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System-wide approaches to mitigate environmental and health impacts of water contamination

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ABSTRACT

There is an urgent need to address the challenges of inadequate safe water and proper sanitation in peri-urban communities in low-income countries. Agencies have tended to focus on a single aspect of the challenge for service delivery, which ultimately fails to capture the full scope of the problem. In this study, 63 household surveys and 15 key informant interviews regarding water and sanitation issues were conducted in a peri-urban area of Dar es Salaam, Tanzania. Results revealed that 87% of households experience water scarcity issues. More than 50% of the homes were surrounded by swampy areas with sewage and stagnant pools, with 40% reporting water source contamination due to seepage and overflowing of sewage collection systems. Key informants reported water scarcity and poor water quality due to poor sanitation practices and a compromised water supply network. We found that a highly integrated approach that invests in cultural, social, political, human, financial, and built community capitals is needed to address these challenges. Community self-efficacy and empowerment will be critical to accomplishing this and protecting public health.

Key words: Community capital framework, Tanzania, Developing country, Water, Sanitation and Hygiene (WASH), Water supply

HIGHLIGHTS

- The current efforts to address water and sanitation concerns in developing countries have failed to capture the full scope of the problem.
- This study identified the barriers to meet Sustainable Development Goal 6 in a peri-urban area of Dar es Salaam.
- We argue that a more system-wide approach is needed, involving multiple actors.
- Findings revealed that a positive change is achieved through investing in the community capital framework.

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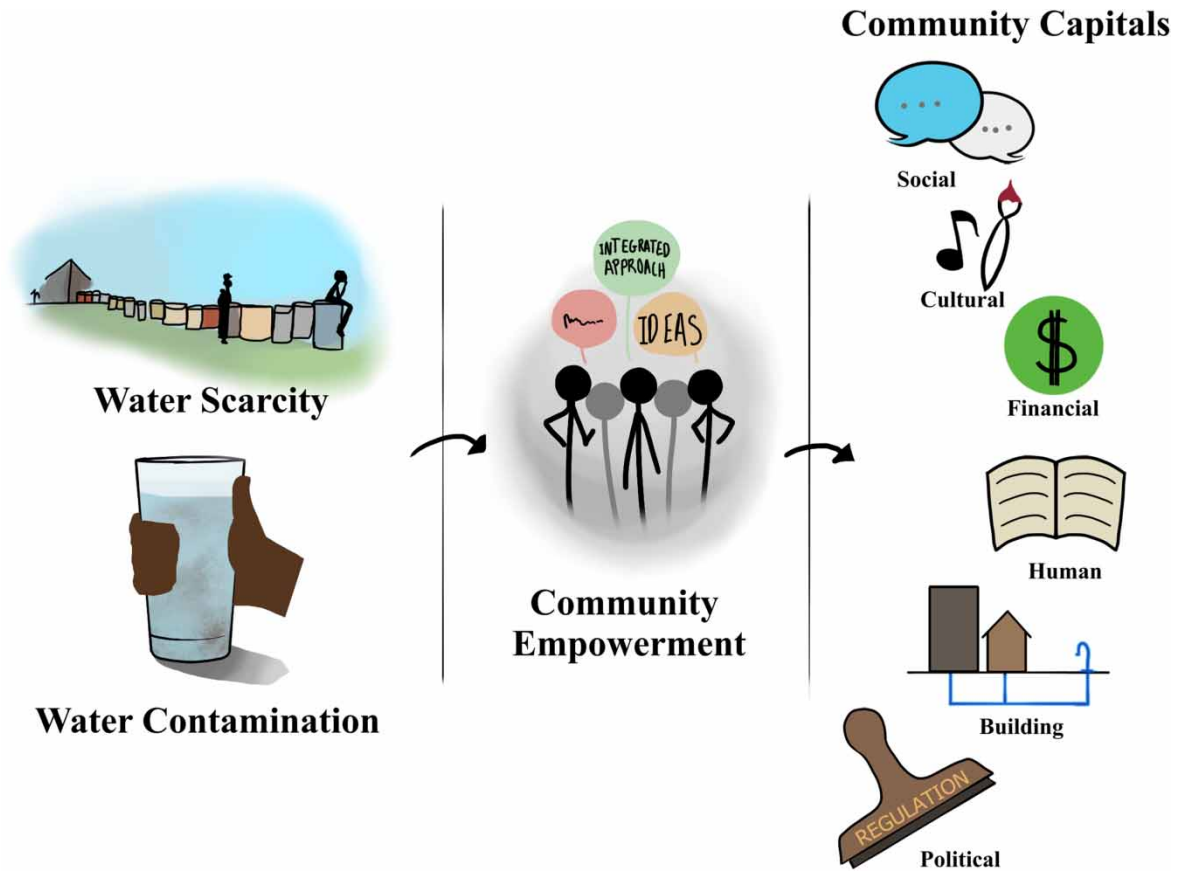
GRAPHICAL ABSTRACT



INTRODUCTION

The United Nations Sustainable Development Goal 6 (SDG6) of 2019 (United Nations, 2019) calls for universal access to water and sanitation by 2030, specifically with the laudable goal of eliminating waterborne disease. Inadequate access to water and sanitation is responsible for millions of deaths a year and debilitating illnesses for countless others (WHO & UNICEF, 2015; Water Aid, 2016). Tackling this problem is critical to achieve improvements in the quality of life and gain in meaningful development. Achieving this in the peri-urban communities in the Global South is particular challenging, as they often have a partial but profoundly inadequate supply of water and marginal sanitation at best. These environments present a high risk of contracting waterborne diseases, including cholera, dysentery, and typhoid, all of which can be fatal.

In this article, we discuss findings from advocacy research (Padgett, 2012) aimed at addressing chronic critical household water quality concerns in one of the peri-urban communities in Dar es Salaam, Tanzania. We build on the work of Schouten & Moriarty (2003), who argued that rural water systems would not be improved through the sole application of technologies, such as hand pumps and borehole wells, but instead needed community-based water management and community-level governance systems. This development approach aims to engage the community in identifying issues, finding solutions, and managing the implemented water systems.

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The results were systems for water delivery in rural communities that incorporated community management structures, such as community-level water committees that oversaw maintenance, the collection of user fees to finance management, and drafting of rules and regulations (e.g., Lockwood, 2004). A critical insight from this work was that communities themselves could identify their concerns, including the issues with water delivery and the risk exposure. However, the recurring problem was that community water committees lacked the resources and the necessary expertise to address these concerns.

Given the need to assess water and sanitation as integrated concerns in the community, we chose the community capital framework (CCF) for our analysis. The CCF conceptualises community development through the interaction of seven integrated stocks and flows of assets: (1) natural, (2) culture, (3) human, (4) social, (5) political, (6) financial, and (7) built, adopted from Beaulieu (2014) and described in detail in Supplementary Material, Table S1. As one capital changes, others will also change. The key to development is making community investments that lead to positive changes across capitals. Emery & Flora (2006) call this process 'spiralling up' and describe its implementation in a community in Nebraska, USA. The community invested in built capital that created inviting spaces for youth in the centre of town, which led to greater engagement of youth in the community (cultural capital), which improved community interaction (social capital) and ultimately the willingness of youth to stay in the community (human capital).

