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Conceptualizing resilience in developing countries: A review of Tanzania water supply systems

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Abstract

Tanzania has expanded the coverage of water service to over 80% of the urban population—such success requires an assurance of service continuity. Without resilience, the water supply systems would – recurrently – be at risk of persistent flood hazards, exacerbated by climate change. The current study examines the rewsilience and related concepts, suggesting the appropriate approach of ensuring water systems' ability to survive the impacts. Whereas Tanzania policies, programs, and strategies focus on sustainability, adopting resilience approaches would ensure sustainability, yet enable the systems to overcome sudden shocks. Furthermore, measuring resilience would ensure an effective operationalization of the concept in the country. Considering the country's hardship in acquiring data, and low resilience expertise, qualitative assessment approaches bring more benefits, particularly the semi-quantitative assessments encompassing both quantitative and qualitative methods. Such methods will enhance the decision-making process on the appropriate interventions for resilience enhancement

Keywords: Resilience; Water Supply System; Developing Countries; Semi-quantitative; Tanzania

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1. Introduction

Resilience relates to the ability to absorb the effects of a disruptive event, minimize adverse impacts, respond post-event effectively, maintain or recover functionality, and adapt in a way that allows for learning and thriving while mitigating the adverse impacts of future events (Stevenson et al., 2015). The concept intends to prepare for the growing threats of terrorism, natural disasters, and other crises (Hwang et al., 2013). Climate change intensifies the frequency and severity of natural disasters. Climate change-induced floods have exerted severe consequences on lifeline infrastructure such as roads, telecommunications, and water supply systems. With their essentiality to provide life-supporting critical services (Brown, 2012), water supply systems need to operate continually. Nevertheless, their inherent natural complexity exposes them to flood hazards and other disasters. The water systems encompass downstream and upstream interdependencies with sectors like transportation, industrial, agriculture, power, and fire; at the same time, interacting closely with the communities and water supply managing organizations. Such interactions exacerbate the systems' vulnerabilities.

Globally, water supply systems have experienced disaster impacts – affecting the water services delivery (Sweya et al., 2018). Similarly, Tanzania's water supply systems are vulnerable to disasters (EM-DAT, 2020), flooding having a significant effect. Floods trigger, among others, infrastructure failures, and water-related diseases (United Republic of Tanzania, 2003) that are linked to inadequate resilience. In 2019, the southern part of the country experienced cyclones Idai and Kenneth at different time intervals; the cyclones significantly impacted Mozambique and Zimbambwe (Sweya et al., 2020a). Earlier 2021, another cyclone was about to hit the southern part of the country, followed by the Jobo cyclone which was in the line of hitting the major city of the country, Dar es Salaam, by April 25, 2021. Such trend suggests a certain level of the country's vulnerability to cyclones.

Despite the expected future climate change influence on extreme weather impacts such as floods, droughts, cyclones, and tropical storms (Shemsanga et al., 2010), the examination of the water supply systems resilience to such disasters has received little attention. This paper examines the resilience and related concepts thereby proposing the most appropriate assessment method as a means of enhancing resilience in developing countries' urban water supply systems. The study defines the position of resilience among other concepts in Tanzania's urban water supply systems, leading to sound decisions on appropriate assessment approaches, and resilience improvement measures. The findings can apply to other DC needing to choose an appropriate approach for resilience enhancement in water supply systems.

2. Water supply systems

Water supply systems are critical infrastructures forming the backbone of the community services, to sustain life in both regular operations and in times of disasters/emergencies (Bruneau et al., 2003). Communities will fail to survive and recover from disruptions such as disasters without water supply systems. Several community operations, including cities, urban and rural settings depend on the water supply systems. For instance, water supply systems support hydroelectricity production, agricultural productions, livestock production, industrial productions, ecosystems well-being, and human life. Such wide-spread significance underlines their criticality and the value of their continued operations and existence. The systems include physical infrastructures requiring organizations that are responsible for their development, protection, and operations to meet the intended goal. Furthermore, water consumers, along with funding entities, and the environment, are integral parts of the systems (Sweya et al., 2020b). Thus, the water supply systems are socio-ecological-technical systems (Newman et al., 2011) in the sense that factors such as technical — physical infrastructures, social — water users, and ecological — water sources need to be integrated for a sustainable water service provision.

2.1. Tanzania water supply systems

In 1891, Tanzania invested in the first piped water supply system in Dar Es Salaam, the system embraced a cost-sharing mechanism, later, replaced by a "free water for all" declaration. The economic crisis of the 1970s constrained the "free water for all" policy, such that, in the mid-1980s the government re-adopted the cost-sharing program. Following the establishment of the National Water Policy in 1991, the cost-sharing program was replaced by a focus on full cost recovery and private sector participation.

Tanzania, Mainland and Zanzibar, encompasses water resources including rivers, lakes, and groundwater, governed by the water policy of 2002 and the Water Resources Management Act of 2009. The latter divides the mainland water resources management into nine water basins. The Regional, District and Township Water Supply and Sanitation Authorities under the Water and Sanitation Act 2009 and its amendment in 2019, manage the water infrastructures. The Energy and Water Utilities Regulatory Authority Act 2001 formed an Energy and Water Utilities Regulatory Authority that became active in 2006, with the responsibility for performance monitoring of all commercial-run water utilities. In addition, the Environmental Management Act 2004 is responsible for environmental conservation assisting in protecting the water sources, catchments, and recharge areas.

