyzed to create a collective narration and visualization of possible land use and development changes for each time step and each zone of the city. The draft elaboration and visualization of the urban development change bandwidth were presented and validated with the stakeholders.

This study developed the local climate scenario by using 25 km × 25 km downscaled and bias-corrected climate projections of European community Earth-System Model (EC-EARTH) under the RCP 4.5 and RCP 8.5 during 2021–2050 [provided by Hydro – Informatics Institute (HII)] and a historical record of local meteorological data of the relevant sub-watershed during 1969–2015 (provided by Thai Meteorological Department). In addition to the statistical analysis of the climate data sets, four water experts at the national and sub-watershed levels were consulted to create the possible range of local climate-related hazard scenarios to ensure local relevance and consideration of water management rules and disaster risk management practices. The proposed range of future climate-related hazard scenarios was validated by nine stakeholders, including representatives from government agencies at national, provincial, and local levels, private sector and academia. According to the stakeholders' validation, the current fluvial flood threshold and the inputs from climate scenarios were defined as the low and high fluvial flood bandwidth (152–155 m Mean Sea Level: MSL), respectively, with the condition that the existing and planned structural flood protection measures failed. Due to the lack of future-oriented and high-resolution geospatial data, the study could not conduct such high-resolution pluvial flood simulation (e.g. FloodArea^{HPC} software model) and projection of micro landscape alteration, which allows specifying the spatial extension of affected areas/buildings and magnitude of pluvial flood in the future. Therefore, this study assumed pluvial flooding is principally possible anywhere in the study area. A similar assumption was also applied for water supply scarcity, although drought could lead to insufficient qualified raw water feed to the production system, disrupting water supply manufacturing and delivery for the whole city; in fact, the effects might not equally be distributed. However, specifying locations or spatial extension of the problem from a long-term perspective requires a separate study to understand the engineering and socio-technological complexes of the local waterwork network. Regarding these limitations, this study conservatively assigned the bandwidth of possible pluvial flooding and water scarcity as a binary, yes and no. A 2 × 2 matrix was applied to couple the bandwidths of possible future climatic and non-climatic changes into four possible scenarios. The scenarios were visualized and validated with 11 representatives of relevant stakeholder agencies through bilateral discussions (i.e. national and provincial planning agencies, provincial and local governments, private sector and academia). Figure 2 shows the overlay between the bandwidth of future urban development change and climate change (fluvial flood).