The concept of community assets has also been applied in the context of low-income countries. Chambers & Conway (1992) incorporated capitals into their 'sustainable livelihoods approach' (SLA) to the community development. They argued that an SLA framework could improve development analysis approaches through attention to built and financial capitals and social and human capital developments. Gutierrez-Montes *et al.* (2009) deepened the connection between the CCF and SLA in international community development, arguing that moving from four to seven capitals allowed for a more robust analysis of where investment was needed to improve development prospects. Sseguya *et al.* (2009) applied the CCF in community development research in rural Uganda, arguing that investments in social capital proved critical to the sustainability of development initiatives.

Kais & Islam (2016) used a community capital approach to assess resilience in the context of climate change, arguing that resilience is connected to the robustness of each of the capitals, given climate disruptions. Recent work by Lachapelle *et al.* (2020) has applied the CCF to assessing community resilience in Latin America, arguing that the framework allows for more holistic assessments of community resilience to economic, political, and biophysical shocks. Gordillo *et al.* (2019) used the CCF as a conceptual framework to understand the assets that need to be developed and potential impacts to improve access to water and sanitation in communities in Chiapas, Mexico. Gasteyer & Araj (2009) used the CCF at the community level in Palestine to demonstrate that access to water challenges was related to natural capital (availability of potable water) and political capital (Israeli colonial restrictions on water access and distribution). Access is also dependent on community-level cultural capital in the form of clan-based vs. participatory, democratic decision-making around water governance.

This paper reports the results from a field study of water quality, sewage contamination, and water supply in the densely populated, peri-urban, informal settlement of Dar es Salaam, Tanzania. Using the community capital framework (CCF) as an analytical tool (Emery & Flora, 2006), we have proposed solutions to this complex, challenging problem of ensuring that the community has an adequate water supply and sanitation. The approach proposed for our study area serves as a model for an asset-based approach that simultaneously addresses infrastructure upgrades, improvements in governance in terms of actions and decisions, and improved individual and household knowledge about water quality, hygiene, and sanitation to mitigate the risk of exposure to waterborne disease in the African peri-urban community context. The CCF approach is a significant improvement over past practices where agencies have tended to focus on a single aspect of the challenge by providing centralised

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infrastructure, such as water delivery systems, implementing decentralised systems for service delivery, or creating regulatory mechanisms. As these sectoral attempts ultimately fail to capture the full scope of the problem, a more comprehensive approach is necessary to solve this complex and challenging problem of providing adequate safe drinking water and proper sanitation.

METHODS

As an advocacy research endeavour, this project aimed not only to identify the causes of chronic household water quality problems, but also to use this knowledge to identify the action to improve conditions. This research required a multi-disciplinary, multi-method approach to assess the biophysical environmental and technical drivers of contamination, the governance decisions by key decision-makers in the water and sanitation sector, and attitudes and constraints that drive household-level decisions and actions around water management. Thus, we present here a nested analysis of biophysical conditions, perspectives of key informant water managers, interviews of women at the household level, and participant observations. Such multi-method, multi-disciplinary approaches are especially applicable to advocacy research, as the research aims to contribute to a social change rather than simply to increase knowledge within a particular field of scholarship (Padgett, 2012).

Study area: water and sanitation challenges in Dar es Salaam neighborhood

The study area is a peri-urban area of Dar es Salaam and is shown in Figure 1 (map). The neighbourhood was chosen as the co-authors had previously assisted in the area with the funding and construction of a well and plumbing system at a neighbourhood church to provide community access to water, as well as with the formation of a community water board to oversee the operation and maintenance of the well. In addition, the area is representative of other peri-urban areas within the city of Dar es Salaam and other African cities, where the populations are growing rapidly despite limited resources (Roudi-Fahimi *et al.*, 2002).

The study site is home to people of different ethnicities representing multiple cultural groups. As with many low-income countries, water scarcity, poor water quality, and poor wastewater management are complex and ongoing challenges facing low-income and underserved communities. The situation in Tanzania is particularly dire as it suffers from multiple forms of water scarcity (Mbani, 2017; Ngasala *et al.*, 2018). Specifically, of interest to our study, research indicates that the lack of access to a consistent and reliable water supply is a widespread problem for households in Dar es Salaam, Tanzania (Kyessi, 2005; Smiley, 2016; Ngasala *et al.*, 2019b). At a micro level, the impact of water scarcity on environmental health is evident in peri-urban areas of Dar es Salaam, where scarcity is compounded by poor sanitation, poor household and public hygiene practices, poor water quality, and poverty. Residents of the study area are low- and middle-income wage earners who spend a high proportion of their income purchasing water for domestic use and wastewater management. Human waste from the area is discharged into poorly constructed septic tanks and pit latrines that subsequently contaminate groundwater sources, affect drinking water quality, and pose significant environmental and human health hazards. Consequently, preventable waterborne diseases like cholera, diarrhoea, and typhoid occur in the study area and Dar es Salaam city every year (Ngasala *et al.*, 2019b). Additionally, the burden of finding clean water and averting the health impacts of waterborne disease falls disproportionately on women and children who constitute the most vulnerable segments of the study area.

Data collection

Prior to data collection, the study was approved from the Tanzania Commission of Science and Technology (COSTECH) and the Institutional Review Board (IRB) at Michigan State University. The pilot study in Dar es Salaam, Tanzania, used a multi-method investigation. We combined household surveys of women, key informant

