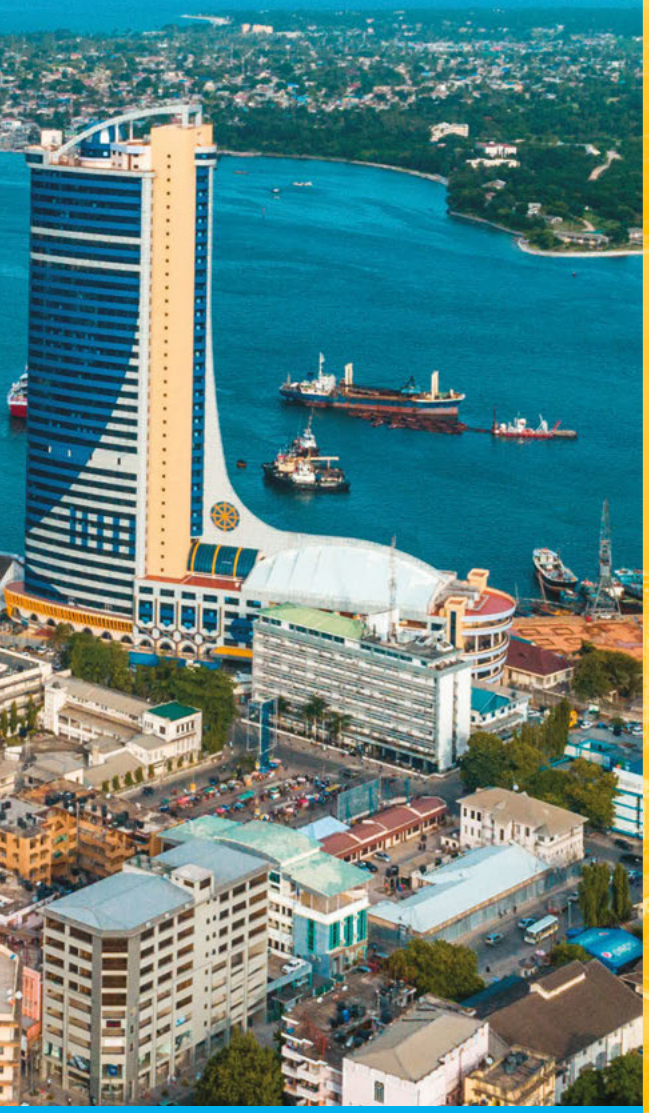
Maintaining and Repairing Accra's and Dar es Salaam's Water Infrastructures:

Sociotechnical Arrangements, Labor Relations and Resilience



Lazarus Jambadu

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Maintaining and Repairing Accra's and Dar es Salaam's Water Infrastructures: Sociotechnical Arrangements, Labor Relations and Resilience

Onderhoud en reparatie van de waterinfrastructuur van Accra en Dar es Salaam: sociotechnische regelingen, arbeidsverhoudingen en veerkracht
(met een samenvatting in het Nederlands)

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Lazarus Jambadu

geboren op 9 maart 1985
te Kojokperi, Ghana

Promotoren:
Prof. dr. J. Monstadt
Prof. dr. A. Rudolph-Cleff

Copromotoren:
Dr. F. Pilo
Dr. K. Hölscher

Beoordelingscommissie:
Prof. mr. A.W.G.J. Buijze
Prof. dr. V. Castán Broto
Prof. dr. J.I. Engels
Prof. dr. S. Frank
Prof. dr. K. Otsuki

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Lazarus Jambadu, 2 May 2024.

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SUMMARY

Water supply in African cities is challenged by inadequate maintenance and repair of water infrastructures. This challenge impacts water quality, quantity, reliability, and urban water systems' overall resilience and sustainability. Despite the pivotal role of maintenance and repair in water supply, policymakers and infrastructure managers in African cities tend to overlook the need to pay more attention to them in water policy formulation, resource allocation and programs. Recent studies on urban water infrastructures in the global South primarily concentrate on sociotechnical heterogeneity and hybridity in access to infrastructures but rarely interrogate how those sociotechnical arrangements influence maintenance and repair practices. Contributing to this gap is essential to understanding the complex relationships in service delivery and how urban infrastructures work in the context of the global South. Furthermore, while it is well documented that maintenance and repair practices affect urban infrastructure operations, their specific impact on water infrastructure resilience in African cities needs to be better understood, especially considering the additional risks posed by infrastructure decay and aging networks.

