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Resilience implementation plan: An example of Tanzania's water supply system

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Abstract

Weather-related disasters are unpredictable due to climate change. Frequent and significant weather-extremities are expected to continue striking, with significant impacts in developing countries that have inadequate contingency funds to prepare against, respond to, and recover from the impacts of disasters. Building resilience through customized approaches to the local environment offers much-needed hope. Resilience enhancement becomes real in the presence of measurements to evaluate weaknesses and suggest appropriate areas of improvement. A number of resilience measurements for water supply systems have been developed in Tanzania, however, inadequate or lack of implementation plans are likely to impede the resilience enhancement measures' effectiveness. The current study evaluated the Tanzania's water supply systems enhancement measures from existing resilience tools and proposed a plan for effective implementations. The developed plan includes context establishment, risk identification and analysis, resilience analysis, resilience evaluation and treatment, and monitoring and review. The plan is built to embrace a committed culture for resilience assessment and improvements.

Keywords: Resilience; Improvement Measures, Water Supply System

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1. Introduction

The world's most significant devastation is currently due to disaster risks, their consequences range from deaths and physical damages of infrastructures to environmental, ecological, and economic losses (Sweya et al., 2018). Environmental risks prevailed in the top ten for the past decade (WEF, 2019) and, have dominated the top five long-term risks by likelihood and impact (WEF, 2020). Extreme weather events, natural disasters, and failure of climate change mitigation measures and adaptation are among the frequently occurring and high impact risks. Moreover, WEF (2020) indicates that climate change is striking harder and more rapidly than expected such that five years before 2020 were on track to the warmest on record, and natural disasters were becoming more intense and more frequent.

Failure of climate change mitigation and adaptation suggests that environmental risks will continue to propagate and cause more harm to communities and infrastructures. The average global temperatures are nearing to increase by at least 3^{o}C, twice as much as what has been warned as the limit to avoid severe economic, social, and environmental consequences (WEF, 2020). About 500,000 Hiroshima atomic bombs' extra heat energy equivalent has been reported to be absorbed by accumulated greenhouse gases in the atmosphere daily, disrupting the water cycle and consequently causing significant evaporation, tropical cyclones, severe rains, and flooding. Hydro-meteorological disasters will worsen, increase in frequency (URT, 2003 and IPCC, 2014), become more unpredictable, and cause more casualties, destruction, and economic losses if current patterns of climate change persist.

Nearly 68.5% of all global economic losses from 2005 to 2017 came from extensive risk events heavily absorbed by poor communities in developing countries (Sweya and Wilkinson, 2021; UNDRR, 2019). Death rates and damages are expected to exceed the already inadequate mitigation, response, and transfer mechanisms (UNDRR, 2019). At the same time, the rising risks will influence coastal flooding causing significant damage around the world than riverine floods; thus, underlining the increase in infrastructure and assets that stand to be damaged. WEF (2020) suggests the current decade for delivering sustainable development goals, also needs to be the resilience decade for climate – requiring governments and businesses to identify and prioritize risks and develop metrics and strategies to manage them in order to have resilient infrastructure that can better cope with the impacts of disasters.

The concept of resilience emerged after the catastrophe of Hurricane Katrina in August 2005 (Tierney and Bruneau, 2007) to prepare for the rising threats of disaster risks (Hwang et al., 2013). The Sendai framework through its priority of action number three recommends investing in disaster risk reduction for resilience, thereby strengthening public and private investments in resilience through structural and non-structural, and functional disaster risk prevention and reduction measures in critical facilities. Also, building better from the beginning through proper design and construction to withstand hazards, at the same time embracing economic, social, structural, technological, and environmental impact assessments (UN, 2015).

Water supply systems (WSSs) are not excluded from the impacts of disasters and the potential need for resilience. Thus, the current study examines the enhancement measures from the existing Tanzania resilience assessment tools for water supply and proposes a sound plan for effective implementation. The study covers the water sources and service provision — through five dimensions, Technical, Organizational, Social, Economic, and Environmental — which are under the water resource division and the urban water supply and sanitation division of the Ministry of Water, Tanzania, and could be applied in other developing countries. The study is organized into sections including 1. Water supply systems and resilience, 2. Tanzania resilience tools and assessment approaches, 3. Resilience problems for Tanzania's water supply systems, 4. Resilience improvement measures, 5. Resilience measures implementation plan, and 6. Resilience implementation plan for WSSs in other developing countries.