According to United Republic of Tanzania (2012a), the Tanzania population was 45 million by 2012, currently estimated to be 60 million, with an annual growth rate of about 3.1%. There are 26 regional water authorities and eight national project Water Supply System Authorities in the Mainland serving about 74.2% of the urban population (United Republic of Tanzania, 2018). The country experiences significant water losses, for instance, for three consecutive production years 2015/2016, 2016/2017, and 2017/2018 about 53.09%, 46.00%, and 46.68% of water lost in the Dar es Salaam water supply systems (United Republic of Tanzania, 2018), due to illegal tapping and structural leakages. The water loss leaves a significant number of people without a reliable water supply in urban areas.

The actual estimated total renewable water resource in Tanzania-Mainland is 125,763 million m^3/year, and the total water demand is 76,716 million m^3/year equal to 61%. A large proportion (66%) of the demand is for ecosystems replenishment, 17% is for hydropower production, 14% for irrigation, and only 2.2% is for domestic purposes (Figure 1). The total human-related consumption is 13,027 million m^3/year dominated by irrigation (82%). Main consumers being from Rufiji and Pangani water basins contribute to about 46% of the total irrigated area. The percentage of water withdrawn for agriculture shows that Tanzania is reliant on the existing water resources for agricultural production. In return, agricultural activities exert pressure on the water supply systems. Furthermore, industrial discharges and emissions impact the water supply systems, whereas a large population "over 80%" uses onsite sanitation facilities generating greenhouse gases and polluting the groundwater. The water resources vulnerability index "10%" suggests there are low

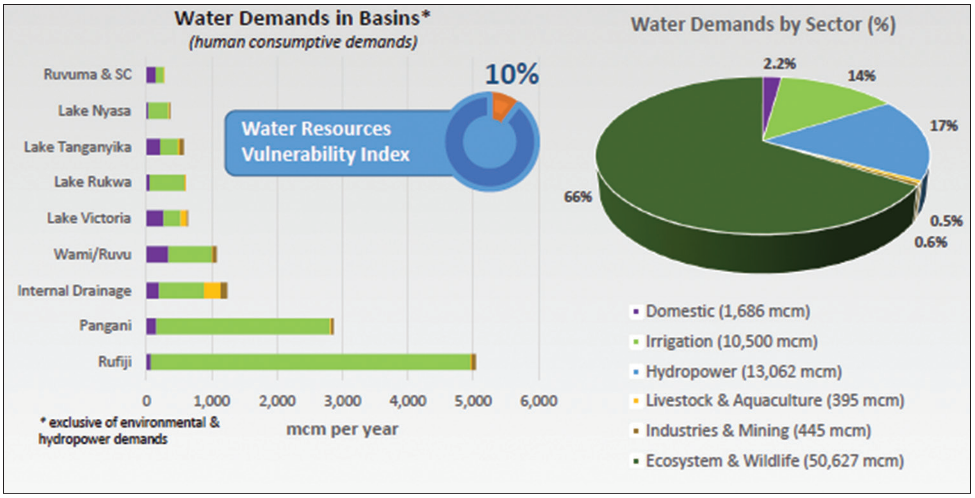

Figure 1. Tanzania water demand (Source; MoW-Tanzania Mainland, 2020). https://www.maji.go.tz/index.php/pages/articles

vulnerabilities in the overall Tanzania water sources, although individual basins such as Wami/Ruvu exhibit high vulnerabilities due to rapid urbanization and population growth.

Tanzania urban water service is through public water utilities—Regional Water Supply and Sanitation Authorities, and National Projects Water Supply and Sanitation Authorities, Community-based Water Supply Organizations, and privately-owned water supply networks and wells/boreholes. The water sector's privatization initiatives in 2003 led to several private companies' investment through building small-scale water infrastructure, and water trucks' water delivery services. Consequently, the water price increased due to vending chains, and the poor population was the most affected. The country's water sector development program running between 2006 and 2025 has shown a noticeable increase in water service coverage. The "access to improved water sources" increased from 54.5% (NBS and ICF Marco 2011) to 61% (United Republic of Tanzania, 2016). Such improvements are significant; however, the resilience of the systems against disasters remains unknown.

2.2. Vulnerability of the water supply systems

UNISDR (2004) defines vulnerability as the propensity of exposed elements such as human beings, their livelihood, and assets to suffer adverse effects when impacted by hazard events. Vulnerability is the function of the hazard to which the system is exposed, the sensitivity, and the capacity for adaptation (Hughes and Healy, 2014; United Republic of Tanzania, 2012b). A hazard is a potentially damaging physical event, phenomenon or human activity that may cause the loss of life, injury, property damage, social and economic disruptions, or environmental degradation (UNISDR, 2004). For water supply, hazards that lead to vulnerabilities range from natural to human-made hazards, from short-term to long-term hazards. Globally, natural, and human-made hazards have had significant impacts on the water supply systems leading to functional failures, and a lack of timely delivery of water services to the communities. Earthquakes, floods, landslides, and climate change are among the prominent hazards with grave consequences to water supply systems. Such hazards have affected Tanzania's water supply systems. The United Republic of Tanzania

(2012b) vulnerability definition is cognizant of the climate change hazards that are already affecting the country, as some areas are battling drought, and others receiving severe rainfall and deadly floods. The 2019 cyclones Idai and Kenneth and the 2021 Jobo cyclone suggest that the coastal areas are vulnerable and would experience significant impacts from cyclones. Moreover, the 2016 earthquake in Kagera, and the April 2020 low magnitude earthquake in the Lake Victoria region suggest a high possibility of high-magnitude earthquakes – in future – that can affect the water supply systems.

Floods seem to be of significant concern due to their frequency and their impacts on people's lives (Table 1). Few recorded disasters, by 2019, registered the total damages, especially none indicated the effects on infrastructures like water supply. Floods have been consistent with epidemic diseases, both claiming the lives of people in the same years (Table 2). Such bacterial diseases are water-related suggesting the water supply systems experienced disruptions. Besides, other studies indicate that, very often, floods obstruct infrastructure and trigger water-related diseases (United Republic of Tanzania, 2003).

