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Understanding Repair and Maintenance in Networked Water Supply in Accra and Dar es Salaam

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ABSTRACT: One of the main challenges undermining water supply in African cities is the rapid decay of networked infrastructures. Urban water managers, policymakers and researchers, however, have paid little attention to repair and maintenance or to their importance for the operation and renewal of urban water utilities. Using a sociotechnical framework, this paper investigates the maintenance and repair practices of utility officials from two water companies, one in Accra and one in Dar es Salaam. More specifically, through the interplay of four variables, we develop a novel analytical framework inspired by science and technology studies to explain and compare the contingent, place-based maintenance and repair practices that shape urban water supply. These four variables are materialities, discourses, institutional arrangements, and the knowledge of local experts. The two aims of this paper are to explain how the 'everyday' repair and maintenance practices of utility officials shape water supply, and to draw lessons for improving water supply in both cities. Our findings show that repair and maintenance practices are strongly shaped by place-based materialities and contextual knowledge in water supply, but at the same time are contingent on wider national and international relations as reflected in discourses, policies, and the supply of technical and material spare parts.

KEYWORDS: Repair and maintenance, non-revenue water, urban infrastructure, urban planning, STS, Accra, Dar es Salaam

INTRODUCTION

Similar to what is happening in many other cities in Africa, one of the main challenges undermining urban water supply in Accra, Ghana, and in Dar es Salaam, Tanzania, is the decay of infrastructure networks. As a result of this decay, water supply in both cities is characterised by interruptions due to leakage, low pressure, and rationing (Peloso and Morinville, 2014; Kjellén, 2009; Smiley, 2013). Neither urban water managers nor policymakers, however, have paid much attention to the need for water infrastructure repair and maintenance to ensure the efficient operation and renewal of water utilities. Instead, urban water research in Africa has predominantly focused on issues of access and inequality (see, for example, Smiley, 2013; Boateng et al., 2013; Bellaubi and Visscher, 2014; Tiwale, 2019) or heterogeneous

infrastructure configurations (Lawhon et al., 2018; Smiley, 2020), while the maintenance and repair of water infrastructure networks has so far received little scholarly attention (exceptions are Alda-Vidal et al.; 2018; Sanchez et al., 2019).

In this paper, we examine and compare how the everyday practices of repair and maintenance by utility officials shape networked water supply in Accra and Dar es Salaam. Our aim is to draw lessons on how to improve urban water supply in both cities and in other rapidly growing cities across the globe. The key question is how we can conceptualise the practices of repair and maintenance by utility officials so as to best understand how they shape, and are shaped by, the interplay of the materialities, discourses, institutions and knowledge in different places. By our definition: (1) *materiality* is the material artefacts, including their properties, that constitute urban water supply systems in a place; (2) *discourses* are the discursive narratives about specific water problems and how various actors see and frame them in media and public discussions in place and time; (3) the *institutional arrangements* in water supply are the formal and informal rules, guidelines, regulations and norms that structure and govern the practices of members of utility companies; and (4) the *knowledge* of key stakeholders is the expertise and experience of local engineers and technicians that enable water networks to be repaired and maintained. We contend that water supply in Accra and Dar es Salaam depends on the everyday repair and maintenance practices of utility officials and that these practices are in themselves contingent on, and shaped by, the variables mentioned above. This conceptual framework helps us to better understand and explain not only how and why repair and maintenance practices of utilities may differ in different places but also the complex sociomaterial relations that underlie and shape the operation of water infrastructure in African cities.

This paper contributes to science and technology studies (STS) by proposing a novel conceptual framework to enhance the understanding of repair and maintenance practices in urban water supply or, more broadly, in urban infrastructure systems. Specifically, this framework refines debates in repair and maintenance studies (for example, Barnes, 2017; Anand, 2017, 2020; De Coss-Corzo, 2020) that seek to broaden knowledge of the complex sociotechnical relationships and the multidimensionality of repair and maintenance that underpin and shape the operation and sustainability of urban water infrastructure. At the same time, we argue that applying this framework offers useful insights on how repair and maintenance practices affect water supply in different contexts. Insights from this paper will therefore promote cross-learning among the staff and administrators of Ghana Water Company Limited (GWCL) and Dar es Salaam Water and Sewerage Authority (DAWASA), as well as within other water companies in Africa.

The remainder of the paper is structured as follows. In the second section, we review the literature on the practices and preconditions of repair and maintenance in infrastructure scholarship and STS in order to highlight their importance for the functioning of urban infrastructure. More specifically, the review articulates the role of incrementality, improvisation and adaptations in infrastructural repair and maintenance. Building on this, in the third section we introduce our conceptual framework with the aim of advancing the understanding of repair and maintenance practices. In the fourth section, we present our research methods and provide details on the main respondents, data collection methods, tools, and data analysis. The fifth section introduces the cities of Accra and Dar es Salaam and describes their water supply. In the sixth section, we discuss our empirical findings based on the four key variables: materiality, institutions, knowledge and discourses. In the final section, we reflect on the implications of our findings for urban water supply and policy and propose avenues for future research.

INCREMENTALITY, ADAPTATION AND TINKERING: STUDIES ON REPAIR AND MAINTENANCE

Repair and maintenance work is crucial to the functioning and renewal of contemporary cities and their infrastructure (Graham and Thrift, 2007; Jackson, 2014). Without repair and maintenance, infrastructure decays, cracks and crumbles, as do the political promises that are associated with them (Barnes, 2017). Steven Jackson (2014) illustrates this crucial importance by emphasising that repair and maintenance is

the fulcrum upon which the "world of things" revolves; infrastructure constantly breaks down due to normal wear and tear, and broken infrastructure is continually being restored through repair work (ibid). Infrastructure decay and break down and the resulting repair and maintenance work is thus characterised as transient, recurring and dynamic (Ramakrishnan et al., 2020) and is necessary for 'welding' together a 'material world' that is constantly falling apart (Jackson et al., 2012).

Many authors have pointed to the potential of repair and maintenance. For Jackson (2019), repair work is not solely conservative, backward-looking, and oriented to returning broken objects to their prior states of functionality; instead, new solutions may be invented through incremental practices of adaptation and tinkering (Baptista, 2019). Pointing to a similar potential, Vinck (2019) contends that these local adaptations and inventive practices by actors (including users) are pivotal in spearheading new technological inventions that better reflect users' everyday needs. Infrastructure breakdown and the resulting repair work are therefore considered to be sites of experimentation, innovation, creativity and learning (Baptista, 2019; Dant, 2019; Barnes, 2017; Graham and Thrift, 2007). STS scholars nevertheless emphasise that repair and maintenance operations are crucial in society not only for sustaining the operation of technical infrastructure, but also for maintaining the social order and power relations surrounding their operation (Barnes, 2017). In this regard, Graham and Thrift (2007) questioned what exactly is being repaired: is it the artefact itself or the negotiated order that it sustains (Graham and Thrift, 2007: 4)? Repair and maintenance practices thus shape, and in turn are shaped by, the technical infrastructure and the sociopolitical and economic relationships surrounding them.

Despite the crucial importance of repair and maintenance, decisionmakers tend to pay little attention to them in the operation of infrastructure; they tend instead to focus on the services derived from the infrastructure (Keough and Youngstedt, 2014; Graham and Thrift, 2007). Only when infrastructure breaks down or malfunctions and thus can no longer deliver its services does their state of repair and maintenance become important to society (Graham and Thrift, 2007; Sormani et al., 2019). Paradoxically, an interruption to service provision thus makes apparent the presence of the infrastructure itself. Anand (2020) further elaborates that the invisibility of repair and maintenance can be linked to the systematic subjugation of the work involved, both in utilities and in society at large. This, he argues, devalues not only the importance of repair and maintenance workers, but also the societal significance of repair and maintenance work itself. In line with this notion, Ramakrishnan et al. (2020) advocate the need to "care for those who care for infrastructure" by remunerating repair workers adequately so that justice and social change prevail.