This study addresses these gaps by examining the role of maintenance and repair in responding to the chronic water problems faced by inhabitants of Accra and Dar es Salaam—two fast-growing African cities where water access is a major challenge. Through qualitative methods such as semi-structured interviews and observations, the research explores how sociotechnical arrangements within and beyond the water network influence maintenance and repair practices, the dynamics of labor relations between public and private workers, the influence of donor funding schemes, and how these practices affect infrastructure resilience in both cities. By focusing on these aspects, the study aims to provide a nuanced insight into the complex relationship between sociotechnical arrangements in water supply and maintenance and repair and their impacts on infrastructure resilience in African cities.

The study's key findings highlight significant differences between Accra and Dar es Salaam regarding their water supply systems, organization of maintenance and repair, and levels of knowledge regarding water system maintenance. For example, Accra

employs a centralized approach to maintenance and while Dar es Salaam adopts a more decentralized approach. However, both cities face challenges stemming from donor funding schemes, leading to a high reliance on expensive imported spare parts and inadequate maintenance and repair practices. The involvement of both private and public plumbers in maintenance and repair is identified as critical for enabling resilience, although it poses regulatory challenges.

The study concludes that maintenance and repair are crucial for supporting technical functionality and the resilience and sustainability of urban water systems. Policy reforms are recommended to incorporate both centralized and decentralized approaches to maintenance and repair, encourage collaboration between public and private sectors, and promote decentralized strategies to enhance the responsiveness and effectiveness of maintenance and repair efforts in African cities and other regions of the global South.

SAMENVATTING

De watervoorziening in Afrikaanse steden wordt uitgedaagd door onvoldoende onderhoud en reparatie van waterinfrastructuren. Deze uitdaging heeft invloed op de waterkwaliteit, -kwantiteit en -betrouwbaarheid, evenals op de algehele veerkracht en duurzaamheid van stedelijke watersystemen. Ondanks de cruciale rol van onderhoud en reparatie in de watervoorziening, neigen beleidsmakers en infrastructuurbeheerders in Afrikaanse steden ertoe de noodzaak hiervan over het hoofd te zien bij de formulering van waterbeleid, toewijzing van middelen en programma's. Tegelijkertijd richten recente studies over stedelijke waterinfrastructuren in het mondiale Zuiden zich voornamelijk op sociaal-technische heterogeniteit en hybriditeit in toegang tot infrastructuren, maar zelden onderzoeken ze hoe die sociaal-technische regelingen onderhouds- en reparatiepraktijken beïnvloeden. Bovendien, hoewel goed gedocumenteerd is dat onderhouds- en reparatiepraktijken invloed hebben op de werking van stedelijke infrastructuren, moet hun specifieke impact op de veerkracht van waterinfrastructuur in Afrikaanse steden beter worden begrepen, vooral gezien de extra risico's die worden veroorzaakt door infrastructuurverval en verouderende netwerken.

Dit onderzoek richt zich op deze lacunes door de rol van onderhoud en reparatie te onderzoeken in het reageren op de chronische waterproblemen waarmee de inwoners van Accra en Dar es Salaam worden geconfronteerd—twee snelgroeiende Afrikaanse steden waar toegang tot water een grote uitdaging is. Door middel van kwalitatieve methoden zoals semi-gestructureerde interviews en observaties, onderzoekt het onderzoek hoe sociaal-technische regelingen binnen en buiten het waternetwerk onderhouds- en reparatiepraktijken beïnvloeden, de dynamiek van arbeidsverhoudingen tussen publieke en private werknemers, de invloed van donorfinancieringsschema's en hoe deze praktijken de veerkracht van infrastructuur in beide steden beïnvloeden. Door zich op deze aspecten te richten, beoogt de studie een genuanceerd inzicht te bieden in de complexe relatie tussen sociaal-technische regelingen in watervoorziening en onderhoud en reparatie, en hun impact op de veerkracht van infrastructuur in Afrikaanse steden.