About 73% of the Urban Water Supply and Sanitation Authorities generate adequate internal funds to cover their day-to-day operation and maintenance expenses, while they cannot generate funds for depreciation and return on investment. Furthermore, 23% generate own funds to meet only operational and maintenance costs without covering a part of plant electricity costs (United Republic of Tanzania, 2018). That situation underlines the Authorities' inability to generate funds for contingency plans and adopt proactive steps to mitigate vulnerabilities in their water supply systems.

3. Resilience perspective

Comfort et al. (2010) and Coppola (2006) indicate that no nation, regardless of its wealth or influence, is so far advanced as to be entirely immune to disasters' adverse effects. Comfort et al. (2010) suggest further that if we cannot predict or foresee the urgent threats we face, prevention and preparedness become difficult; thus, the concept of resilience holds the promise of an answer. Boin and McConnell (2007) suggest that administrative and societal capacities can be enhanced to cope with those conditions by introducing a

Table 1. Summary of the disasters that have affected Tanzania between 1964 and 2019.

Disaster type	Disaster subtype	Events count	Total deaths	Total affected	Total damage ('000 US$)
Drought	Drought	10	0	12,737,483	0
Earthquake	Ground movement	6	26	148,592	458000
Earthquake	Tsunami	1	10	0	0
Flood	-	20	333	748,010	7510
Flood	Flash flood	5	69	78,246	2000
Flood	Riverine flood	22	431	382,347	280
Landslide	Landslide	1	13	150	0
Storm	Convective storm	4	47	6394	0
Storm	Tropical cyclone	2	4	2,002,500	0

Source: EM-DAT: Last accessed June 2020

Table 2. Floods versus bacterial diseases over the years.

Year	Disaster type	Disaster subtype	Total deaths	Total affected
1990	Epidemic	Bacterial disease	200	
1990	Flood	-	6	868
1990	Flood	Riverine flood	183	162000
1997	Epidemic	Bacterial disease	2329	42350
1997	Flood	-	46	7104
1997	Flood	Riverine flood	37	3028
1998	Epidemic	Bacterial disease	1871	35824
1998	Flood	Flash flood	61	4600
2000	Epidemic	Bacterial disease	16	254
2000	Flood	Riverine flood	36	1817
2001	Epidemic	Bacterial disease	3	103
2001	Flood	Flash flood	5	200
2002	Epidemic	Bacterial disease	9	149
2002	Flood	Riverine flood	9	1200
2009	Epidemic	Bacterial disease	12	600
2009	Flood	Riverine flood	38	50000
2015	Epidemic	Bacterial disease	582	37712
2015	Flood	-	12	5000

Source: EM-DAT: Last accessed June 2020

complementary strategy — the promotion of resilience. Resilience points to the qualities that are central to disaster management, namely, the ability to restore or sustain required operations by responding in the situation by being prepared when the disturbance happens and finally by using the lesson learned to rearrange or restructure how it works (Masys, 2015). Thus, effective response during immediate aftermath critically depends on the resilience of citizens, first-line responders, and operational commanders (Boin and McConnell, 2007). Furthermore, resilient systems reduce the probability of failure, the consequences of failure, and the time of recovery (Tierney and Bruneau, 2007) leading to enhanced capacity of the communities to survive disaster risks.

As the magnitude and frequency of natural disasters are increasing due to the failure of climate change mitigation and adaptation measures (World Economic Forum, 2020), communities living in urban areas with complex networks of societal systems and critical infrastructures are at high risk. Lacking the ability to predict future climate change patterns contributes to the need for building resilience. The Hyogo framework of action 2005–2015 assisted the efforts of nations and communities to become more resilient and to cope better with the hazards threatening their developments (UNISDR, 2005). Indicating that disaster risk reduction should be part of our everyday decision from how people educate their children to how they plan their cities and that each decision can make us either more vulnerable or more resilient. The Sendai

Framework of Action advocates the sustainable reduction of disaster damage to infrastructure and disruption of basic services including developing resilience and investing in disaster risk reduction for resilience (UNISDR, 2015). The framework aligns with the Sustainable Development Goals (9) recommending resilient infrastructures capable of surviving disaster risks.

3.1. Local policies related to resilience building in the country

Developed to align with the United Nations Framework Convention on Climate Change (1992), Tanzania's National Adaptation Program of Action NAPA (United Republic of Tanzania, 2007) aims to identify and develop immediate and agent activities to adapt to climate change and climate variability, and protect life and livelihood of people, infrastructure, biodiversity, and environment. To address the vulnerabilities, NAPA suggests potential adaptation activities such as developing alternative water storage programs and water harvesting technologies for communities, strengthening integrated water resources management (IWRM), and developing both surface and subsurface water reservoirs. Furthermore, promoting community-based catchments conservation and management programs, promoting new water serving technologies in irrigation, developing recycle, and reuse facilities in the industrial sector and potentially in households, developing early warning systems, and desalinizing and defluoridating water in areas with saline and fluoride content, respectively.

The National Climate Change Strategy (United Republic of Tanzania, 2012b) enables effective adaptation to climate change and participation in global efforts to mitigate climate change with a view of achieving sustainable development. The implementation of the strategy enables the country to put in place measures to adapt to climate change and mitigate GHG emissions to achieve sustainable development through climate pathways, thereby, reducing vulnerability and enhancing resilience. The strategy acknowledges that the projected effects of climate change could have significant effects on the nation's infrastructure system. As infrastructure assets have long operational lifetimes, they are sensitive not only to the existing climate at the time of their construction but also to climate variability over the decades of their use. Preparedness — in planning and managing the impacts of climate change is unavoidable to increase the resilience of both new and existing infrastructure. Thus, the strategy suggests an infrastructure system that is resilient to climate change through mainstreaming climate change aspects and promoting the deployment of appropriate technologies in infrastructure designing and development.