2. Water supply systems and resilience

Critical infrastructure systems play essential roles in community-wide disaster mitigation, response, and recovery, making them high-priority targets for resilience enhancement (Tierney and Bruneau, 2007). Resilience consideration must, initially, focus on service and functionality of the critical infrastructure forming the backbone of the community functioning (Bruneau et al., 2003; Cantelmi et al., 2021). Despite the communities' dependence, such systems have become complex and interdependent such that the failure of one or drastically reducing its performance, may affect the performances of others (Mattsson and Jenelius, 2015). Resilience improvement for such critical infrastructures is crucial for overall community resilience (Choi et al., 2019; Mottahedi et al., 2021). Enhanced resilience in water supply, among other critical infrastructures, enables communities to respond, provide for the well-being of their residents and initiate recovery activities (Bruneau et al., 2003).

Principally, water supply systems provide essential services that support communities' lives (Brown et al., 2010). The systems are multi-dimensional encompassing a direct relation to the communities and the managing organizations, natural, physical, and social networks (Zhou et al., 2022; Newman et al., 2011). Such a composition provides significant opportunities for disaster risks (Karamouz et al., 2010), requiring a systemic approach (UNDRR, 2019) to ensure adequate risk reduction.

Tanzania suffers flood risks which have shown significant impacts on water supply systems. The country's urban water supply systems encompass twenty-six (26) Regional Water Supply and Sanitation Authorities (R-WSSAs) and eight (8) National Project Water Supply and Sanitation Authorities (NP-WSSAs) in the mainland. The authorities are the principal services providers serving an average of 86% and 57%, respectively in 2021/2022 operation year (URT, 2023). The Kahama Shinyanga Water Supply and Sewerage Authority (KASHUWASA) is an NP-WSSA supplying bulk water to other WSSAs and villages along the water transmission main. Other water services come from community-based organization facilities, individual boreholes, and water from streams, rivers, lakes, and locally dug wells (Sweya and Wilkinson, 2021). The country's water supply systems serve about 80% of the urban population, and less than that in rural areas. Thus, some people are either in water crisis or consume water from unimproved sources and the country's residents are likely to suffer from water related issues during flooding.

Resilience is an integrating concept allowing multiple risks, shocks and stresses and their impacts on the ecosystem and vulnerable people to be considered jointly in the context of development programs (Mitchell and Harris, 2012). The concept helps address natural hazards that can impact anyone and anywhere. Water supply systems have suffered greatly as a result of global catastrophes like the 2011 earthquake in Christchurch, the 2007 Bangladesh flood event, the 2000 floods in Chokwi and Xia-Xia cities of Mozambique, the 2008 snowstorm in China, the 2004 Tsunami in Asia, and the 2003 North American power grid blackout (Sweya et al., 2018). Likewise, the Tanzania 1992/1993 and 1997/1998 El Nino episodes, and 2011, 2014, 2015, 2016, and 2017 floods affected the country's water systems (Sweya et al., 2018) leading to water-related diseases and infrastructure destruction among others (Paavola, 2008; URT, 2003 and EM-DAT). That said, resilience is needed by both developed and developing countries, wealthier and more deprived communities as no one is immune to the impacts of disaster risks (Comfort et al., 2010; Coppola, 2006).

Resilience increases the ability of systems, communities, or societies to resist, absorb, accommodate, and recover from the effects of hazards in a timely and efficient manner, through preventing damage and restoring essential basic structures and functions (UNISDR, 2009). In other words, the concept reflects on improving the capacity of physical and human systems to respond to and recover from extreme events (Tierney and Bruneau, 2007). For infrastructure systems, resilience enhances the ability of a system to reduce the chances of a shock and to recover quickly after the shock (Bruneau et al., 2003). Therefore, resilient systems reduce the probability of failure; the consequences of failure, and the time of recovery (Tierney and Bruneau, 2007). And the more resilient is the system, the larger the disturbance it can absorb without shifting into an alternate regime (Walker et al., 2006).

3. Tanzania resilience tools and assessment approaches

Sweya et al. (2020a; 2020b; 2021a; 2021b) and Sweya and Wilkinson (2020; 2021) developed tools and used the tools to evaluate the resilience of Tanzania's water supply systems. The tools are semi-quantitative indices encompassing dimensions, principles, and indicators. The indicators have measures with graduated scales indicating the performance levels from 1 for very low performance to 5 for very high performance. Apparently, as the resilience assessment aggregation proceeded from the initial scores to overall indices, the problems identification began from the overall resilience indices towards the assessment measures (Sweya and Wilkinson, 2021). As such, all variables with wanting performances were traceable.

