Resilience Improvement Needs for Public Water Supply Systems in Dar Es Salaam

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ABSTRACT

The impacts of natural hazards in the form of floods are severe, and lifeline systems such as water supply are at risk. Tanzania is no exclusion to this risk. A 30” water transmission main in Dar es Salaam was broken and dragged away following recent floods on 30th October 2017, while several other distribution pipes were also affected. The quality and quantity of water were compromised, while the alternative water sources are unreliable, due to salinity, and contamination from waste and flooding water. This study was conducted to determine the on-ground and current resilience issues related to public water supply, and the needs for improvement. Questionnaire surveys to the residents of Vingunguti, Jangwani and Tandale wards, and interviews to DAWASCO, DAWASA, and Wami/Ruvu basin officials were conducted during the study. Standard descriptive and thematic approaches were used to analyse the questionnaires and interviews. The system experiences inadequate redundancy and lacks additional capacity to serve in case of shocks. Also, the system is suffering a severe loss (NRW) of about 50% and shows a high degree of interdependency to the National electric power grid. The natural vegetation in catchment and recharge areas have been affected by human activities while the water sources are also at risk of pollution and lack of continuous monitoring of the withdrawal and water balance. The impact of flooding seem significant to the water users, and the poor population is the most affected. Besides, the only significant alternative supply is buying, which is costly. The majority of the poor population are not prepared against floods. The findings suggest that while improving technical aspects of the water supply system would address most social issues, environmental aspects showed the need for a separate assessment. Further work is needed to develop tools for measuring the resilience from which appropriate improvement measures will be determined.

TABLE OF CONTENTS

1.0 INTRODUCTION

Environmental-related risks such as extreme weather events and failure of climate change mitigation and adaptation as well as water crises has emerged as a consistently central feature of the GRPS risk landscape, strongly interconnected with many other risks for the past decade: the risks are listed in the top 5 global risks in terms of likelihood and impacts (World Economic Forum, 2017). Natural hazards such as floods are the extreme weather events whose impacts are exacerbated by climate change (URT, 2003 & IPCC, 2014). Floods have diverse impacts to people, buildings and infrastructures such as water supply systems are particularly at risk (Arrighi, 2017). Floods damage to infrastructures is classified as direct and indirect depending on the occurrence of the event either in space or time and can cause cascading effects. The flood risks for water supply systems are such as contamination of the water, breaks of pipelines, damage to infrastructures, water shortage, and collapse of the entire system (Pan American Health Organisation, 1998). Thus calling for resilience building in the systems to ensure that the service is continuous.

The concept of resilience applies to many disciplines (Agarwal, 2015; Hughes and Hearly, 2014; Manyema, 2006; Perry, 2013). It was first introduced by Holling (1973) and undergone several modifications depending on the field of application. For infrastructure systems, it is related to the ability of a system to reduce the chances of shock, absorb the shock and recover quickly after shock (Bruneau et al., 2003). They further suggested four dimensions of resilience: technical, organisational, social and economic (TOSE), upon which several studies have modified to meet their requirements. Water supply systems are socio-ecological-technical systems (Newman et al., 2011) that include several aspects such as infrastructures, organisations that run the systems, water users, funding entities and the environment within which the water sources and catchments exist. To that understanding, Vugrin et al. (2010) and Balaeli et al. (2018) suggested an additional dimension i.e. environmental dimension that need to be considered together with TOSE for improvement of resilience of infrastructures such as water supply.

Resilience is an integrating concept that allows multiple risks, shocks and stresses and their impacts on ecosystems and vulnerable people to be considered together in the context of development programming (Mitchell & Harris, 2012). If flood risks are managed, there will be an increased chance of enhancing resilience and reduce the chances of failures in the water supply systems. The management of the risk entails a combined approach comprising mitigation, preparedness, response and recovery (Aertgeerts, 2011) which also represent the four phases of managing disasters (Rubin, 1991). The best time to act is in the first phase of the cycle, when preventive and mitigation measures can strengthen a system by reducing its vulnerability (Pan American Health Organisation, 1998). Among the mitigation activities, the identification of hazards and comprehensive vulnerability analysis are recognised as pre-eminent (Arrighi et al. 2017). This is a fundamental support for decision making because it increases awareness and foster adoption of the mitigation strategies.

The study for the current work is based on Dar es Salaam, which is the major city of Tanzania in the East Africa region with a total population of 4,364,541 (URT, 2012) which is about 5 million at present. The total water demand is approximately 195.24 million m^3/year equivalent to 545,000m^3/day (URT, 2017a). Water supply is in the form of piped water and boreholes; piped water is managed by Dar es Salaam Water and Sewerage Corporation (DAWASCO), a company that has nowadays merged to the Dar es Salaam Water and Sewerage Authority (DAWASA). DAWASA therefore is the primary water service provider serving about 75% of the population by producing approximately 488,000m^3/d of water[1] across all five municipalities of the city the percentage improved from the 68% reported by EWURA for the year 2016/2017 (URT 2017a): in addition, there is expectations of 22,000m^3/d water yield capacity from Kimbiji and Mpera well fields. The main public water source is Ruvu River with two treatment plants namely Lower Ruvu, and Upper Ruvu, followed by the Kizinga River that has Mtoni treatment plant: the three treatment plants define the three water schemes within the city. Complimentary supply is from water vendors ranging from pushcarts, water trucks to small private networks (Kjellen, 2000) and over 2200 official boreholes (JICA, 2012).

Flood hazards have been of recent years the most disruptive events in Tanzania[2] Dar es Salaam city in particular, resulting into widespread of diseases, and destruction of infrastructures. Recently in October 2017, flooding water in Mbezi River dragged away a 30” water transmission main from the Upper Ruvu treatment plant while other small distribution pipes were also affected. As a result, the quality and availability of public water in the areas served by the water transmission main were compromised. Alternative sources such as wells during these periods became flooded and hence unsuitable for consumption, and boreholes from the shallow aquifers are

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[1] http://www.dawasco.go.tz/waterservices.html
[2] EM-DAT: The Emergency Events Database - Universite catholique de Louvain (UCL) - CRED, D. Guha-Sapir - www.emdat.be, Brussels, Belgium

unreliable due to direct recharge from flooded onsite sanitation facilities and flood water from crude/unofficial dumping sites

Issues such as poor planning, poverty, weak infrastructures, and un-functioning storm water drainages have grieved the impacts of flooding in the city (Earhart & Twena, 2006; Sakijege, Lupala & Sheuya, 2012; Kebebe & Nicolls, 2011). Whereas, water systems are also facing common resilience problems that exist elsewhere in the world (Sweya, 2018) leading to the need for immediate interventions to improve the resilience. The current study assesses the factors that affect resilience in three dimensions of resilience for water supply systems: technical, social, and environmental and identify on-ground problems that intensify the impacts of flood risks to the systems in Dar es Salaam. The findings could be a fundamental support for decision makers because it increases awareness and foster adoption of the mitigation strategies hence improving the resilience.