The National Water Policy (United Republic of Tanzania, 2002) develops a comprehensive framework for sustainable development and management of the nation's water resources. Effective legal and institutional frameworks for implementation are introduced ensuring beneficiaries participate fully in planning, construction, operation, maintenance, and management of the community-based domestic water supply schemes. The policy addresses three sub-sector issues; *Water Resources Management* — providing a comprehensive framework for promoting optimal, sustainable, and equitable development and use of water resources for the benefit of the present and the future generation; *Rural Water Supply* — improving the health and alleviating poverty of the population through improved access to adequate and safe water; *Urban Water Supply and Sewerage* — achieving an efficient development and management of urban water supply and sewerage services. In general, the policy emphasizes on sustainable water development; thus, entailing maintaining water quality and ensuring that human actions do not impair the long-term availability of freshwater stocks. Furthermore, the policy institutes IWRM, putting in place effective and sustainable strategies to address natural and human-made water resources problems.

The National Water Sector Development Strategy (United Republic of Tanzania, 2008) sets out how the Ministry responsible for water implements the National Water Policy to achieve the National Strategy for Growth and Reduction of Poverty targets. It guides the Ministry's formulation of the harmonized National Water sector Development Plan and Water Sector Development Program as an input to the financial planning Framework for Medium-Term Expenditure. While acknowledging that disaster management in the country relies on the intersectoral coordination placed "only for policy formulation and provision of guidelines" under the Prime Minister's Office-Disaster management Department, the response for mitigation of disaster impacts rests on the sectors, local government authorities, and other technical institutions. Thus, water-related disasters have been managed based on limited intersectoral coordination, inadequate early warning systems, and inadequate enforcement of preventive measures. That way, disaster mitigation actions focus on remedial rather than preventive approaches. The strategy suggests the provision of advanced warnings of possible disasters, including those related to long-term climate change, and contingency plans and resources available to minimize the impacts of natural and other disasters. Among other things, the strategy embraces instituting contingency plans, adaptation and mitigation measures, and procedures for minimizing the impact of droughts, floods, climate change, accidental chemical pollution, and other disasters.

3.2. The position of resilience concerning other concepts

The policies, strategies, and programs reveal the awareness of the presence of disaster risks in the country, especially climate-related risks such as floods and drought. The research draws a few themes, based on common concepts, from the policies, programs, and strategies; (1) risks affecting Tanzania water supply systems, (2) measures for ensuring water supply availability, and (3) interactions of IWRM, sustainability, risk management, vulnerability, and resilience.

3.2.1. Risks affecting Tanzania water supply systems

Water insecurity is the major threat, involving the lack of enough water to meet all critical water needs as well as the inability to adapt to major water disasters (Habiba et al., 2013). Disasters such as drought, floods, landslides, and climate change are the main drivers of water insecurity in the country. During the outset of such disasters, water supply systems become unable to support the community's functionality adequately and continuously – in terms of acceptable quantity and quality of water. Acknowledging such risks in the policies, programs, and strategies underlines the awareness of the responsible organization on the potential impacts the community would face because of inadequate water services. The country has strategized several measures to ensure the water service is available. Nevertheless, the National Water Policy is reliant on demand-based planning and designing for water supply infrastructure focusing on the coverage. Such a focus may not adequately prepare the systems to withstand the impacts of disasters.

3.2.2. Measures for ensuring water availability

Several measures exist on ensuring continued water service. Few of such measures relate to responding to disruption, emphasizing on traditional disaster management and risk management approaches. Such measures are usually ineffective and do not adequately prepare the water supply systems to survive the sudden shocks of disasters — and they are more tailored to enhance sustainability rather than resilience. Most of the measures situate in the first two phases of disaster management pertinent to disaster risk management. Examples of such measures are, mitigating the impacts of floods, replacing aging infrastructures, promoting management of water quality and conservation, improving community-based catchment conservation and management programs, and adapting to climate change and mitigating GHG emissions, and maintaining and repairing distribution networks, and preparedness. In fact, the measures focus on the water sources management rather than the infrastructure. Contingency plans, promoting infrastructure insurance systems, and disaster response, rest on the second phase of disaster management; although, the measures are not resilience-based and could easily be ineffective against disasters. The mitigation and response measures rest on the sectorial ministry, more so the Water Supply System Authorities are responsible. Although, their financial incapacities suggest that they are unable to effectively implement the measures, thus tend to focus on remedial actions.

3.2.3. IWRM, sustainability, risk management, vulnerability, and resilience

The emphasis – throughout the water policy and strategies – is on using the IWRM approach, to ensure sustainability. IWRM is a framework designed to improve the management of water resources through four fundamental principles adopted at the 1992 Dublin Conference on Water, and the Rio de Janeiro Summit.

1. Freshwater is finite and vulnerable resource essential to sustain life, development and the environment
2. Water development and management should rely on a participatory approach, involving users, planners, and policymakers at all levels
3. Women play a central part in the position, management, and safeguarding of water
4. Water has an economic value in all its competing uses; thus, it is an economic good.