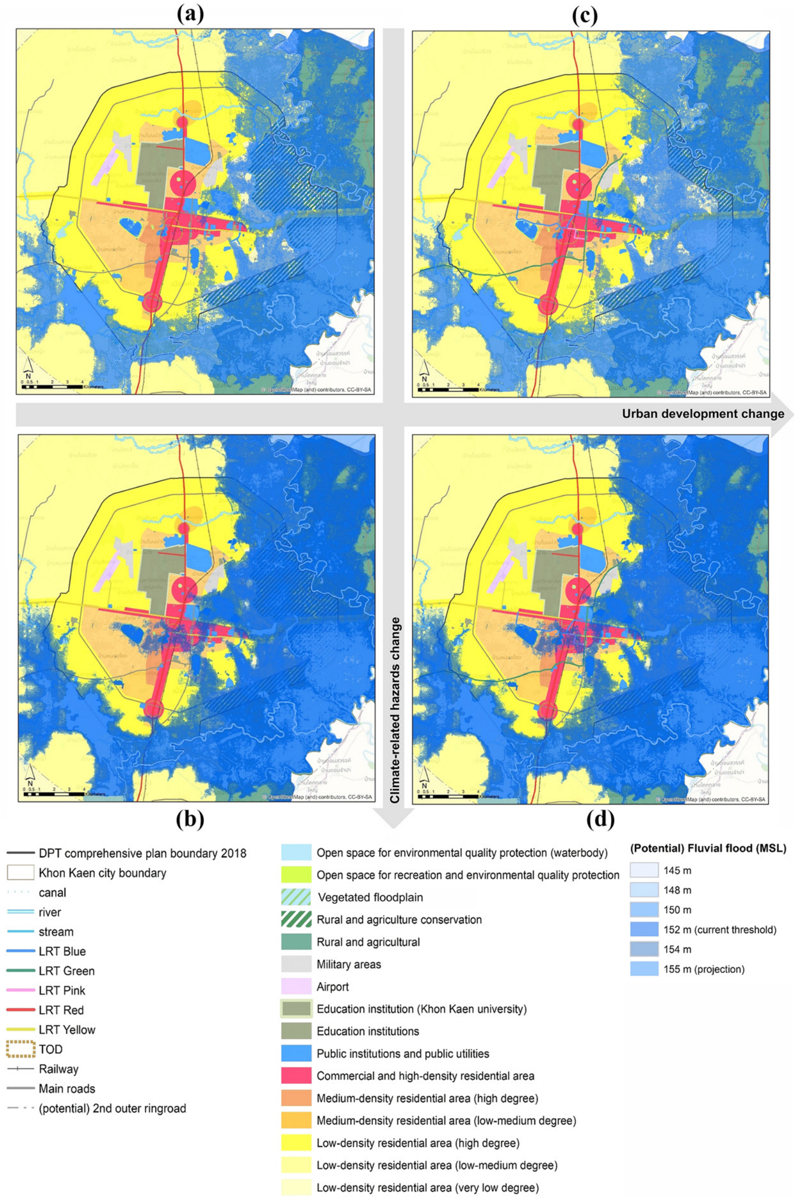
3.2 Scenario storylines

Storylines for different scenarios were created based on stakeholders' survey (n = 9) on their perception towards climate risk protection worthiness targets as well as the result of interaction analysis and climate impact chain analysis, which help to articulate theoretical interplays among urban development, climate-related hazards and public health services in each city zone. Possible convergence and divergence in internal and interactional perspectives were defined and used to determine scenario storylines. Detailed elaboration and visualization of the scenarios were presented to 14 stakeholders through bilateral discussion sessions and a workshop. The stakeholders included representatives from various institutions responsible for local urban development, disaster risk management and public health care. As a result, all stakeholders agreed on the proposed storylines and suggested only minor supplementary details. Thus, the scenario storylines of Khon Kaen city in 2037 can be briefly described as follows:

- Validated plausible scenario

Khon Kaen city is expected to grow about 3.6% of its population. The unclear boundary between urban and rural settlements is prominent. Low residential areas expand in all directions; however, in the eastern part of the city, urbanization might be limited at the edge of the outer ring road. The city aims for denser and mixed-use development of the city center and surrounding transit-oriented development (TOD) nodes along with the Light Rail Transit (LRT) lines. In parallel to urban development change, the eastern part of the city may experience a 155 m MSL fluvial flood that may interrupt economic and administrative activities, especially the public administration quarter. Besides serving increasing service demands due to demographical changes, Khon Kaen Hospital and its primary health-care nodes could be affected by flooding or isolated due to water blocking safe accessible routes. Moreover, a clear trend of water supply scarcity can be serious as an invisible threat to the continuity of health-care operations and city's socio-economic development. Visualization of the scenario in the case of fluvial flooding is shown in Figure 2 (d):

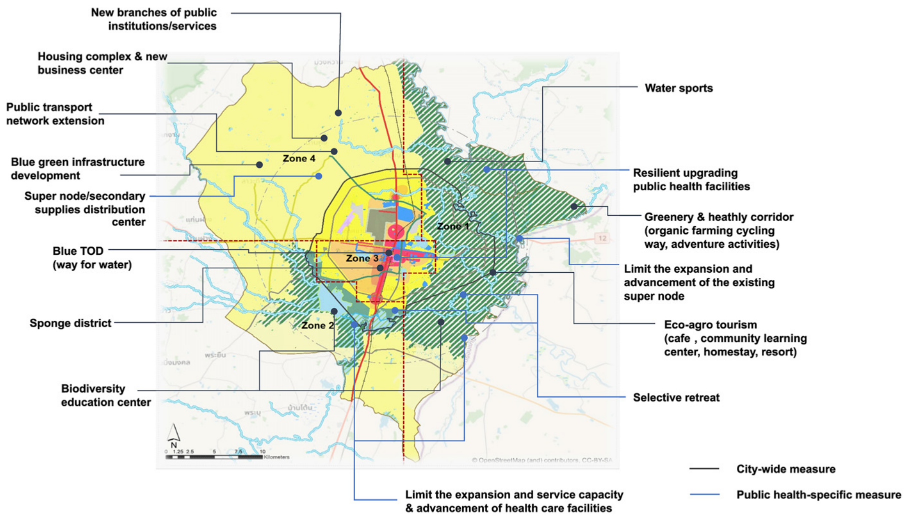
- Desirable scenario



Notes: (a)Low urban developement and Low climate-related hazards;
(b) low urban development and high climate-related hazards;
(c) high urban developement and low climate-related hazards;
(d) high urban developement and high climate-related hazards
Source: Puntub (2021)