2.0 METHODOLOGY

The study was conducted in Dar es Salaam, the major city of Tanzania to assess the three dimensions of resilience for water supply systems: technical, social and environmental and identify on-ground problems that escalate the flood risks to water supply systems in the city and the need for improvement. Identification of problems was based on the factors that affect resilience for infrastructure systems (see Table 2.1). Households were sampled in Vingunguti, Tandale, and Jangwani wards to represent the Dar es Salaam population living in low-laying areas that are vulnerable to floods: the information was used in the social dimension assessment. Interviews were conducted to three water supply institutions namely DAWASA, DAWASCO, and Wami/Ruvu basin to identify problems for the technical and environmental dimensions. Ethical approval was obtained from the ethics committee of the University of Auckland (approval number 019619), and consent for participating in the study was obtained from each participant.

Table 2.1 Factors that can affect resilience of water supply infrastructures

S/N	FACTOR AFFECTING RESILIENCE	DIMENSION	REFERENCE
1	Population composition in terms of education level, employment status and house ownership	Social	Sherifi, 2016
2	Likeliness of being affected by floods	Social	***
3	Flood experience	Social	Sherifi, 2016
4	Effects of floods on water supply system	Social	***
5	Alternative water supply	Social	***
6	Preparedness for future floods	Social	Jovanovic et al. 2016
7	Additional system capacity	Technical	Mugume et al. 2015
8	System exposure to flood hazards	Technical	Hughes & Hearly, 2014
9	Water losses	Technical	***
10	System redundancy	Technical	Hughes & Hearly, 2014
11	System upstream interdependencies	Technical	Hughes & Hearly, 2014
12	Use of local knowledge and native species	Environmental	Sherifi, 2016
13	Soil erosion protection	Environmental	Sherifi, 2016
14	Availability and accessibility of water	Environmental	Sherifi, 2016
15	Pollution stresses in the ecosystem	Environmental	Sherifi, 2016
16	Human encroachment in catchment areas	Environmental	Brenket & Malone, 2005
17	Water withdrawal	Environmental	Brenket & Malone, 2005
18	Natural flood buffers	Environmental	Sherifi, 2016; Cuter et al. 2014

*** Factors added by Researchers

Both quantitative and qualitative methods were used in this study. One hundred and six (106) semi-structured questionnaires were administered in three wards: Vingunguti, Tandale, and Jangwani to assess the problems and resilience needs in the social dimension. The target population was the households that are highly vulnerable to floods. For Vingunguti the target population was selected along the Msimbazi River valley, for Jangwani in the Msimbazi River valley/floodplain, and for Tandale along the Ng'ombe River. A total of 140 houses were targeted in the three wards: 65 in Vingunguti, 40 in Tandale and 35 in Jangwani. The difference in the target population reflected the general population in the respective wards: 106,946 for Vingunguti 54,781 for Tandale, and 17,647 for Jangwani (URT, 2012). The sample size (106) was determined based on the confidence level (CL) of 95%, Z-score of 1.96, and margin of error of 8% (see Table 2.2). In that regard, 45 households in Vingunguti, 32 in Tandale and 29 in Jangwani were studied.

Table 2.2 Sample size determination

Ward	Target population	Confidence level (%)	Margin of error (%)	Z-score	Sample size
Vingunguti	65	95	8	1.96	45
Tandale	40	95	8	1.96	32
Jangwani	35	95	8	1.96	29

Random sampling was adopted to identify the participants. Heads of households, in particular, were the main targets. Questionnaires were administered in Kiswahili to the heads of the households after obtaining their consent to participate in the study. In addition, three interviews were conducted. Two at the Dar es Salaam Water Supply and Sewerage Authority (DAWASA), and Dar es Salaam Water Supply and Sewerage Cooperation (DAWASCO) to assess the problems and resilience needs in technical dimension and one at the Wami/Ruvu river basin main office to assess the resilience improvement needs in the environmental dimension. The interviewees were asked for their consent to recording the interviews.

A standard descriptive analysis using a Statistical Package for Social Sciences (SPSS), IBM SPSS Statistics 25, was used to describe information obtained from the questionnaires. The percentages were calculated to assess the problems and resilience improvement needs in the social dimension of the water supply. Recorded interviews were transcribed by the researcher and a thematic approach (Luborsky, 1994) was used to analyse the information. The emerging themes were studied to assess the problems and needs for improving resilience in the technical and environmental dimensions.

3.0 RESULTS

This section of the paper presents the results obtained from questionnaire survey and interviews: it entails the resilience problems that exacerbate flood risks in water supply systems in the city of Dar es Salaam. The problems were assessed in the three dimensions of resilience for water supply systems namely technical, environmental and social dimensions and results are presented as follows;

3.1 Resilience problems that escalate flood risks to water supply systems

3.1.1 Technical dimension

Dar es Salaam total water demand is approximately 195.24 million m^3/year equivalent to 545,000m^3/d (URT, 2017a) while the combined production following the 2011-2015 upgrade of the public water utility is 488,000m^3/d (see Figure 3.1). The water produced serves almost 75% of Dar es Salaam and parts of the coastal region[3]. That means the utility at present lacks additional capacity in case of failure or abrupt increase in demand.

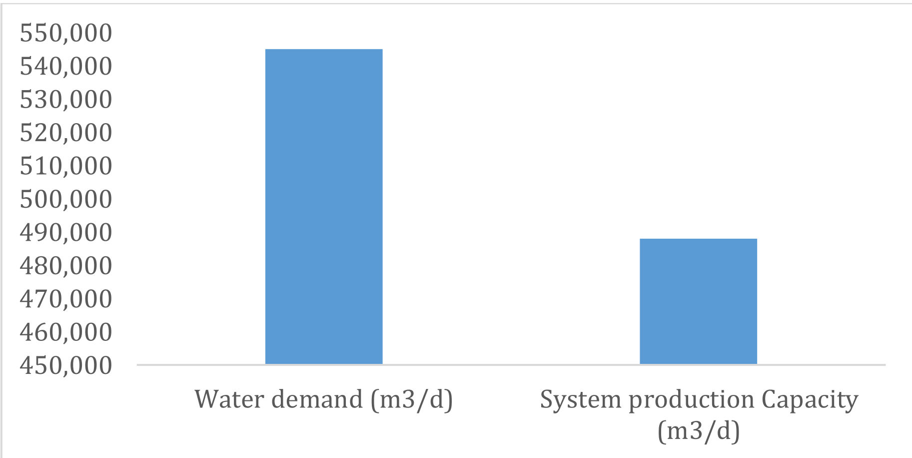


Figure 3.1 Water demand vs system production for Dar es Salaam city

In each pumping station, there is one standby pump, and transmission mains are partially looped with alternative pipes running parallel to each other. The system is also partially interconnected between the Upper and Lower Ruvu networks only along Mandela road. Results show that some of the critical assets such as the intakes,

[3] http://www.dawasco.go.tz/waterservices.html

pumping system for the Mtoni network, and all the transmission mains are exposed to flood hazards, and do not have alternative facilities or routes during flooding (see Plate 1 & Table 3.1). That also includes several distribution pipes that cross rivers within the city.

