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Dar es Salaam's Bus-Rapid-Transit system in view of systemic criticality

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A R T I C L E I N F O

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A B S T R A C T

The Dar es Salaam Bus Rapid Transit (DBRT) system is a cornerstone of urban mobility and socioeconomic development. However, its fixed-route, centralized design makes it highly vulnerable to flood-related disruptions, a risk exacerbated by climate change, unplanned urban development, and the loss of green spaces. Using DBRT, as case study this paper assesses systemic criticality of a transport system through surveys, key-informant interviews, participatory scenario workshops, and secondary research. The findings reveal profound logical and physical interdependencies between the DBRT and key economic sectors; a disruption could therefore cascade through critical infrastructures vital to the regional socioeconomic systems. To mitigate these risks, the study recommends integrating disaster risk management into transit planning, formalizing informal transportation for redundancy, and promoting nature-based solutions, such as recuperating wetland and green covers, to buffer against flooding and sea-level raise. Long-term strategies should pursue polycentric urban design to decrease reliance on centralized infrastructure. This study underscores the necessity of systemic criticality assessments for building resilient transit systems in rapidly growing cities.

1. Introduction

The urban transport sector is strategic for achieving a greener urban future. It is central to global efforts to combat climate change by reducing CO2 emissions and is an instrument for shaping sustainable and compact cities (Dodman et al., 2022; Poku-Boansi, 2021; UN-HABITAT, 2022). This is reflected in the UN's Sustainable Development Goals (SDGs) 9 and 11, which highlight resilient infrastructure and cities as foundational to human settlements (United Nation, 2015).

Globally, however, existing transport infrastructures requires modernization and rehabilitation to become both green and resilient to climate-related disasters (Ali et al., 2023; Ara Begum et al., 2022; Das & Roy, 2023; Gebremeskel et al., 2022; Hicke et al., 2022; Nadeem & Matsuyuki, 2025; Rahman et al., 2012; Salvo et al., 2025). This challenge is particularly acute in Sub-Saharan Africa, where rapid urbanization strains an underdeveloped transport sector. The region struggles to introduce greener systems, facing significant governance hurdles and difficulties in integrating new modes with entrenched informal and paratransit services (Kumar et al., 2021, 2021; Poku-Boansi, 2021; Rahman et al., 2012).

Modern transit systems like Bus-Rapid-Transit (BRT) are celebrated for providing safe, reliable, and efficient commutes (Ajayi, 2017; Venter, 2013). Compared to informal paratransit, BRT leverages technology and dedicated infrastructure to enhance service quality through features like online trip planning and digital payments (Asimeng & Jauregui-Fung, 2025; Bartels et al., 2016). However, introducing BRT in contexts dominated by informality poses profound governance challenges. Successful implementation requires robust institutional frameworks to coordinate the new system with existing services (Boulle & Ryneveld, 2015; Joseph et al., 2020; Poku-Boansi & Marsden, 2018), while ensuring the financial sustainability of dedicated infrastructure, such as segregated lanes, remains a critical hurdle (Lashari et al., 2022; Ojadi et al., 2024; Ugo, 2014). Consequently, scholars argue, BRT rollout must be viewed as a governance reform, necessitating a managed transition to a regulated multi-modal system (Poku-Boansi & Marsden, 2018). In practice, these challenges often lead to delayed, incomplete, or failed projects, as evidenced by cost overruns in Dar es Salaam (Jacobsen, 2022) and the collapse of the Accra BRT (Asimeng & Jauregui-Fung, 2025).

Despite this focus on governance and implementation, a critical gap remains in the literature on African BRT: the assessment of systemic risk inherent to its centralized design. While documented institutional gaps (Ajayi, 2017; Jacobsen, 2021b, 2021a, 2022; Kumar et al., 2021; Poku-Boansi & Marsden, 2018; Rahman et al., 2012; Venter, 2013) are crucial, they do not fully address the vulnerability posed by a high-density, fixed-route system. Disruptions to such centralized infrastructure can

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cascade, severely impacting interconnected services and socio-economic stability, a core concern in critical infrastructure literature (Folkers, 2018; Greiving et al., 2016; Helderop & Grubesic, 2019; Katina & Hester, 2013; Renn, 2021; Schmitt, 2020; Schweizer & Juhola, 2024). This risk perspective is especially urgent in cities like Dar es Salaam, where highly regulated, centralized transit is a new phenomenon in a flood-prone environment.

Dar es Salaam's existing transport landscape is characterized by a diverse, but uncoordinated array of informal and paratransit modes, which are flexible but suffer from safety and reliability issues (Brugulat-Panés et al., 2023; Cervero & Golub, 2007; Kumar et al., 2021). The DBRT system, serving approximately 180,000 daily riders (Global BRT Data), offers reliability but lacks flexibility. This creates a central vulnerability: a single point of failure on its fixed network can cascade across the city. Key DBRT infrastructure, including depots, bridges, and lane segments, is already frequently inundated during rains, causing service halts and damage (The Guardian, 2018; World Bank, 2019a). Major flood events in 2018 damaged 79 DBRT buses, and service disruptions continued into 2024 (Citizen Reporter, 2022; Mkanaka, 2024).

Current research in Sub-Saharan Africa predominantly focuses on technical performance, accessibility, sand integration, (Chengula & Kombe, 2017; Gauthier & Weinstock, 2010; Klopp et al., 2019; Nnene et al., 2023; Okoro et al., 2022; Poku-Boansi & Marsden, 2018; Venter, 2013; Vergel-Tovar and Landis, 2022), overlooking systemic vulnerability to shocks like flooding. This gap is critical, as limited resources force a difficult choice between expanding transit systems and funding effective disaster risk management. Therefore, this study aims o to explore the critical role of the DBRT in Dar es Salaam's socio-economic systems, with a specific focus on flood-related risks. It assesses both historical disruptions and potential future vulnerabilities to provide actionable recommendations for building a more resilient transit system.

2. Critical infrastructures (CI) and systemic criticality

Critical infrastructure (CI) comprises assets, facilities, networks, and systems essential for providing vital services upon which societal and economic wellbeing depend (CI) (Directive (EU) Directive, 2022). The criticality of an infrastructure is determined by its potential to cause significant disruptive effects, as outlined by specific criteria in CER Directive (Directive (EU) Directive, 2022). These include:

- The number of users relying on the essential service.
- The dependence of sectors on the service.
- The potential impact (in degree and duration) of incidents on economic and societal activities, public safety and security, environmental health, or public health.
- The entity's market share for the essential service.
- The geographic area, cross-border regions, that could be affected.
- The entity's importance in maintaining a sufficient level, considering the availability of alternatives.

These criteria underscore that criticality stems not only from an infrastructure's direct societal relevance but also from its profound interdependence with other systems (Fekete, 2019; Kruse et al., 2021; Referat KM 4, 2009; Lenz, 2009). This interconnectedness means that a disruption can trigger cascading effects, impacting sectors far beyond the initially affected CI (Fekete, 2019; Rehak & Hromada, 2018). Infrastructures such as transportation, communication and power are deeply embedded within broader socio-economic systems, creating a complex logical interdependencies. Disruptions within these networks can therefore trigger cascading failures, the full extent of which is often difficult to predict due to indirect and non-linear connections (Kays et al., 2024; Rinaldi et al., 2001). A seminal illustration is provided by Rinaldi et al. (2001), who documented how a failure of a single telecommunications satellite cascaded to disrupt critical communications for healthcare and emergency services.

The modern concepts of CI is rooted in the German idea of "Daseinsvorsorge" or "services of general interest," which refers to public services necessary for life in a modern society (Folkers, 2018). At the European level, this is reflected in Services of General Economic Interest (SGEI), public goods that markets would not adequately supply without government intervention, granted a special status under the TFEU (EU, 2011, p. 3). Despite its state-centric origins, the focus of Daseinsvorsorge on ensuring access to basic services like water, energy, and transportation aligns closely with contemporary CI protection goals, which are embedded in legal frameworks worldwide to insure economic stability, national security, and public safety (Critical Infrastructure Protection Act, 2019; Referat KM 4, 2009).