The tools were evaluated in selected case studies in Tanzania, the level of resilience in the indicators, principles, and dimensions indicated the need for improving the system's resilience. Such information prompted the identification of resilience improvement measures. The assessment for the appropriate measures took place based on the need to enhance the absorptive capacity, adaptive capacity, coping capacity, and learning capacity (AACL). The AACL measures applied in addressing the problems towards enhancing the overall water supply systems resilience. The improvement in this case meant to improve a measure, indicator, principle, or dimension to performance level-5, very high resilience; thus, the development of the improved measures was consistent with suggesting features that would increase the resilience to level-5.

4. Resilience problems for Tanzania’s water supply systems

Like in other developing countries (Sharma et al., 2023), and based on the Tanzania resilience tools, the water supply systems experience moderate resilience with less than desirable performances. Besides, the systems need prioritized measures for enhanced resilience across Technical, Organizational, Social, Economic, and Environmental dimensions. Table 1 indicates the summary of the critical issues needing immediate interventions to improve the resilience of Tanzania's water supply systems.

The interactive nature of the dimensions suggests that resilience problems in one dimension can affect other dimensions; for instance, a technical problem such as failure of securing spare parts on time during flooding can affect both technical and social resilience, as such, failure will affect the timely recovery of water services in the communities. Also, organizational problems such as lacking strategies to encourage and reward staff for using their creativity and innovative ability in addressing issues during floods will affect the efficiency of the physical infrastructure in terms of operation, while affecting further the revenue collection – economic dimension, service delivery – social dimension, and the environmental sustainability – environmental dimension. Similarly, social problems affect revenue collection – economic dimension, and the environmental well-being due to rapid urbanization and living in informal settlements – environmental dimension, and the functionality of the physical infrastructure. Moreover, less community participation or engagement in water supply projects and water-related disaster management activities means the community lacks the sense of ownership of the infrastructure leading to uncontrollable vandalization and illegally tapping, intensifying the vulnerability of the physical infrastructure.

Table 1. Summary of the resilience problems from evaluation results

Dimension	Principle	Resilience problem
1.0 Technical	1.1 Flexibility	Only 20-40% of physical components have options for future expansion
		Most spare parts and equipment are ordered from abroad and take a few weeks.
		Less than 20% of the service areas receive water from more than one scheme.
	1.2 Safe to fail	The safe-to-fail concept is not included in the current design approaches, although there're plans to include in future.
	1.3 Robustness	There are no existing plans and controlled renewal or upgrades of assets
		Only less than 20% of the critical assets are above the current design codes.
2.0 Organizational	2.1 Leadership and culture	No strategy exists to encourage and reward staff for using their creativity and innovative ability in addressing issues during floods
		No procedures in place to assign authority to make quick decisions, reduce excessive bureaucracy in relation to deployment of staff and resources during flooding
		There is no resourcing to resilience planning, and roles and responsibilities not clearly defined with regular meetings and documented processes for implementing the improvements.
		There is no resilience culture, although plans are in place to initiate and promote the culture within the water authorities.
		Staff have limited engagement and involvement in internal resilience discussion, training, or exercises.

Table 1. *Cont.*

Dimension	Principle	Resilience problem
	2.2 Change readiness	Staff have only some awareness of the possible disruptions caused by the impacts of floods. Also, taking only ad hoc processes to reward staff for identifying new hazards, weak links and warning signs.
		Plans are still under development for robust risk identification and assessment practices, including planning for unforeseen risks.
		Discussions are still ongoing to establish cross-sector and authority emergency plans.
		Ad hoc contingency plan drafted to identify ahead of time alternative water pipelines and other facilities required for response, rehabilitation and protection from further disasters
	2.3 Network and relationship	Only some information sharing takes place across sector or utilities, and there is no updated cross-sector infrastructure register containing structural information important in crises.
3.0 Environmental	3.1 Environmental capacity	The annual per capita internal renewable water resources are 1000-1700m^3/yr.c – suggesting water stress with intermittent or localized water shortage
	3.2 Natural assets	There is less evidence of reducing the environmental impacts on the water resources as less than 20% of the population uses off-site sanitation
	3.3 Environmental resources sensitivity	The mean annual percentage of the tree cover removed for urbanization, commodity production, and agriculture is 0.5-15%
4.0 Social	Togetherness	Less than 20% of the households within the communities have joint ownership on water facilities such as boreholes, water trucks, water storage tanks/facilities
	Social structure	More populations "43.9%" are young dependents aging between 0-14
		At least 70% of the houses are within unplanned settlements.
	Preparedness	The community lacks awareness on the existence of either mitigation or responsive plans to reduce flooding impacts on the water supply systems.
		Medium community participation or engagement in water supply projects and water-related disaster management activities
5.0 Economic	Dynamism	Heavy investments on some components of the WSSs, e.g., production components than distribution components
		There is only ad hoc public-private-partnership, MoUs underdevelopment and contracts are not signed.