Plate 1 Water transmission (30" diameter) dragged away by flooding water across Mbezi river in October 2017

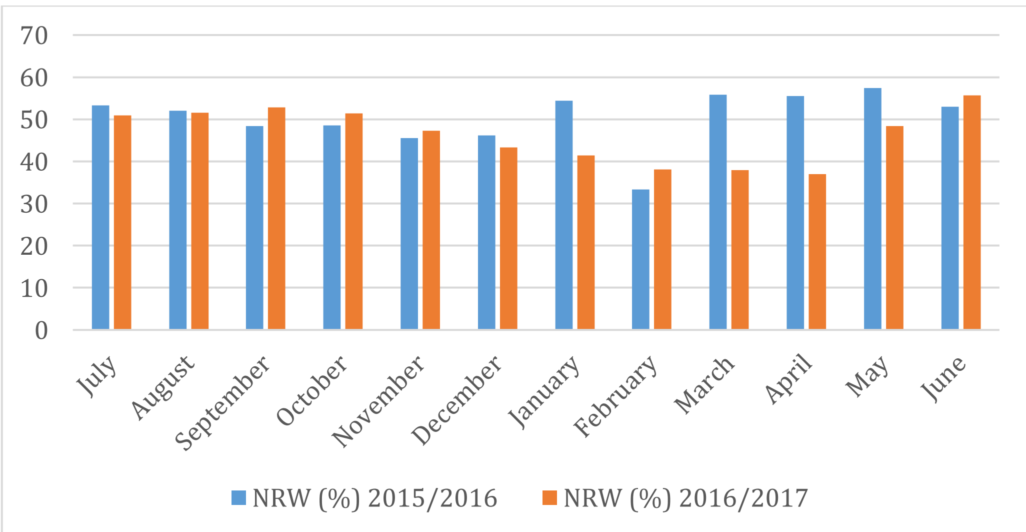
Table 3.1 Alternative facilities for critical assets

Facility	System	Flooding Hazards	Alternative
Intake	Mtoni	Affected	No alternative facility
	Lower Ruvu	Affected	No alternative facility
	Upper Ruvu	Affected	No alternative facility
Water Treatment Plant	Mtoni	Not affected	
	Lower Ruvu	Not affected	
	Upper Ruvu	Not affected	
Pumping system	Mtoni	Affected	No alternative facility
	Lower Ruvu	Not affected	
	Upper Ruvu	Not affected	
Transmission Mains	Mtoni	Affected	No alternative routes

	Lower Ruvu	Affected	No alternative routes
	Upper Ruvu	Affected	No alternative routes
Reservoirs	Mtoni, Lower Ruvu, and Upper Ruvu	Not affected	

The system has suffered water losses (see Plate 2) in terms of average non-revenue water (NRW) per month ranging from 33.28% to 57.44% between 2015/2016 and 2016/2017 operation years (see Figure 3.2). The highest values are 57.44% in May and 55.62% in June for the 2015/2016 and 2016/2017 production years respectively (DAWASCO). In Tanzania, May and June are preceded by the rainy season, where the demand from a public utility is low, as some people use rainwater and other sources.

Plate 2 Structural leakages that contribute to water losses in Dar es Salaam



Source: DAWASCO

Figure 3.2 Non-Revenue Water (NRW) in the city of Dar es Salaam

Water production for Dar es Salaam public water utility depends entirely on the power supply from the Tanzania Electric Supply Company Limited (TANESCO). The available standby generators are mainly for lighting and cannot support production. During flooding there is high a chemical demand for water purification, consequently water production is low as some pumps are stopped to reduce production costs, and lower the chances of damaging the system.

3.1.2 Environmental dimension

Ruvu River is the main source of water for the city of Dar es Salaam and is found in the Wami/Ruvu water basin: the basin has seven sub-catchments namely Kinyasungwe, Mkondoa, Wami, Upper Ruvu, Ngerengere, Lower Ruvu and Coastal Rivers. Of the seven sub-catchments, only Ngerengere sub-catchments seem to have significant natural vegetation especially in the Uluguru highlands. It is only in these highlands, traditional practices for water management exist. Most other areas have become potentially suitable for agricultural activities and grazing. Thus, the use of local knowledge and natural species in many areas is diminishing.

The basin has experienced severe erosion due to inadequate soil protection measures against activities such as sand-cement blocks making, agriculture, overgrazing, sand quarrying, and mining. Soil erosion in the upstream of the Ruvu river source for example has resulted in severe deposition downstream at Kidongozero. The deposition has widened the river at that location, changing its regime and affecting the water availability further downstream where the two Ruvu water treatment plants are located.

Surface water being the main source for the city is insufficient and affected by management concerns due to the large number of unregistered water users. Groundwater is the second most used source in the city, its quality is still unpredictable due to susceptible discharge from uncontrolled waste disposal sites and on-site sanitation systems such as Vingunguti un-engineered dumpsite that also receive waste from the adjacent abattoir (see Plate 3) and several onsite sanitation setups in the city during rainfall. In addition some recharge areas are thought to be affected by urbanisation, and the source is also at risk of seawater intrusion due to over-pumping. Rainwater is still rarely considered as a viable potential alternative source of water in the city.

Plate 3 Vingunguti un-engineered dumpsite

Human encroachment has put the surface source in particular at risk from industrial, domestic, and mining pollutions. Both industrial and domestic effluents discharged in the water bodies such as rivers have contributed to pollution of the water. Besides, there are mining activities conducted along and within rivers especially in the Ngerengere sub-catchment of the Ruvu River (see Plate 4), “the biggest concern is the susceptible pollution from mercury, if it is used as one of the chemicals for extracting gold” (Research Participant).

Plate 4 Mining activities and farming in the Ruvu river catchment areas

Water balance and withdrawal monitoring are rarely conducted. Most infrastructures are built first, and the permits applied afterward; and hence it becomes difficult to reject the applications. “For example right now there are five projects, one of Mkulazi sugarcane production started the project, but then the sugarcanes started to dry due to lack of water, there was no option but to grant a permit to abstract water from Wami River," (Research Participant). Inadequacy of information regarding the water users has also affected the withdrawal monitoring and consequently the water balance.

3.1.3 Social dimension

Results from the questionnaire survey show that more than 80% of the respondents are unemployed (see Figure 3.3a), whereas highest education level for more than 80% is primary school (see Figure 3.3b).