A more expansive view frames CI as a "system of systems" (SoS), where infrastructures are deeply interconnected across administrative boundaries(Schmitt, 2020, p. 8 ff). In this model, a change or failure in one subsystem can propagate throughout the entire SoS, highlighting CI's fundamental role in sustaining political administration and socio-economic stability (Birkmann et al., 2016; OECD, 2019). Consequently, criticality is a relative measure of infrastructure's importance within these socio-economic systems and is defined by its interconnections and interdependencies. These relationships determine how a local disruption can ripple through other CIs, compromising the functionality of entire urban and regional systems (Kruse et al., 2021; Schmitt, 2020). This necessitates a systemic approach to risk management to mitigate potential failures and their cascading effects (Renn, 2021; Schweizer, 2021; Schweizer & Juhola, 2024).

This leads to the concept of **systemic criticality**, which captures the complex, nonlinear, and transboundary risks that emerge when a disruption in one CI causes unforeseen impacts on directly and indirectly connected systems (Centeno et al., 2015; Masys, 2022; Renn, 2021; Schweizer, 2021). Systemic criticality emphasizes the pivotal role of CI within broader socio-economic frameworks. Evaluating infrastructure's systemic criticality involves assessing its structural, functional and technical roles to understand its potential for cascading impacts on regional and global socio-economic systems (Centeno et al., 2015; Kays et al., 2024; Renn, 2021; Schnittfinke et al., 2024; Schweizer, 2021).

A practical model for this evaluation focuses on three determining factors (Renn, 2021; Schweizer & Juhola, 2024):

- **Relevancy** refers to the degree to which an infrastructure system provides essential public services required to sustain life and basic societal functions. This concept is increasingly recognized in global frameworks, such as the Sustainable Development Goals (SDGs). Transportation infrastructure, for instance, demonstrates high relevancy by ensuring access to livelihood, social services and the overall functioning of socio-economic systems (Kays et al., 2024; Rinaldi et al., 2001).
- **Dependency** describes the extent of an infrastructure's functional interrelationships and interdependencies with other critical systems (Fekete, 2019; Kruse et al., 2021;Lenz, 2009). These dependencies are characterized by both physical and logical connections, making the network's integrity vital for safety and stability across scales (Lenz, 2009; Schmitt, 2020; Schweizer, 2021). The physical dependencies involve tangible, material linkages. For example, a transportation network is physically dependent on the bridges and roads that form its infrastructure. While logical dependencies involve functional or operational linkages, where the service output of one system is required for another to function. A pertinent example for this study is the logical dependency of economic hubs (e.g., business centers, ports) on transportation services to facilitate the daily commute of their workforce.
- **Exposure**: The local and technical susceptibility of an infrastructure to disruption. Risk arises not only from internal weaknesses but also from exposure to external natural and manmade hazards. This factor indicates the probability and potential magnitude of a disruptive event (Fig. 1).

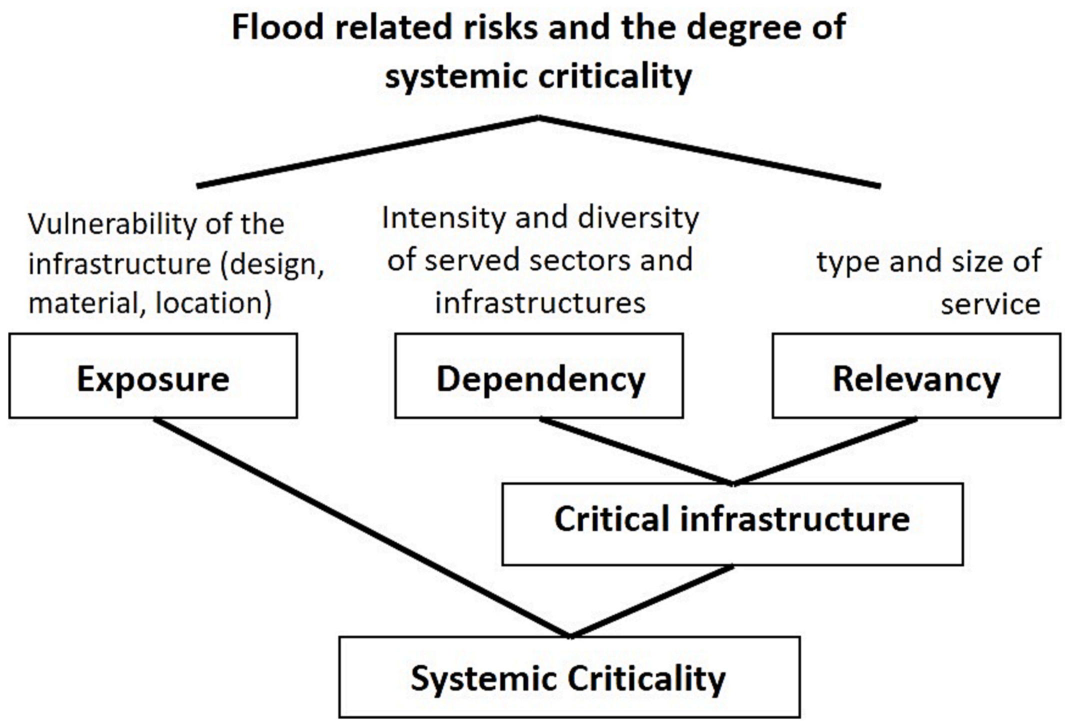

Fig. 1. Systemic criticality.

3. Materials and methods

Using a case study approach, this study aims to explore the critical role of the Dar es Salaam Bus-Rapid-Transit (DBRT) in supporting the city's socio-economic systems, with a specific focus on flood-related risks. Building on the preceding discussion, the following research questions are formulated:

1. **System Relevance**: How crucial is DBRT to t Dar es Salaam's overall public transport system, and which sectors and infrastructures already depend on its services?
2. **Sectoral dependency**: What are the implications of DBRT service disruptions for broader socio-economic systems, including potential cascading effects on national and international economic sectors?
3. **Exposure to flood-related hazards**: To what extent is DBRT infrastructure exposed to flood hazards, and what are the specific risks of service disruption caused by such events?

Answering these research questions requires both qualitative and quantitative data. Quantitative data, such as ridership figures, assesses the service's relevance and role within the public transportation system. Qualitative data is key to understanding disaster risks and their potential impacts on service functionality and dependent sectors (Barella et al., 2024; Creswell & Plano Clark, 2018; Ruth et al., 2023). Consequently, the research design combines surveys, document reviews, participatory scenario development, and key-informant interviews. These methods collectively explore the transit system's exposure to flood hazard and the sectors it primarily serves. Furthermore, key-informant interviews are used to validate the findings from the surveys and document analysis (Fig. 2).

3.1. Surveys

Survey method is a valuable instrument for gaining quantitative insight into a research problem, allowing for the systematic collection of data on specific social groups (Barella et al., 2024; Groves, 2011; Ali et al., 2023). In this study, surveys measured the relevancy of DBRT system by gathering data on passenger numbers, o trip frequency and purpose, and the percentage of employees in key sectors dependent on this transport.

Surveys were conducted in two phases: the first (2019–2020) and the second (2021) gathered general ridership data, including origin, destination, trip purpose and frequency, from 390 passengers interviewed at key nodal stations like Kimara and Morocco (DART, n.d.). A second phase (2021) targeted sectors identified as heavily reliant on DBRT. This included surveying 135 laborers from the DSM Port Services and 311 individuals from the diverse downtown economic sector, comprising small business owners, employees, and traders.