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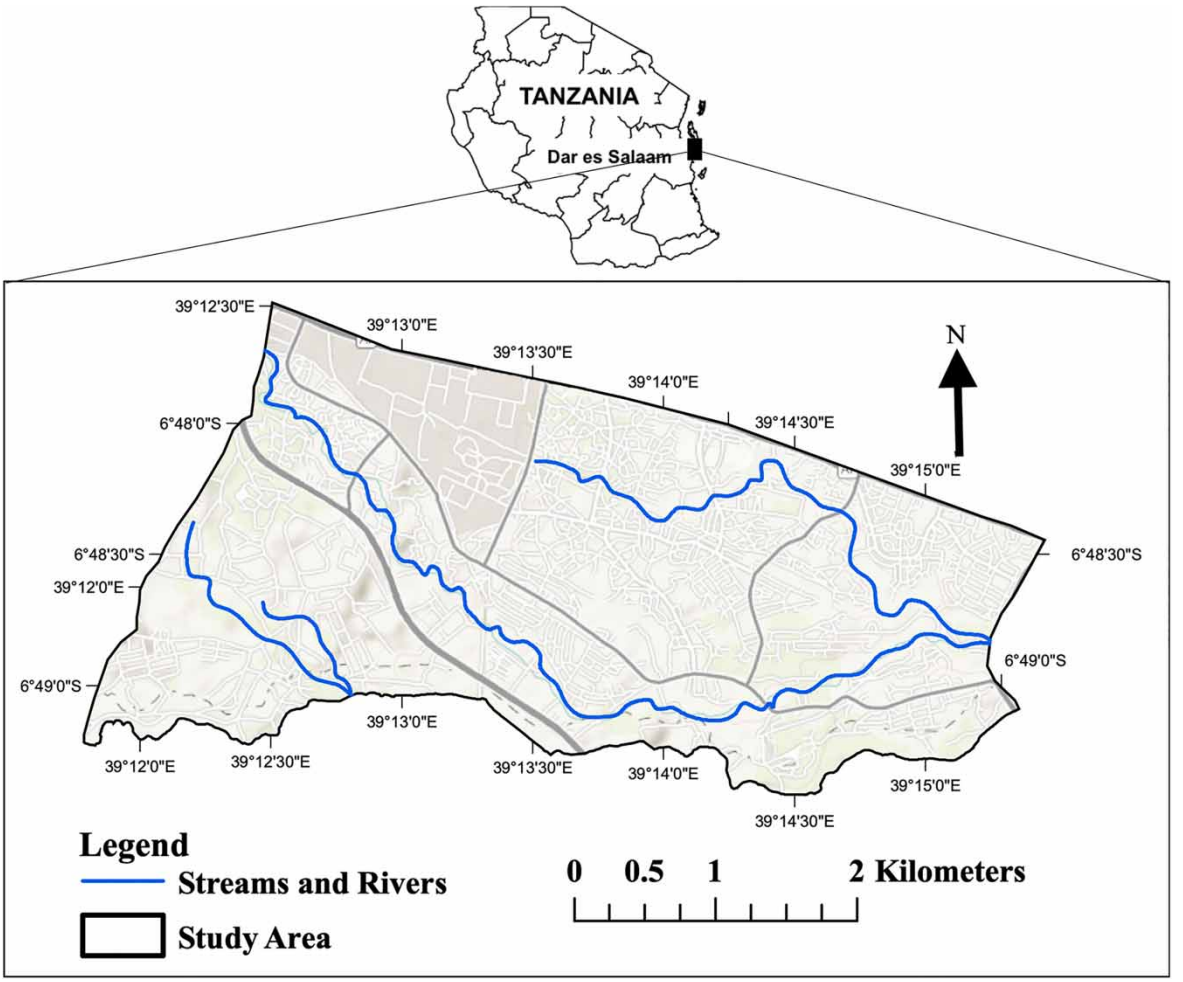

Fig. 1. | Map showing the study area neighbourhood in Dar es Salaam.

interviews, and field observations. We implemented these methods to make deductions about household water storage and hygiene practices and assess the attitudes and knowledge level of household members regarding water and sanitation issues. The household survey of the study area involved a stratified cluster sampling technique that combined a random starting point with a standard assessment interval to determine the selection of households from which to choose survey respondents. The study area was divided into four sections. With the help of the local authorities who are familiar with the area and know the arrangement for the houses, we were able to identify and select houses for each cluster, making sure that they relatively evenly spread throughout the population. Households from each of these groups or sections were randomly selected to form a sample population (Figure 2) (Lemeshow, 1988). In the Global South where population lists are not readily available, and the households are not arranged in any order on the ground, or because transport between households is very difficult, such cluster sampling techniques have been considered adequate for making valid assumptions about the representation of community profiles (Henderson & Sundaresan, 1982).

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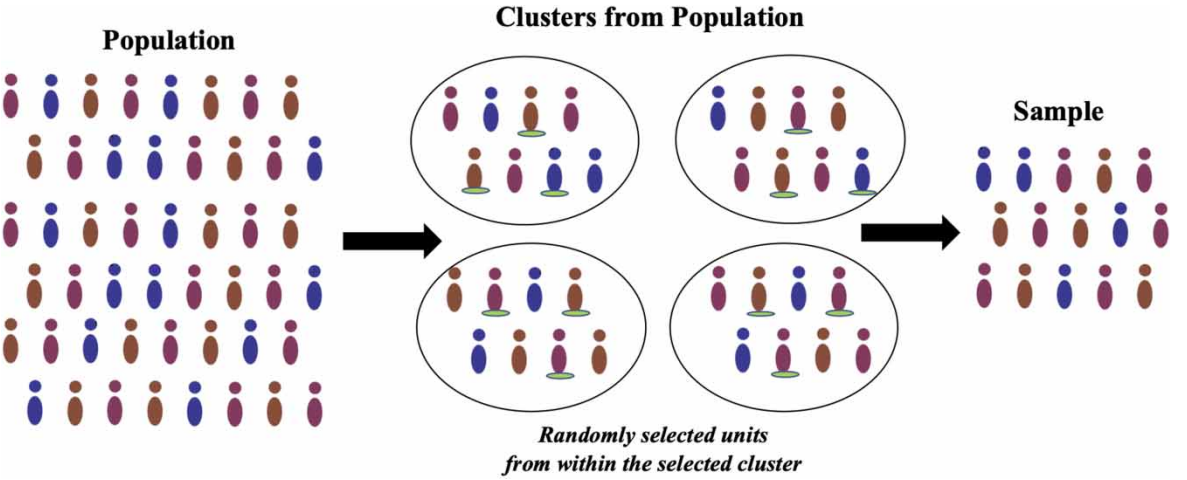

Fig. 2. | An example of randomly selected households from clusters created from the population.

The research team conducted face-to-face surveys with adult women aged 18 years and above from 63 households, representing 6% of the households in the community. Face-to-face surveys at the household level are frequently used in contexts where it is not feasible to implement telephone, email, or mail surveys. This method has been specifically used to understand the predominant household knowledge, attitudes, and practices around drinking water, sanitation, and hygiene within a given community (e.g., Mimi & Salman, 2008). The response rate was 97%; two households were not surveyed because there was no adult in the home. The survey was designed to assess respondents' knowledge, attitudes, practices (KAP) and perceptions related to water sanitation, water quality, and water management issues.

Key informant interviews are increasingly recognised as an essential method for assessing the challenges and opportunities associated with water governance (e.g., Abu, *et al*., 2021). We interviewed 15 key informants representing community and religious opinion leaders, water vendors, public health workers, water and wastewater management officials, and local government officials responsible for the city water supply and wastewater management. They were interviewed about the status of water quality, water supply, water sanitation, and what they know about household water storage practices, as well as community environmental conditions. The findings from these interviews and household surveys are presented in this paper. Household surveys and key informants' interview questions are provided in the Supplementary Material (see Appendices B and C).