De belangrijkste bevindingen van het onderzoek benadrukken significante verschillen tussen Accra en Dar es Salaam wat betreft hun watervoorzieningssystemen, organisatie van onderhoud en reparatie, en kennisniveaus met betrekking tot het onderhoud van het watersysteem. Zo hanteert Accra een gecentraliseerde aanpak voor onderhoud en reparatie, terwijl Dar es Salaam een meer gedecentraliseerde aanpak hanteert, die effectiever blijkt te zijn vanwege de lokale kennis van de systemen. Beide steden staan echter voor uitdagingen als gevolg van financieringsregelingen van donoren, wat leidt tot een afhankelijkheid van dure geïmporteerde reserveonderdelen en ontoereikende praktijken. De betrokkenheid van zowel private als publieke loodgieters bij onderhoud en reparatie wordt geïdentificeerd als cruciaal voor het mogelijk maken van veerkracht, hoewel dit regelgevende uitdagingen met zich meebrengt.

Het onderzoek concludeert dat onderhoud en reparatie niet alleen essentieel zijn voor technische functionaliteit, maar ook voor de veerkracht en duurzaamheid van stedelijke watersystemen. Beleidshervormingen worden aanbevolen om zowel gecentraliseerde als gedecentraliseerde benaderingen van onderhoud en reparatie op te nemen, samenwerking tussen publieke en private sectoren aan te moedigen, en gedecentraliseerde strategieën te bevorderen om de responsiviteit en effectiviteit van onderhouds- en reparatie-inspanningen in Afrikaanse steden en andere regio's van de wereld te verbeteren.

CHAPTER 1

INTRODUCTION

1.1 Background to the study

Access to safe and reliable water supply is a basic human need for survival. For this reason, the United Nations Sustainable Development Goal 6.1 has encouraged governments at all policy levels and other decision-makers to ensure universal, non-discriminatory access to safe water for all persons by 2030 (United Nations, 2015). Access to safe water supply has many benefits linked to good sanitation and hygiene, public health, societal resilience, and higher productivity (WHO and UNICEF, 2018; Heymans et al., 2016). However, many inhabitants of African cities still lack access to a reliable and clean water supply, resulting in unequal water access, many waterborne diseases and sanitation challenges (WHO and UNICEF, 2018; WHO et al., 2022). In many African settings, urban water supply systems are characterized by splintered network coverage and frequent interruptions (Peloso and Morinville, 2014). Thus, even if urban residents are physically connected to water networks, they can barely access affordable, reliable, high-quality water supply (Schramm, 2018; Bartels et al., 2018; Peloso and Morinville, 2014). Due to these challenges, many city inhabitants also depend on various water infrastructures beyond the network (Dakyaga et al., 2023).

In the African context, even though water access rates in cities are higher than in rural settings, cities are increasingly confronted with severe water challenges due to the rising impacts of climate change (McDonald et al., 2014; Heymans et al., 2016; Livingston, 2021). Scientific and technical reports by various international organizations have highlighted climate change impacts as the biggest threat to global water security and, more significantly, in contexts where water resources are already scarce (IPCC, 2021; WHO et al., 2022). For example, the WHO et al. (2022) and the IPCC (2021) reveal that climate change increases the frequency of flood events, which can cause physical destruction to urban water infrastructures, increasing water contamination and the frequency of droughts, during which water resources become even scarcer (IPCC, 2021). Equally, climate change can lead to rising sea levels, salination of groundwater resources, and frequent drought events, which can provoke water scarcity and overexploitation of freshwater resources (IPCC, 2021; World Bank, 2016).

With all these challenges, some reports discursively frame the water crisis in African cities as a 'climate crisis' (World Bank, 2016; 2021; IPCC, 2021).