The principles align with sustainability, risk management, and resilience. The first principle acknowledges the vulnerability of the water resource in line with the exposure to different risks, thus, needing risk management activities to avoid (prevent) or to limit (mitigation and preparedness) the adverse effects of hazards (UNISDR, 2004). Furthermore, the IWRM principles lead to sustainable water resources through efficient use and protection of the resource for future demands. Sustainability aims to reduce or eliminate environmental impacts; such that, the water resource utilization and functionality entail sustainable water supply services to the communities and the environment. Resilience's primary goal is to have cities, structures, systems, or resources that can survive disasters or sudden changes. Resilience focuses on the response of systems to both extreme disturbances and persistent stress (Marchese et al., 2018). Both sustainability and resilience refer to a state of a system over time, focusing on the persistence of the system under normal conditions, and in response to disturbances (Fiksel et al., 2014). The way sustainability and resilience interact when used concurrently is significantly important since, given their similarities, they are separate and distinct concepts that are subject to misuse if neglecting their differences.

There is a significant opportunity to develop sustainability practices that are more consistent with resilience methods. An example of such approach is to set sustainability as a critical function of the project, policy, or system to maintain during and after disturbances; here the emphasis is put on evaluating and building resilience for sustainable components of the system (Marchese et al., 2018). The Tanzania Water Policy's emphasis is on sustainability, so is the strategy indicating that there is already a certain level of sustainability in the water supply systems. Building on that and acknowledging the ever-increasing impacts of climate change and its influence on the frequency and magnitude of floods, embedding resilience methods to enhance sustainability in both normal conditions and during disturbances are crucial. Such methods will also assist the implementation of NAPA, and its strategies to ensure the country's water supply resources and infrastructures can better cope with climate change and its impacts.

Likewise, vulnerability can be a component of resilience and vice versa. Although, Hughes and Healy (2014) suggest that vulnerability is a deficit concept; thus, resilience and vulnerability are two ends of the continuum with resilience as a positive measure. Such argument is consistent with Folke et al. (2002) cited in Hughes and Healy (2014), indicating that vulnerability is the opposite side of resilience. As such, a resilient system is less vulnerable than a non-resilient system. The current research recommends such a fact, viewing resilience as the positive end of vulnerability; thus, by improving the resilience of water supply system will imply a reducing vulnerability and increasing sustainability.

3.3. Defining resilience

Resilience encompasses many definitions; infrastructure systems resilience relates to the system's ability to reduce the chances of a shock, absorb the shock, and to recover quickly after a shock (Bruneau et al., 2003). In ecological and environmental aspects, resilience refers to the ability to absorb disturbances and reorganize itself into a better configuration while retaining its fundamental characteristics (Walker and Avant, 2004). In social aspects, resilience is the ability of groups or communities to cope with external stresses and disturbances because of social, political, and environmental change (Adger, 2000). For organizations, resilience concerns the ability to adapt, the need to detect the drift toward failure or weak signals, the organization's preoccupation with failure, and the level of organizational reliability (Lee et al., 2013). Furthermore, for economic aspects, resilience is the ability of an economy or a local community to absorb and adapt to negative effects of economic shocks and move toward pre-disaster equilibrium or stability (Bastaminia et al., 2017).

In all cases, resilience definitions contain features that are similar to one another. The analysis for 32 definitions revealed that resilience contains features like *anticipate, resist, reduce, withstand, recover, bounce on, adapt, organize itself, and timely recovery.* The commonest features include absorb/withstand, adapt, and recover appearing in 53%, 44%, and 41% definitions, respectively, others are resisting (16%) and organize themselves (19%). The critical characteristic is stability (Barnes et al., 2012); therefore, an efficient, resilient infrastructure or enterprise depends on the ability to anticipate, absorb, adapt to, and rapidly recover from a potentially disruptive event (Soldi et al., 2015). The features align with Stevenson et al., (2015) definition developed by analyzing 120 definitions "*The ability to absorb the effects of a disruptive event, minimize adverse impacts, respond effectively post-event, maintain or recover functionality, and adapt in a way that allows for learning and thriving, while mitigating the adverse impacts of future events*." The definition is general and acknowledges both engineering resilience — the system returning to a single equilibrium after a disaster, and ecological resilience — the possibility of the system to adapt to one of the multiple equilibriums. The definition draws together several features consistent with IWRM, vulnerability, risk management, and sustainability. Such features form a benchmark for understanding the concept of resilience for multi-dimensional systems like water supply.

3.4. Measuring resilience

Since resilience is a concept with ambiguous definitions, the gap between theory and application can be closed by the ability to measure it (Prior, 2015). Just as there is no standard definition of resilience, there is no standard measure (Willis and Loa, 2015). Assessing resilience relies on the functionality of a system and recovery time to a pre-disaster state (Tierney and Bruneau, 2007). The assessment can be hazard-based, or consequence-based; however, applying a holistic approach considering non-specific hazards should be a priority for organizations (Hughes and Healy, 2014). Bruneau et al. (2003) developed a conceptual framework with four dimensions—Technical, Organizational, Social, Economic — for measuring community resilience. The framework emphasizes a holistic approach beyond physical and organizational systems to the impacts of social and economic networks (Tierney and Bruneau, 2007). With the same dimensions, different performance measures such as *robustness*, *redundancy*, *resourcefulness*, and *rapidity* are requisite for different systems subjected in the analysis.

A robust system withstands the impacts of disasters; robustness works well with redundancy, where the system possesses substitutable components at the time of extreme events. Besides, redundancy contributes to robustness (Agarwal, 2015). A resilient system easily and quickly recovers from a potential disaster. Properties such as resourcefulness and rapidity relate to each other when resources are available, the recovery speed is high, and time is shorter than in situations of scarce resources.