While emphasising incrementality in repair and maintenance, De Coss-Corzo (2020) contends that repair work involves patchwork that aims to make broken infrastructure functional in any way possible. This may include altering, tweaking or reconfiguring various components in order to make them work in a particular desired way (Barnes, 2017). Patchwork practices thus rely on incremental and ad hoc improvisations by workers; these need not follow a fixed pattern, but are highly dependent on the workers' embodied expertise, creativity, practical knowledge and prior material configurations, as embedded in a particular time and place (De Coss-Corzo, 2020). Every incidence of repair is thus unique and specific to its local idiosyncrasies, and therefore its completion requires different patchwork practices and combinations of skills, experience, resources, materials and logistics. The repair worker's previous experience and knowledge of the system's conditions, the geography, and the environmental conditions are therefore still relevant for anticipatory planning and for identifying which types of breakdowns are more likely to occur in what areas (Anand, 2020; Sanchez et al., 2019).

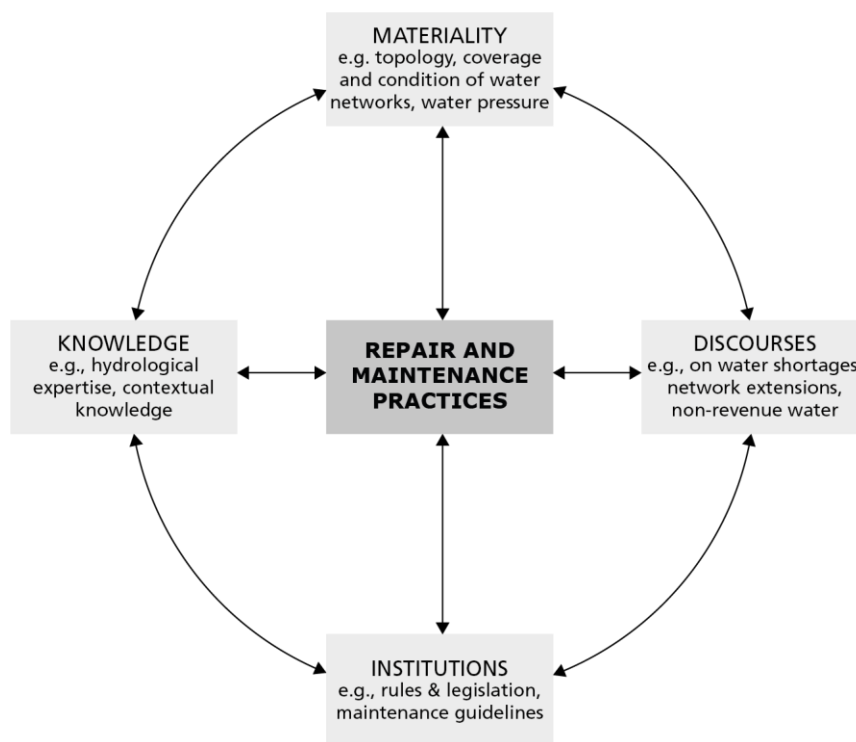
The above literature review shows that there is growing scholarly interest in studying infrastructure repair and maintenance. Previous studies, however, have mainly approached maintenance and repair in their situated contexts and have often focused on specific utilities. Our case study is thus a unique addition to repair and maintenance literature because it employs a comparative lens in order to better understand not just the situated practices of utilities but also those practices that transcend different geographical and institutional boundaries. We thus build on the literature above to provide a conceptual

framework that offers a more systematic approach to investigating and explaining infrastructure repair and maintenance in African cities and beyond.

CONCEPTUALISING REPAIR AND MAINTENANCE IN WATER SUPPLY

To improve the understanding of everyday repair and maintenance practices in networked water supply and other sociotechnical systems, we propose a new conceptual framework that articulates the discourses on water supply, the materialities that constitute water supply systems, the institutional arrangements that regulate them, and the knowledge required to maintain and repair them in different places. We argue that the interplay of these four variables shapes, and in turn is shaped by, the everyday practices of repair and maintenance by utility officials in water supply (Figure 1).

Figure 1. Conceptualising infrastructural repair and maintenance practices.



Source: Authors’ construct.

In Figure 1, *materiality* refers to the physical artefacts or material components, including their properties, that constitute networked water supply systems in a place (Tiwale, 2019). This includes pipe networks, water treatment plants, reservoirs, and water resources, which function together to facilitate water treatment, transport, storage and distribution to various users in the city (Alda-Vidal et al., 2018; Keough and Youngstedt, 2014). Technical properties of infrastructure that are acquired during manufacturing, such as size and diameter, are intrinsic and therefore change little over time; however, the physical properties (such as conditions) can change over time due to decay, appropriation and/or tinkering by human interventions (De Coss-Corzo, 2020; Tiwale, 2019; Graham and Thrift, 2007). An infrastructure’s materiality thus provides a 'space of possibility' within which various actors (including engineers and users) can make use of their knowledge and labour to manipulate, tinker, adapt or appropriate various artefacts in line with their specific goals (Barnes, 2017). As different authors emphasise, however, the ways of manipulating a material artefact are not infinite, but there are certainly ways that an original

system design can be modified that were not anticipated (Mayntz, 2009). As a result, working with the material artefacts in water supply also continuously challenges, broadens and shapes utility engineers' knowledge and expertise about the infrastructure.

Discourses refer to the discursive narratives or controversies around specific water problems and to the ways in which the various actors see and discursively frame and situate them in public discussions. According to Hajer (1995: 44) discourses involve a "specific ensemble of ideas, concepts, and categorisations that are produced, reproduced and transformed in a particular set of practices and through which meaning is given to physical and social realities". As a discourse progresses, key actors begin to form coalitions and alliances to protect and project their interests and agendas (ibid: 3); when actors extend their knowledge, however, they can shift or change their positions within the discourse. Discourses are thus shaped by time, knowledge and the availability of information. Even though discourses often involve disagreements and contrasting views by actors (Darmame and Potter, 1997), they provide an opportunity for stakeholders to engage and deliberate in the process of shaping state policy responses to common societal problems (Bakker, 1999). As a result, discourses influence the ways stakeholders make sense of, and draw attention to, pertinent repair and maintenance needs; discourses also influence the policy pathways for addressing these needs. In the context of water supply, discourses shape the everyday practices of utilities, wider national water policies, and the allocation of resources and investment priorities in the water sector. Discourses thus shape policies, laws, rules and practices across local, national and international levels.

Institutions here are defined as the 'formal' rules and regulations, as well as the 'informal' norms, work routines and standard guidelines (North, 1991) that guide and structure the operations of repair and maintenance at the two water companies and, more broadly, within their respective countries. At the very least, institutions create mechanisms for conformity and 'social order' in the practices of companies and regulate how various actors (such as utility officials, users and local plumbers) relate to each other and to the technical artefacts (Tiwale, 2019). Institutions thus regulate the interrelationships between the different actors involved in infrastructure systems and how these actors engage with technical artefacts in their everyday practices. In utility companies, various rules, policies and standard protocols define specific responsibilities, practices, and the ways in which repair and maintenance work should be organised and executed. At the same time, various informal norms and practical guidelines structure and regulate 'workplace order' during repair work in terms of labour responsibilities, relationships, and hierarchies. These standards and guidelines are also influenced by wider national and international standards and principles. As social constructs, institutions are also dynamic and can change as a result of new knowledge, discourses and technologies. Institutions are often tailored to a specific organisation or city and can thus help us to better explain the differences in repair and maintenance practices in different places.

Lastly, *knowledge* refers to the embodied expertise, experience and 'contextual knowledge' within the city in which the water infrastructure operates. These pieces of knowledge are relied upon by utility officials to facilitate repair and maintenance operations; they include being able to navigate the city, trace network leaks, and fix them efficiently, especially in a context where official maps either do not exist or are inaccurate (Björkman, 2018; Anand, 2020). This knowledge also empowers various actors to improvise, tinker and experiment with new solutions during repair and maintenance (De Coss-Corzo, 2020). Over time, however, as engineers and technicians engage continuously with infrastructure assets, they tend to gain more knowledge of, and familiarity with, the systems' diverse components, functionalities, properties and vulnerabilities, and with their situatedness in the context of their operations; they thus become increasingly adept at dealing with them. To a large extent, repair and maintenance knowledge is acquired and developed through experiential 'learning by doing' (Houston, 2019); however, it is also shaped by hydraulic and mechanical engineering principles that are acquired through formal education and online learning resources (ibid). We argue that technical expertise alone is not sufficient to accomplish repair and maintenance goals, and that it is equally crucial for efficient repair

and maintenance operations that there is detailed place-based knowledge of the city and of the state of infrastructure networks.