In addition to weather extremes, water supply in African cities is further challenged by rapid demographic and settlement growth (OECD, 2020; WHO et al., 2022). While global urbanization growth is slowing in many regions, sub-Saharan Africa's population and urbanization rates are rapidly growing (Korah et al., 2022; UN-DESA, 2022). In 2022, approximately 1.1 billion people lived in Africa (UN-DESA, 2022), and about 43% of this population lives in urban areas (Jean-Michel Bos, 2023). This demographic turn has challenged the capacity of many city authorities, national governments, and public utility companies to effectively plan, manage, and provide adequate water supply for all city residents (World Bank, 2021; UN-DESA, 2022; McDonald et al., 2014; Livingston, 2021). In response to these challenges, a variety of private water co-providers (e.g., private tankers operators, local water vendors, private sachet and bottled water providers) and self-organized decentralized infrastructure constellations (e.g., private boreholes and wells) become alternative solutions for residents of many African cities (Monstadt and Schramm, 2017; Peloso and Morinville, 2014; Guma, 2021; Ahlers et al., 2014; Alba and Bruns, 2022). These heterogeneous, decentralized water infrastructure constellations complement or sometimes substitute the centralized water networks in meeting residents' diverse water needs (Jaglin, 2014; Smiley, 2020). However, scholars have cautioned that some alternative water supply channels are environmentally unsustainable, more expensive, and lack safety control (Peloso and Morinville, 2014; Smiley, 2020; Morinville, 2017). For instance, bottled and sachet water proliferation can result in vast amounts of plastic waste polluting the environment (Morinville, 2017), or drilling private boreholes can lead to overexploitation of underground water resources (Mato, 2015; Smiley, 2020).

Inadequate financial and technical investments in water sectors also deepen the water crisis in many African cities. For example, Africa's water sector requires at least US$30 billion in annual investments to meet the sustainable development goals (SDG 6) by 2030 (Eriksson and Said, 2020). However, investment is insufficient, with only US$10-US$19 billion annually, leaving behind a massive backlog of infrastructure investment needs (United Nations, 2023; Gouredou, 2023; Eriksson and Said, 2020). Insufficient investments affect the ability of city authorities and water providers to construct new water infrastructure and renew existing ones to increase water systems capacity and efficiency to match growing water needs (United Nations, 2023; World Bank, 2021). Thus, whereas cities' water requirements are increasing steadily, water systems' capacity tends to stagnate (or, in some cases, decline), further exacerbating urban water crises.

Beyond expanding urban water infrastructure capacity, one major water supply problem in African cities relates to infrastructure decay, obsolete equipment, and aging water networks (Livingston, 2021; Kjellén, 2009). Many water networks were constructed during the colonial era and barely renewed over decades (Schramm, 2018; Smiley, 2020). Hence, most of the water networks and infrastructures are obsolete and constantly leaking, resulting in a high share of water losses and non-revenue water in public utilities (Alves, 2022; Alda-Vidal et al., 2018; Kjellén, 2009). For instance, in Accra and Dar es Salaam, about 50% of treated water fed into the public utility networks was classified as non-revenue water in 2018 (EWURA, 2018; GWCL, 2018). The high share of non-revenue water indicates that about half of the limited water resources are lost before reaching consumers due to various structural problems. These losses reduce the quantity and quality of water resources available for cities' consumption and contribute to the inability of many public utilities to ensure cost recovery (Monstadt and Schramm, 2017; Nganyanyuka et al., 2014). Ultimately, the water providers resort to rationing schemes to allocate the remaining water resources to residents. From the above, it is apparent that many African cities' water problems are not only influenced by climate and demographic change. More importantly, relates to structural decay, obsolete systems, and aged networks and highlights the critical need for more attention to the role of maintenance and repair in urban water supply.