Source: Sweya et al. (2020a; 2020b; 2021a; 2021b) and Sweya & Wilkinson (2020; 2021)

5. Resilience improvement measures

The resilience improvement measures intend to enhance the absorptive, adaptive, coping, and learning (AACL) capacities. The absorptive measures are also called mitigation measures, including any physical or nonphysical actions taken to reduce the frequency, magnitude, or duration of a specific threat/flooding (Sweya et al., 2018). Adaptive measures refer to the form of modification of a particular element or property of the system to enhance the ability to deliver the same level of service in variable conditions continuously. Coping measures are any preparations or actions taken to reduce the frequency, magnitude, or duration of an impact or recipient. And learning, refer to embedment of experience and new knowledge in the best practices. The AACL measures apply across the five dimensions; that means, the problems in each dimension are addressed by the AACL measures to enhance the overall WSSs resilience.

5.1. Interaction of resilience improvement measures

The multi-dimension nature of the WSSs (Sweya et al., 2020b) suggests that measures deployed to improve the resilience in one dimension will have an impact on other dimensions. That means technical measures will improve the technical dimension, the social dimension, economic dimension, organizational and environmental dimension. In this case, improving the technical dimension implies sustainable service delivery to the community, high revenue collection, and fund availability to invest in resilience planning and environmental protection. Social dimension measures will enhance revenue collection, environmental sustainability, and lessen physical infrastructure vulnerability. Environmental measures ensure water resources availability in terms of quantity and quality, improve infrastructure functionality and the community's health and wellbeing. Likewise, organizational measures improve the efficiency of the physical infrastructure, improve service delivery and revenue collection, and environmental sustainability. Economic measures mean funds well spent on systems development and improvement in all other dimensions, whereas strong partnership ensures continuity of the services.

Of all measures, learning is a crosscutting measure for improving Tanzania's water supply systems – since resilience is still a theoretical concept to most water supply organizations in the country. As such, learning measures such as 1. learning from past events, 2. generating pilot schemes to generate knowledge for the best practices, 3. learning to get the right data and efficient communication strategies, and 4. learning from other water supply organizations whose performance is high and practice resilience culture in their systems "this may go beyond systems other than water supply that embrace resilience approaches" will catalyze the desire to develop resilience culture and enhance the resilience in the WSSs. Table 4 presents the specific improvement measures. In this case, one of the measures or a collection of measures will enhance the principle resilience; for instance, "control of urbanization" is an absorptive measure that will reduce the mean annual percentage of the tree cover removed thereby improving the "environmental resources sensitivity." Also, establishing, and accelerating assets replacement/renewal strategy, and accelerating assets upgrade strategy, thereby introducing updated design with resilience approaches are both absorptive measures that can enhance the "robustness" of the infrastructure. Collectively, the improved principle resilience can enhance the dimension resilience, whereas the dimension resilience can jointly enhance the overall water supply system resilience.

5.2. Prioritization of the measures

Sweya et al. (2020a; 2020b; 2021a; 2021b) and Sweya and Wilkinson (2020; 2021) indicate, from experts' elicitation results, that the technical dimension is the most important dimension with low mean and median close to 1 than other dimensions followed by organizational and environmental dimension in the third place. Social dimension ranks the least important many times than any other dimension and scored the mean 4.417 and median 5.000 very close to 5 and higher than for any other dimensions (see Table 2).