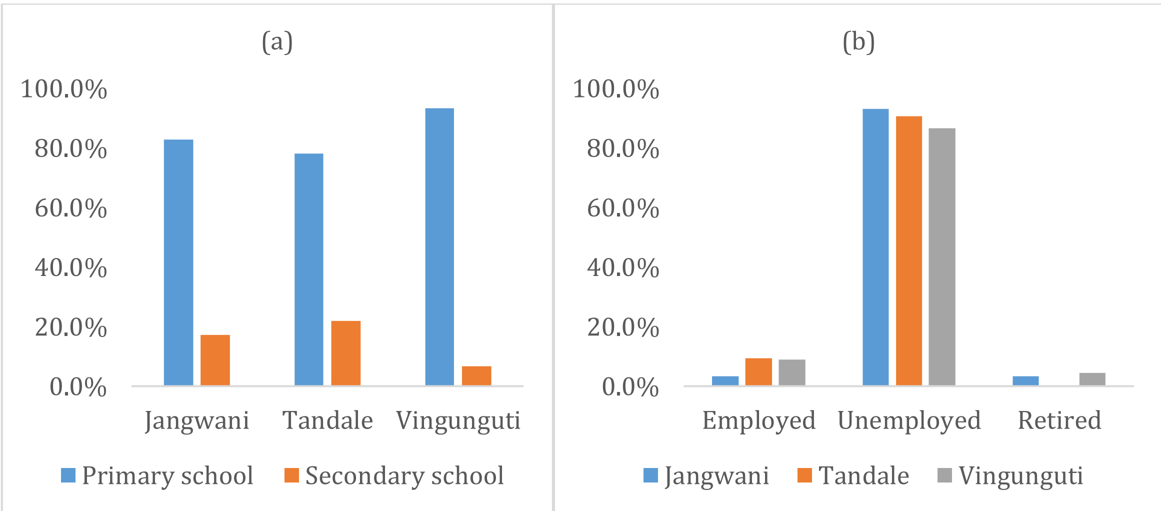


Figure 3.3 (a) education level of respondents and (b) employment status of the respondents

Above 50% of the respondents in Tandale own the houses they live in, similar results were observed in Vingunguti, while in Jangwani more than 50% are tenants. Besides, 3.4%, 6.3%, and 6.7% of the respondents for Jangwani, Tandale, and Vingunguti, respectively, inherited houses they live in, while about 3.4% in Jangwani alone live in temporary shelters, neighbours' houses, during floods (see Figure 3.4) and all the houses are not insured.

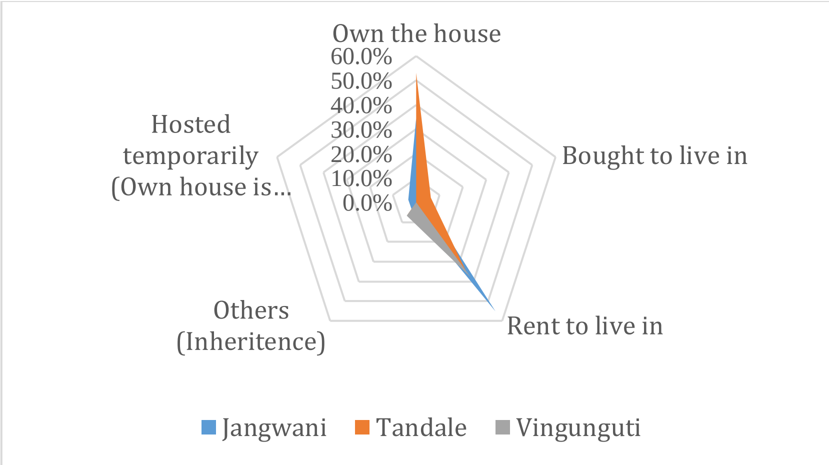


Figure 3.4 House ownership

According to the respondents, flood is the only natural hazard that is likely to occur in the city of Dar es Salaam. The average of 63.2% of the respondents are highly likely affected during flooding. Also, 36.4% are quite likely affected by floods (see Figure 3.5a). In line with that observation, the average of 88.7% of the respondents have experienced floods in the past. Implying that the majority of the respondents are exposed to the impacts of floods (see Figure 3.5b).

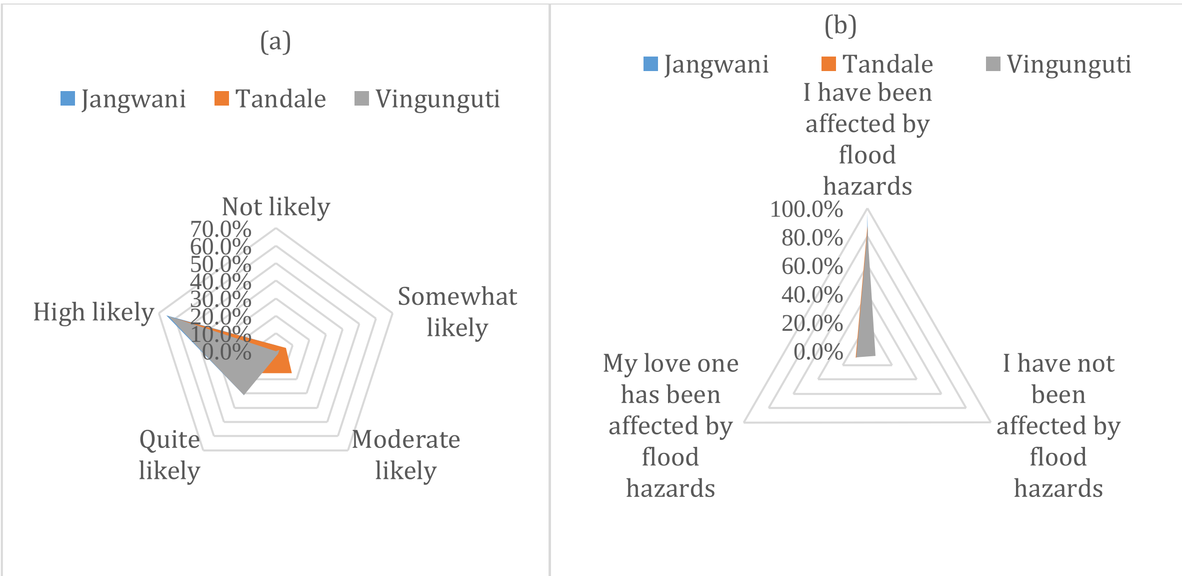


Figure 3.5 (a) possibility of being affected by floods and (b) experience with flood hazards

As shown in Table 3.2, 3.3, and 3.4, the average of 34.5%, 40.2%, and 45.6% of the respondents indicated that the water quality, quantity, and services, respectively are highly likely affected during flooding. Also, 53.9%, 40.7%, and 38.4% said the water quality, quantity, and services respectively are quite likely affected by flooding. In all cases, it was revealed that a combined result of over 90% for respondents from Vingunguti was between quite likely and highly likely, suggesting that, the water quality, quantity, and services in the ward are vulnerable than in Jangwani and Tandale wards.