RESEARCH METHODOLOGY

Inspired by our conceptual framework above, the following sections present findings from in-depth empirical studies of the repair and maintenance practices of two water companies, one in Accra and one in Dar es Salaam. We build on various qualitative methods, including extensive literature reviews, discourse analysis, and semi-structured interviews conducted in each of the cities between January 2018 and September 2021. A comparative approach was adopted for studying key differences and similarities in the repair and maintenance practices of utility officials across the two cities. This approach allowed us to appreciate the everyday practices of utility engineers and technicians in their real-life contexts (cf: Goodrick, 2014) and to generate theories beyond the local idiosyncrasies of a place while at the same time highlighting local specificities for cross-learning among utilities (Kantor and Savitch, 2005). The two cities were purposely selected for this study for three main reasons: (1) in both cities, networked water supply is challenged by infrastructure decay, leakage, and a high share of non-revenue water, all of which indicate inadequate maintenance and repair; (2) both cities have persistently experienced recursive water crises which are blamed on mismanagement by water authorities and rapid urban growth; and (3) both countries have experienced economic and structural reforms in their urban water sectors, which led first to the privatisation of GWCL and DAWASA and subsequently to their Renationalisation. These commonalities thus provide a suitable context for comparing repair and maintenance practices across both cities.

We first conducted a detailed literature review that covered various academic literatures, official government reports, online media reports and policy documents on the repair and maintenance of water supply across the two cities and both countries. The insights that were thereby gained helped us to - better understand the overall water sector policies of both countries and the situated repair and maintenance challenges; it also helped us develop the conceptual framework based on materialities, discourses, institutions and knowledge, in order to compare and explain the repair and maintenance practices of the two water companies.

Second, building on the literature review, we analysed the discourse of various media and public reports, official policy documents and academic literature; with a focus on full cost recovery, universalisation of access, and non-revenue water. Our aim was to understand how various discourses on water supply affect repair and maintenance in the two cities. It is important to note that the government of Tanzania curtailed press freedom in Dar es Salaam in 2019. Although such media restrictions have the potential to curtail opinions and discourses that contrast with the government's position, we did not encounter difficulties in accessing somewhat critical perspectives and opinions on non-revenue water and on the water crisis in Dar es Salaam, as articulated in news articles and online media.

Third, we then conducted two rounds of field studies in each of the cities, using semi-structured interviews, field observations, and informal conversations with employees of GWCL and DAWASA; these included technicians, engineers, pipefitters, administrators and managers and was aimed at studying their everyday practices relating to water infrastructure repair and maintenance. For two months in the respective cities, we followed repair workers around to different locations in order to observe their everyday practices as they fixed leaks and repaired broken equipment. This offered us opportunities to ask various questions for clarification and to take photographs where necessary. In total across the two cities, 51 semi-structured interviews were conducted with utility employees and 11 interviews with representatives of government administrations, NGOs and international donors. The combination of different qualitative methods helped us analyse the views of the different actors involved, giving us an enhanced and nuanced understanding of multiple perspectives on repair and maintenance. The

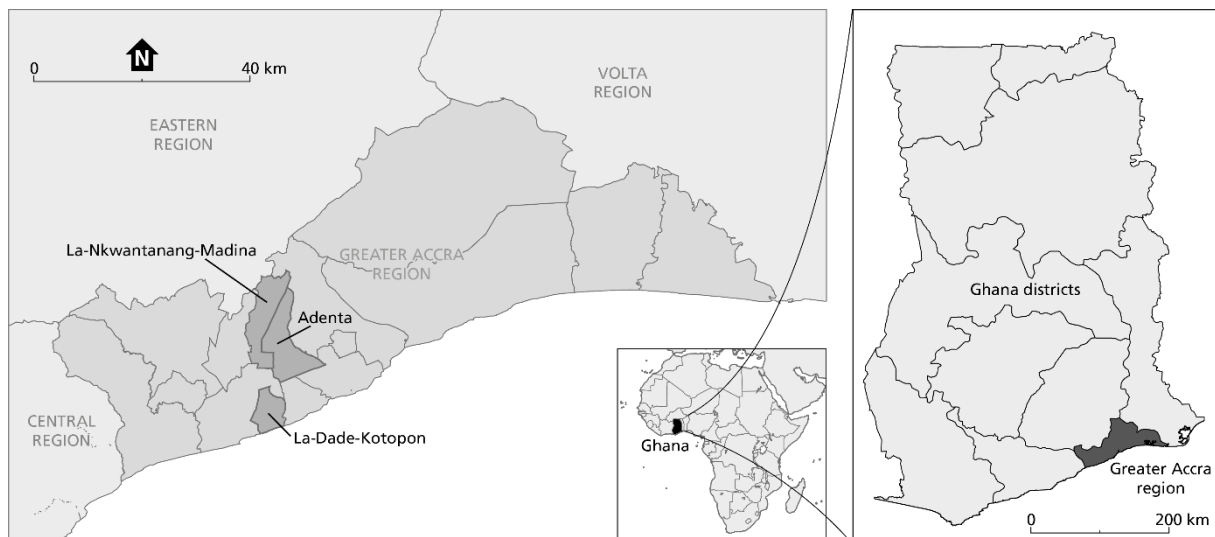
interviews focused on diverse issues in repair and maintenance and cut across materialities, discourses, institutions and knowledge. All field interviews were transcribed, coded and analysed in line with the above-mentioned analytical categories.

WATER SUPPLY IN ACCRA AND DAR ES SALAAM

Accra, Ghana

Accra is Ghana's capital and largest city, with a coastline on the Gulf of Guinea. The Greater Accra Metropolitan Area occupies about 1585 km² of land (Addae & Oppelt, 2019). Accra city alone (Figure 2) has about 2.5 million inhabitants, but the entire Greater Accra Region has more than 5.4 million residents, accounting for about 18% of Ghana's total population (GSS, 2021). Approximately 4 out of 10 residents of Accra live in informal settlements (Mensah and Birch, 2021) where access to basic infrastructure services like water, electricity and sanitation is inadequate (Silver, 2014).

Figure 2. Map of Accra, showing the districts in which data was gathered.



Source: Authors.

Water supply in Accra works through hybrid configurations of networked and non-networked infrastructure and a mix of public and private arrangements; added to this are several informal and private networks that include boreholes, illegal networks, tankers, vendors and producers of sachet and bottled water (Peloso and Morinville, 2014; Alba et al., 2019). Households may use any one of these or a combination of them, depending on factors such as financial capacity, location and cost. The GWCL is the major state water utility company responsible for supplying potable water to residents across the urban areas of Ghana. GWCL's official estimates indicate that 50% of Accra's population has direct access to water supplied by its public water systems (GWCL, 2017); several studies, however, including Ghana Statistical Services' Multiple Indicator Cluster Survey (GSS, 2018), have disputed this figure. The Ghana Statistical Services' survey, for example, indicates that only approximately 22% of the Greater Accra Region's population has access to official water networks (ibid). Similarly, Afriyie and Ferber (2018) found that only about 30% of the population in Accra has direct access to GWCL's water supply for at least 12 hours a day and a further 35% has access three to four times per week. Most people rely on other 'off-grid' systems such as sachet water, private boreholes, vendors, wells, tankers and bottled water (GSS,

2018; Alba and Bruns, 2021; Harris, 2019). The GWCL's water supply comes from treated surface water and seawater desalination plant, which together have a capacity of about 900,000 m³ per day (GWCL, 2018); however, the desalination plant has only operated intermittently due to disputes over contractual arrangements. While this capacity is far less than the average daily water demand in Accra, about 54% of the water fed into GWCL's distribution system is lost due to leakage, illegal water connections, and metering inaccuracies (GWCL, 2018). This situation, coupled with low-pressure problems, further aggravates the city's water crisis. According to GWCL's policies, individual residents are responsible for the private water networks on their premises, whereas GWCL employees are responsible for maintaining and repairing all public water infrastructure including pipes, valves and reservoirs. Maintenance and repair of water infrastructure is thus a responsibility that is shared by state agencies and by water users themselves.