3.4.1. Why measure resilience?

Technological, natural, and social systems' vulnerabilities are not predictable, while the ability to accommodate changes without catastrophic failures is critical. People and properties fair better in resilient cities during disasters as fewer buildings collapse, fewer power outages occur, fewer businesses become at risk, and fewer deaths and injuries occur. Furthermore, the complex interdependencies and more complex and interconnected modern infrastructures lead to the need for an approach to thoroughly analyze where vulnerability lie and where resilience can be improved (Hughes and Healy, 2014). Thus, measuring resilience;

- Deepens the understanding of resilience, shifting from abstract construct to concrete phenomenon
- Serves critical communication roles, providing people with a shared language and the means to enlist others in the common aim of improving resilience to disasters
- Provides strategic and decision-making assistance by helping to identify where to begin work and apply the limited resources (Schoch-Spana et al., 2019)
- Characterizes resilience through the articulation of resilience constituents
- Raises awareness — using the measurement results as a method of communicating the need for resilience. Assisted by observable measures, it helps managers to direct resilience-related information to the entities whose resilience is lower
- Enhances effective allocation of resources for resilience

- Assists in building resilience through detection and management of disruptions and their effects of low resilience entities, thereby helping risk management agencies to direct their assistance measures adequately
- Helps monitor policy performance by assessing the effectiveness of resilience-building policies through longitudinal comparisons of resilience in those entities targeted by the policy (Prior and Hagmann, 2014).

3.4.2. The complexity of measuring resilience

Resilience is inherently complex, and with increasing complexity comes greater difficulties in establishing measures to interpret the results (Prior and Hagmann, 2014). Developing a tool that meets the important interpretations while capturing the complexity of the concept as a policy-relevant phenomenon can be time-consuming and expensive. An index is a way of simplifying the complexity, and many variables denoting the phenomenon are the proximal representation of the actual subject of measurement and only assumed to be representative. Suggesting that most indices only reflect *relative* measures than an *absolute* measure. However, the *relative* measure comparing between places, entities, or overtime, is useful when someone wants a relational understanding of resilience. Literature also indicates the presence of *arbitrary* indicators, suggesting that it is almost impossible to choose indicators measurable on the same scale — transformation is necessary. Besides, *data quality, data availability,* and *data sustainability* may limit the resilience assessment process; for instance, since indicators are proxies, data may be accessible but not directly relevant to the measure. Moreover, developing a generic and direct resilience measure is challenging, due to enormous measures and theoretical conception in literature. Thus precise framing of resilience to avoid vagueness is needed including a sound definition, explicit policy linked to the definition, and explicit articulation of scale and context (Prior and Hagmann, 2014).

3.4.3. Resilience of what? And resilience to what?

A common question "resilience to what?" is essential to specify the specific system configuration to be assessed. The current study focuses on the urban water supply systems encompassing the water supply services, and the water resources management issues. The primary function of the urban water supply is to provide water services to the community through the lawful organizations — Water Supply System Authorities. Such organizations are responsible for the functionality of the urban water infrastructures and the respective water sources. Thus, the study addresses the *resilience of* urban water supply systems for all aspects of functionality and the wellbeing of the environments.

The *resilience to what?* attempts to respond to the type of disturbance of interest (Hughes and Healy, 2014). It describes the potential resilience threats to the system of concern (Liu, 2014). There is a wide range of hazards that can have significant consequences to water supply systems. However, Hughes and Healy (2014) suggest that a resilience assessment also requires an awareness that the hazard itself may be unpredictable and that the organization may require to think beyond the typical disaster scenarios. Thus, the consequence scenario directly relating to the loss of service as well as other impacts would be important to apply. Nevertheless, such consideration should not right-off an assessment of known hazards.

3.4.4. Resilience assessment approaches

3.4.4.1. Bottom-up versus top-down

Assessing resilience encompasses two approaches; bottom-up approaches, also known as *ideographic* (Cutter, 2016) — usually employing qualitative data and input from experts and non-experts (Schoch-Spana et al., 2019) — using community surveys and stakeholders' interviews to derive indicators directly and assess resilience (Parsons et al., 2016). Cutter (2016) suggests that such measures are locally generated and customized to a place through engaging communities or experts to develop resilience goals and to increase their capacity to achieve them. Top-down approaches, also known as *nomothetic* (Cutter 2016), are the products of an organization outside the community intended for use by oversight or expert-driven body, and reliant on standardized and centralized data to quantify resilience (Schoch-Spana et al., 2019). They use secondary data, like census or economic data to indirectly derive proxy indicators in assessing resilience (Parsons et al., 2016). Top-down approaches involve an initial extensive literature review to identify common principles that can guide the resilience assessment process. The process establishes dimensions of resilience, which then allow an indicators identification process. Subsequently, experts are involved in identifying indicators that practitioners and policymakers consider essential.

3.4.4.2. Formative versus summative

Top-down and bottom-up resilience assessment approaches can be formative or summative — formative assessment relates to ex-ante "accounting for future uncertainty/based on forecasts" evaluations and continuous monitoring of the condition from early stages of the planning process (Sharifi, 2016). It is a process-based methodology aiming at enhancing adaptive capacity through the incremental improvement of the conditions. The assessment provides learning opportunities and can be suitable for dynamic issues. On the other hand, summative assessments rely on ex-post "actual" measures of the effectiveness of interventions — they are outcome-based, helping communities understand where they stand in terms of resilience and providing evidence needed for deciding about the necessity of modifying intervention strategies.

3.4.4.3. Standard assessment versus context-specific assessment

Further assessment approaches include standard and context-specific. Standard approaches are generic, considering key resilience characteristics without specific contextual attributes. Assessments like all-hazard assessments falling under this category are high-level assessments looking at resilience measures in response to all hazards (Hughes and Healy 2014). Context-specific, are tailor-made assessments to specific hazards, specific to different community levels and specific to different geographical settings (Saja et al., 2019). Hazard-specific are more detailed assessments focusing on a certain hazard; therefore, such assessments are more appropriate to certain critical assets (Hughes and Healy, 2014). In all cases, the assessments can be conducted against baseline conditions, against thresholds that reflect the program objectives, against principles of good resilience, against peer (benchmarking), and based on the speed of the recovery (Sharifi, 2016).