Table 3.2 Effects of floods on water quality

	Not likely	Somewhat likely	Moderate likely	Quite likely	High likely
Jangwani	6.9%	3.4%	0.0%	65.5%	24.1%
Tandale	9.4%	0.0%	6.3%	40.6%	43.8%
Vingunguti	0.0%	0.0%	8.9%	55.6%	35.6%
Average	**5.4%**	**1.1%**	**5.0%**	**53.9%**	**34.5%**

Table 3.3 Effects of floods on water quantity

	Not likely	Somewhat likely	Moderate likely	Quite likely	High likely
Jangwani	13.8%	3.4%	3.4%	48.3%	31.0%
Tandale	6.3%	0.0%	28.1%	25.0%	40.6%
Vingunguti	0.0%	0.0%	2.2%	48.9%	48.9%
Average	**6.7%**	**1.1%**	**11.3%**	**40.7%**	**40.2%**

Table 3.4 Effects of floods on water service

	Not likely	Somewhat likely	Moderate likely	Quite likely	High likely
Jangwani	10.3%	6.9%	3.4%	41.4%	37.9%
Tandale	6.3%	0.0%	18.8%	25.0%	50.0%
Vingunguti	0.0%	0.0%	2.2%	48.9%	48.9%
Average	**5.5%**	**2.3%**	**8.1%**	**38.4%**	**45.6%**

Results show that, more than ten alternative water supply options are used when the quality, quantity, and service of water from the public utility are affected by flooding emergencies. Few responses are such as; “There is no water service at all”, “We find it very difficult to find water because all infrastructures are being destructed including electricity", "We buy bottled water because other waters become mixed with wastewater", and "We buy saline water from wells". Notable overall results are the three responses, where 23.6% of the respondents said it is very hard to get water, 19.8% said they have no alternative water supply, and 15.1% said there is no service at all during flooding. The three responses form a combined result of 58.5% suggesting that the majority suffer from the impacts of flooding on the water supply system. The most preferred alternative is buying reserve water from vendors which accounts for 13.2% of the respondents. Other alternatives are; getting water from neighbours, in-house storage, and traveling long distances to get water from vendors. There are also situations where other respondents buy bottled water, use water from traditional wells, use rainwater, get water from lowlands, and vacated their houses until flood is receded (see Table 3.5).

Table 3.5 Alternative water supply during floods emergencies

Alternative	Jangwani		Tandale		Vingunguti		Overall results	
	N	%	N	%	N	%	N	%
None	5	17.2	10	31.3	6	13.3	21	19.8
Get water from neighbourhood	2	6.9	1	3.1	0	0	3	2.8
Get water from neighbours	3	10.3	0	0	2	4.4	5	4.7
In-house water storage buckets/facilities	2	6.9	0	0	2	4.4	4	3.8
Buy reserved water from vendors	0	0	6	18.8	8	17.8	14	13.2
No service at all	2	6.9	7	21.9	7	15.6	16	15.1
It is very hard to get water	9	31	5	15.6	11	24.4	25	23.6
Buy bottled water	2	6.9	0	0	1	2.2	3	2.8
Buy from water trucks vendors	0	0	0	0	1	2.2	1	0.9
Vacate the house and return when the flood is receded	1	3.4	0	0	1	2.2	2	1.9
Use well waters	0	0	0	0	3	6.7	3	2.8
Use rainwater	0	0	0	0	1	2.2	1	0.9
Travel long distance to get water from vendors	3	10.3	2	6.3	1	2.2	6	5.7
Search water from lowlands (valleys)	0	0	1	3.1	0	0	1	0.9
Use water from unimproved wells	0	0	0	0	1	2.2	1	0.9

	29	**100**	**32**	**100**	**45**	**100**	**106**	**100.0**

Furthermore, over 71.7% of respondents said that they had taken no actions to prepare for the future impacts of floods on water supply system, some respondents said "We are not prepared because if we reserve water it can also be contaminated" and "Because of the economic situation, I have have not done anything". Reserving water for use during floods was the only significant action reported to prepare for future floods, accounting to overall 10.4% of the respondents. It is also notable that, a few respondents, especially in Tandale and Vingunguti, were willing to be relocated after being compensated. In the same wards, some respondents called for the Government to build houses for the victims. Other actions include pre-flooding shifting to safer places, use of rainwater, and use of water treatment chemicals (see Table 3.6).

Table 3.6 Actions taken for self-preparation regarding future floods

	Jangwani		**Tandale**		**Vingunguti**		**Overall results**	
	N	**%**	**N**	**%**	**N**	**%**	**N**	**%**
No actions	27	93.1	18	56.3	31	68.9	76	71.7
To have reserved water	1	3.4	8	25	2	4.4	11	10.4
To use water guard chemicals	1	3.4	0	0	1	2.2	2	1.9
Use rainwater	0	0	0	0	2	4.4	2	1.9
Vacate to a safe place after being informed	0	0	1	3.1	3	6.7	4	3.8
Asking the government to build houses for victims	0	0	2	6.3	2	4.4	4	3.8
Asking government for relocation, after compensation	0	0	0	0	1	2.2	1	0.9
Have been told by the government to vacate yet not compensated	0	0	2	6.3	2	4.4	4	3.8
No money	0	0	1	3.1	0	0	1	0.9
Water is always available	0	0	0	0	1	2.2	1	0.9
	29	**100**	**32**	**100**	**45**	**100**	**106**	**100.0**

3.2 Interplay of the problems between technical, environmental and social dimensions

Findings show that there is a strong relationship due to the way the problems interact across the three dimension: technical, environmental and social. Social dimension that involves all types of water users is the major source of pollution stresses and degradation in the environment. Pollution aggravates climate change impacts, and together with polluted and degraded environment they increase the flood risks to water supply infrastructures, affecting the sources and consequently the water users pays back due to lack of public water supply therefore consuming water from alternative sources which are highly likely contaminated. Water users also weakens the infrastructures through actions such as vandalization and illegal connections that also contribute to high water losses (see Figure 3.6) and increased vulnerability of the system to flood risks.