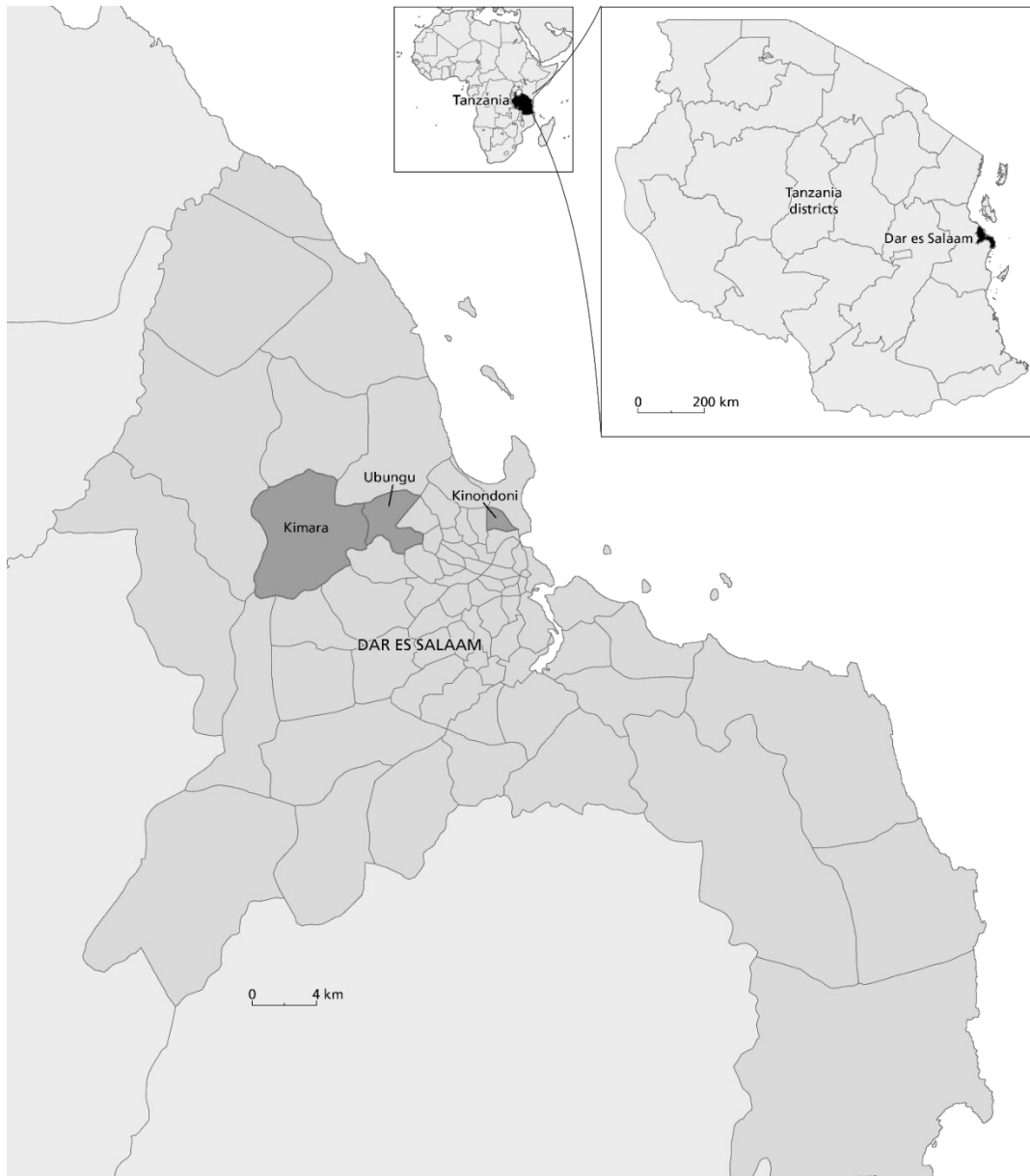
Dar es Salaam, Tanzania

Dar es Salaam was established in 1862 as a port city (Brennan and Burton, 2007). Having rapidly grown to become Tanzania's busiest and most populous city (Kjellén, 2006: 80), it has overtaken Nairobi as the fastest growing city in East Africa (UN-HABITAT, 2014: 149). Situated on the margins of the Indian Ocean and covering an area of about 1400 km² (Figure 3), Dar es Salaam's initial growth was finger-like, extending out along major roads and following water and electricity networks (Monstadt and Schramm, 2017).

Dar es Salaam is one of the fastest growing cities in sub-Saharan Africa and now has a population of about 5.4 million (the United Republic of Tanzania [URT], 2021). As a result of rapid urbanisation and sprawl, about 80% of Dar es Salaam's population lives in unplanned settlements (Nganyanyuka et al., 2014) with inadequate access to water and electricity services (Monstadt and Schramm, 2017). As in Accra, most residents of Dar es Salaam access water through a combination of diverse configurations including networked water supplied by DAWASA, private mini-grids provided by individuals, individual boreholes, vendors, pushcart operators, tanker services and bottled water (Kjellén, 2006; Nganyanyuka et al., 2014). DAWASA is the state-owned water provider that is responsible for the provision of water and sanitation services to residents of Dar es Salaam region and its surrounding districts. Unlike in Accra, there is no sachet water in Dar es Salaam because in 2019 the national government prohibited the use of plastic bags. DAWASA supplies water to roughly 75% of the population, although many studies suggest far lower access rates (Monstadt and Schramm, 2017; Smiley, 2013). Like GWCL, DAWASA's water supply system consists of surface water treatment plants and boreholes, which together have a total capacity of 520,000 m³ per day (EWURA, 2018; Sippy, 2021). According to an Electricity and Water Utility Regulatory Authority (EWURA) report, DAWASA loses approximately 48% of the water fed into its system through leaks, water theft, and poor metering (EWURA, 2018).

The main challenge facing DAWASA's water supply system is its high pressure, which utility engineers say has resulted in many and frequent burst pipes and leaks. To avert damage, DAWASA's managers decided to operate the plants at 80 to 90% of capacity; thus, although DAWASA's technical capacity is officially adequate to meet the city's daily water demand (EWURA, 2018; URT, 2020), in reality most residents still grapple with various water challenges including intermittent shortages, rationing, and water quality issues. EWURA reports show, for instance, that in an average week DAWASA customers receive an average of 20 hours of continuous water supply per day, but that only about 57% of customers receive 24 hours of water supply every day (EWURA, 2018). Most of DAWASA's water networks are also old and leaking, which accounts in part for the high percentage of non-revenue water.

Figure 3. Map of Dar es Salaam, showing the districts in which data was collected.



Source: Authors.

SITUATING REPAIR AND MAINTENANCE PRACTICES IN ACCRA AND DAR ES SALAAM

This section presents results under four subsections, each of which addresses one aspect of our overall framework: materialities, discourses, institutions and knowledge. In each of these sections, we highlight key differences and similarities between the two cities, to demonstrate how and why repair and maintenance practices might differ, and how they shape and are shaped by those variables across different places.

Materiality

Despite many similarities between Accra and Dar es Salaam, there are considerable differences in their networked water supply. Whereas the GWCL's water supply system consists of surface and seawater treatment plants, that of DAWASA is a blend of underground sources (boreholes) and surface water treatment plants. Approximately 50% of Accra's population is connected to GWCL's systems (GWCL, 2017), whereas 75% of Dar es Salaam's population is connected to the DAWASA network (EWURA, 2018). Those figures, however, do not necessarily imply actual access, household connections, nor uninterrupted water access (GSS, 2018; Smiley, 2013); water supply is shaped instead by conditions of low pressure, leakage and rationing.