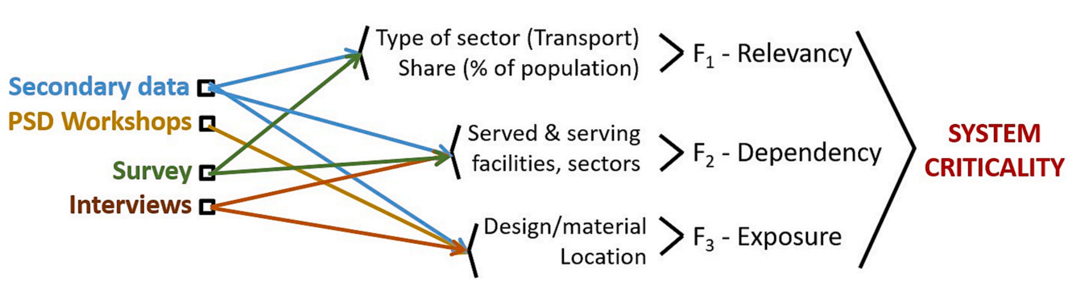

Fig. 2. Key variables, type of data and methods.

3.2. Participatory scenario development (PSD)

PSD workshops were utilized to collect qualitative data on historical flood events, evaluate the impact on DBRT, and develop future flood risk scenarios. Conducted in March 2020, these workshops engaged community leaders, local and municipal officials, and disaster management experts (Fig. 3). Participants mapped recent flood events, identified critical infrastructure bottlenecks, and analyzed traffic flow disruptions. Subsequently, they developed future scenarios of flood risk scenarios for DBRT, outlining key challenges and potential mitigation strategies.

3.4. Document review

Document review was conducted to gather secondary data for triangulating and complementing qualitative and quantitative findings. The reviewed materials contained information on DBRT infrastructure, such as route lengths, ridership, facilities, as well as data on planned expansions, population growth, the economic significance of DSM port, and flood risks. This secondary data provided essential context, enabling a broader understanding of the potential implications of disruptions to the DBRT system.

4. Results

4.1. Key context factors strengthening systemic criticality of current and future DBRT services

Dar es Salaam, Tanzania's economic capital, is the country's largest city with an urban population of 6.4 million (NBS, 2013), projected to reach 10 million by 2030. The city's public transport is dominated by informal and paratransit systems, posing a significant challenge for a hub of its economic stature. Dar es Salaam's port is a critical logistics center for landlocked neighboring countries such as the Democratic Republic of Congo, Rwanda, and Zambia (JICA, 2018; TPA, 2015, 2022). The port is handling 30 % of its 14 million tons of annual traffic for this purpose (TPA, 2015, 2022). The port is also a hub for water public transportation in Tanzania, thereby solidifying the city's role as regional logistic center.

A 2008 transport master plan (JICA, 2008, 2018), aligned with Vision 2030, proposed a bus Rapid Transit (BRT) system as a central solution (JICA, 2008). The city's road and transportation network radiate from the center, where the port, public transportation hub and key economic facilities are located, along major corridors like Bagamoyo and Morogoro, Roads. Consequently, the DBRT system was planned along these radial roads to link the city center with the periphery (Fig. 4). Implementation occurs in six phases. Phase one became operational in 2016. The construction of the phase two is completed, phase three and four are currently under construction (Gowela, 2023; JICA, 2018; Mwesigwa et al., 2024; Nachilongo, 2023).

Fig. 3. Key variables, type of data and methods.

4.2. Relevancy of and dependency on DBRT transport system

Since the inception, DBRT has faced significant service disruptions from flooding, which has damaged key infrastructure and drawn public criticism (Jacobsen, 2022; Kajubi, 2018). Although the current system's reach may appear limited within the broader public transportation network (see Fig. 4 and 5), It provides a crucial high-quality service. The DBRT offers greater passenger comfort, more efficient ticketing, and shorter travel times compared to informal and paratransit systems (Chengula & Kombe, 2017; Jacobsen, 2022; Joseph et al., 2020).

The first phase of the DBRT spans 20.9 km, connecting Kimara to downtown Dar es Salaam to via one major and two shorter routes (Fig. 5). This phase includes one major route and two shorter ones: Kivukoni, to Kimara along Morogoro Road (15.8 Km); Magomeni to Morocco (3.4 Km); and Fire to Kariakoo (1.7 Km) (DART. (n.d.)., 2023; JICA, 2018). Shortly after its 2016 launch, daily ridership rapidly increased from 134,695 to 269,000 (JICA, 2008). Current figures indicate an average of 180,000 daily passengers, representing 7.8 percent of the city's public transport modal share. However, this underutilizes the system's full capacity, and when considering the actual modal split, DBRT's share is closer to one-fifth (Global BRT Data).

The system primarily links Ubungo municipality to the downtown business center, a hub for the nationally critical port, major economic activities, and rail and water transportation. A ridership survey confirms its vital role in commuting from various neighborhoods, such as Magomeni, Kimara and Tabata, to workplaces in downtown and surrounding areas (Fig. 6). Over 60 percent of passengers use it to reach jobs in businesses, shops and informal enterprises, while 8 percent are laborers at the Dar es Salaam port (Fig. 7). For these commuters, DBRT provides shorter travel times and more reliable, higher-quality service compared to other options (Chengula & Kombe, 2017; Jacobsen, 2021b; Shauri & Mimano, 2022).

Although the DBRT system is more expensive than the conventional public transport modes, it proves cost-effective for longer journeys, such as those between Kimara and downtown (Chengula & Kombe, 2017, p. 19). Despite serving a limited number of neighborhoods, the system is heavily relied upon by the downtown workforce. The survey revealed that 68 percent of port service laborers (Fig. 8) and 84 percent (Fig. 9) of surveyed downtown population frequently use DBRT, with 44 percent of all respondents use it five or more times per week (Fig. 10). Some of these commuters combine it with other modes like Daladala (paratransit minibus) or Bodaboda (motorcycle). This high usage demonstrates that the DBRT's relevance extends beyond immediate corridors, serving a broader segment of public transport users (Fig. 11).

To assess a sector's dependency on DBRT, we defined it as a situation where a service interruption disrupts the sector's operations, impacting other economic or social sectors for a day or more. For instance, a port service disruption could affect financial and trade organizations, ultimately harming individual livelihoods. this is critical as 36 percent of surveyed commuters are traders and small business owners who rely on daily income (Fig. 7), and many port laborers are paid daily, meaning missed workday results in immediate lost wages.

However, the informants reported no such significant income loss has occurred. This is attributed to two factors: the continued availability of alternative transport (e.g., Daladala, Bodaboda) and the infrequency of prolonged DBRT interruptions. The survey shows that while 19 percent of commuters experienced multiple weekly interruptions, only 4 percent of port service disruptions lasted a day or more (Fig. 12). Interviews with key informant, small business owners, shop employees, supervisors at the DSM port, TPA HR officer confirmed that the impact has been minimal due to these alternative options.

Challenges persist nonetheless. Laborers from Mbezi and Kibha area (Fig. 6; Fig. 8), rely on DBRT due to poor alternative service. A foreman

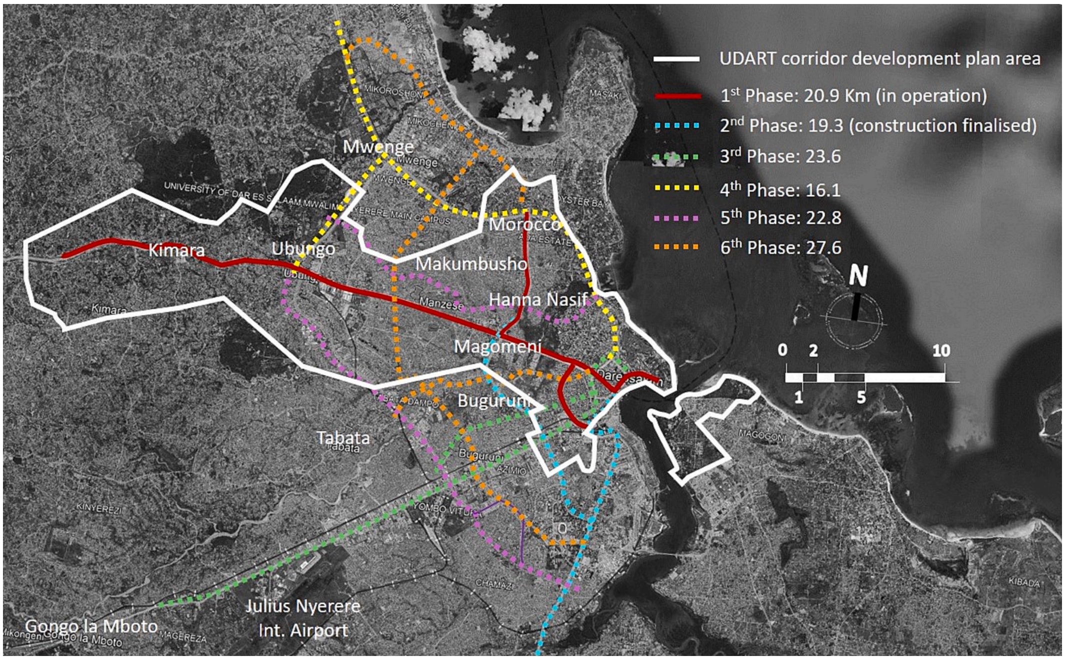

Fig. 4. DBRT's 6 phases and 1st Phase corridor development area. and World Bank 2018a.
Source: Own construct on GoogleEarth based on JICA 2018