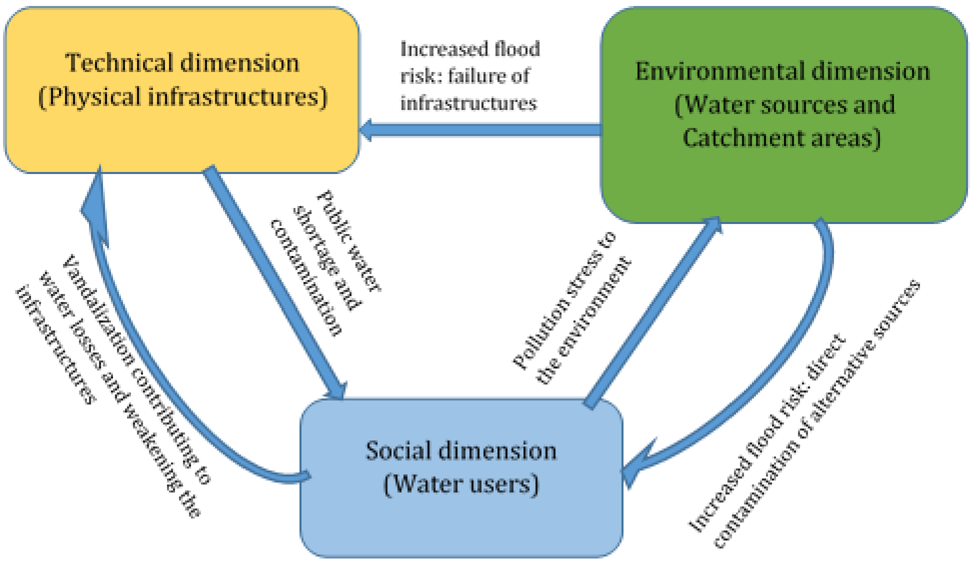


Figure 3.6 Relationship between technical, environmental and social resilience problems

3.3 Flood risk implications to the water supply system in Dar es Salaam

Flood risk to water supply systems in Dar es Salaam leads to direct and indirect effects: direct effects are such as degradation of the water sources through soil erosion and deposition, contamination of the water sources, and failure of the water infrastructures. Water source degradation has affected the Ruvu River for example at Kidongozero affecting the water quantity downstream to the Upper and Lower Ruvu treatment plants. Degradation causes indirect effects such as public water scarcity leading to the use of unreliable sources or spend too much money on buying water and consequently increase the chance of water related diseases and economic losses to the people. Contamination is for both main and alternative sources: contamination of main sources is both primary and post contamination, Primary contamination leads to a secondary effect such as increase of water treatment expenses resulting into economic losses for the water supply authority while post contamination causes a secondary effect of contaminating the water in the distribution network thus increasing the chance of water related diseases. Failure of the infrastructure leads to three secondary effects namely public water scarcity, public water contamination, and demands for repair and maintenance: the first two increase the chance of water related diseases, while the later leads to economic losses for the water supply authority (see Figure 3.7).

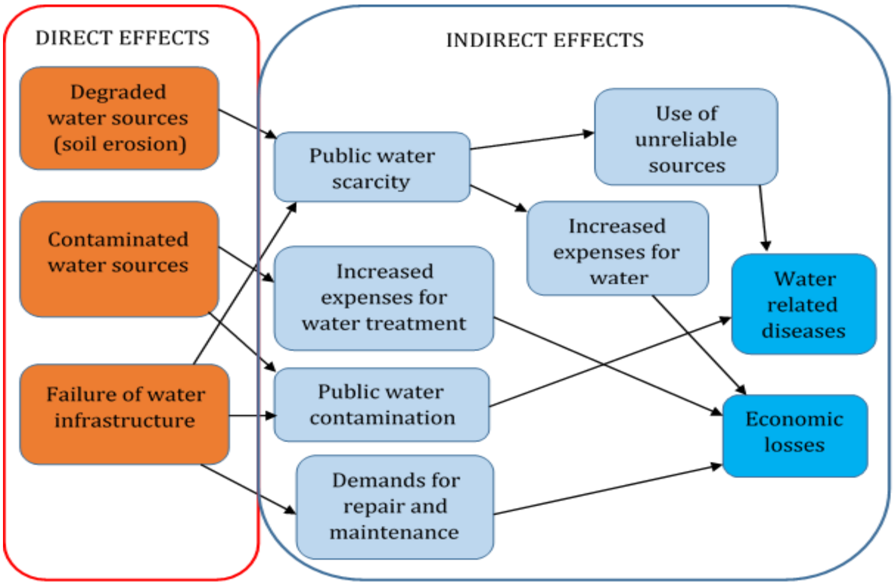


Figure 3.7 Impacts of flood risks to water supply systems in Dar es Salaam

4.0 DISCUSSION

The research assessment involved three dimensions of the water supply systems: technical, social, and environmental and their response during flooding. The three water schemes in Dar es Salaam: Mtoni, Lower Ruvu, and Upper Ruvu are partially inter-connected. The only interconnection is between Lower Ruvu and Upper Ruvu in the areas along Mandela road. That means the schemes are divided into service zones, and the failure of one scheme means the served areas/zones face interruption of public water supply services. This is evident from DAWASCO adverts regarding water shortage, and one example is the up to 48hours water interruption announcement from

DAWASCO on 23/24th January 2015[4]. That was due to the installation of interconnection between an old pipe and a new pipe at the Lower Ruvu water treatment plant. All customers served by this scheme from Bagamoyo district in the Coastal region, about 31 wards in Dar es Salaam, and the Muhimbili National Hospital were victims. According to Proag (2016), lack of connectedness of the water schemes implies the lack of redundancy, thus, affects the resilience of water supply systems.

Other redundancy issues include lack of additional capacities in the critical assets and lack of alternatives for some critical facilities. Although the Ruvu treatment plants were expanded to double their capacities by 2015, the whole public water system can only serve 75% of the total demand at present[5]. That means there is a shortage of 25% of the total demand, and that the system cannot accommodate any shocks, regarding abrupt water demand increase, or during disruptive events such as floods. Critical facilities such as the water intakes for all schemes, a pumping station for Mtoni scheme, and the water transmission mains for all schemes are exposed to floods, and they lack alternative facilities or routes in case of supply interruption due to flooding events.

The system has experienced a monthly average Non-Revenue Water of 50.29% and 46.31% in 2015/2016 and 2016/2017 production years, respectively. That means, approximately a half of water produced is lost, leaving even the majority who are connected wondering due to insufficient water. The water loss is associated with structural leakages (Kjellen, 2008) as a result of ageing infrastructures, illegal connections, and bursting of pipes along roads due to traffic loads accompanied by insufficient soil cover. Water loss is also associated with water pressure due to unbalanced system development: in 2011-2015, the Ruvu water schemes were upgraded to double their capacities from 82,000m^3/d to 196,000m^3/d and 180,000m^3/d to 270,000m^3/d for Upper Ruvu and Lower Ruvu respectively[6]. While that upgrade was made to enhance the capacity of the treatment plants and transmission mains, the sizes of the distribution networks remained the same. Thus, high-pressure water from the production sites is forced into smaller size distribution pipes leading to pipe bursts in some areas. Although there are current efforts to upgrade the distribution systems, this area needs immediate improvement to enhance the robustness of the systems.