As per methods advised for the assessment of WASH programmes (Achermann & Almasri, 2020), the research team used field observations to verify interview responses. After each household interview, the team conducted field observations with additional questions to the residents if needed. The observations included the location of water sources and environmental pollution caused by poor sanitation practices and inadequate water and wastewater management.

RESULTS AND DISCUSSION

Results are reported into two sections. The first section includes the findings from the surveys, interviews, and field investigation from the field study of water quality, sewage contamination, and water supply. This section is divided into three categories: water scarcity, sanitation practices, and water quality. Additionally, we report some observed behaviours and narratives from the field about the water and sanitation problems in the study

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area. In the second section, we proposed six CCFs as an analytical tool for solutions to this complex, challenging problem of ensuring that the community has an adequate water supply and sanitation.

Field study findings

Water scarcity

Household interview responses. Our survey indicates that 87% of household respondents reported water scarcity issues. The municipal water supply was insufficient for household needs, leading residents to use a combination of sources to meet their needs. This combination consisted of connections to the city water supply system, water sourced from city vendors, rainwater harvesting, shallow wells, and deep wells, or boreholes. Most households, 51%, said they prefer to get their water from the city supply system, but this is frequently unavailable; therefore, they turn to other sources (Supplementary Material, Figure S1). Thirty-nine per cent of respondents reported having a connection to city water supply lines operating as standpipes. Half of those said water flows through the pipes infrequently. Respondents to household interviews reported many reasons for the unreliability of city water supply, including poor infrastructure design, inadequate management, and suspicion of corruption by city officials. In other words, household respondents associated the deficit in water supply – natural and built capital – with weak management and governance – political capital – and poor infrastructure design. Figure 3 shows the alternative water sources used by interviewees, considering availability, with more than 50% of households surveyed relying on domestic wells.

One consequence of the water scarcity problem is that women spend a disproportionate part of their day fetching water (Figure 4). In 9 of 10 households surveyed, women were primarily responsible for fetching water. They reported to spend an average of 20 min a day fetching water with the longest time of 45 min, with most of the time due to waiting. Similarly, UNICEF (2016) reported that in urban areas of sub-Saharan Africa, the average time required to collect water is 25 min. Other studies in peri-urban areas of various countries reported that long water collection and waiting times is one of the most serious water problems, with times ranging between 20 and 38 min (Adams, 2016; UNICEF, 2016; Geere & Cortobius, 2017). Surveys also revealed that 44% of the households surveyed use between 7.5 and 12.5 litres of water per day per person for cooking, bathing, laundry,

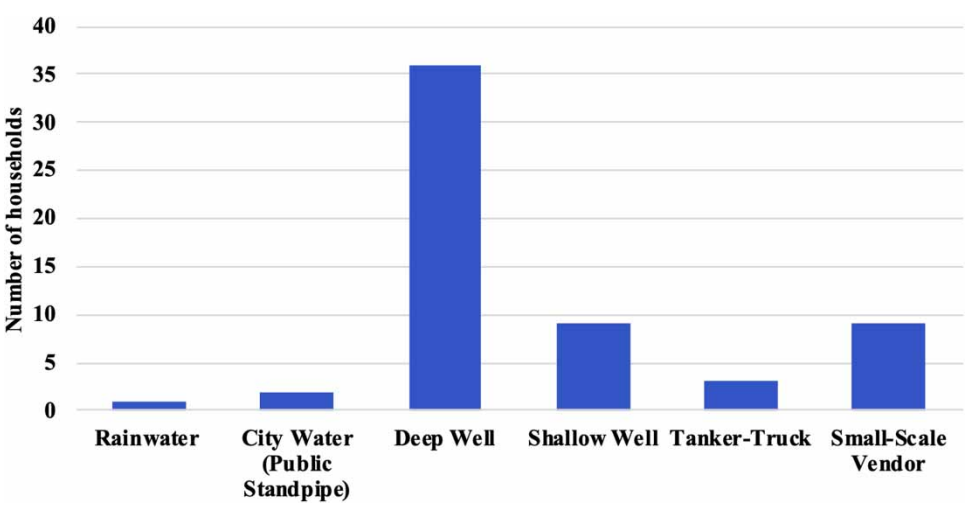

Fig. 3. | Immediate alternative water sources used by interviewees, considering the availability.

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Fig. 4. | Woman waiting to collect city water from a public standpipe.

and cleaning. The recommended WHO standard is 20 litres per person per day for food and drinking only. As shown in Figure 4, the lack of reliable water significantly affects human capital at the community level.

Key informants and field observations. Interviews with key informants such as city officials and local water vendors confirm the reports from the households about the infrequency of city water supply in the study area. City water is available from once a week to once a month. The officials attributed the instability of the water supply to frequent breakages and leakages of the city water piping system. Our field observations and investigation show that water scarcity impacts sanitation, proper hygiene, disease prevention, and public health. For example, medical practitioners who spoke about hygiene practices in the community said few people wash their hands after using the toilet, thus heightening the likelihood of infections and disease outbreaks. In interviews, health officials stated that 80% of school-aged children who miss school do so due to waterborne disease. Urinary tract infections are prevalent, especially among women, due to a lack of water and proper hygiene (Graham *et al*., 2021). Water scarcity also compromises the quality of sanitation in public hospitals and clinics. Informants reported that the recurrence of waterborne disease is frequent.

Sanitation practices

Household interview responses. More than 50% of respondents to our household surveys reported that they dispose of wastewater from household cleaning, laundry, and dishwashing on the surface of the ground outside their premises or in septic systems. More than half the homes we visited were surrounded by swampy areas, stagnant pools, soap residues, green slime, and foul odours (Figure 5). Nearly 51% of the homes surveyed had toilets that collect sewage in a single pit, 39% had an outside pit latrine, and 8% had an unimproved pit latrine. In comparison, a properly designed and constructed sewage collection system, i.e.,

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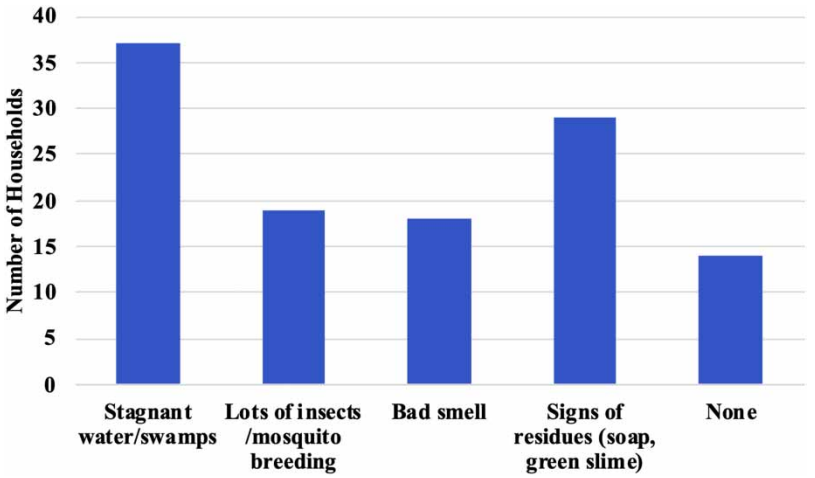

Fig. 5. | Observed site conditions of households interviewed.

septic tank, must have two parts to separate between heavy solids and wastewater before emptying or further treatment (U.S. EPA, 2018). More than 50% of households state that their sewage pits fill up as frequently as 6 months to 2 years. A properly constructed septic tank should take 3–5 years to fill up with solids, depending on the household size and frequency of use (US EPA, 2015).