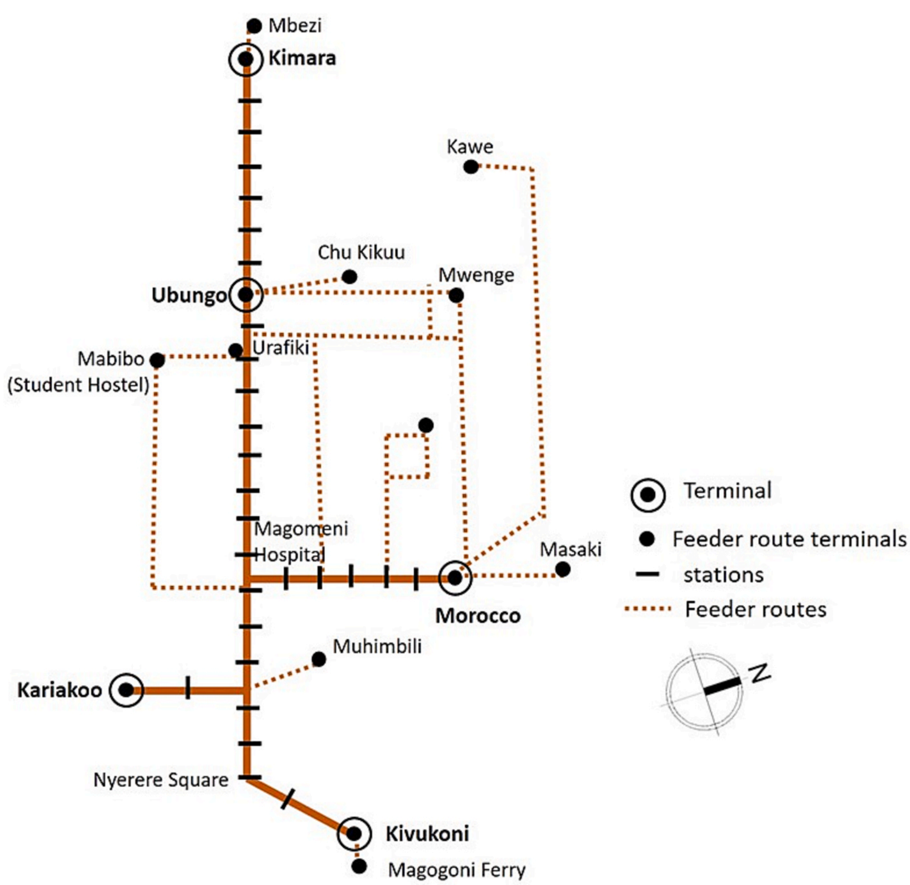

Fig. 5. DBRT current routes, terminals and stations. .
Source: Own based on Chengula and Kombe 2017

noted that flooding-related DBRT interruptions cause lateness and absenteeism, stressing operation, though they have never completely halted port activities:

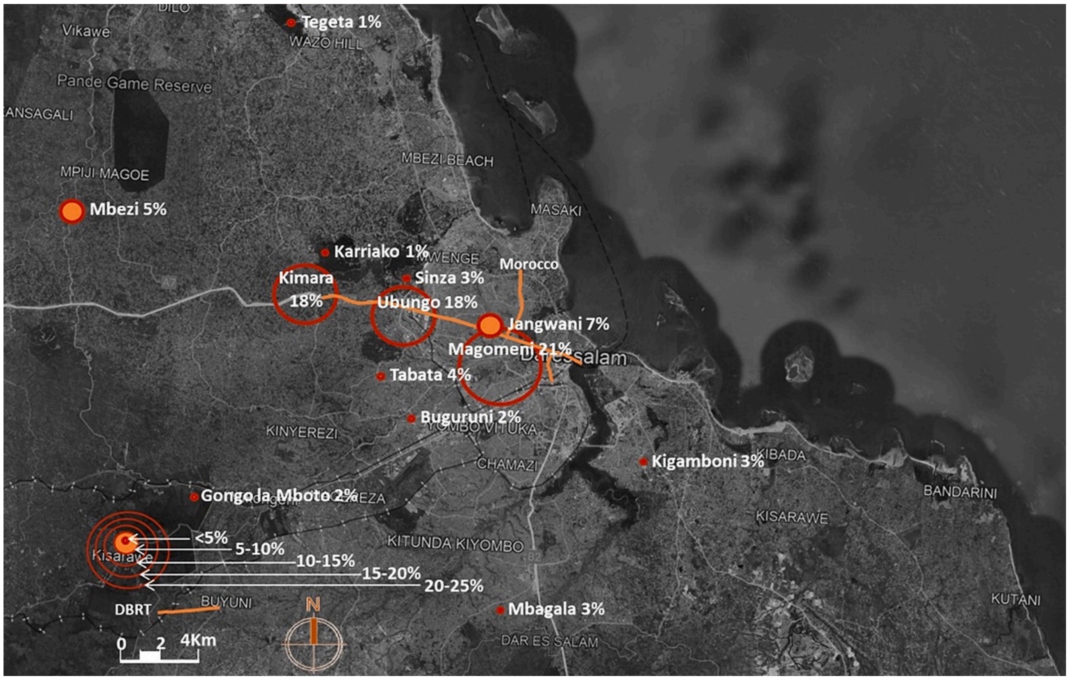

Fig. 6. Origin of commuters using DBRT system.

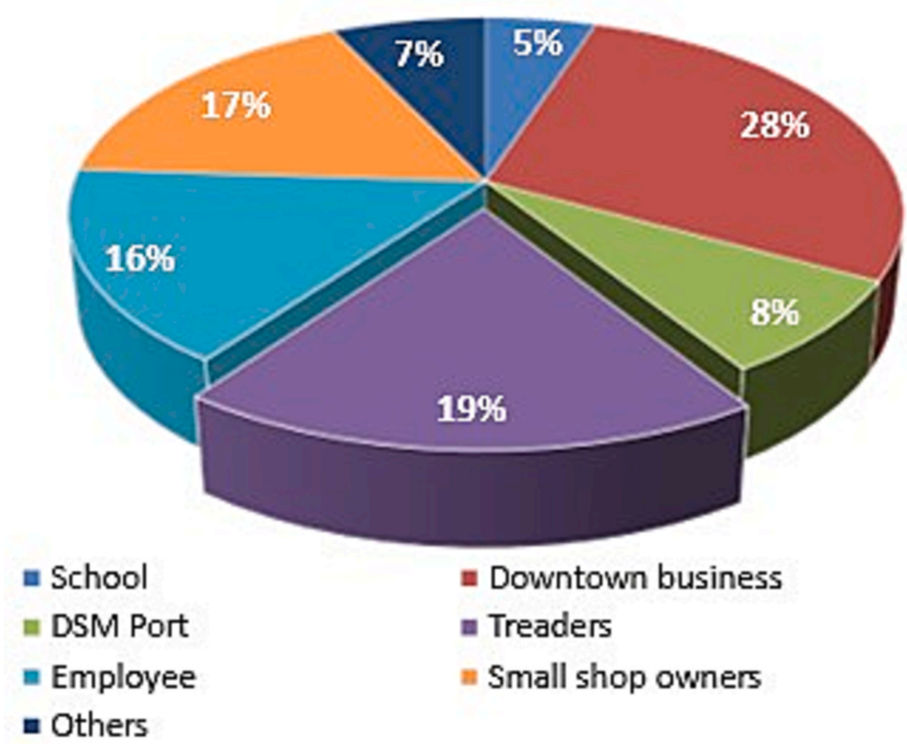

Fig. 7. UDART ridership per sector.