[4] http://www.tanzaniatoday.co.tz/news/dawasco-yatangaza-kukosekana-huduma-ya-maji-kwa-siku-mbili-jijini-dar
[5] http://www.dawasco.go.tz/waterservices.html
[6] http://dawasa.go.tz/facilities

Water production in the three schemes depends entirely on the power supply from the National electricity grid. It is also important to note that it is not uncommon for power supply to be interrupted during heavy downpours, where production processes are affected. The Ruvu schemes have a power substation, which are connected to both the Coastal region and Dar es Salaam networks to reduce the impacts of failure. The whole system shows a high degree of interdependency on the national power grid, in line with Proag (2016) who identified a similar problem to the water supply system in Mauritius. The backup generators that are available at the production sites can only support lighting and other small load uses. Additionally, during flooding where the water at the intakes is highly turbid, the production is lowered to avoid massive consumption of chemicals leading to the shortage of water supply in the city and consequently affecting the resilience of the system.

Catchment and recharge areas for the sources of water in Dar es Salaam are within the Wami/Ruvu basin. Their management is one of the overarching problems for Dar es Salaam water managers. The use of local knowledge and native species has the potential to support the management activities (Watts, 2012). However, the local knowledge had received little recognition in the past; thus the practices and values used to be passed down through generations are diminishing, except for few areas in the highlands of Uluguru. Also, despite the potential of native vegetation to increase rainfall interception by trees and the litter layer which stores water and allow time for a greater degree of infiltration, there is a decline in the native vegetation cover within the basin which has been linked with an increase in flash floods, drying up of springs, and increase in turbidity in rivers. The *miombo* woodlands amidst savanna grassland in the lowlands of the basin have been degraded by 43% from 1970 to 1990s the trend that continues (GLOWS-FIU, 2014). The Eastern Arc Mountains in the uplands of the basin, have dwindled by 60% to 90% over the 20th century and slowed down to 6% towards the end of the century due to reserve status and distance from Dar es Salaam (GLOWS-FIU, 2014). The removal of native vegetation cover “deforestation” has spread out from Dar es Salaam due to urbanisation, demands for charcoal, agriculture, and low to high-value timber, leading to immediate runoff, soil erosion, flash floods, and low groundwater recharge during rainfall. Besides, lowlands deforestation has thinned out the canopy cover with significant effects on water and soil resources.

Ecosystem sensitivity for water resources includes the management of catchments and recharge areas. “Encroachment of human activities in these areas is evident and severe” (Research Participant). Also, the Minister for water and irrigation while addressing the audience during the water week on 20th March 2018 mentioned the importance of deploying strategies to tackle the ongoing pollution in different catchments within the country[7]. There are a number of income generating activities taking place in the catchment areas. Parts of the catchments and recharge areas have become potential areas for human settlements. These areas are also regarded as fertile and wet throughout the year, thus, have attracted agricultural activities. The abundance of appropriate tree species has attracted people to produce charcoal and timber. Other activities include sand-cement block making, sand quarrying, grazing, and mining. Such activities along the river banks and loss of riparian vegetation have contributed to the erosion of river banks, changes in river morphology, and deterioration of the water quality especially during flooding. These findings are consistent with the findings of a study by Sumerlin and Gritzner (2007) on Rapid Assessment of the Interdependence of the Wami River to the Ecosystems and Biodiversity of Saadani National Park.

Human encroachment has affected the natural buffers within the basin. Natural buffers in the form of wetlands and floodplains are capable of regulating hydrology by storing rainwater and surface runoff during the wet season and discharging it into rivers during the dry season. However, natural floods management which involves a whole catchment approach to manage floodwater through managing soil, wetlands, woodlands, and floodplains seems to be in jeopardy. According to Hirji, Davis and Brown (2007), major wetlands in the Ruvu system which are found in the southeast of the Uluguru Mountains have been affected by human activities such as agriculture, land conversion, water abstraction, brick making and pollution. Also, the wetlands for saline water in the estuaries of the Ruvu River comprising of the mangrove forests have been affected by deforestation due to land clearing for other uses like panning, and tree felling for firewood and charcoal making (JICA, 2013). Similar effects are observed in the estuary of the Kizinga River, which in addition is at risk due to urbanisation (Hirji, Davis and Brown, 2007). Furthermore, the rivers are polluted and face severe erosion due to rare existence of riparian vegetation. This finding is in line with the river health analysis report which indicates that most of the rivers in the Wami/Ruvu basin are devoid of Macrophytes, hence they have bare riverbanks (UTD, 2017b).

[7] https://issamichuzi.blogspot.co.nz/2018/03/waziri-wa-maji-azungumzia-umuhimu-wa.html

The water sources management is at risk due to lack of sufficient information about water users. According to the Wami/Ruvu basin officer, it is thought that the number of unregistered water users including for domestic, agriculture and industries is higher than the registered users. JICA, (2013) revealed that even registered users hardly conduct monitoring of abstraction volumes, as many intake facilities do not have flow measuring devices. That means the total water withdrawal monitoring is rarely practiced, and the sensitivity of the water resources is partially known. Besides, no systematic water balance has been conducted since 2012 when the same was conducted by JICA (2013), meaning that there is no clear trend on the efficient use of water within the basin. The water balance conducted for the entire Wami/Ruvu basin by JICA, (2013) cited in Schaefer & Dietrich (2015) showed that the risk of groundwater over-exploitation is significant and the surface water deficit will rise in the basin within the next two decades despite stable rainfall levels. The problem is exacerbated by flooding as the stress shifts from water scarcity alone to water scarcity and contamination, and more people become vulnerable

The highest education level of more than 80% of the people residing the study area and are exposed to floods is the primary school, and many have no formal employment. The majority about 60% are either small-scale entrepreneurs or food vendors. These findings are in agreement with the findings of Douglas et al. (2008); Independent Evaluation group (2006); Rashid (2000); Chauthry & Ruysschaert (2007); and Proag (2016) who observed that, the poorest in the low-income countries, have no choice but to locate themselves in unsafe settings and consequently they are most vulnerable to disasters. More than 50% of these residents in Tandale and Vingunguti, in particular, own the houses that they live in. However, in Jangwani over 50% have rented the houses they live in: the area attracts more low-income tenants due to its prominence for urban agriculture (Pallela, 2000) and close proximity to the city centre and “Kariakoo” the main business area for Dar es Salaam with affordable housing (Lumbumba & Ngware, 2016). The three wards have developed to be potential business areas in Dar es Salaam, and probably that is the main reason people do not want to leave even though the areas are vulnerable to flooding. The houses in these areas are not insured, such that the owners incur a total loss when their houses are affected by floods. It was also found that, since these areas are regarded as floodplains of the Msimbazi River, there is severe deposition in some parts; thus water distribution pipes and standpipes became completely buried in sediments.

Regarding water supply, over 90% of the respondents revealed that water quality, quantity, and services are affected by flooding. From the technical and environmental dimensions findings that the leaking and broken water distribution pipes are likely to reduce the quantity of water for supplying the consumers, and allow flooding water to contaminate the potable water in the pipes during supply interruption and low-pressure times. The DAWASCO technical officer indicated further that, during flooding, water at the intakes is highly turbid and contains a lot of suspended matters such that the production cost increases due to the need for more frequent removal of screenings, and more chemical to address the turbidity at the treatment plants. In that regard, the water production is lowered to avoid the likely extra production costs and damages of the screens. Besides, pumping stations at the Mtoni treatment plants are usually stopped due to the effects of the flooding water, while the transmission mains are currently at risk, as they cross rivers, thus affecting both quality and availability of the water within the city.