3.5. Methods for measuring resilience

Resilience measurement occurs in many ways, and the techniques used depend on the measure's requirement and the characteristics of the system of interest (Prior and Hagmann, 2014). In general, resilience evaluation encompasses quantitative and qualitative methods (Hosseini et al., 2015). The methods are compatible with several studies like Hughes and Healy (2014), and most studies fall into such categorical methods.

3.5.1. Quantitative methods

Quantitative methods involve resilience measurements of specific networks leading “in most cases” to indices resulting from the modeling of networks and possible failure modes (Hughes and Healy, 2014). Hosseini et al. (2015) describe two sub-categories of quantitative methods; *general resilience methods* encompass techniques that offer domain-agnostic measures to quantify resilience across applications (Hosseini et al., 2015), relying on numerical data (Sharifi, 2016). They produce quantitative means to assess resilience by measuring systems performance regardless of their structures. Such methods develop quantitative metrics through more detailed analysis or modeling (Hughes and Healy, 2014). They can be classified further into deterministic — performance-based approaches which do not incorporate uncertainties, and stochastic — approaches that capture the stochasticity associated with the system behavior (Hosseini et al., 2015). *Structural-based modeling approaches* entail techniques that model domain-specific representations of the components of resilience (Hosseini et al., 2015). Such techniques examine how structures of systems impact resilience. Thus, observation of the systems’ behavior is a must, and characterization must be modeled or simulated. Further classifications are optimization models, simulation models, and fuzzy logic models.

3.5.2. Qualitative methods

Qualitative methods are top-down, starting big, and then drawing conclusions on small components (Juan-García et al., 2017), assessing resilience without numerical descriptions (Hosseini et al., 2015). They rely on public perceptions and the experts’ judgment for evaluating performances (Sharifi, 2016). Sometimes, qualitative methods complement well quantitative resilience studies — achieving a more beautiful grain in the descriptions and coping phenomenon. The limited resources in quantitative approaches seem to require us to switch horses midstream and look more closely at differences between individuals (Ungar, 2003). Ungar (2003) suggests further that qualitative methods include aspects such as “discovery of unnamed processes,” “contextual specificity,” “the power of marginalized voices,” “transferability,” and “researcher standpoint bias.” Prolonged contact with participants, files, or organizations brings the researcher close enough to his or her data detecting trends that may not otherwise be apparent. The assessment focuses on contexts, highlighting the highly individual and contextual specificity risk solutions that communities use to cope with high-risk environments. Since it aims to describe a concept centered on experiences of the communities, studies strive to affirm the transferability of their results, not the generality. The specificity of the qualitative approaches in which participants and researchers participate in the process of dialogical reciprocity enables many truths claims to rise by co-construction of the meaning. Giving voice to those who are otherwise marginalized in knowledge production contributes to a deeper understanding of the localized resistance discourse which permeates oppressed communities. The provision of a forum for the expression of the minority voices through research encourages tolerance for localized construction and avoids the generalization of findings. The researcher is the research instrument when using qualitative methods, and as such, must deconstruct his or her relationship with participants and data to minimize subjectivity. Qualitative methods contain conceptual frameworks, and semi-quantitative indices sub-components (Hosseini et al., 2015).

Conceptual frameworks constitute most of the qualitative methods by offering best practices (Hosseini et al., 2015). Conceptual frameworks development is by setting out principles to measure the resilience (Hughes and Healy, 2014). For instance, the DROP model uses several dimensions such as social, economic, institutional, community, and infrastructure for measuring the community disaster resilience (Prior and Hagmann, 2014). For *semi-quantitative methods,* Ungar (2003) indicates that both qualitative and quantitative approaches form a crucial combination producing the most informed findings — the arbitrariness and contextual problems of resilience researchers resolve through using qualitative approaches. Integrating both qualitative and quantitative methods, yields reliable findings at each site that account for how local communities perceive resilience. In accounting the whole set of properties of a resilient system, it is necessary to use both quantitative and qualitative methods (Juan-García et al., 2017). Thus, *semi-quantitative* embraces resilience assessment methods with mixed qualitative and quantitative techniques (Hosseini et al., 2015). The methods are particularly applicable to assessing the community resilience, social interaction between communities, their environment and the structural aspects on which they depend. Despite many authors arguing that the complexity of the concepts like resilience is best explainable qualitatively, such methods explore the human elements of exposure to threat and the way the elements interact with the structural features of the social systems (Prior and Hagmann, 2014). They are usually constructed with a set of questions designed to assess different resilience-based system characteristics on a Likert scale (0-10) or percentage scale (0-100) (Hosseini et al., 2015; Clarke et al., 2016). The assessments of the system characteristics from experts' opinions aggregate in some ways to produce indices of resilience (Hosseini et al., 2015; Clarke et al., 2016). The indices outline the resilience domains of the investigated systems where resilience improvement could be specified (Clarke et al., 2016). Semi-quantitative tools are useful in quantifying and evaluating critical infrastructure resilience because they offer a tangible operational measure that operators can recognize and used as a benchmark for further resilience strategies (Clarke et al., 2016). Furthermore, unlike the sole use of qualitative or quantitative methods, the application of a hybrid method makes it possible to tackle important soft societal, organizational, and infrastructure aspects of critical infrastructure operations that are difficult to quantify as well as physical/technical and economic dimensions affecting the overall resilience of the systems (Clarke et al., 2016).