Table 2. Importance ranking of dimensions

Description	**Technical**		**Organizational**		**social**		**Economic**		**Environmental**	
	F	(%)	F	(%)	F	(%)	F	(%)	F	(%)
Most important	4	33.3	3	25.0	1	8.3	1	8.3	5	41.7
Important	4	33.3	4	33.3	-	-	3	25.0	1	8.3
Fairly important	2	16.7	3	25.0	-	-	3	25.0	2	16.7
Somehow important	1	8.3	2	16.7	3	25.0	3	25.0	2	16.7
Least important	1	8.3	-	-	8	66.7	2	16.7	2	16.7
Mean	2.250		2.333		4.417		3.167		2.583	
Median	2.000		2.000		5.000		3.000		2.500	
Rank	**1**		**2**		**5**		**4**		**3**	

Further importance ranking results from Sweya et al. (2020a; 2020b; 2021a; 2021b) and Sweya and Wilkinson (2020; 2021), indicate that; principles for technical dimension rank from 1-robustness, 2-redundancy, 3-flexibility, and 4-safe-to-fail (Sweya et al., 2021a); for organizational dimension, 1- change readiness, 2-leadership and culture, 3- legal framework and institutional set-up, and 4-networks and relationships (Sweya et al., 2020a). For the environmental dimension, the importance ranking for the principles is 1-environmental resources sensitivity, 2-environmental capacity, 3-natural flood attenuation, and 4-natural assets (Sweya and Wilkinson, 2020); Social dimension's principles rank from 1-education, 2-preparedness, 3-social structure, 4-safety and wellbeing, and 5-togetherness, (Sweya et al., 2021b) whereas the economic dimension has only one "dynamism" principle (Sweya and Wilkinson, 2021). Such ranking results and the indicators rankings presented in Table 3 suggest the priority setting for the measures to enhance the resilience of Tanzania's water supply systems. In Table 4, the dimensions and principles are presented in the order of their priorities, whereas the enhancement measures' priorities are presented based on the color codes in the capacities' column.

Table 3. Prioritization of the measures for resilience improvement in WSSs

Dimensions	Principles	Indicators
1.0 Technical	1.1 Robustness	1.1.1 System maintenance
		1.1.2 System renewal
		1.1.3 System design
		1.1.4 Standards/ codes
	1.2 Redundancy	1.2.1 System decentralization
		1.2.2 System redundancy
	1.3 Flexibility	1.3.1 System future expansion capability
		1.3.2 Critical spare parts and equipment availability
		1.3.3 Connectedness of the system
	1.4 Safe-to-fail	1.4.1 Design approaches in guidelines
2.0 Organizational	2.1 Change readiness	2.1.1 Awareness
		2.1.2 Emergency Response Plan (ERP)
		2.1.3 Communication and warning
		2.1.4 Planning strategies
		2.1.5 Proactive posture
	2.2 Leadership and culture	2.2.1 Leadership
		2.2.2 Political will
		2.2.3 Engagement and involvement
		2.2.4 Decision making
		2.2.5 Innovative and creativity
	2.3 Legal framework and institutional set-up	2.3.1 Organizational structure
		2.3.2 Laws and policies
	2.4 Network and relationships	2.4.1 Learning
		2.4.2 Effective partnership
		2.4.3 Leveraging knowledge
		2.4.4 Internal resources
3.0 Environmental	3.1 Environmental resources sensitivity	3.1.1 Human encroachment
		3.1.2 Water use
	3.2 Environmental capacity	3.2.1 Population density
	3.3 Natural floods attenuation	3.3.1 Protection of wetlands
		3.3.2 Control of urbanization
	3.4 Natural assets	3.4.1 Accessibility of freshwater resource
		3.4.2 Quality of water sources
		3.4.3 Reduction of environmental impacts
		3.4.4 Soil erosion protection
4.0 Economic	4.1 Dynamism	4.1.1 System investment proportionality
		4.1.2 Public-private partnership (PPP)
		4.1.3 Cost recovery
5.0 Social	5.1 Education	5.1.1 Adoption of new technologies
		5.1.2 Community awareness
	5.2 Preparedness	5.2.1 Mitigation plan
		5.2.2 community participation

Table 3. *Cont.*

5.3 Social structure	5.3.1 Location of houses
	5.3.2 Population composition
	5.3.3 Level of education and skills diversity
5.4 Safety and wellbeing	5.4.1 Preventive health measures
5.5 Togetherness	5.5.1 Shared water facilities

Source: Sweya et al. (2020a; 2020b; 2021a; 2021b) and Sweya & Wilkinson (2020; 2021)

6. Resilience implementation plan

Understanding the resilience enhancement measures alone may become ineffective if proper guidance for implementing these measures to enhance the resilience of water supply systems is not provided. The lack of such guidance can leave stakeholders without a clear path to follow, leading to inconsistencies in the resilience assessment process, as highlighted by Heinimann and Hatfield (2017). This inconsistency can be particularly problematic when different stakeholders interpret and apply the measures in varied ways, potentially undermining the overall goal of enhancing resilience. Moreover, the absence of standardized implementation guidance can make the outcomes from different tool users difficult to compare. This lack of comparability not only affects the effectiveness of water organizations but also has implications for policy and regulatory bodies.