Figure 2. Overlay between the future development change and possible fluvial flood level according to the proposed possible scenarios

This scenario shares the same climate-related hazards trajectory and demographical figure as the validated plausible scenario; however, integrating climate resilience measures (see Figure 3) might alter the city land use and development as follows. In the flood-prone areas (eastern and southern parts of the city, Zones 1 and 2), agro-eco tourism and environmentally friendly recreation activities could be promoted as core market-driven strategies to boost the local economy while limiting urbanization and protecting agricultural areas functioning as the city's flood retention. Future climate risks are prioritized and mainstreamed in city-wide development policies on the basis of participatory decision-making. Hence, the moderate tempo of economic development could slow down health-care service demands in hazard-prone areas; therefore, further extension or provision of service advancement of public health-care infrastructure in flood zones (Zones 1 and 2) may not be necessary. Nevertheless, resilient upgrading and managed retreat strategies shall be mandatory for public health units exposed to climate-related hazards. Moreover, promoting blue-green infrastructure development could mitigate hazards, reduce direct injuries and loss of life due to flood risk, and enhance the local population's environmental health and well-being. This cobenefit may contribute to lowering service demands and costs of the health sector and society. Although reducing impermeable surfaces, increasing water retention capacity and improving a drainage system could mitigate the impact of urban inundation, the success of the city-wide measures cannot be guaranteed. Thus, health-care facilities in the inner-city area (Zone 3) could be surrounded by water. To redirect the economic growth to the safer zone (Zone 4), public infrastructure and livability must be invested to attract new development and serve the demands of new inhabitants, especially transportation and water supply provision. From the public health perspective, instead of increasing service supply and advancement in response to these growing demands (in Zone 4), using the existing service capacity is considered a practical alternative.

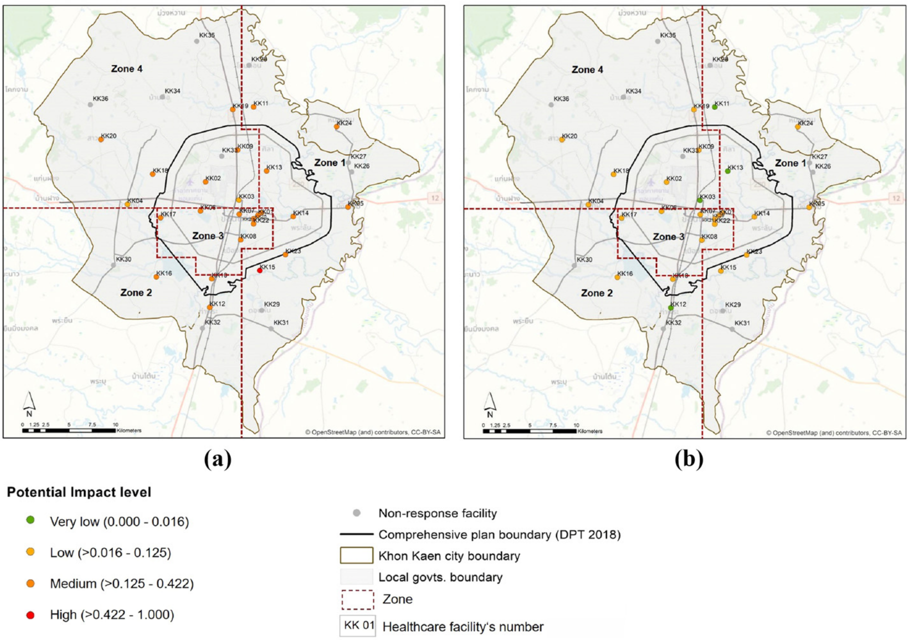


Source: Puntub and Greiving (2022)

Figure 3. Measures preferred by multistakeholders in the context of spatial development

3.3 Scenarios assessment

The composite indicators were developed based on IPCC's climate risk concept (Oppenheimer *et al.*, 2014; Reisinger *et al.*, 2020), where the climate risk is the outcome of the non-compensable relationship among hazards, exposure and vulnerability. The structure of the composite indicator consists of pillars, indicators, subindicators and variables. 13 public health experts (from national to local levels) and academia were involved in the design and validation of the composite indicator system. Input data fed into the composite indicators are derived from scenario storyline, sectoral policy and practice, interviews of seven local public health facility managers and questionnaire surveys of local public health facilities (25 out of 36 surveys received). Multiple data normalization and aggregation schemes were used according to the nature of input data, operationalization of the climate risk concept, and traceability promotion. Figure 4 shows different patterns of climate risk outcomes of the local public health services under (a) the validated plausible scenario and (b) the desirable scenario , medium level and low level, respectively. However, to achieve a very low level, besides the public health sectoral efforts to reduce internal exposure and vulnerability, substantial endeavors at the city-wide level have to be pursued, especially on hazard mitigation and exposure avoidance. A full elaboration of the scenario assessment can be found in Puntub and Greiving (2022).