Both cities are experiencing rapid, informal urban growth that is characterised by limited space for infrastructure corridors (Silver, 2014; Nganyanyuka et al., 2014). As a result, water networks are typically laid below physical structures such as buildings, 'containers', and kiosks. Such informal development affects repair and maintenance in two main ways. First, those responsible for, or benefiting from, illegal water networks are often reluctant to share information about them, making it difficult for utility officials to discover them. Illegal networks lead to loss of the revenue that could have been used to finance repair and maintenance; they also reduce water pressure and undermine the larger system's operation because they are mostly developed using inexpert practices and substandard materials (Interview 8, 2019). Second, if water infrastructure is built below informally developed buildings (Figure 4), repair and maintenance are hampered because engineers find it difficult to inspect networks and to discover and repair leaks.

Figure 4. Pipelines under frontage of a building in Dar es Salaam.



Source: Authors.

Hydraulic pressure differs between the GWCL and informal water systems. The GWCL's system, for example, suffers mostly from low-pressure problems because of limited natural gravity and because of the distance between the water source and the city. As a GWCL engineer explained it,

Low pressure is still a problem. Because of that, some areas such as AU village don't get a constant water supply in the daytime. As a result, we have to pump water to them every Thursday in the daytime. Because of low pressure, some people have also installed booster pumps on the system, which is affecting the flow. We have identified and removed some of them (Interview 3, 2018).

As the above statement reveals, the immediate effect of low pressure is water rationing, which involves cutting off supply to some areas in order to allow other areas to have an adequate supply. This can subject the hydraulic system to a level of stress that is about 30 times higher than occurs with continuous supply (Darmame and Potter, 1997), which leads to frequent breakdowns. Low pressure can also motivate residents to install booster pumps in an attempt to raise the system's pressure; such interventions, however, usually put even more stress on the networks, causing pumps to fail and pipes to leak (Interview 5, 2018). Equally problematic is the fact that during times of low pressure water tends to stay longer in the pipes, potentially causing reverse flow to occur; this allows contamination through cracks and leaks, with a corresponding risk to health (Interview 10, 2019).

DAWASA's systems, by contrast, are experiencing excessively high pressure due to the increased technical capacity of the water treatment plants. As one interviewee states, "Our main problem now is high pressure. Because most of the pipes are old, the least pressure usually leads to a lot of bursts of pipes, sometimes more than 20 per day. This gives us a lot of work" (Interview 2, 2019).

Unlike low pressure, high pressure increases the frequency of burst and leaking pipes in the network and can worsen minor leaks, holes, and cracks. Most of the pipes are old and weak and therefore burst easily with slight overpressure. Utility officials' workload thus increases and can exceed their capacity; they may therefore opt to ignore or overlook minor leaks in order to prioritise major ones (Interviews 1 and 2, 2019).

The water companies of the two cities are similar in that both experience frequent equipment breakdowns. In Accra, severe water turbidity (due to farming and mining activities upstream) frequently causes filters to break, plus filters also need to be changed regularly because of the use of large amounts of water treatment chemicals. Overuse of chemicals also promotes corrosion, which shortens the lifespan of the equipment (Interview 6, 2018). In Dar es Salaam, however, water levels in the lower Ruvu River frequently fall, usually due to drought or low rainfall; this makes it necessary for some of the water plants to be shut down temporarily. If the equipment is idle for long, it tends to rust and deteriorate, and it then breaks down easily when the plants resume operation (Interview 9, 2019). In both water companies, limited access to spare parts is a challenge, as most water plant equipment is imported and therefore most parts needed for maintenance and repair are also imported. In Accra, interviewees indicated that importing spare parts is costly because of the depreciation of the Ghanaian cedi (Interview 4, 2018). If the company cannot afford the spare part, the equipment is simply abandoned (as in Figure 5). In Dar es Salaam, interviewees indicated that importing spare parts is not only costly, but its delivery also tends to be delayed, which can aggravate minor faults or trigger new breakdowns.

Figure 5. Malfunctioning booster pumps at Dodowa, Accra.



Source: Authors.

In both cases, if importing spare parts is either not feasible, too expensive, or delayed, local engineers may resort to improvising with local solutions and using available resources. If DAWASA cannot afford to import simple spare parts, equipment or materials such as nuts, bolts, and shafts, it usually contracts with local blacksmiths to fabricate them (Interview 5, 2019). Such improvisations and the existence of informal or illegal network extensions and non-networked solutions mean that in both cities the water supply is highly heterogeneous; it is shaped by patchy solutions and add-ons whose functioning depends on repair and maintenance practices that use temporary solutions and informally customised spare parts. Hence, rather than applying standardised, universal technical solutions, repair and maintenance personnel rely on tinkering with place-based configurations and with the local specificities of water infrastructure.

Discourses

In Accra and Dar es Salaam, urban water discourses do not explicitly focus on the maintenance and repair of existing networks; rather, they are centred around the universalisation of water access, cost recovery, and non-revenue water. In both cities, human rights-based advocacy and civil society discourses frame water access and sanitation as a basic human right, in line with the Sustainable Development Goals (Eguavoen and Spalthoff, 2008; Nkonya, 2011).¹ Building on these institutional frameworks, various civil society groups hold the state responsible for universalising water access, calling on it to prioritise network extensions, upgrade the technical capacity of the water system, and ensure the affordability of water tariffs for the urban poor (Nkonya, 2011; Moulton, n.d; Tarlue, 2018). The investment priorities of both utility companies, of state authorities, and of international donors has been driven by this discursive framing of the water crisis. Meanwhile, the need for repair and maintenance is largely neglected in the discourse, which partly accounts for the insufficient allocation of financial resources and of repair and maintenance workers in both cities.

¹ In Ghana, both the National Water Policy (2006) and the Water Sector Strategic Development Plan (2014) recognise water access as a basic human right (MWRWH, 2006, 2014). In Tanzania, the National Water Policy (2002) and the Water Supply and Sanitation Act (2019) explicitly recognise water access as a basic human right (Nkonya, 2011).

Although the necessity of upgrading the water systems is uncontested, in discourses by international donors such as the African Development Bank, the International Monetary Fund and the World Bank, the need to recover costs through adequate tariff structures is emphasised as a key prerequisite for the universalisation of water access and for sustainable water management (see, for example, World Bank, 2018). In both countries, water sector policies and programmes anticipate that urban water users should pay higher tariffs so that the full costs of water supply can be recovered, and repair and maintenance operations can be carried out (URT, 2002; GWCL, 2018; MWRWH, 2014). Civil society discourses, however, have contested such tariff adjustments; instead, they urge public utility companies to improve the efficiency of their bill collection, establish adequate metering, and reduce physical water losses so that water tariffs can be affordable and lifeline rates in the form of targeted, consumption-based subsidies can be available to the poor (Water and Sanitation for the Urban Poor, 2017; Afriyie and Ferber, 2018). We argue that discourse coalitions by civil society groups, plus politicians' election promises, have restricted tariff increases to levels that are able to cover only the cost of supplying water, and that the funds needed for everyday repair and maintenance work are thus limited. In both cities, discourses frame repair and maintenance as the responsibility of the public state utility; this could explain why both companies are reluctant to outsource repair and maintenance work to private plumbers.

Apart from debates on adequate tariffs, another major issue in water discourses in both cities is non-revenue water, that is, water that does not reach the user because of leaks, water theft, or metering inaccuracies. Official data from GWCL indicates that in 2018 54% of water was non-revenue (GWCL, 2018); the situation with DAWASA, at 48%, is only slightly better (EWURA, 2018). As several authors suggest, these statistics may considerably underestimate the magnitude of water losses in both utilities (see, for example, Sweya et al., 2018; Shushu, et al., 2021). In any case, the high percentage of non-revenue water reveals the poor state of networked infrastructure and indicates the inadequate repair and maintenance practices of both companies. Importantly, the resulting revenue losses by both utility companies provoke a vicious circle whereby funding is decreasingly available for repair and maintenance work; such funding is critical for the purchase of necessary materials and spare parts, for logistics, and for the employment of skilled staff who can perform the everyday repair and maintenance work.