This dissertation examines maintenance and repair practices in Accra's and Dar es Salaam's water supply systems in response to the persistent water problems in those cities and many others in Africa. I define maintenance and repair as systematic practices undertaken to ensure the proper functioning, longevity, and safety of infrastructures and to enable the restoration of functioning after infrastructure breakdown or failures (Walia et al., 2010; Henke and Sims, 2020). These activities include both proactive and reactive practices such as regular inspections, servicing, adjustments, replacements, and troubleshooting to prevent breakdowns, optimize performance, and address malfunctions or failures that arise (Walia et al., 2010; Henke and Sims, 2020). Maintenance typically focuses on proactive measures aimed at preventing failures and preserving the condition of assets over time, and optimizing performance, while repair practices mainly involve reactive measures taken to fix breakdown or malfunctioning infrastructure (Graham and Thrift, 2007; Henke and Sims, 2020). A focus on maintenance and repair practices is crucial because water infrastructures in African cities are rapidly decaying and failing. The need for more attention to maintenance and repair is further deepened when considering that they affect water quality, quantity, and reliability, and overall systems' resilience and sustainability.

In the remainder of this introduction, I will discuss the state of research on urban infrastructures in the global South (section 1.2) to outline the critical debates on infrastructures in African cities and research gaps. Following this literature review, I will present aim and questions (1.3) and conceptual framework (section 1.4). I will then discuss the research design and methodology in section 1.5 and section 1.6. I will conclude the chapter with an outline of the dissertation.

1.2 State of research on urban water infrastructure in the global South

This section reflects on critical debates on urban infrastructures in the global South, specifically on water infrastructures. It focuses on debates on different forms of water supply systems (networked and non-networked) and their maintenance, repair, and resilience. Reviewing these critical debates helps move/reframe the water problems in African cities beyond narratives of climate change and demographic dynamics in these settings by situating it in the context of maintenance and repair and existing socio-technical arrangements in the water supply system.

1.2.1 The modern infrastructure ideal and its critique

The 'modern infrastructure' ideal is a globally accepted socio-political ideal that promises universal, standardized, uninterrupted water services through piped networks independent of time and location (Graham and Marvin, 2001; Lawhon et al., 2018; Monstadt and Schramm, 2017). Although this normative ideal has influenced urban water planning policies, programs and practices in Africa since colonial times, the vision of a universally 'networked city' remains elusive (Schramm, 2016; Lawhon et al., 2018; Nilsson, 2016).

Over the last decade, urban water debates in the global South have centered on critiques on this normative ideal of networked infrastructure, interrogating its fragmentation, absence, and incompleteness (Coutard and Rutherford, 2015; Monstadt and Schramm, 2017; Jaglin, 2014; Schramm, 2016; Furlong and Kooy, 2017). These studies revealed that cities in the global South are not fully covered by the centralized water networks but rather consist of archipelagos of fragmented networks (Bakker et al., 2008; McFarlane and Rutherford, 2008; Kjellén, 2006). Scholars have argued that centralized networks have (re)produced urban socio-spatial fragmentation, reinforcing already existing socioeconomic inequalities in cities (Smiley, 2020; Furlong and Kooy, 2017; Tiwale, 2019). In these debates, some scholars trace back the fragmentation of African cities to colonial planning history and practices that segregated cities

along racial lines (Schramm, 2016; Monstadt and Schramm, 2017; von Schnitzler, 2008; Cirolia and Pollio, 2023). As centralized networks are often not reliable, some scholars have argued that having access to centralized networks in Southern cities is of limited use because it does not guarantee access to a reliable and safe water supply due to frequent breakdowns and failures of infrastructures (Beard and Mitlin, 2021; Peloso and Morinville, 2014; Kjellén, 2006). Thus, scholars in post-colonial studies (e.g., Smiley, 2020; Cirolia and Pollio, 2023; Nilsson, 2016) have argued that the network ideal (despite dominating planning practice for many years) has fallen short of its promised goals. Much like the modern infrastructure myth, Wahby (2021) contents that there exists an imaginary of a 'repair ideal' held by the state and donor agencies. In reality, she cautions, this ideal does not exist because the conduct of maintenance and repair of infrastructure in Southern cities involves hybrid labor arrangements between state and non-state actors. Following the above limitations of the modern infrastructure ideal, new studies attempted to go beyond this limited focus on the normative modern infrastructure ideal by engaging with alternative debates and conceptualization of urban water supply that recognizes socio-technical heterogeneity in the global South. This conceptual shift emphasizes technological pluralism and hybrid modes of organizing access, maintenance, and repair of water infrastructure in Southern cities.