About 23% of respondents stated that they separate bathing water from sewage, but they release bathwater on the ground surface outside their homes. Also, 23% of households surveyed said their pits overflow, especially during the rainy season, and 18% reported that they allow shower water to run freely in front of their yard (Supplementary Material, Figure S2). When asked if public health inspectors visit their households for sanitation inspection, 50% said they do so occasionally, averaging once a month. The other 50% said public health inspectors had never visited them. Most household respondents stated that they could not afford to pay private companies to empty their septic tanks. Residents of the study area reported that they commonly discharge their overflowing septic tanks and toilet pits into the Ng'ombe River, especially at night or during the rainy season.

Key informants and field observations. Our field observations indicated that none of the homes in the study area are connected to the city sewer system. Wastewater management officials from the city reported that all residents rely on private companies that use tanker trucks to empty the sewage from their septic tanks and pit latrines. In some cases, homes do not have access to roads, thereby preventing truck access. Officials also stated that the contamination of well water by sewage results from poor municipal planning and the proximity of water sources to septic systems, which was confirmed by Ngasala *et al*. (2019a). Sewage management officials stated that the private contractors' sewage management practices pose significant risks to water sources.

Public health officials reported that inspections are infrequently conducted unless official agencies receive reports of wastewater being discharged improperly due to a lack of resources. When public health officials visit homes and find wastewater being discharged improperly, they alert health authorities or local government officials by filing reports to the appropriate agency. These reports rarely result in action, but even more rare were efforts to provide technical assistance to improve household wastewater management.

We also interviewed representatives of private waste management companies. They reported that a recurring issue was that residents place a low priority on waste removal, including the evacuation of pit latrines, because they cannot afford the cost. Consequently, the residents allow pit latrines to fill beyond capacity and overflow,

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resulting in visible and significant health risks. Furthermore, waste stabilisation ponds that serve the community are quite distant from the community, increasing emptying and disposal costs.

Water quality

Household interview responses. As indicated by the survey responses and shown by Ngasala *et al.* (2019a, 2019b), poor sanitation practices impair water quality. To determine the level of sensitivity and the implications of poor sanitation practices for water quality in the study area, we assessed respondents' knowledge, attitudes, practices, and perceptions concerning water quality issues. Forty per cent of survey respondents reported wastewater overflowing septic and storage tanks during rainy seasons, contaminating both surface and groundwater. As shown in Supplementary Material, Figure S2 and discussed earlier, more than one-half of the households surveyed had wastewater discharge, soapy residue, and green slime outside their premises. Nearly 7 in 10 had never repaired their septic systems, thus increasing the likelihood of sewage leaking into groundwater and contaminating domestic wells. As reported earlier, domestic wells are the most reliable water source in this area, with more than 50% of households relying on them (Figure 3). The respondents rated the quality of well water as average, although it is the most common alternative source of supply; however, 22% respondents stated that well water tastes very salty. Most respondents (63%) rated the quality of city water as relatively clean, but stated that they believe it becomes contaminated during storage. Most interviewed residents reported not treating their water before drinking because of the associated high cost.

Key informants and field observations. The community leaders interviewed stated that well water is readily available and safe to drink, but the taste is poor. They admitted that water from shallow wells is unsafe to drink because the wells are too close to septic systems and pit latrines and are likely contaminated by sewage. Leaders are aware that deep wells are preferable to shallow wells as a source of drinking water; they said most people could not afford the cost of installing deep wells for their homes, so they resort to installing shallow wells. Community leaders also recognised that the quality of city water is sometimes compromised by soil, dust, and sewage contamination because of frequent breaks in the pipe network and leaks, which expose the pipes to sources of contamination.

Interviews with water vendors that service the community show that there is a great deal of uncertainty about the source of the water sold (Supplementary Material, Figure S3). Some vendors admitted that they collect water from leaks in the public pipes and retail the likely contaminated water to unsuspecting households. As one informant vendor put it,

> '*We think water is clean, but because our delivery containers are dirty, we end up contaminating clean water. Our customers complain because most of the contamination is coming from our containers*.'

Small-scale vendors admitted that their customers complain about the quality of water they supply. The vendors suspected some of these complaints might be legitimate because they are uncertain about the provenance of the water that they purchase from wholesale water distributors. Vendors also said the quality of city water is very poor after a prolonged interruption in the supply, with city water being heavily tainted by soil, dust, malodorous compounds, and the taste of chlorine, especially during the rainy season. Vendors also cast doubt about the quality of well water that they retail to their customers. They said wholesale distributors sometimes mix city water with well water to dilute the taste, so that the wholesalers can sell more to increase their profit margins.

Additional field observations

Other endemic structural and systemic issues affect water quality and water sanitation in the study area beyond those previously mentioned. Local officials and some community leaders said these issues are no less critical

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and represent intrinsic factors needed to manage and improve the overall environmental conditions of the neighbourhood. They alleged that some residents engage in illegal practices, such as tapping into the water distribution system, which threatens public health. Our field observations showed that the pipe network is often exposed above ground, and sometimes the pipes are located near sewage disposal sites. Officials at the city water agency, Dar es Salaam Water and Sewerage Corporation (DAWASCO), also said that water pipes are frequently damaged during road construction projects. They regard such damage as avoidable if road projects are properly coordinated between the water management agency and the city road-building authority, TANROAD.

Summary of findings

Although more than 80% of households say they rely on water sourced from domestic wells, survey respondents consider the quality of this water to be mediocre. In addition, the water tastes salty and is contaminated with bacterial matter, potentially from septic tanks, as reported by Ngasala *et al.* (2019a). Furthermore, we reported that even though one-third of the households are connected to the city water pipe network and the availability of this water is not reliable. We also reported that city water is often contaminated because of pipes exposed above the ground level. These findings are consistent with Ngasala *et al.* (2019b, 2021), who found that city water in this area is contaminated at home during storage. The primary source of contamination of city water is when water from domestic wells that are located too close to septic tanks and pit latrines are mixed with the city water at either the household or vender level.