“We have several laborers who lives in Kibaha, Kimara and Mbezi areas. Hence the transit system is the most convenient and reliable means to reach here. We always feel the stress whenever there is flooding and the DBRT is interrupted as several laborers arrive late and few fail to come (interview with Foreman, December 2021)”.

The TPA HR officer (December 2021) concluded that while the DBRT service is important, it is not yet critical to port functions. These assessments are based on current experiences, but the potential for future flood risks and DBRT expansion to alter this situation remains uncertain.

Despite limited actual workday loss, seasonal flooding causes significant commuting stress for the surveyed population. Key informants described the difficulty of navigating around flooded roads and bridges. Traders and small business owners reported income declines from

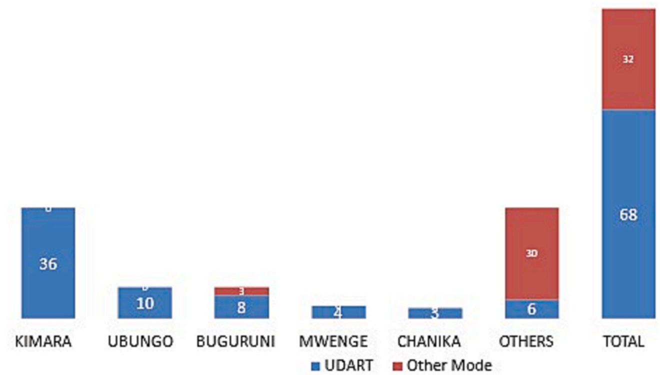

Fig. 8. Percentage of DBRT users and their origin for surveyed DSM Port laborers.

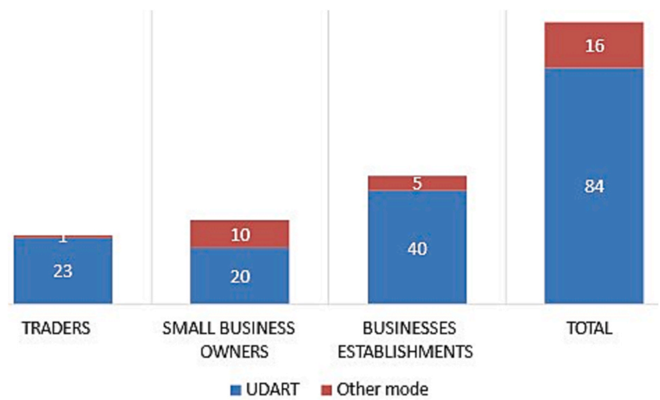

Fig. 9. Percentage of DBRT users working in downtown.

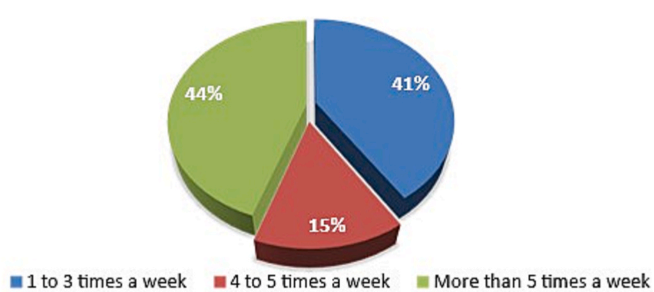

Fig. 10. Frequency of commuting with DBRT for surveyed groups in Downtown.

reduced downtown customer traffic. The DBRT service is particularly valuable for this group, as it facilitates goods transport at a fixed fare, unlike minibuses with demand-based pricing or motorcycles that cannot accommodate bulky items. A trader from Kimara noted:

> "During service interruptions, alternatives like Bodaboda or Bajaji cost me each time 10,000 to 15,000 Shillings compared to the standard DBRT fare of 700 Shillings f (interview note, December 2021)."

Consequently, those relying on daily wages face a triple burden: longer commute times, higher transport costs, and reduced business earnings.

Currently, DBRT service interruptions are minimal (Fig. 5). However, this is expected to change with the operationalization of the second phase, which is projected to double The system's coverage and increase its public transport share from 7.8 to over 15 percent (JICA, 2018). The expansion, coupled with planned transit-oriented corridor development (World Bank, 2018a) and increasing frequency of extreme flood, could exacerbate disaster risks (see Sect. 4.3). In the near future, prolonged service interruptions could become more common; further jeopardizing livelihoods and the provision of essential downtown services.

4.3. Exposure of DBRT transport system to flood related hazards

Flooding accounts for 25 percent of all disasters in Sub-Saharan Africa (Bhavnani et al., 2008). It poses a significant challenge in Dar es Salaam, where it severely damages infrastructure, disrupts public transportation, and hampers urban mobility (Bhavnani et al., 2008; C40 Cities Finance Facility, n.d.; Fan & Beukes, 2021; JICA, 2008; Krüger et al., 2021). Since its inception, DBRT's infrastructure have suffered extensive damage from seasonal flooding (Citizen Reporter, 2022; Krüger et al., 2021; World Bank, 2019b). The coastal region of East Africa is highly vulnerable to sea-level rise, a vulnerability exacerbated by its socioeconomic and infrastructural conditions and rapid population growth (Kebede & Nicholls, 2012; Vergel-Tovar and Landis, 2022; World Bank, 2019b). In addition to rising sea-levels, urbanization has intensified flood-related disasters and infrastructure damage by reducing permeable surfaces and altering or destroying natural drainage systems (Bhavnani et al., 2008; Gajjar et al., 2021; TURP, 2018; World Bank, 2019a). Climate change projections indicate that global warming will increase rainfall, further aggravating these challenges (Kebede & Nicholls, 2012).

The rainy seasons in Dar es Salaam typically occur from March to May and from October to November. However, since 2014, the city has experienced a shifting rainfall patterns, with increasingly erratic and intense precipitation (World Bank, 2019b). In 2018, severe flooding during both the short (October to November) and long (March to May) rainy seasons significantly disrupted the DBRT system (World Bank, 2019b).

Interview with key-Informants, including the Mtaa Chairman and Ward Executive Officer of Hananasif (conducted in March 2020 and December 2021, respectively), described how the main route over the Jangwani Bridge, along with DBRT bus stations and the terminal, was submerged. This inundation led to widespread service interruptions (Kwayu, 2019; The Guardian, 2018) (see also Fig. 14). The flooding at the DBRT terminal not only damaged several buses but also delayed the vehicle maintenance, further crippling transport services. Consequently, the number of operational buses was severely limited, causing significant delays. Commuters from the Kimara/Mbezi area were particularly affected, as the remaining buses become overcrowded and began skipping stations (The Guardian, 2018). These observations are corroborated by the results of PSD workshops held in March 2020.

4.3.1. Scenarios of flooding affecting DBRT

Flood risk is a persistent concern in Dar es Salaam with significant social and economic implications. During a Participatory Scenario Development (PSD) workshops and key-informant interviews, the Usafiri Dar es Salaam Rapid Transit (DBRT) system was identified as a major factor exacerbating this risk. A critical concern is the location of the DBRT depot in a flood-prone area of the city center. This placement not only increases the transport network's vulnerability but also complicates broader urban flood management, amplifying the overall risk to the city's residents and economy.