1.2.2 Beyond the network: alternative conceptualization of urban infrastructures

In the last two decades, there has been a dramatic shift in Southern cities' infrastructure debates from the incompleteness of the modern infrastructural ideal to the alternative socio-technical arrangements that challenge this ideal (e.g., Jaglin, 2014; Koepke et al. 2021; Alba and Bruns, 2022; Rateau and Jaglin, 2022; Pilo', 2022; Lawhon et al., 2018). This shift enables new theorization and conceptualization of urban infrastructures through *heterogeneity, hybridity, and co-production*. These concepts have (re)positioned urban (water) infrastructures in Southern cities, enabling a better understating of the socio-technical arrangements in water supply in and beyond the modern infrastructure networks. The concept of heterogeneity emphasizes the diverse and multiple socio-technical arrangements in water supply channels coexisting in place and time (Jaglin, 2014). Heterogeneity contrasts with the networked city ideal (Lawhon et al., 2018), revealing the range of differentiated socio-technical constellations that coexist in the provision, management, and use of urban infrastructures (Lawhon et al., 2018; Smiley, 2020; Alba and Bruns, 2022). The heterogeneous socio-technical arrangements in water supply are neither finite nor static. Instead, they reflect the shifting characteristics of the system and place based on situated needs, differentiated uses, and user preferences

within the city (Jaglin, 2014; Allen et al., 2017; Smiley, 2020). Recently, scholars have used the concept of heterogeneity to analyze energy and water infrastructure access and use in various cities in the global South (e.g., Pilo', 2022; Koepke et al., 2021; Smith, 2023; Smiley, 2020). These studies have revealed how heterogeneity in urban infrastructures manifests differently in different socioeconomic neighborhoods in Southern cities and how heterogeneous constellations beyond the formal grid can transform and shape power relations (Pilo', 2022). Heterogeneity is a powerful lens for understanding infrastructures in Southern cities because it allows to account for the full range of actors, technological constellations, uses, socio-material relations, and distinct modes of organizations (Koepke et al., 2021; Smiley, 2020). In the context of infrastructure maintenance and repair, understanding heterogeneity is even more relevant because it enables us to think beyond the grid toward a position that recognizes the socio-technical diversity of actors and practices in maintenance and repair in cities. Thinking beyond the grid defuses the notion of an imaginary repair ideal held by the state (Wahby, 2021).

A second notion that post-colonial scholars mobilize to challenge the modern infrastructure ideal is *hybridity*. While heterogeneity merely describes the coexistence of diverse and multiple socio-technical arrangements, hybridity further examines how the different socio-technical constellations interplay and shape each other in service delivery. It describes how 'formal' and 'informal' networks and incrementally developed socio-technical constellations beyond the grid interplay in co-producing urban infrastructure services (Cawood et al., 2022; Jaglin and Rateau, 2022; Coutard and Rutherford, 2015; Jaglin, 2015). The formal and informal socio-technical constellations are interdependent and intertwined in dynamic ways, changing and evolving over time and space (Jaglin, 2015). Hence, hybridity suggests interconnectedness, fluidity, and complementarity between the formal and informal constellations in service delivery (Peloso and Morinville, 2014; Ahlers et al., 2014). In African cities, Cirolia and Pollio (2023) identified a spectrum of hybridity enabling urban infrastructure provision and management, interfacing between formal and informal arrangements, private and public actors, centralized and decentralized solutions, etc. In such hybrid constellations, the position of infrastructure categories (i.e., formal or informal or private and public) is not permanent but constantly shifts in time and space. Thus, an infrastructure constellation can become classified as formal or informal only in reference to specific temporal and spatial contexts (Misra, 2014). In the context of maintenance and repair, hybridity is analytically productive because it enables an understanding of the dynamic labor relations and complex intersection of actors' roles, practices, and socio-technical arrangements in maintaining and repairing water supply infrastructures in Southern cities.