When the public water supply is affected by flooding, the residents have different alternatives they use to secure the service. The findings show that the majority 58.5% of the respondents experience hardship regarding water supply during flooding, as they are at risk of no access to tap water. Besides, few people store bulk water in buckets to cater for the periods of emergencies, suggesting that, they are forced to minimise their consumption so that they don't completely run short of water. The findings are in line with the findings of Bayliss (2011) whose study shows that, in water scarcity areas such as Vingunguti in Dar es Salaam, households have already reduced the consumption of piped water to a bare minimum, a similar situation was observed during flood emergencies. Although buying water is the only significant alternative, it is expensive and almost unaffordable to the majority. Bayliss (2011) indicates that, the most expensive water originates from a public tap: the water is transported by vendors such that the long supply chain translates into substantial mark-up prices and most people already use more than 5% of their income (acceptable poverty threshold) for water, while the quality also remains questionable due to lack of monitoring. Borehole water is largely described as salty while other alternative water supplies such as from lowlands and traditional wells are susceptible to pollution.

There were some signs of preparedness for future flooding, and few respondents showed dependence on the Government, they claimed to be ready to leave if they get from the government compensation of properties to be abandoned. Also, there are a few people who claimed that they are prepared to vacate temporarily to a safer place until there are no more floods before they go back. Others indicated the desire to reserve water in their houses for use during a crisis, use of rainwater, and use of water treatment chemical agents for household water treatment. However, the majority "over 60%" indicated that they are not prepared at all, one of the reasons being inadequate finances, the finding that testifies to the fact that the poor are the most affected.

The problems that intensify flood risks in the technical dimension are partly related to inadequate assets management. High water loss measured in terms of Non-Revenue Water (NRW) is due to reason such as vandalization and illegal tapping resulted from inadequate protection of the system and enforcement of the DAWASA Act 2001 sect. 18.4 which acknowledges these actions as offences, broken pipes due to traffic along roads, intentionally defected pipes to get free water, and improper construction methods in some areas: in addition, part of the distribution network and the oldest scheme since 1951 are aged and inadequate measures are being taken for renewal thus they remain weak and vulnerable to flood risks. Likewise several distribution pipes are exposed on the ground due to soil erosion which is attributable to insufficient soil cover as a result of ineffective use of guidelines during construction especially for small projects. Generally, there is little in the current design guidelines (i.e. Design Manual for Water Supply and Wastewater Disposal, 2009) regarding consideration of resilience based approach in planning, designing and construction of critical assets in or across flood risk areas.

Most of the problems in the environmental dimension are associated with inadequate enforcement of measures for pollution control stipulated in the Environmental Management Act (EMA) 2004, and the water resources management including enforcing effluent discharge permits, water abstraction, withdrawal monitoring and water balance, and banning human activities within 60m from the water sources as stipulated in the Water Resources Management Act (WRMA) 2009. There is also a sense that political influence plays a big role in slowing down enforcement of the regulations. It is not uncommon in Tanzania for the technical officials to have different views with political leaders and more pressure prevails during electoral campaigns where officials are discouraged from reporting issues (McCrickard et al., 2017). The two National Environment Management Council taken to court over corruption in 2013[8], and the five officials charged with several economic crimes related to offences in 2018[9] shows further that, there is ethical and professional issues that need to be resolved within the government agencies to ensure that enforcement is successfully accomplished.

People at high risk live in low-lying areas close to urban rivers the majority of which are poor and unable to secure land in safer areas or rent in safer residents. Poverty is deepened by what is referred by Pavlova, (2016) as a simple demolition rather than applying a phasic relocation programme to places with needed services. The Water Policy 2002 puts emphasis on the public-private partnership, which is also one of the objectives of the Water and

[8] www.dailynews.co.tz/news/two-nemc-officials-in-court-over-bribery-charges.aspx)
[9] www.thecitizen.co.tz/News/Five-NEMC-officials-charged/1840340-4831472-14b4pt3z/index.html

Sanitation Act 2009 and its amendment. The most popular attempt to implement the objective was establishment of partnership between DAWASA and City Water Services which prematurely ended in 2005. The existing public-private partnership involves small private networks most of which are unregulated, and vendors whose water cost more than tap water (Kassenga et al. 2009) due to the long vending chain. The most popular is the public-public partnership through which DAWASCO took over from City Water Services and the existing Community Water Supply Organisations (COWSOs) which operate in distant areas from the main networks. Some COWSOs are middlemen, tapping water from the main water supply, thus they offer little alternative when the main network suffers from flood hazards. The human right in the water sector on the other hand is still a pending problem in the city. Although the Water Policy 2002 acknowledges that every citizen has an equal right to access and use the water, there is an even supply of water (Smiley 2016): some receive regular water supply, some have pipes but receive intermittent supply, and some do not receive piped water at all. Under this scenario, the poorest residents of the city suffers the most.

5.0 CONCLUSION

The water supply system has experienced inadequate redundancy, due to lack of alternative facilities for critical assets and connectedness of the schemes. The system is also suffering significant water losses, thus affecting the ability of the authority to generate sufficient income for critical activities such as renewal, operation, and maintenance. Despite the efforts invested by the government through the ministry of water, DAWASA, and DAWASCO to extend the water supply service to a large population, Dar es Salaam public water supply can only suffice 75% of the total population, leaving about 25% of residents most of them being poor without access to portable water. The highest value of NRW, 57.44%, means that at certain times even those who have access to public water supply can only get less than half of their demand. The water sources are at risk of pollution due to the encroachment of human activities in the catchments and recharge areas. The poor population is the main victim of the impacts of floods to public water supply systems: during flooding, the majority are unable to access portable water from the system, and even when the water is available usually it becomes costly due to the vending chain. Furthermore, the majority of the respondents are already spending more than 5% of their income (the acceptable poverty threshold) for water on normal days in Vingunguti in particular. Thus, they are unable to prepare for the future impacts of floods regarding water supply. These findings suggest that, improving technical resilience would have high influence on the social resilience regarding water supply. Also, environmental degradation has implications on the integrity of water sources in Dar es Salaam. Therefore, there is a need for improving the resilience of the system altogether to ensure that there is a continued supply during flood emergencies. In addition, justice, rights for water, effective enforcement of policies and regulations, and a well-coordinated public-private partnership will foster the continuity of public water supply in the city. In that regard, further work is in progress to develop tools that can be used to systematically measure the resilience of the water supply system. Results from the measurement would be useful to determine the appropriate measures for improving the resilience.

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