In Ghana's national water policies and programmes, non-revenue water is attributed to infrastructure decay which has arisen because of the government's underinvestment in network renewal over the years; most of the network, as a result of this underinvestment, is obsolete (MWRWH, 2006, 2014; GWCL, 2018). In various public discussions, government officials point to the urgent need for investment in network renewal to tackle physical water losses (Smith-Asante, 2015; Agyei Annim, 2020; Larte, 2017). During one such media discussion, the Managing Director of the GWCL revealed that, "Due to the current state of the [pipe] lines, we are losing about 50% of non-revenue water, which results in frequent water shortage [...]. This 42-inch in diameter pipeline has a lifespan of 30 years but these lines are close to 60 years [old]" (Yankah, 2021).

While the need for investment in infrastructure renewal is uncontested, various academic experts and civil society stakeholders have framed the matter as being a result of GWCL's poor management (Afriyie and Ferber, 2018; Van Rooijen et al., 2008). Civil society discourses, for instance, emphasise that if the GWCL could halve the non-revenue water, households' water access could be improved and more revenue could be raised for maintenance, repair and renewal without increasing the water system's capacity (Smith-Asante, 2015; Water and Sanitation for the Urban Poor, 2017; Afriyie and Ferber, 2018).

In contrast to the situation in Ghana, in Tanzania the government blames non-revenue water on commercial water theft and on fraudulent connections by residents, which they say is condoned by corrupt utility officials (Kazoka, 2015; URT, 2020; EWURA, 2018). The Minister of Water, for example, has stated that "rogue water authorities within DAWASA" are pocketing the revenues of the company through commercial water theft (Kazoka, 2015). He insists that such corrupt practices are costing the company about \$2.9 million annually in revenue (Ester, 2020). This narrative de-emphasises the crucial need for the state to invest in maintenance and repair of worn out networks; however, an official

performance report attributed DAWASA's problems with non-revenue water to the utility company's failure to deploy pragmatic strategies to tackle the network's decay, which it saw as the major cause of water loss (EWURA, 2018). Although regulatory authorities and academic experts have diagnosed Dar es Salaam's water challenges are being largely due to worn out infrastructure, leakage, and inadequate maintenance and repair (cf. Sippy, 2021; Kjellén, 2009; Smiley, 2013), this analysis is mostly neglected in public policy and media discourses; they generally frame non-revenue water as being a matter of water theft and thus belittle the urgent need to invest in network infrastructure repair and maintenance.

Institutions

Responsibility for the repair and maintenance of water supply in Accra and Dar es Salaam rests with the respective states. In Accra, that responsibility is given to the GWCL, the national water company that supplies water to residents throughout Ghana's urban areas. The GWCL is vertically integrated, with headquarters in Accra and several regional and district offices throughout the country. In Dar es Salaam, however, DAWASA's responsibility is limited to only the Dar es Salaam region and its surrounding communities (EWURA, 2018). DAWASA's operational mandate includes both water and sanitation services, whereas the GWCL focuses solely on urban water supply. As a national utility, GWCL's maintenance and repair budgets are approved and disbursed from national headquarters; this means that various administrative and operational needs across Ghana's regions compete for limited financial resources. The national government thus sometimes scales down repair and maintenance budgets in order to finance priority projects such as network extensions; this is especially likely if there are revenue shortfalls (Interview 13, 2018). Repair and maintenance are therefore undermined in that reduced budget allocations make acquisition of vital materials and logistics more difficult, which leads in turn to delays or postponement of repair and maintenance work. In DAWASA, however, about 10% of all water revenues are dedicated to financing repair and maintenance operations (Interviews 2 and 9, 2019). These funds are deposited in a dedicated bank account and are used specifically for financing everyday repair and maintenance and minor renewals. This allows for adequate, secured, and equitable resource allocation for financing repair and maintenance operations. Unsurprisingly, inadequate funding for repair and maintenance operations is a greater challenge for GWCL than for DAWASA (Interviews 7 and 13, 2019).

In both utility companies, repair and maintenance operations are weakly institutionalised. Neither company has formal repair and maintenance policies, nor do they officially document such work. At best, informal policies, practices and norms exist but are mostly guided by the rich institutional memories of individual experienced technicians. In Accra, respondents framed repair and maintenance operation as practical work; for that reason, "documented policies are seen as not so relevant in that people learn the work by doing the work" (Interview 10, 2018). In Dar es Salaam, one interviewee contended that since most maintenance workers lack formal education and are barely literate, written policy documents would be of limited value to them (Interview 11, 2019). The absence of practical guidelines and rules affects repair and maintenance in that the supervision and enforcement of universal standards by utility officials becomes problematic, as engineers tend to operate based on their experience, guidance from senior engineers, or personal intuition. This can undermine the quality of repair and maintenance operations and can trigger decay or breakdown of water systems. It can also lead to engineers deliberately neglecting or genuinely overlooking basic routines such as inspections, cleaning, greasing of equipment, and tightening of nuts and bolts; this can accelerate decay and can trigger or worsen breakdowns in technical systems. The utility companies' ad hoc, incremental, and situated practices can be seen as tailored to local contexts in both Accra and Dar es Salaam. Water supply is shaped by heterogeneous, place-based, sociotechnical configurations and by an interplay of formal networks, informal network extensions, and non-networked solutions; universal technical standards and formalised guidelines may thus not work for highly situated repair and maintenance work.

There are nonetheless considerable differences between the companies in terms of their respective approaches to repair and maintenance. Whereas GWCL has established single maintenance teams in each of their district offices, DAWASA has multiple maintenance teams per district. In Dar es Salaam, maintenance teams usually operate in specific zones on a long-term basis, whereas their counterparts in Accra are generally assigned to a larger district. Importantly, DAWASA's districts are further divided into smaller zones to which specific teams are assigned, while in the case of GWCL, a single repair and maintenance team travels to different locations in the district. DAWASA's maintenance teams develop detailed knowledge of a locality, of its situated infrastructure conditions, and of the hotspots of infrastructural vulnerability, which helps them to better address repair needs. As DAWASA engineers work for long periods in the same area, over time they develop close relations with residents, who thus more readily report problems to them for repair. GWCL's maintenance teams, on the other hand, can be split into multiple groups if necessary; they can thus attend to different repair problems at different locations concurrently. This flexibility enables them to adjust to daily contingencies in repair and maintenance operations.

Under GWCL's rules and policies, minor leaks and burst pipes should be fixed within 12 hours of detection (Interview 10, 2018), while in DAWASA, the stipulated time frame is 6 hours (Interviews 12 and 15, 2019). This variability may result from the different approaches adopted by the two water companies and the sizes of the respective operational zones covered by their employees. Theoretically, employees of GWCL have more time to fix repair and maintenance problems than their counterparts in DAWASA; in reality, however, in both cases the target timeframes are rarely met because of challenges regarding access to spare parts, materials and tools.

Employees of the two companies have developed particular working relationships with local plumbers in their respective cities. GWCL employees have conflictual (and sometimes confrontational) relationships with private plumbers, who they suspect of facilitating illegal water connections (Interview 5, 2019; Interview 6, 2018). Most GWCL employees thus see local plumbers as an impediment to efficient water supply:

We do not have any relation with them. Those people are not trusted because they are the ones doing illegal connections for the customers. As a company, we have conflicts with them because they usually tamper with our networks, which is causing us a lot of revenue losses (Interview 10, Accra, 2018).

In contrast, DAWASA employees have developed cordial working relations with local plumbers, with whom they occasionally collaborate in repair and maintenance operations (Interviews 1 and 2, 2019). Rather than seeing them as a threat, DAWASA's employees see potential in private plumbers, whose expertise and cheap labour they exploit to improve repair and maintenance operations. The following statement by an official of DAWASA supports this conclusion:

We collaborate with them in several ways. I have some of the good ones on my list as casual workers. When we have a lot of work, I call them to support [us] and we compensate them financially. I have only four technicians in my ward. But this number is not adequate, so I use some [local plumbers] (Interview 1, Dar es Salaam, 2019).