Notes: (a) Plausible scenario; (b) Desirable scenario
Source: Puntub (2021)

Figure 4. Climate risk outcome of the local public health services under the scenarios

3.4 Implementation

Based on the scenario assessment, the draft Khon Kaen climate resilience roadmaps, climate resilience public health service; and climate resilience urban development, were developed to suggest transitional steps for Khon Kaen city toward their climate resilience targets from both public health and spatial planning perspectives. The roadmaps aim to minimize the climate risk from *medium* to *very low* level in 2037 with short – medium- and long-term milestones. The draft roadmaps were reviewed, and positive feedback was received, with minor supplementary inputs and clarifications from the Ministry of Public Health and Khon Kaen Provincial Town and Country Planning Office. Particularly, the Climate resilience urban development roadmap was acknowledged at the Khon Kaen Provincial Planning Committee Meeting on July 14, 2021. The committee took up recommendations from this research for further consideration in Khon Kaen city's comprehensive plan revision process.

4. Discussions

HICRAF combines scenario planning and mixed-methods approach of quantitative and qualitative techniques to demonstrate how different methods and scales (spatial and temporal) can be linked and create new knowledge on climate risk patterns. The framework not only improves understanding of climate risk outcomes interconnecting the process of urban development, climate risk and health-care system, it also calls for revitalizing the vulnerability concept from purely place-based to considering functionality and network operation of urban infrastructure systems. The following discussions highlight the findings and lessons learned from the development and contest of HICRAF in promoting integrated climate-sensitive urban public health service.

4.1 Closing gaps between global climate trajectories to local climate adaptation scenarios

"Oh, it might theoretically be possible but indeed unbelievable" is often an immediate reaction from stakeholders when showing the analysis of downscaled global climate projections. Usually, the presentation of the climate trajectories is meant to trigger the discourse on the possible future climate-related hazards with awareness of deep uncertainty embedded in climate projection. However, with a lack of normative perception of climate risks and integration of local water management context, the story could become just a dystopia in the view of local stakeholders. With this gap in mind, HICRAF adjacent mesoscale climate trajectories to a relatable local scale and combining them with local water management practices and thresholds to formulate plausible local climate scenarios. In mainstream practice, stakeholder involvement is often limited to the formation of local or regional SSPs, while justification of a climate scenario is usually dominated by climate services and experts due to scientific and technical sophistication. However, this study argues that although the climate trajectories involved rigorous analysis of downscaling climate data sets and expert judgment, stakeholders were the key actors who shaped the bandwidth of future climate scenarios and adhered to their risk perceptions and normative risk mitigation target(s). Taking into account stakeholders' normative risk perception during local climate scenario formulation helps get their buy-in of the scenario planning process and further uptake the outcomes in the formal planning process.

With the recognition of stakeholder challenges in conceptualizing spatio-temporal dynamics among various scenarios of the long-term future (Bradfield *et al.*, 2005; Birkmann *et al.*, 2015: 64) in the explorative scenario element, HICRAF facilitates the stakeholders to depart from today's reality to future possibilities with a small fraction of time (several snapshots) and asserts opportunities for experts/the researcher to bring in missing pieces, particularly external factors (e.g. global geopolitics, pandemic), to consummate the future canvas. Current/near-future development plans and disaster risk management thresholds are essential precursors that enable the local stakeholders to explore and discourse on the tendencies of possible future conditions. These do not only encompass the stakeholders to articulate their normative targets but also explore appropriate measures to minimize future climate risks. However, HICRAF creates a nexus between reality and future uncertainties from the stakeholders' normative standpoints; this raises a question of whether the approach can unbind stakeholders from the influences of recent and current events/developments and departure for a more systematic exploration and look for transformation (Robinson *et al.*, 2011; Vergragt and Quist, 2011: 750; Höjer *et al.*, 2011: 820–821; Butler *et al.*, 2020; Kishita *et al.*, 2023). For example, wildcard, extreme utopia/dystopia or trend-breaking scenarios did not clearly emerge or were quickly set aside from the discussion on a spectrum of possible future conditions. Moreover, concentrating only on validated plausible scenarios instead of considering the full array of rigorous future possibilities is a key trade-off between technical process quality and practical process implementation, which aims to endure stakeholders' engagement and motivation along the lengthy process of collaborative scenario planning. Thus, to strengthen the explorative scenario element of HICRAF, scenarios beyond the locally validated one should be laid out and analyzed alongside stakeholders' inputs to consider a full bandwidth of possible future conditions. A hybrid between participatory and computer-aided techniques could help design the scenarios more systematically (Kishita *et al.*, 2023).