6.1. Establishing the context

This concerns translation of stakeholders' needs into specific, actionable, and customized goals cascade from high-level water organization goals to enabler goals. The enabler goals can later be associated with best practice, standards, and compliance requirements from the relevant area of concern.

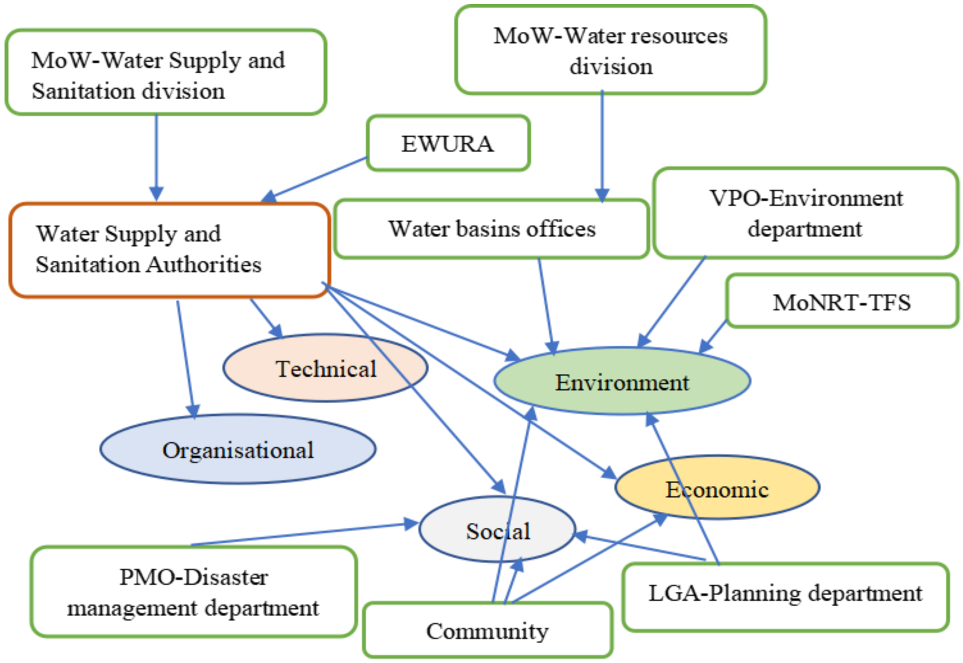
Taking the example of Tanzania WSSs, the key stakeholders are water supply and sanitation authorities (WSSAs). The WSSAs are responsible for infrastructure development, operation and maintenance, service delivery, revenue collection, and environmental safeguarding. However, building partnerships with other players helps the WSSAs anticipate actions, and clarify roles and responsibilities leading to a successful resilience building in the water supply system, and efficient response and recovery should the system be severely damaged. Such stakeholders include the water basin offices responsible for water resources monitoring and conservation, EWURA for regulating the water supply utilities, LGA – planning department for settlements development and land use planning, and PMO – disaster management department for emergency response. Others are the VPO - Environment Department for enforcement of environmental protection regulations; the Tanzania Forest Services (TFS) agency for forests conservation; the community for paying bills, protecting the water resources and infrastructure; the Tanzania Meteorological Agency; Non-governmental organizations; community organizations; and academic institutions (see Figure 1).

Cadete et al. (2018) and Albano et al. (2021) suggest that a Goal Cascade Methodology (GCM) would be a viable approach in translating stakeholders' needs. In this methodology, stakeholders' drivers such as technical, organizational, social, economic, and environmental issues can be used in defining the needs, and the needs are applicable in defining the WSSAs' goals and cascading them to divisions, departments, and enabler goals.