Relations between plumbers and utility officials affect repair and maintenance operations in diverse ways. As in the case of GWCL, conflictual relations tend to undermine potential collaboration between employees of the public utility and private actors; public maintenance personnel thus forfeit benefits such as access to critical (but undocumented) local knowledge, information and experience, and the option of engaging local labour to facilitate repair and maintenance operations. DAWASA's more cordial relationship with area residents, on the other hand, enables mutually beneficial collaborations with local plumbers; within this dynamic, the contribution of labour and expertise by local plumbers reduces the workload of utility officials while the local plumbers can, at the same time, improve their knowledge and technical capacity and earn extra income.

Knowledge

Interviewees in both cities were confident that their company's engineers and technicians had the required technical knowledge and capacity to deal with most of the repair and maintenance problems; however, our findings indicate that employees of both water companies have imprecise knowledge of their respective water supply systems. Employees do not know, for instance, the exact number of leaks and burst pipes in their respective networks, nor do they have accurate data on the share of non-revenue water; neither do they know the exact physical layout of their networks. Reasons for their lack of knowledge include: the imprecise cartographic documentation of existing public utility networks; the prevalence of illegal networks; dysfunctional meters; and weak leak-detection mechanisms. Repair and maintenance operations in both companies are thus not based on official maps, layout diagrams or measuring equipment; rather, operations depend mostly on approximation, personal experience, intuition, and engineers' or technicians' contextual knowledge of the systems.

Given the complexity of the networks, the number of leaks and burst pipes reported by residents may be far below the actual numbers as the majority of the leaks that are not visible – and even the visible leaks that are being deliberately concealed by dishonest residents – may escape the attention of water engineers. We argue that, in this sense, both companies repair and maintain only a fraction of the actual leaks and burst pipes, while numerous unknown problems may persist unattended for several days. It is also possible that water engineers and technicians who are overstretched may "feign ignorance" (Anand, 2015) of leaks, even visible ones, in order to prioritise those they consider to be major and more urgent. Figure 6, for example, shows a huge leaking transmission network located close to Ardhi University in Dar es Salaam. According to residents, this 72-inch diameter pipe has been leaking for many years; they asserted that even though it is visible and close to the road, DAWASA's employees claimed ignorance of it – an ignorance which may be motivated by the desire of water authorities to avoid costly repair and maintenance work.

The water supply systems in the two cities are highly heterogeneous with regard to their sociotechnical constellations, which are shaped by informal network extensions and an interplay of formal networks and non-networked solutions such as boreholes. This heterogeneity also applies to their spatiality, with different connectivity rates and the splintering of networks. Maintenance and repair work thus require situated and context-specific knowledge, and solutions to repair and maintenance challenges are highly place-based and contextual, and may not be applicable elsewhere. We found differences between the companies even so, in that their employees varied in terms of their contextual knowledge of their respective water systems. DAWASA's employees, for instance, appear to have more in-depth knowledge of their water networks and can pinpoint local vulnerability hotspots and layouts, while such detailed knowledge is rare among their GWCL counterparts. This difference has arisen because DAWASA's employees operate in specific zones over a long period of time, allowing them to accumulate detailed local knowledge of the systems and of their localities; their counterparts in GWCL, on the other hand, work in relatively large areas, which makes it difficult to develop such detailed knowledge. In contexts such as Accra and Dar es Salaam, where urban development mostly occurs outside the scope of formal planning systems and official layouts and maps cannot be relied upon, such detailed local knowledge is a key facilitator of repair and maintenance operations; it is crucial to detecting, tracking and locating leaks and breakdowns in the network. The everyday repair and maintenance of the water supply is thus much more contingent on the repair workers' personal experiences and rich local knowledge than it is on formal hydraulic maps.

Figure 6. Leaking pipe in Dar es Salaam.



Source: Authors.

Finally, water engineers and technicians in both companies have limited knowledge of some of the technical equipment, and thus occasionally rely on external experts. According to an engineer from GWCL's Weija water plant, "There are a few of the equipment we can't fix. Not because we lack the skills but sometimes because of the lack of tools, technology or equipment" (Interview 10, 2018). Like their colleagues at DAWASA's Ruvu plant, if workers at the Weija water plant lack the expertise required, they may resort to foreign experts for solutions; however, if that is not feasible or is too costly, local engineers must improvise and tinker with the equipment based on their experience, manuals, and/or online instructions, in the hope of finding a solution (Interviews 7 and 12, 2019). While this experimentation and tinkering may drive creativity and inspire low-cost innovations, the results are not always successful; in the end, the equipment is sometimes damaged beyond repair, or damaged such that it is too costly to repair even if the right experts are found (Interview 6, 2018). Whether or not such acts of tinkering are successful, however, they give local experts an opportunity to learn and develop their knowledge and experience about new equipment; such lessons are vital to improving their subsequent repair encounters with similar devices or problems. Tinkering should thus be seen not just as a coping mechanism necessitated by technical limitations; rather, it can be perceived as an opportunity to nurture the capacities of local experts. This confirms the broader STS literature (see Graham and Thrift, 2007; Baptista, 2019; Jackson, 2019), which emphasises the vital role played by repair and maintenance in shaping learning, creativity, innovation and discovery in contemporary societies.

DISCUSSION AND REFLECTION

The analysis above highlights several important similarities and differences between the two cities; these are summarised in Table 1 in relation to our four key dimensions. Overall, significant differences were identified in the levels of hydraulic pressure and in the repair and maintenance approaches adopted by the two companies; differences were also found in the relations between the employees of the two companies and private plumbers, and in the levels of contextual knowledge demonstrated by their respective employees. These differences may result from the companies having different mandates and geographical scopes with regard to water supply, but they are also due to place-based variables such as levels of informality, politics, and local socio-economic contexts. GWCL is a national water utility, whereas DAWASA is a regional utility with a limited geographic mandate; this has implications for the complexity of administrative bureaucracy and for policies on repair and maintenance.

As a national utility, GWCL's maintenance and repair budgets are approved and disbursed from national headquarters; as a consequence, various administrative and operational needs across all regions of Ghana compete for limited financial resources. This sometimes leads to budget diversions and downscaling to fund the state's priority projects such as new extensions, especially if there are revenue shortfalls (Interview 13, 2018). This undermines repair and maintenance in that logistics and acquisition of vital materials become problematic, which leads in turn to delays or postponement of repair and maintenance work. In DAWASA, although there is also competition for revenue, its relative size allows it to allocate more financial resources to repair and maintenance. Inadequate funding of repair and maintenance operations is therefore a greater challenge for GWCL than it is for DAWASA (Interviews 7 and 13, 2019). As a national utility, GWCL's maintenance and repair rules and policies are designed to cover work in all urban areas across the country; they are therefore less specific for Accra's local contexts and challenges. In contrast, DAWASA's maintenance and repair rules, practices, and strategies are developed in, and tailored to, the local contexts and situated challenges of the city of Dar es Salaam and can thus be more effective.

The two cities also differ in terms of how utility employees relate with private local plumbers in repair and maintenance operations. Partnerships with private contractors can entail both benefits and risks for urban water supply. The local expertise and cheap labour offered by private plumbers can help improve repair and maintenance operations; however, there is also a risk that the utility's repair and maintenance standards will be disregarded and that fraudulent plumbers will exploit knowledge gained in this collaboration to develop illegal networks for their own gain. This may at least partly explain why water theft is more prevalent in Dar es Salaam than in Accra. On the other hand, the conflictual relations between GWCL's employees and private plumbers point to power struggles between state and non-state actors over water infrastructure (Barnes, 2017). We contend that those contestations and tensions are not merely struggles over the repair and maintenance of water infrastructure, but that they are also an attempt to maintain the utility company's power and a certain social order that surrounds repair and maintenance operations (Graham and Thrift, 2007; Barnes, 2017). Whereas the responsibility for repairing and maintaining the urban water supply traditionally rests with public utility companies, our case study reveals that various private actors are involved, including local plumbers, water users, entrepreneurs and communities. This finding, which concurs with many other studies (Wahby, 2021; Björkman, 2018; Barnes, 2017), calls for a rethinking of conceptual notions of urban water repair and maintenance, in that repair and maintenance are not always the sole responsibility of state-owned utilities, they are often shared with the private sector.