4.2 Drifting away from purely place-based to operationalizing interwoven spatial-systemic risks in climate vulnerability research

It is important to be aware of the fact that boundaries of urban infrastructure systems are rather fluid (Keating *et al.*, 2003), which is not limited by "local" exposure to the potential hazards under the context of place-based vulnerability (Etzold and Sakdapolrak, 2016; Kruse *et al.*, 2021). To better reflect real-world environments, HICRAF offers to revitalize the climate vulnerability/risk assessment framework by ensuring the nexus between spatial risk and systemic risk of local critical infrastructure. This research underlines this concern in the backcasting domain of HICRAF through stakeholder discourse on target settings (protection worthiness and risk perception on urban operation systems). Moreover, HICRAF composite indicators also highlight a configuration of dependencies and interdependencies of the local public health services to enable the sector to link their day-to-day operation with long-term climate resilience planning (Puntub and Greiving, 2022). However, HICRAF is helpful and practical for health-care managers to address criticality in health-care facilities and service networks using the configuration of working systems' dependencies and interdependencies. This may not be sufficient from a system engineering point of view. Developing a more advanced version of HICRAF requires a criticality analysis using technological engineering aspects of essential working systems, service networks and relevant lifeline infrastructures. By analyzing these systems, we can determine which system elements are most crucial in terms of cascading effects on other infrastructure sectors (Kruse *et al.*, 2021). Interestingly, this perspective has recently been incorporated into European legislate acts (see Council Directive 2022 / 2557/EC on the resilience of critical entities). EU legislation now requires critical entities like hospitals to conduct a comprehensive risk assessment (Art. 12 § 2 CER Directive). The assessment must account for all relevant risks and consider the interdependence between sectors relying on essential services provided by the entity. This assessment could be inspired by HICRAF.

4.3 Enabling robust policy decision-making and planning process

Coexisting between cohesions and fractions occurs within and among spatial planning, climate-risk management and public health service. Therefore, identifying internal and intersectoral matches and mismatches in plans, policies and responsible areas is crucial for creating robust policy design and decision-making. Hence, a simple matrix analytical format (Table 1) helps streamline the interactions in spatio-temporal boundaries, targets and interests among spatial planning, climate change and public health services. This analysis promotes the design of low-regret measures/strategies that benefit all parties in both business-as-usual and unusual situations. Moreover, the result of matrix analysis could render essential inputs in tuning scenario storylines and designing climate risk minimization measures that strengthen horizontal and vertical integration among local governments, public health sectors and other urban domains. Furthermore, HICRAF sparks spotlights on adaptive planning and iterative process of backcasting approach that allows planners and decision-makers to optimize climate risk outcomes, preferred interventions and targets as well as enhances M&E process, which leads to desirable planning outcomes. Although the visualization of scenarios was well accepted by most stakeholders, they are still too broad from the public health decision-makers' perspective. Additional actions shall be carried out to trigger changes in investment and operation practices for climate-resilient health services, such as conducting feasibility studies for particular proposed measures, testing proposed roadmaps such as using gaming simulation technique (Greiving *et al.*, 2023), drawing cost-benefits or risk aversion analysis and ensuring meaningful public participation (Puntub, 2021). However, as aforementioned, there is, at least in the European Union, a recently adopted legal stimulus for conducting scenario-based and system-oriented risk assessments.

4.4 Collaborative scenario planning trade-offs: participatory, dissensus and inclusiveness

In the case study, stakeholders were identified based on their legitimacy roles and relevance in both vertical layers (i.e. central, provincial and local levels) and horizontal relations (i.e. government, private, academic and civil society). The view of the future urban development changes presented in this research stemmed from a circle of key stakeholders who are actively involved in formal planning and decision-making, usually senior officials or experts. Even though this research promotes multistakeholders collaborative scenario planning, it also risks groupthink (Nilsson *et al.*, 2017) and may only capture the interests of certain groups of society and generations.