> "Since the DBRT depot near Jangwani Bridge was constructed, we, residents have noticed a significant increase in the frequency and severity of flooding. Now, every rainy season, our neighborhood is submerged for days. Despite this, the response is always to dig and clear sand from the depot's compound after it floods. This effort is futile, as the same problem recurs every season. (Comment of PSD participant, December 2021)"

Dar es Salaam's monocentric structure concentrates transport hubs

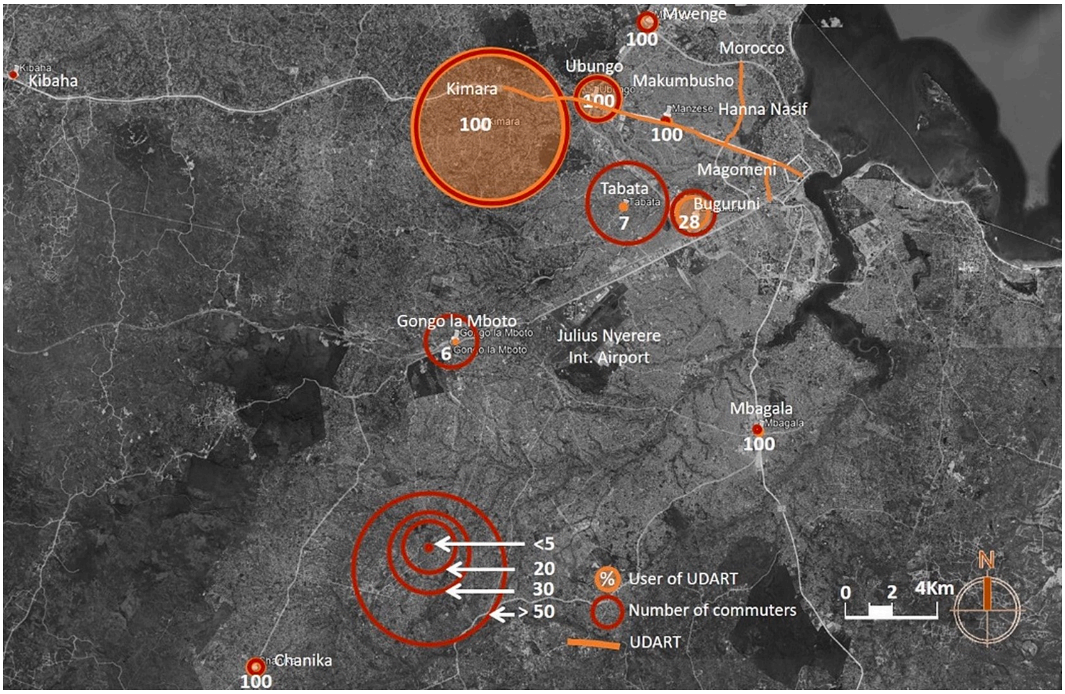

Fig. 11. DSM Port laborers, their residential area and use of DBRT.

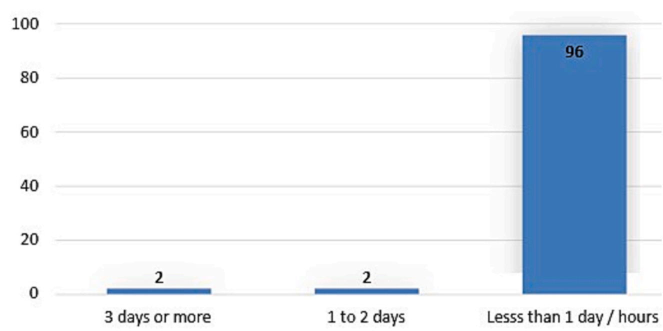

Fig. 12. Longevity of DBRT service interruptions as experienced by surveyed population

and commercial center in one location. Consequently, when key arterial roads and bridges in this area flood, large sections of the city are severed from essential services. This disconnection severely affects residents in neighborhoods like Hananasif, Magomeni, and Makumbusho, which are situated within the Msimbazi River delta (Fig. 13). For these communities, flooding results in periodic displacement, property loss, increased risk of waterborne diseases, and a range of other related challenges.

The PSD workshops analyzed both historical and current flood risks to identify key affected areas. Participants across all workshops consistently identified similar flood risk hotspots. The most significant ones include:

- The Jangwani Bridge area, which encompasses the DBRT depot;
- Kawawa Road Bridge and its surrounding neighborhoods;
- The neighborhoods of Hananasif and Makumbusho;
- The Ali Hassan Mwinyi Road Bridge (Selandar Bridge);
- The Mpiji Street Bridge over the Msimbazi River; and
- The Kigogo Road Bridge over the Luhanga River (Fig. 14).

These findings align with several studies evaluating flood risk vulnerability in Dar es Salaam (C40 Cities Finance Facility, 2021; Hellmuth et al., 2019; Kironde, 2016; Krüger et al., 2021; World Bank, 2019a).

These flood hotspots intersect major arterial and feeder roads connecting the downtown area with the rest of the city. Consequently, flooding in these locations cripple mobility between the city center and its outskirts (Fig. 14). Notably, besides the Jangwani Bridge, the other identified sites are crucial segments of both the current and planned DBRT routes. As a result, the entire DBRT network, particularly the segments linking the city center to surrounding neighborhoods, is highly vulnerable to flooding.

During the PSD workshops, participants developed future scenarios based on their personal and communal experiences with flood disasters in Dar es Salaam, as well as academic research and professional expertise. The workshops brought together a diverse group of stakeholders, including:

- Local actors, such as community members and leaders from flood-affected neighborhoods along the DBRT routes;
- Municipal officials, including spatial planners and disaster risk management experts from various Dar es Salam's municipalities; and
- Academics from Ardhi University (ARU).

The local participants contended that the construction of DBRT infrastructure, particularly its depot, along with other building and road developments, has significantly increased land sealing. They identified these large-scale projects in a densely populated, ecologically sensitive area as the primary driver of the recent drastic increase in flood disasters. To substantiate their claims, they provided films and photos of flood events in their neighborhoods, specifically around the DBRT depot and Jangwani Bridge (Fig. 15). Their observations align with international literature on the role of socio-economic changes in future risk scenarios (Greiving et al., 2018; Van Ruijven et al., 2014) and with research on flood affected neighborhood in the northern part of the Dar es Salaam (Alem & Namangaya, 2021).

The perspectives of officials and academicians differed from those of residents though, both groups contributed to developing future scenarios. The former group drew on general academic discourse about urbanization and their professional experience in planning and public services. They emphasized that dense informal settlements along river