3.5.3. Why qualitative methods?

Sharifi (2016) indicates several reasons for the importance of employing qualitative methods based on normative judgments. Among others, the methods are useful for circumstances where data availability is a problem. Furthermore, resilience is a value-laden concept, influenced by factors such as preference, attitudes, and perceptions, community members have a better knowledge of needs, vulnerabilities, and coping capacities of their community, and qualitative assessment is needed to understand the opinion of the people. Hughes and Healy (2014) suggest that qualitative methods are flexible, encompass none/minimum computational requirements, ease to implement, can be applied with complete or incomplete data sets, useful in wider organizational resilience assessments, and useful in assessing physical networks asset resilience. Such advantages align with the water supply systems containing several aspects of physical, organizational, social, economic, and environmental. More so, they concur with the situation in developing countries like Tanzania facing difficulties in data availability. In such countries, resilience is still a theoretical concept, because limited studies for measuring resilience, thus needing qualitative methods that are easy to implement. The adoption of qualitative methods, particularly semi-quantitative methods, is advantageous to multi-dimensional systems like water supply systems encompassing aspects ranging from physical systems, organizational, environmental, economic, and to social systems.

The previous resilience assessments have often measured systems performance using abstract indices or more qualitative approaches by relating the impact directly to the level of service measures used in the water sector (Butler et al., 2017). Wang and Blackmore (2009) indicate that since the 1960s, several studies have developed quantitative measures for the resilience of water resources systems. Quantitative assessments for water systems such as Hashimoto et al. (1982) developed indices related to how systems would recover from short-term supply shortages. In most cases, the indices have been applied only to specific external hazards such as flooding or a system attribute like pipe internal energy dispersion (Perry, 2013). Most of such quantitative methods are focused on small systems, typically certain parts of the water supply systems. To address the multi-dimensional resilience for water supply systems need the application of qualitative methods-particularly semi-quantitative.

3.6. Examples of Semi-quantitative WATER SUPPLY SYSTEM assessment in Tanzania and their implications

The significance of qualitative assessment tools is portrayed by Sweya et al. (2021a, 2021b, 2020a, and 2020b) and Sweya and Wilkinson (2020) who developed qualitative, semi-quantitative, tools for assessing the resilience of water supply systems in Tanzania. The tools were designed to address technical, organizational, social, economic, and environmental aspects that have an influence on the ability of the water supply systems to survive the impacts of flooding. In the technical dimension, Sweya et al. (2021a) suggest that the technical aspects/physical infrastructure resilience can be influenced by robustness, system redundancy, safe-to-fail and flexibility – robustness being considered the most important factor. Sweya et al. (2021b) suggest that an economic factor that influences the resilience of water supply systems is dynamism – the efficient use of resources over time for investment in repair and reconstruction focusing on the speed of recovery of water supply from the impacts of flooding. Dynamism encompasses public-private-partnership (PPP), cost recovery, and systems investment proportionality. The systems also entail organizational factors that affect their resilience. The factors include change readiness, leadership and culture, networks and relationships, and legal frameworks and institutional setup (Sweya et al., 2020a). Sweya and Wilkinson (2020) suggest further that environmental factors such as environmental resources sensitivity, environmental capacity, natural floods attenuation, and natural assets, affect the resilience of water supply systems. Furthermore, the social aspects have significant contribution on the resilience; as such Sweya et al. (2020b) proposed education, preparedness, social structures, safety and well-being, and togetherness factors to assess the water supply systems resilience. Moreover, Sweya et al. (2020b) developed a qualitative multidimensional tool encompassing all the five dimensions under which principles and indicators were proposed. The tool includes an aggregation of the factors into a final semi-quantitative overall system resilience index.

When tested in selected water supply systems in Tanzania, the tool showed simplicity, had no critical data requirements, and entailed less computational requirements, while serving the purpose of determining the systems' resilience weaknesses, thereby suggesting the appropriate improvement measures. For instance, all dimensions portrayed a moderate/medium resilience, with specific needs for improvements. The findings unveiled limited preparedness of water users on emergencies, location of some houses in flood-prone areas (Sweya et al., 2021b), technically low systems' future expansion capability, and lack of renewal plans (Sweya et al. 2020b). It was evident that qualitative tools would be biased because the assessment is based on the opinions of the experts; thus, a group of skilled experts is suggestive to take part during the assessment.

4. Conclusion

Given the strides made in increasing the coverage of the water services, resilience in Tanzania is inadequately attended. The systems are subject to several hazards, particularly floods. Evident floods are associated with bacterial infections suggesting that water supply systems failed to provide adequate quality water to the community. Disaster management activities such as mitigation, preparedness, and response rest on the Ministry of water and its organs. However, Water Supply System Authorities are failing to execute adequate mitigation and preparedness due to lacking adequate funding for contingency planning. Recognition of disaster risks in policies, strategies, and programs underlines the need to incorporate resilience-based mechanisms to ensure water service provision to the community. Such mechanisms would enhance IWRM, improve risk reduction, reduce vulnerabilities, and enhance sustainability. Defining resilience entails the knowledge of its complexity to understand the multi-dimensional nature of the water supply system. Assessing the resilience, however complex, implies bridging the gap between theory and operationalization and encompasses several benefits such as proper resources allocation for resilience, resilience awareness improvement, and deepened concept understanding. Relative measures are useful in simplifying the measurement complexity offering the relative resilience value for the system while needing close evaluation of the availability, quality, and sustainability of data. The assessment of the *resilience of* urban water supply systems encompasses their respective water resources and the aspects responsible for providing continued water service. The hazard to which the assessment is conducted needs to be specified in line with the adoption of a top-down approach, formative, and context-specific. A semi-quantitative, including both quantitative and qualitative methods designed to involve experts at later stages would be appropriate for developing countries like Tanzania.

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