Many studies criticize stakeholder participatory scenario planning, mostly in a workshop format, as time-consuming, complicated preparation and distressing in keeping stakeholders motivated throughout the iterative processes (Shaw *et al.*, 2009; Robinson *et al.*, 2011; Oteros-Rozas *et al.*, 2015: 13). Although this research recognizes and values stakeholder participatory workshop, bilateral talks provide an enabling environment for stakeholders to address their concerns and interests or criticism on particular issues or a third party without/less pressure from their peers or superiors. Hence, their ideas and opinions, especially inter/intra institutions conflicts or controversial issues, could be more freely expressed. Bilateral talks aim to conserve the diversity of stakeholders' thoughts, fitting well with the HICRAF scenario exploratory phase and target-setting that promotes planning under dissent. It is important to note that in formal planning processes, seeking consensus is often preferred. Therefore, a bilateral talk format may raise concerns about fulfilling procedural requirements when incorporating scenario outcomes into the formal planning process. Thus, this study recommends conducting a validation process or workshop to close the gaps in the bilateral talk methods to transform individual inputs into collective ideas. Importantly, bilateral talk is a practical stakeholder participatory technique, especially for a young researcher who often has limited financial resources and political capitals. Bilateral talks may alleviate some burden and can be handled by one researcher; iterative processes of the backcasting approach remain time-consuming and challenging to maintain stakeholder engagement and process quality.

Strong collaborations and active stakeholders/actors are key factors that enable political buy-in on climate risk-informed planning in the case study. 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 real-world practice. Despite the fact that it was very helpful that stakeholders in Khon Kaen city shared mutual understanding/ single storytelling of the local circumstances and prospects. However, conducting the same research strategy in a city with a high disparity of self-perceptions among stakeholders may face challenges in capturing diversities and bonding fragmentations of stakeholder inputs in both the explorative and normative domains of scenario planning. On the contrary, mutual/ single storytelling also has its drawbacks in narrowing the width of the scenario spectrum as well as hindering wildcards and the emergence of encounter trends in the exploration phase of HICRAF.

5. Conclusions

Addressing the collision of global mega-trends, future climate change and urbanization, at the local level is often not systematically addressed and operationalized based on empirical evidence. Yet, stakeholder normative perception toward future climate risk is usually not practiced or brought up in the planning process. This paper offers a playbook for conducting local climate adaptation scenario planning for urban public health services, the so-called HICRAF. HICRAF is structured based on the embroidery of explorative and normative scenario planning approach combined with mixed methods of quantitative and qualitative techniques through the stakeholder participation process. The approach demonstrates how different methods and scales can be linked and exhibit climate risk outcomes of different future pathways. HICRAF framework draws into four phases:

(1) create shared understanding;

(2) define the bandwidth of possible future of climatic and non-climate changes;

(3) operationalize target(s) and desirable future; and

(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 stakeholder participation. Lessons learned from Khon Kaen city confirmed that HICRAF had been successfully implemented to bridge the gap between global climate trajectories and local climate adaptation scenarios. By taking into account the perceptions of local stakeholders and addressing cross-scale interactions, HICRAF has made climate scenarios more relatable and justifiable to local stakeholders. However, it is important to acknowledge that stakeholders's perception of the long-term future could be greatly influenced by recent developments/events, hindering a systematic exploration of climate resilience transformation. Moreover, the stakeholder collaborative process could also serve as a vehicle for climate justice discourse among key stakeholders and settlement typologies at a local level. Furthermore, HICRAF offers a new perspective on climate vulnerability research by drifting away from a purely place-based approach to a spatial-systemic risks hybridization. This ensures a better reflection of the real-world phenomena and provides a more comprehensive understanding of climate risks to local critical infrastructure, especially public health services. Overall, the HICRAF approach has shown great potential in addressing climate risks and promoting integrated climate-sensitive planning for urban public health care, especially in a country that has been hit hard by climate impacts. Nevertheless, the application of HICRAF should be further explored with a variety of local settings and hazard profiles to strengthen the robustness and universal applicability of the tool. HICRAF not only has replicating potential in other health-care settings but could also encompass evidence-based climate resilience planning in different focusing urban infrastructure domains.

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