From the findings we have reported, the study area residents appear highly vulnerable to the outbreak of serious waterborne diseases. Frequent outbreaks of cholera, diarrhoea, and urinary tract infections occur every year (Graham *et al.*, 2021). Eighty per cent of school-age children in this area who miss school each year do so because of illness attributed to waterborne disease. Lacking the financial resources to treat their water regularly, many community members reported using untreated water. Ngasala *et al.* (2019b) confirmed that treatment cost appears to be a significant barrier to the availability of clean water. This is a common problem in Tanzania's urban and rural areas, as shown by Ngasala *et al.* (2020) as sewage and wastewater disposal practices at the household level contribute to the contamination of water that people depend on for drinking, cooking, and bathing. Particularly troubling is the apparent lack of any real sense of urgency on the part of public health and local government authorities to do something about the situation to prevent disaster.

Solutions using the community capital framework

As Schouten & Moriarty (2003) note, the empowerment of community members is critical to the success of programmes that aim to educate, inform, and galvanise the residents of Dar es Salaam to take actions that will protect their health. Incorporating new technologies and changes in knowledge, attitudes, and practices involves investments not only in top-down human and built capital, but also the social and cultural capital that build community capacity for adaptation and resilience (e.g., Gasteyer & Araj, 2009; Sseguya *et al.*, 2009; Lachapelle *et al.*, 2020). The investments in social and cultural capital are critical to building the trust and empowerment at the community level for people to take the steps that will effectively ensure public health. Solving the problems related to water and wastewater infrastructure and availability will need a highly integrated approach, whereby a positive change is achieved across community capitals. As was shown by Emery & Flora (2006), in their case study in Nebraska, USA (Emery & Flora, 2006), but also reiterated in studies in the context of communities in the Global South (Gasteyer & Araj, 2009; Sseguya *et al.*, 2009), investments in cultural, social-political, human, and built capital are essential.

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Social capital

Social capital is an area of investment that impacts the level of cooperation among people, groups, and organisations in the community. It includes key elements in collective action to solve problems including leadership, collaboration, mutual trust, and a sense of a shared future (Uphoff, 2000; North Central Regional Centre for Rural Development, n.d.). In our study area, community leaders such as school headteachers, public health officials, church pastors, and mosque imams are highly respected, and their voices are regarded. We recommend that community leaders should organise to form a Water, Sanitation, and Hygiene (WASH) committee that has a shared vision. This committee can collaborate with the local government in the community to build the gap and strengthen the relationship between the residents and the local government leaders within the community.

Our findings and the literature have shown that water scarcity and poor sanitation challenges affect women in low-income countries more than men because women are responsible for obtaining and managing household water supply, sanitation, and health (e.g., UN Water, 2006b; Wutich, 2009; Graham *et al*., 2016). As shown in our survey results, women are responsible for water collection in 90% of households. There are many challenges that women in East Africa and other low-income countries in Africa face daily due to the time they spend collecting water, which includes travel and waiting times (e.g., Graham *et al*., 2016).

To address WASH issues, women can use already existing groups as a platform for collaboration. For example, women groups in this area meet regularly for different community and social events. One of the popular women programmes is called Village Community Banking (VICOBA), which provides essential microfinance management and enterprise development skills to low-income people (usually groups of 25–50 people, mostly women) who need capital to start their own businesses (Kitega Community Centre, 2016; Muganda, 2016). The concept of VICOBA is self-empowerment, community ownership of projects, capacity-building, and the mobilisation and management of local resources (Muganda, 2016). These women groups can be used to provide organised leadership training to enable young girls, women, and even older women to pursue solutions to address the lack of water and poor sanitation, making sure that young girls, particularly, are taking an active part in decision-making.

Cultural capital

Cultural capital refers to the way people live and act within the community, their traditions, cultural heritage, art, local beliefs, values, history, festivals, and language. It includes, for example, what voices are heard and which voices influence what areas (Emery & Flora, 2006; North Central Regional Centre for Rural Development, n.d.). Cultural celebrations, especially religious and tribal ones, are highly regarded in urban and peri-urban areas of Dar es Salaam and Tanzania in general. It is a place where people of all ages, youth and old, women and men, gather for a common purpose. Obviously, in human life, we cannot separate culture and WASH. How water is used and valued accounts for an integral part of a society's cultural identity (WHO, 2006). Therefore, through these celebrations, leaders within the community can use this opportunity to promote the understanding about water, sanitation, and hygiene through cultural festivals with the theme of WASH and by raising awareness, providing education, and capacity-building that involves cultural diversity, stakeholders, and the entire community.

People can use these celebrations as a platform to talk about issues related to WASH that usually affect the community in general and foster the dialogue of cultures to find solutions for water-related problems. In addition, specific groups can use artistic expression, such as drawings, photographs, audio-visual materials, and the performing arts related to water issues, to foster understanding and share information across cultural borders.

Financial capital

Financial capital refers to the available financial resources that can be used to invest in community training and capacity-building, support business development and social entrepreneurship, and expand resources for future

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community development (Emery & Flora, 2006). In Tanzania, many urban and rural areas still function under traditional customs that put women at a social and economic disadvantage, including less access than men to property ownership, training, and employment and not to mention the daily water scarcity challenges they face. Women often lack economic freedom and access to decision-making opportunities at all levels. To build on the social and cultural capital framework, existing women groups, such as VICOBA, can organise their communities to fundraise and take out small loans to cover the cost of materials to construct water supply sources such as communal domestic wells, water storage tanks, and water treatment, provide for well maintenance, and construct latrines and private spaces for menstrual hygiene care, with the shared vision that nobody, especially young girls, women, and children, should have to walk or wait for hours for water or suffer from water-borne diseases caused by poor sanitation practices (UN Women, 2018). Based on these efforts, with the knowledge and training they have received, they will have the capacity to extend their reach to more households and even neighbouring communities. The main challenge for these community organisations to becoming reliable service providers is low operating revenues and a lack of access to finances. It is suggested that users such as households and small business owners around the area be charged an affordable fee to use the service, thereby increasing revenue to support operating and maintenance of the system and ensuring sustainability.

Human capital

Human capital can be defined as investments that contribute to the education, health, and well-being of people, for example, the abilities of people to develop their resources and access outside resources, to access bodies of knowledge and data for community-building (Emery & Flora, 2006; Flora *et al*., 2016). In this community, programmes for sanitation and public health and capacity-building for public health workers should be developed and made freely available to the community. It is essential to incorporate these programmes into the primary and secondary school curriculum with interactive and age-appropriate WASH education materials designed to encourage children to become agents of change in their community.

There is evidence from the literature that health education can significantly reduce water contamination at the household level (Metwally *et al*., 2007). Ngasala *et al*. (2019b) assessed water collection and water-use practices at the household level. They determined how water becomes contaminated because of practices such as mixing and storage in this community. Findings revealed that poor water storage practices and unhygienic behaviours are the leading cause of contamination of city water at the household level. One of the ways to improve hygiene is to integrate hygiene promotion and environmental awareness-related interventions. Through governmental and non-governmental organisations, hygiene promotion should involve (1) interpersonal communication, such as house-to-house visits, public support meetings, as well as the development and distribution of promotional materials such as posters, flyers, and booklets; and (2) education efforts related to personal hygiene such as hand washing, especially after using the toilet, before eating, before preparing and serving food, and personal hygiene for children. Other relevant practices that can be taught to the community are proper drinking water storage and proper use and maintenance of latrines, for example, covering the latrine while not using it. In addition, it is necessary to implement a multi-barrier approach, such as improving the availability of affordable and reliable water storage containers to help residents make better decisions when storing water.