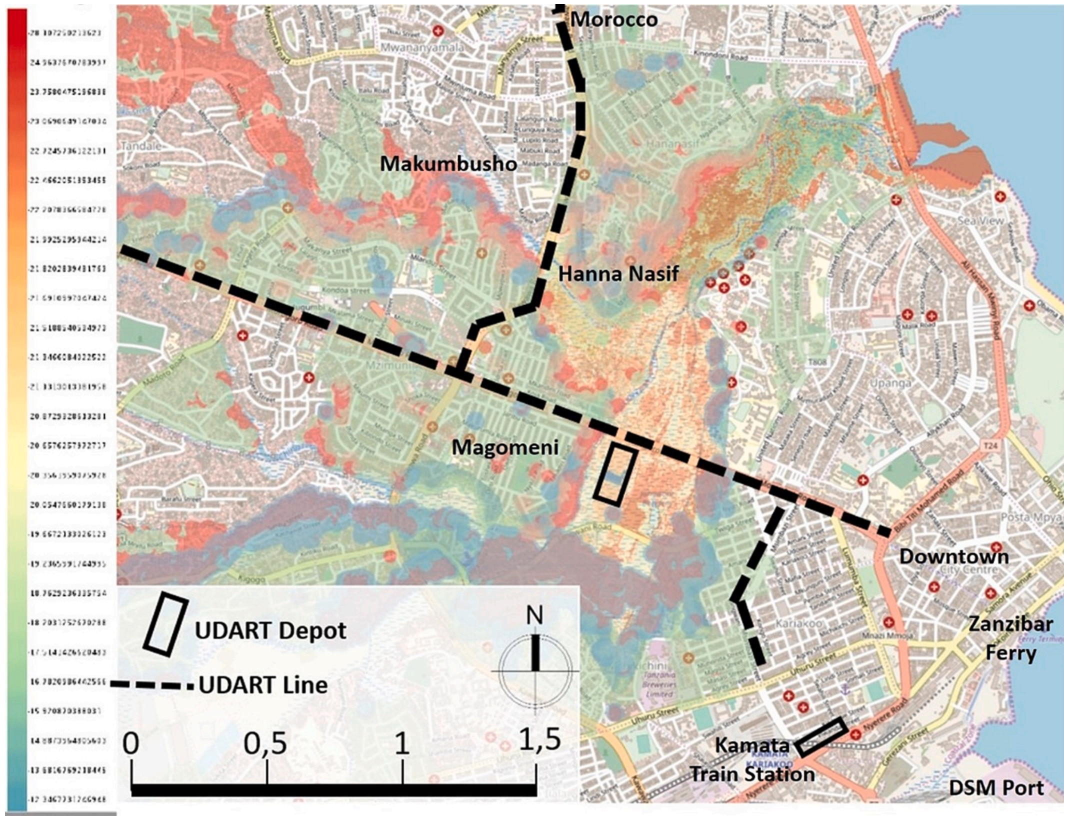

Fig. 13. Msimbazi river flood depth and extent (from green minimum to red maximum depth). Source: Adopted from Msimbazi Digital Elevation Model, open access (LiDAR, 2019). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

valleys and the absence of a proper drainage systems are major contributors to the increasing flood risk. The discussions extensively covered the role of these settlements in exacerbating flood, distinguishing it from the general densification of built-up areas.

Nevertheless, the experts and academicians concurred with the local participants that constructing the DBRT depot on the Jangwani and Msimbazi river floodplain was a significant planning error that has contributed to current flood disaster and risk. The group also considered the planned DBRT corridor development strategy (Fig. 4), which aims to promote Transit-Oriented Development (TOD) along DBRT routs (World Bank, 2018a, 2018b). In the workshop, academician noted that the corridor's land use plan and ongoing high-rise development will intensify land sealing and disrupts natural drainage lines. While a key informant from DART (Dar Rapid Transit Agency) (June 2019) framed this strategy in the context of sustainable mobility, most PSD participants viewed tits implementation as a potential factor in increasing flood risk.

Despite differing opinions on the causative factors, the overlapping scenario maps consistently identified the same flooding hotspots in areas bordering the inner city. A flood event in these Zones would severely impede access to the city center. This indicates that, in addition to the current DBRT routes, the following segments of the planned phases are also exposed to flood risk (Fig. 4):

- Phase 2: The segment connecting radial part of the Phase 2 with Phase 3 and the current route (Phase 1).
- Phase 4: The segment connecting Mwenge, main campus of University of Dar es Salaam, Ardhi University, Kunduchi and the northern Dar es Salaam along Bagamoyo Road with Msimbazi Bay area and inner-city;
- Phase 5: The segment linking Phase 4 with Phase 6; the segment connecting the University of Dar es Salaam with Msimbazi Bay; and the segment connecting Kimara with Phase 3, Tabata industrial area, Phase 2 and the National stadium.

The Msimbazi Opportunity Landscape Design Project was a recurring topic all workshops. Some participants had been involved in the design workshops hosted by the World Bank in 2018. The project's primary goal is to mitigate flood risks through integrated land use and socio-economic planning in the densely populated Msimbazi Basin, notably by creating a city park designed to absorb floodwaters (World Bank, 2019b). The project site coincides with areas the PSD groups identified as high-risk. However, none of the groups chose to build their scenarios around this initiative.

Participants expressed skepticism about the feasibility, viewing it as overly ambitious and unrealistic. Local leaders and residents also perceived it as a threat, as the plan involves relocating neighborhoods along the Msimbazi river. This lack of consensus and enthusiasm led to the project's exclusion from the groups' risk scenarios. The prevailing assumption was that the construction density in the Basin, where the center is also located, would continue to increase, thereby exacerbating flood risks.

From this paper's perspective, focusing on factors that increase flood risk is beneficial. However, the strategies proposed by the Msimbazi Opportunity project are still considered in analyzing risk management options. In a recent development, TARURA (Tanzania Rural and Urban Roads Agency) press release announced the project's commencement, stating that the demolition of structures in the Jangwani area and along the Msimbazi Riverbanks had already begun (Msimbazi Basin Development Project).

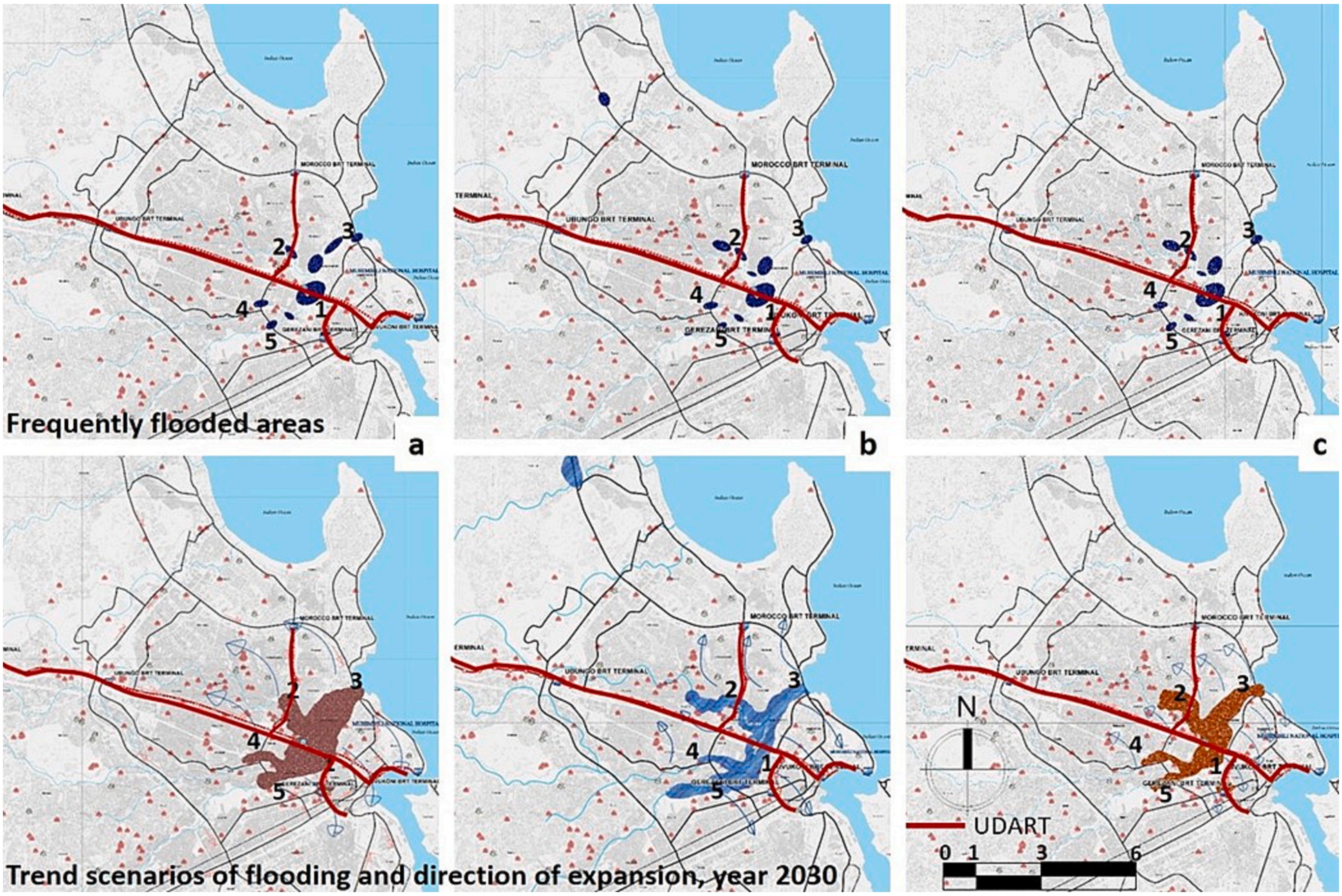

Fig. 14. Historical (top) and trend flood scenarios for the area affecting current UDART transport system: academicians (a); community members and leaders (b); officials of government offices (c). Jangwani bridge over Msimbasi delta (UDART Depot) (1); Kawawa road bridge over Sinza river (Sam Nujoma Road) (2); Selandar bridge (Ali Hassan Mwinyi road (3); Mpiji street bridge over Msimbazi river (4); Kigogo road bridge over Luhanga river (5). Source: PSD Workshops, March 2020.