Table 4. Specific improvement measures to the resilience problems

Very high priority	High priority	Medium priority	Low priority	Very low priority

Dimension		Resilience problem	Improvement measures	Capacity
1.0 Technical	1.1 Robustness	There are no existing plans and controlled renewal or upgrades of assets.	Establish and accelerate asset replacement/renewal strategy	Absorptive
		Only less than 20% of the critical assets are above the current design codes.	Accelerate assets upgrade strategy thereby introducing updated design with resilience approaches	Absorptive
	1.2 Flexibility	Only 20-40% of physical components have options for future expansion.	Adapt planning and designing approaches allowing projected systems development with options for expansion to cope with ever-increasing demand due to rapid population growth, and contingency demands during crises.	Adaptive and Coping
		Most spare parts and equipment are ordered from abroad and take a few weeks.	As much as possible use equipment and facilities whose spare parts are locally available or are readily available and obtained within a short time	Adaptive
		Less than 20% of the service areas receive water from more than one scheme.	Modify operation by connecting service areas to multiple water schemes	Adaptive
	1.4 Safe to fail	The safe-to-fail concept is not included in the current design approaches, although there are plans to include it in the future.	Introducing resilience design approaches in the design guidelines "Water supply and wastewater disposal design manual" acknowledging that failure cannot completely be eliminated-safe to fail	Adaptive
2.0 Organizational	2.1 Change readiness	Staff have only some awareness of the possible disruptions caused by the impacts of floods. Also, taking only ad hoc processes to reward staff for identifying new hazards, weak links, and warning signs	Promote staff awareness on a range of flood risks to WSSs, and establish procedures to reward staff who manage to identify new risks, weak links, and warning signs	Adaptive and learning



NOTES: EWURA stands for Energy and water utilities regulatory authority; MoW stands for Ministry of water; PMO stands for Prime minister office LGA & MC stand for Local Government Authorities and Municipal Councils; MoNRT stands for Ministry of Natural Resources and Tourism, and TFS stands for Tanzania Forest Services Agency

Figure 1. Key stakeholders in the implementation of the WSSs resilience in Tanzania

6.2. Risk identification and analysis

Identification of the potential flood risks and other crises that can occur and damage key assets of the water supply systems is crucial (Lawrence et al., 2020). A risk scenario is useful, encompassing the description of a possible event that, when occurring, will affect the achievement of the WSSAs' objectives. In the current study, the possible effects that can influence the achievements of the water organizations' goals range from technical, organizational, social, economic, and environmental.

A top-down approach could be applied, starting from the overall WSSAs' objectives, and identify water supply services objectives and scenarios with the highest impact on the achievement of the water supply services objectives. Also, the frequency and the impacts can be estimated using risk factors, such as those conditions influencing the frequency and impacts on the water supply services. The variables developed in the current tool provide a comprehensive platform for understanding and determining the factors that may exacerbate the risk impacts, also known as vulnerabilities/weaknesses; this may be conducted based on the experience, known current events, and possible future circumstances.

6.3. Resilience analysis

By applying the Sweya et al. (2020a; 2020b; 2021a; 2021b) and Sweya and Wilkinson (2020; 2021) multi-dimensional tools, analysts can relate the risk scenarios with current and predicted technical, organizational, social, economic, and environmental capability levels to determine the existing weaknesses/vulnerabilities. Scores on the measures based on the graduated qualitative measurement scales will initially be applied to operationalize the tools. Scales relate to the performance of a measure in five levels from 1-very poor performance to 5-very high performance. The tools will lead to semi-quantitative indices at an indicator level, principle level, dimension level, and the overall water supply systems. These indices entail the possible weaknesses in the water supply systems based on the level of performance of the variables.

6.4. Resilience evaluation and treatment

The comparison of the outcomes of the resilience analysis with the criteria set to determine whether the resilience level is acceptable and identify areas for improvement is crucial. The assessment tools provided the decision means on resilience acceptability. The final indices were visualized in levels of resilience from 1-very low resilience, 2-low resilience, 3-moderate resilience, 4-high resilience, to 5-very high resilience. Each level implies the system performance. For instance, "very low resilience" means very poor performance and extensive improvement measures are required, "low resilience" indicates poor performance and improvements are required, "moderate resilience" shows less than desirable performance and specific improvements should be prioritized, "high resilience" indicate acceptable performance in relation to a measure (s) and some improvements could be made, and "very high resilience" meets all requirements. Levels 1 to 4 show the need for improvements; such needs are determined from the lowly performed dimensions, principles, and indicators. Cadete et al. (2018) and Kahan et al. (2009) suggest that the resilience responses (improvement needs) should be integrated into a common decision-making process and contribute to a single security, safety, and resilience strategy. However, the implementation of specific resilience improvements may be realized by specialized projects, within a coherent portfolio.