At the household level, education to promote better choices of water treatment technologies will help improve drinking water quality. As mentioned in the financial capital section, financial resources from programmes such as VICOBA can include cost-effective household water treatment technologies and community education. Community education about household water treatment methods, such as boiling, use of inexpensive water filters, chlorine tablets, and UV light disinfection, has proved to be successful in rural Tanzania and other low-income countries (Chaidez *et al*., 2016; Mohamed *et al*., 2016; Ngasala *et al*., 2020). The introduction of these

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easy-to-use household water treatment technologies could provide a multi-barrier system to protect water quality. Additionally, community education about the quality of water sources is the key to improving water quality and human health at the household level. When residents become aware of the differences in water quality from different sources, it will change their perspective and encourage them to pay more attention during storage. The key is to empower the community to feel that they are responsible for making changes in their community. Once the community is aware of the condition of their water, education about proper water storage practices and cost-effective household drinking water treatment methods can be implemented.

Political capital

Political capital can be defined as a measure of social engagement within the community by allowing all groups to have a voice in public issues and engage in actions that contribute to their well-being (Emery & Flora, 2006; North Central Regional Centre for Rural Development, n.d.). In other words, political capital reflects access to power, organisations, and connection to resources (Emery & Flora, 2006; Flora *et al*., 2016). This community and others in peri-urban areas of Dar es Salaam must increase access to water and sanitation through community-based institutions. These community-based institutions should follow community-centred approaches such as community-based natural resources management (CBNRM). This approach uses integrated strategies through user self-organising into recognised local organisations, e.g., associations, committees, and cooperatives (Adams & Zulu, 2015). To succeed, community members must have significant participation and ownership to ensure sustainability. Additionally, it is critical that the number of women participating in these community-based institutions through management, implementation, operation and maintenance, water distribution, decision-making, and regulations be increased. According to the World Bank (2019), water projects that included women were about seven times more effective than those that did not.

Enforcing standards and regulations. The primary importance of community-based institutions is community empowerment, local relevance, increased productivity, and integrity through formulating locally agreed operational rules on management, use of resources, user practices and behaviour community members, key stakeholders, and public-sector agencies or non-governmental entities (Adams & Zulu, 2015). A community can agree on enforcing regulations to ensure that community-based institutions are functional and public health is protected. More importantly, regulations must be supported by adequate policies, programmes, guidelines, standards, and codes of practice. Regulations that apply to the operation of water vendors and wastewater haulers (tanker truck drivers) and related to latrines and domestic well sittings must be enforced. Specifically, those who tamper with the existing systems, including those who tap illegally into the city water supply, must be held responsible for such illegal action.

Small-scale water vendors provide an essential service for households in this community and the city of Dar es Salaam as a whole. However, there are many challenges that community members and vendors themselves face, such as poor water quality, high cost, and reliability of water. Similarly, wastewater hauler or tanker truck drivers are hired by residents to empty their septic tanks or pit latrines. Fees for these services vary depending on the location of the house and the size of the pit. As reported in this study under the results section, the cost is usually almost double the cost of public service. Also, poor management of sewage disposal collected by these wastewater haulers results in significant contamination of surface and groundwater sources (Ngasala *et al*., 2019a). There is a need for more regulatory supervision through the local government related to informal wastewater disposal and wastewater haulers and water delivery from water vendors to address these issues.

Sanitation could also be improved through the development and enforcement of standards for the siting of domestic wells. These standards should be based on the depth of the proposed wells, the type of sanitation

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system, the pumping rate, and hydrogeological properties. Enforcing standards and regulations for siting and proper construction of septic systems or latrines in this area will help ensure that sewage is safely and adequately managed. For example, Ngasala *et al*. (2021) developed and demonstrated a method that could be used to determine site-specific separation distances based on the available information (i.e., soil type and aquifer properties) that can be obtained from well boring logs. They found that based on the soil type and aquifer properties in the study area, wells must be placed at least 34 m from a pit latrine to minimise contamination to an acceptable level. This study demonstrated that new standards and regulations could be enforced to minimise contamination and protect public health by using readily available data and groundwater models. In addition, challenges related to poor road access and lack/inadequacy of sewerage systems must be addressed.

Where latrines operate at greater than their design capacity, additional latrines should be constructed except in areas where latrines and drinking water wells are already in proximity. In this case, other proposed sanitation practices can be implemented, as mentioned later in this section. Additionally, proper training of local masons in the construction of raised, lined, and ventilated improved pit latrines, and the use of the composting latrines (dry sanitation and container-based sanitation practices) should be implemented through education and capacity-building.

Unions for alternative informal service providers. Water scarcity, poor water quality, and sanitation challenges can be addressed by developing and implementing mechanisms that ensure better standards of practice. Given our findings, we believe that vendor unions and wastewater hauler unions or trade associations may help address these challenges. These unions should have membership and community engagement to improve the quality of water delivery services (Wutich *et al*., 2016; Sarkar, 2020). Organised water vendor unions should involve community meetings and advisory boards to improve water delivery outcomes by facilitating vendor cooperation around establishing and enforcing rules and norms. Because wastewater is usually disposed of in waste stabilisation ponds that DAWASCO owns, organised wastewater haulers unions should involve DAWASCO, community members, and advisory boards to improve services. The outcomes will facilitate these haulers' cooperation around the establishment and enforcement of rules and norms. The roles of these unions include:

- Discussing fair prices for the service based on the location and the economic status of the residents.
- Holding those vendors or haulers who charge more than they should or refuse to give service to those who live far from populated areas or on rough roads responsible for their actions.
- For water vendors, participating in the development, implementation, and enforcement of water quality standards.
- Holding regular community meetings to discuss complaints from community members and assessing how water can be delivered to the community clean and safe.
- Being available for emergencies, such as during fires, droughts, and overflows during rainfall seasons.
- Managing wastewater disposal areas properly to avoid overflows and contamination of surface water for wastewater haulers.

Built capital

Built capital includes all the human-constructed infrastructure supporting social, cultural, human, political, and financial capitals mentioned previously, including sewers, water systems, roads, buildings, and housing (Emery & Flora, 2006). Community-led centralised water supply and wastewater management systems and implementing alternative sanitation practices that the community can easily manage have proven to work in other locations.