Fig. 15. Hananasif neighborhood along Msimbazi River (a); overflowed Jangwani Bridge on Morogoro Road and adjacent DBRT Depot (b).

5. Discussion

5.1. Implication: Introduction of DBRT as new public transport mode

Infrastructural assets require long-term policies and meticulous planning. Their development, construction, and management demand substantial public resources and reflect regional and national ambitions for driving socioeconomic development. Transport infrastructure, in particular, forms the foundation for sustainable and equitable development. Central to the development agendas of governments and intergovernmental organizations, including the United Nations and its Sustainable Development Goals (SDGs), are objectives such as affordable housing, basic services, and quality education. Achieving these goals depends on robust transport infrastructure.

In cities like Dar es Salaam, providing affordable transportation is a key challenge linked to ensuring access to jobs and social services, such as healthcare. Dense and precarious informal settlements in and around the inner-city continue to expand due to their proximity to employment opportunities. However, accessing low-paying jobs in downtown business and the informal sector remains difficult because of the city's costly and unreliable transport system. In this context, the bus rapid transit (BRT) system represents a significant step toward improving access to jobs and socioeconomic services. By enhancing mobility, the BRT can contribute to better living conditions and support broader development goals.

While informal and paratransit transportation modes have weaknesses, they are highly flexible, capable of quickly adapting routes and schedules. This flexibility has minimized the impact of recent flood disasters, preventing major disruptions to key economic facilities such as Tanzania's main port. In the future, however, Dar es Salaam is likely to see a greater reliance on the DBRT system. Once all six phases are operational, its modal share could increase from the current 7.8 percent to over 50 percent. For a city of this size, any disruption to the DBRT could have far-reaching, disastrous effects on major economic sectors. Households dependent on trade, small businesses in the downtown businesses, and regionally significant water-based logistics services would be severely impacted.

The DBRT system's exposure to hazards is a significant concern. The very features that ensure its effectiveness, such fixed routes, high-quality infrastructure, and well-equipped facilities, also make it vulnerable to flood. As a geographically fixed system, it lacks the flexibility to alter routes in response to flooding, which is predicted to become more frequent and extreme (C40 Cities Finance Facility, 2021; Hellmuth et al., 2019; Kironde, 2016; Kwayu, 2019; World Bank, 2019a; World Bank, 2019b.

The findings from the PSD workshops support this analysis. First, the planned DBRT expansion is likely to stimulate corridor development along its routes (JICA, 2008, 2018; World Bank, 2018a). Workshop participants confirmed this, observing that the operational first phase has already intensified land-use changes and increased building density. As more phases are completed, this trend is expected to continue, resulting in further loss of green spaces and the sealing of unpaved areas. Second, the construction of high-rise buildings in the sensitive costal area of downtown Dar es Salaam has already demonstrated negative consequences in disrupting natural water flow and aggravating flooding.

The DBRT has become a crucial transportation system with significant impacts on key economic sectors. Once all planned phases are operational, it will serve the entire city, benefiting industries, port services, downtown businesses and social facilities. The growth of small businesses and street vending is expected to rise, as current data indicates that over 35 percent of traders and small business owners already rely on the current DBRT system (Fig. 7).

Further the study highlights three major findings and implications in managing transport network with high systemic criticality in Dar es Salaam and similar cites in Sub-Saharan Africa:

1. **Strategic and policy related implications**: Integrated urban and transport planning is essential to manage DBRT-induced growth, prioritize climate resilience, and leverage flexible informal transit to build a robust, multi-modal network and mitigate flood risks.
2. **Operational and management implications**: Implement immediate flood protection for the DBRT's critical infrastructure and develop comprehensive contingency plans to ensure operational continuity and minimize economic disruption. Additionally enforce strict regulations on construction in sensitive areas to preserve natural drainage and mitigate flood risk.
3. **Socioeconomic implications**: The city's economic prosperity is now critically dependent on the reliable operation of the DBRT. Frequent system disruptions would not only cause widespread economic damage but also undermine the core socioeconomic gains and broader development goals the system was designed to achieve.

5.2. Options to manage risk and possible impacts of disruptions on DBRT system

The Dar es Salaam Bus-Rapid-Transit (DBRT) system is a critical infrastructure asset, not only for its current service level but also for the following three reasons:

- **Expansion potential**: There is strong policy and resource commitment to fully implementing the DBRT. Once complete, it will serve the entire city by linking socio-economic systems that support the industrial, business, and service sectors, as well as national and international logistics connected to the port of Dar es Salaam's. This positions the DBRT as a transport system with relevance beyond local boundaries.
- **Growing modal share**: As the DBRT network expands, the city's reliance on other public transport services is likely to diminish. The system's share of the city's overall mobility could exceed 50 percent. Currently, public transport accounts for 43 percent of mobility (World Bank, 2018a, 2018c), a figure the DBRT is poised to increase. This shift will heighten the dependency of the city's socio-economic systems and logistics networks on DBRT, while reducing the redundancy provided by multiple transport modes.
- **Exposure to flood hazards**: DBRT's design and its location in flood-prone areas make it highly vulnerable. Approximately 40 percent of the segments in Phases I, II, and IV, along with associated facilities such as depots and terminals, are at risk of flooding.

  To addressing these vulnerabilities, several strategic options can be considered:

- **Decreasing infrastructure exposure**: This can be achieved by locating new facilities like depots in less flood-prone areas or by mandating minimum elevation standards for all infrastructure.
- **Reducing system vulnerability**: Enhancing the system's flood resistance by constructing lines in high-risk areas on elevated pillars or viaducts.
- **Protect and improving alternative transport systems**: Strengthening informal and semi-formal public transport networks can provide vital redundancy and alternative options for commuters, thereby enhancing overall transport resilience.
- **Support nature-based solutions**: Actively implementing projects like the Msimbazi Opportunity Plan, which proposes nature-based solutions, can effectively mitigate flood risks at a catchment level.
- **Develop a polycentric urban structure**: Dar es Salaam's future development should focus on a polycentric model. Distributing economic activity across multiple centers would reduce dependence on a single core and make the city less vulnerable to disruptions in critical services like the BRT.

6. Conclusion

The Dar es Salaam Bus Rapid Transit (DBRT) is a critical system for urban mobility and socio-economic development. However, its fixed-route design creates significant vulnerability to flooding, a risk exacerbated by climate change and rapid urbanization. As the city's reliance on this transit system grows, a major disruption could trigger cascading failures across the economy, affecting downtown commerce and regional logistics.

To enhance resilience, integrating and formalizing the city's flexible informal transport networks is essential to provide alternative routes during disruptions. Furthermore, the planning of any new mass transit must include a comprehensive, systemic risk assessment from the outset. This involves evaluating interdependencies with other critical infrastructure and embedding proactive disaster management strategies to ensure long-term sustainability against compounded environmental and urban pressures.

Authors contribution

The first draft of the article was prepared by the corresponding author (G.A.) and S.G. edited, complemented the whole article and wrote considerable part of Chapter 5 (Discussion).

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Genet Alem Gebregiorgis: Writing – original draft. **Stefan Greiving:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

All raw data can be provided by the corresponding authors upon request.

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