Despite the above differences, the two cities share some similarities. One possible explanation for these similarities is that both water companies underwent similar restructuring and institutional reforms under the guidance of the World Bank. Another is that both cities have similar levels of informality, which makes water supply extremely dynamic and complex to ascertain (Anand, 2017). Finally, our findings suggest that, compared to their investments in extending the system and upgrading its capacity, both cities are underinvesting in their respective networked infrastructure maintenance and repair. Consequently, due to leaks, burst pipes, and low-pressure problems resulting from worn out infrastructure, even urban residents with mains connections do not have reliable, uninterrupted access to water supply. Official reports of both utility companies claim considerable progress in increasing urban connectivity rates (often framed as access rates: URT, 2006; GWCL, 2017); however, in reality, even urban residents who can afford to pay for water supply often lack access to water due to factors such as unreliable service provision and temporary water rationing (Boateng et al., 2013; Smiley, 2013). As a result of these shortcomings in centralised water supply, in both cities even residents who are connected to public water networks depend on various complementary off-grid systems to meet their water needs (Harris, 2019; Peloso and Morinville, 2014; Smiley, 2013).

Table 1. Key difference and similarities in water supply in Accra and Dar es Salaam.

Dimension	Accra	Dar es Salaam
Materiality	<ul style="list-style-type: none"> * Networked infrastructure decay * Illegal booster pumps * Low pressure * Leaking networks 	<ul style="list-style-type: none"> * Networked infrastructure decay * Illegal networks * High pressure * Leaking networks
Discourses	<ul style="list-style-type: none"> * Human right to water access * Cost recovery/affordability * Non-revenue water is attributed to network decay 	<ul style="list-style-type: none"> * Human right to water access * Cost recovery/affordability * Non-revenue water is attributed to water theft
Institutions	<ul style="list-style-type: none"> * National water company * One maintenance team per district * GWCL's employees have conflictual relations with local plumbers 	<ul style="list-style-type: none"> * Regional water authority * Several maintenance teams per district * Employees of DAWASA have cordial relations with local plumbers
Knowledge	<ul style="list-style-type: none"> * Employees of GWCL have limited knowledge of the local networks * Engineers rely mainly on approximations * Limited expertise on some equipment 	<ul style="list-style-type: none"> * Employees of DAWASA have rich contextual knowledge of the systems * Engineers rely on approximation * Limited expertise on some equipment

Source: Authors.

Note: GWCL = Ghana Water Company Limited; DAWASA = Dar es Salaam Water and Sewerage Authority.

CONCLUSION

This article uses a sociotechnical perspective to explore and compare the everyday maintenance and repair practices of the staff of two water companies in Accra and Dar es Salaam. To better understand and systematically explain the incremental, contingent, and place-based maintenance and repair practices of utility officials in both cities, we proposed a novel conceptual framework based on four interrelated variables: materialities, discourses, institutions, and knowledge. This conceptualisation offers a comprehensive framework for critically explaining how and why repair and maintenance practices in water supply networks and, more generally, in networked infrastructures may differ geographically; it further investigates the place-based challenges, opportunities and implications for their operation. This framework provides a multidimensional and nuanced understanding of the embeddedness of maintenance and repair practices in specific geographical contexts, while also allowing us to identify key variables that influence local repair and maintenance practices.

Many studies either reflect on repair and maintenance practices without considering their situatedness in geographical contexts or focus on single cities or neighbourhoods, while our research compares and contrasts the everyday practices of water utilities in different national and urban contexts. By identifying core differences and similarities across discourses, materialities, institutions and knowledge, we revealed how sociospatial, political, and physical contexts shape repair and maintenance practices. In doing so, our analysis reveals striking differences in the situated repair and maintenance practices of the water companies. We offer an explanation of these differences in terms of the interplay of our four variables, including: different hydraulic pressures, local discourses on non-revenue water, the geographical scope of the respective companies, their centralised and decentralised administrative

management and geographical knowledge, and their working relations with the private sector. These observed differences emphasise the dynamic, contingent and place-based character of repair and maintenance operations, which may not necessarily align with the promotion of universal repair codes, rules, principles and managerial approaches.

Apart from refining academic discourses, our comparative case study approach provides important practical lessons for water companies, policymakers, international donors and NGOs in urban water supply in Africa. The case of Dar es Salaam, for example, shows that utilities can improve repair and maintenance if they decentralise its scope to specific neighbourhoods or zones. This approach is advantageous because it allows repair workers to embed themselves in the local context in order to better understand the local realities, challenges and vulnerabilities related to improved repair and maintenance operations. This approach can help facilitate prompt leak detection and proactive maintenance and repair in water systems, especially because both water companies lack reliable technology to trace and detect leaks in their networks. Early detection of leaks and burst pipes would ultimately improve timely repair and maintenance and, more importantly, it would reduce the share of non-revenue water. This approach could therefore be replicated by the GWCL or other utilities in similar contexts. Another important lesson is the need to separate repair and maintenance from the installation of new water connections and to allocate separate teams for these two responsibilities. Concentrating both responsibilities within the same team tends to disadvantage repair and maintenance in that engineers and technicians may prioritise new connections over the repair of leaks in existing networks. This tendency partly explains why engineers in both companies are struggling to meet maintenance and repair needs in their respective systems.

Our study has also shown that while discourses frame the problem of non-revenue water as a universal challenge facing both cities, an examination of the materialities of water supply in the two cities reveals that there are highly heterogeneous sociotechnical configurations within individual neighbourhoods. Repair and maintenance workers face spatially uneven rates of connectivity to centralised networks and numerous instances where residents access water through a combination of incremental network extensions and non-networked solutions. Their practices are thus carried out in networks that have been shaped by incrementality rather than by uniform metrics and forms, and their work is characterised by patchy solutions, ad hoc spare parts, and other forms of situated practices. This sociotechnical heterogeneity and the need for localised solutions have important implications for a more effective design of repair and maintenance policies and approaches by international donors. On the one hand, the heterogeneity restricts the applicability and appropriateness of universal norms, work routines, technical standards and standardised protocols that could guide repair and maintenance practices by utility employees; on the other hand, it may inspire a rethinking of organisational matters, since more decentralised approaches to repair and maintenance may be advantageous, as the Dar es Salaam case indicates.

Finally, our findings highlight the need to anticipate repair and maintenance needs more systematically at an earlier stage of technology design, planning and construction of water systems. Particularly problematic is the dependence of water utilities on foreign technology and expertise; this produces a situation where spare parts can be expensive to buy and can take a long time to be delivered, and where fixing them may require specific expertise that local engineers and technicians lack. Ignoring such future requirements and the 'repairability' of water technology can have long-term consequences for an infrastructure's functionality, sustainability and urban water access in general. In addition to anticipating future repair and maintenance needs in the design and planning of infrastructure, more financial, technical and institutional resources need to be allocated and more intensive professional training approaches need to be promoted. Further research is required to understand how international donor funding schemes and conditionalities could be better tailored to situated repair and maintenance practices in water supply. Although this study focuses on 'formal' repair and maintenance practices by

utilities, further research is also needed to better understand how formal and informal practices by state and non-state actors interplay and shape urban water supply in African cities.

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2. Regional Manager, DAWASA, Dar es Salaam, 21 February 2019
3. GWCL Technician, Accra, 17 December 2018
4. GWCL Engineer 4, ATMA production, Accra, 21 January 2019
5. DAWASA Engineer 3, Lower Ruvu plant, Dar es Salaam, 20 February 2019
6. GWCL Engineer 1, Weija water treatment plant, Accra, 21 January 2019
7. GWCL Engineer 2, Kpong water treatment plant, Accra, 10 December 2018

8. GWCL Engineer 3, Accra, 17 January 2019
9. Manager/Engineer, DAWASA, Dar es Salaam, 27 February 2019
10. Deputy MD GWCL Accra, 12 January 2019
11. DAWASA official 1, Dar es Salaam, 22 February 2019

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