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Decentralised water supply. The existing centralised water supply system in Dar es Salaam fails to meet the community's demand due to rapid population growth, poor infrastructure, and outdated, under-sized water treatment and distribution systems. Instead, the needs of the communities could be met by decentralised systems due to their low capital and operating costs. In addition, the systems can be right-sized for a specific community. Since surface water sources in this area are not highly reliable, groundwater (shallow or deep wells) or rainwater are the recommended sources. Pumping costs will be significantly lower as the water does not have to be pumped at great distances, and the risk of recontamination in smaller networks is less than in larger ones.

A decentralised water supply system can help address water quality issues because water can be treated at water source intake before it is distributed to the community. Cost-effective water treatment technologies, such as heat or radiation methods (e.g., solar water disinfection (SODIS) and chemical disinfection methods (e.g., chlorination)), can be used in decentralised systems. Physical removal processes such as sedimentation or filtration techniques can also be used at the source. Management at the local level is much easier for smaller systems. Local community members can be employed to operate and maintain the system, and the community-based water boards can oversee the operation to increase sustainability. In addition, this can provide an opportunity for collaboration between community members and other stakeholders such as small-scale vendors, informal markets, and small-scale businesses.

Decentralised wastewater and sewage management. In Dar es Salaam, the traditional centralised wastewater management system (lagoons) has not worked effectively for more than 15 years, treating sewage from only 8% of the population. Although the system seemed to be cost-efficient when it was first constructed, rapid population growth, poor maintenance of infrastructure, and its inability to keep up with the population growth are the main reasons for system failure. The best alternatives and long-term solutions for sewage management in this community are onsite treatment or decentralised wastewater systems, due to their reliability and cost-effectiveness, including low capital costs, low operation and maintenance costs, and even the creation of business and job opportunities (Chirisa *et al*., 2017). Additionally, decentralised systems allow for better local management and are simple and effective, as compared to centralised treatment systems, which are often expensive and challenging to operate. As Jung *et al*. (2018) found in their cost comparison study, the cost of operation and maintenance of the decentralised wastewater management systems is 20–30% less than that of a centralised system. Also, community education will provide community members with the ability to oversee the operation and provide employment, which is critical to ensuring the system's sustainability.

Another advantage of decentralised wastewater treatment is the ability to use greywater recycling. Water recycling can help solve water scarcity and reduce expenditures for purchasing water and for wastewater management and treatment in peri-urban areas of Dar es Salaam (Morel, 2005). Greywater used from laundry, bath, showers, and house cleaning can be recycled for reuse.

Alternative sanitation practices. Due to poor road access to many homes in the study area, the development of new and improved ways of sewage management for the collection and transportation to a treatment system is essential. Dry sanitation toilets, for example, allow for the treatment and disposal of human waste without the addition of water. The composted solids can be used as fertiliser on crops not meant for human consumption. Dry sanitation toilets are advantageous over traditional pit latrines as they are economical, environmentally acceptable, and hygienic (Aburto-Medina *et al*., 2020). The main advantage of dry sanitation practice in this community is that the sewage overflow from pit latrines will be minimised since urine will be separated from solids. Another recommendation is the use of container-based sanitation (CBS). These toilets collect human

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excreta in sealable, removable containers that are then transported to a treatment system. CBS could help minimise drinking water contamination in peri-urban areas such as Dar es Salaam, where sewage management is challenging due to poor road access. CBS can be used in water-scarce areas because it uses little water, is hygienically safe with proper handling, and is affordable (World Bank, 2019).

CONCLUSION

This research aimed to comprehensively identify the barriers to meet SDG6 in a peri-urban neighbourhood of Dar es Salaam, Tanzania. Waterborne disease remains a significant challenge for this community, with significant effects on health. Recognising the integrated nature of this challenge, we took a community asset approach to address the issue. In setting out our objectives for this pilot study and reporting the data, we wanted to explore the extent to which we could identify not only the ecological/natural, infrastructural, financial, and human drivers of water quality contamination, but also the investments that could be made in community capitals to improve conditions. As evidenced by the frequent outbreaks of cholera, urinary tract infections, and typhoid, along with the continued transmission of COVID, there is an urgent need to address the public health and environmental problems related to water scarcity, sanitation, water quality, and household hygiene practices (e.g., Livingston, 2021).

Our findings indicate that achieving SDG6 in a peri-urban environment such as our study area must involve an integrated approach. The water quality challenge is itself multi-faceted – the result of: inconsistent urban water supply from DAWASCO; the overcrowding and lack of planning so that groundwater wells are too close in proximity to septic systems; poor quality of groundwater; insufficient regulatory control of tankers so that the quality of water they supply is suspect; insufficient storage in the household to segregate water from clean and impaired sources; and lack of knowledge and attitudes at the household level about how to keep water safe. The realities of lack of capacity of urban government in Dar es Salaam, as with other African cities, mean that an integrated community approach is essential to achieving SDG6 (Schouten & Moriarty, 2003). The CCF provides a heuristic framework through which the problem can be understood holistically. Our findings indicate that while the problem will necessitate not only infrastructural (built capital) solutions, but also (1) significant investment building on existing social capital to create the systems of community-level collaboration to monitor and regulate water quality; (2) investments to build on significant human capital among women at the household level to improve household water management and protect against contamination; (3) investments in cultural capital to empower the people of this community and similar peri-urban communities to change conditions; (4) investments in political capital to begin creating the planning and zoning systems that facilitate water and sanitation provision and protection of water sources; and (5) investment in the natural capital of the water source itself – eliminating the impairments of water quality to benefit the natural ecosystem as well as human health. Ultimately (building on Lachapelle *et al*., 2020), investment in these capitals will improve the resilience of the study area, given that conditions on the ground now are likely to be exacerbated by climate change and the economic effects of the SARS-CoV2 pandemic.

Our findings demonstrate the value of an integrated approach that uses a whole system framework to analyse the challenges to achieving the goal of SDG6 in a peri-urban community. The CCF allowed us to address the challenge of chronic water, sanitation, and health impairment by focusing on the integration of issues. Additionally, we were able to identify the existing assets in the community, and how those could be built upon to identify strategic investments for long-term change.

Some of the limitations of this study include a lack of data and information about the community from the local government to support the framework of the research. Because of this, researchers spent longer time than expected during data collection and field investigations, especially in the process of sample size selection,

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which also limited the creation of larger sample size. There was a great value in the training the locals to assist with the data collection such as surveys and interviews, which contributed to capacity-building in community; however, culture differences, language barriers, and ongoing local training were among the challenges that researchers experienced, adding time and cost.

Future work should focus on investigating the type of investments within different community capitals that will lead to sustainable water management as well as investments that build capacity at the level of peri-urban neighbourhoods of Dar es Salaam. Based on our work so far, we hope that we have provided some insight about the way forward in addressing some of the enduring and endemic public health and environmental conditions affecting peri-urban areas of Dar es Salaam. We believe that people who are targets of attitude and behaviour change programmes must be active participants in the conception and design of solutions to problems affecting their health.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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