6.5. Monitoring and review

Governance bodies must be involved in monitoring and review to ensure that resilience improvement measures are effective and efficient in all dimensions of the water supply systems (Butler et al., 2017). Additional information must be gathered to strengthen resilience, analyze and learn lessons, detect changes in internal and external contexts, and identify emerging risks. The Energy and Water Utilities Regulatory Authority (EWURA) is responsible for regulating the technical and economic performances of the regional and national project water utilities in Tanzania. In their review report for water utilities performance for the financial year 2017/2018, they used 20 indicators. The indicators are rather situated on the traditional performance of the water utilities than the resilience against disasters. Since EWURA is an existing regulatory body, suggestions are that their list of indicators be improved to encompass resilience indicators to be able to review the resilience performance of Tanzania's water utilities.

Similarly, the National Environmental Management Council (NEMC), Tanzania is a designated body to ensure that environmental and social impact assessments (EIA and ESIA) are conducted before execution of any project in the country. Besides, NEMC is a designated body responsible for all environmental audit activities in the country. Some resilience aspects could be incorporated in the procedures for conducting EIA and later on be audited or reviewed to determine the effectiveness of the implementation of the measures for improving the water supply systems' resilience, especially in the environmental and social dimensions.

Moreover, a separate government authority can be established to oversee all critical infrastructure resilience issues in the county, including for water supply systems.

7. Resilience implementation plan for water supply systems in other developing countries

Tanzania is not the only developing country whose water supply systems are vulnerable to the impacts of disasters. In 2019 Mozambique and Zimbabwe experienced two cyclones leading to severe floods in the countries. Mauritius is always under the threat of cyclonic events, and heavy rainfalls and their water supply systems are affected. Many developing countries in Asia and Pacific are also vulnerable, and their water supply systems are not secure. Such countries experience similar problems that affect Tanzania's water supply systems ranging from technical, organizational, environmental, social, and economical. For instance, Mauritius water supply systems experience problems like aged infrastructure and political influences (Proag, 2016) affecting the resilience of water supply systems. Zimbabwe's annual per capita internal renewable water resource is less than 1000m^3/yr.c far less than that of Tanzania suggesting that the communities experience similar problems to Tanzanian when floods hit the water supply systems. Also, the country experiences coastal floods caused by cyclone, and leading to water borne diseases and damage to critical infrastructures, among others (Mavhura, 2019). Other developing countries also encompass informal settlements with poor populations which are highly vulnerable to flood risks that affect the water supply systems; for instance, Kenya's Mombasa coastal city has a history of significant severe incidences of flooding with the health of the population leaving in the informal settlement being under great danger. Studies have shown that the majority experience problems getting drinking water during floods whereas some get water from flood-contaminated wells because of inadequate alternatives (Okaka and Odhiambo, 2019). Moreover, most developing countries have inadequately implemented resilience strategies to prepare their water supply systems against the impacts of disasters (Johannessen et al., 2014). As such, the majority experience similar resilience problems to Tanzania's water supply systems. Since the Tanzanian tools for water supply systems resilience assessment contain variables initially derived from wide-range of literature-based variables from various resilience measurement tools, there is high confidence that they have a generality nature and could be applied in other developing countries. Little modifications may need to be conducted to tailor the variables appropriately to other developing countries since the current forms were based on the expert's judgement elicitation focusing on Tanzania's water supply systems. Implementation of the resilience improvement measures, thus, embraces a similar approach developed in the current research. Minor adjustments may exist in the setting of the context as stakeholders may differ from one country to another.

8. Conclusion

Resilience improvement measures discussed in this study align with the broadness of water supply systems in terms of the aspects that influence resilience including technical, organizational, environmental, social, and economical. The improvement measures are interactive such that measures from one dimension can influence improvements in other dimensions. Generally, the measures focus on enhancing the absorptive, adaptive, coping, and learning capacities in the water supply systems. In all cases, learning measures are required across all dimensions to ensure that water organizations continually refresh their management approaches to adapt to resilience-based approaches that will always enhance the capacity of their systems to deliver services continuously. The resilience improvement measures were derived from a broad consultation of world-wide resilience best practices; such measures will bring changes in resilience capacities of Tanzanian water supply systems and in other developing and developed countries. The resilience implementation approach developed in this study aligns with the need to carry out the resilience assessment in a consistent manner such that outcomes from different tools users may be easily comparable – enhancing the effectiveness of the water organization, policy, and regulatory bodies. Water authorities should identify relevant stakeholders who would appropriately define the organization's goal and analyze the risks that would impede achievement of the goal, determine the existing vulnerabilities, and suggest the systems' improvement measures. Relevant government bodies must be involved in the monitoring and review process to ensure resilience measures are effectively and efficiently implemented, seek for additional information to strengthen resilience, analyze and learn lessons, detect changes in internal and external contexts, and identify emerging risks.

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