Finally, *co-production* is a third way to understand the production of infrastructure services in Southern cities' infrastructures. Joshi and Moore (2004) defined co-production as the long-term, institutionalized collaboration between the state and organized citizen groups and various private individuals in service provision, whereby actors contribute substantial resources for service delivery. The scope of co-production arrangements is broad and entails both large-scale formal collaborations (e.g., public-private partnerships) and various small-scale, informal arrangements through which urban infrastructure services are co-produced at the interface between state and non-state interventions (Bartels et al., 2018). Rather than focusing solely on the infrastructure constellations, co-production pays critical attention to the relationships between state and non-state actors, their roles in service delivery, and the ensuing power dynamics in co-producing urban infrastructure services (Ahlers et al., 2014). Hence, co-production differs from both hybridity and heterogeneity because it engages more with institutional arrangements that define and shape relations between the multiple actors and their roles in relation to 'who does what, why, when, how, and to what end' in the process of service delivery (Moretto et al. 2018; Adams and Boateng, 2018). As actors play distinct roles and responsibilities in service delivery, co-production relations can be highly contentious because different actors have different goals and interests, which sometimes lead to contradictions and competition (Adams and Boateng 2018). Co-production relations are also dynamic and shaped by broader socio-political, environmental, biophysical, and infrastructural drivers in specific contexts and times (Ahlers et al., 2014). It has thus become a productive analytical concept for understanding the complex relations, institutional arrangements, and power relations in service delivery in Southern cities (Ahlers et al., 2014; Moretto et al., 2018; Adams and Boateng, 2018). Co-production is useful in relation to maintenance and repair because it helps reveal the roles of private and public actors in maintenance and repair and how these actors' practices complement and sometimes challenge each other in service delivery.

Overall, the three concepts discussed above highlight urban water supply (more broadly, urban infrastructures) in the global South as a complex and dynamic socio-technical arrangement involving multiple technologies, institutional structures, actors' knowledge, and discourses. This conceptualization recognizes socio-technical heterogeneity beyond modern infrastructure networks and emphasizes interconnectedness between those multiple socio-technical arrangements. However, the literature does not yet account for how those socio-technical arrangements in water supply within and beyond the grid shape maintenance and repair practices in African cities. The next section reviews the literature on urban infrastructure maintenance and repair, focusing on Southern cities.

1.2.3 The maintenance and repair of urban infrastructures

Infrastructure maintenance and repair refers to the set of practices and procedures implemented to ensure optimal and continuous functioning of the infrastructure and to enable the restoration of functioning after breakdowns or failure (Jackson, 2011; Walia et al., 2010). These processes encompass a spectrum of proactive and reactive strategies, including routine checks, upkeep activities, adjustments, replacements, and diagnostic interventions aimed at forestalling breakdowns, enhancing performance, and rectifying malfunctions or failures as they occur (Walia et al., 2010; Henke and Sims, 2020). In theory, maintenance and repair are portrayed as two different but intertwined dimensions of infrastructures, crucial for enabling infrastructure's continuous functioning and sustainability (Ramakrishnan et al., 2021). Yet, maintenance primarily centers on preventive actions to slow down decay, forestall failures, and uphold infrastructure assets over time, while repair entails responsive actions to rectify, restore, and rebuild after breakdowns or malfunctioning infrastructures (Graham and Thrift, 2007; Henke and Sims, 2020). On the one hand, some scholars conceptualize maintenance as preservation, conversation, or 'caring' for infrastructure (Ramakrishnan et al., 2021; Buser and Boyer, 2021; Jackson, 2011). On the other hand, repair goes beyond restoring broken infrastructure to include innovating and inventing new ways to improve the infrastructure's functionality (Jackson et al., 2019).

Infrastructure maintenance and repair is still an emergent field of study despite its critical importance for urban infrastructure operations and renewal. Most existing studies on urban infrastructure maintenance and repair are centered on urban contexts in the global South (e.g., Anand, 2017; Alda-Vidal et al., 2018; Barnes, 2017; Wahby, 2021; de Coss-Corso, 2020). From these studies, it is possible to identify four main themes: 1) how maintenance and repair practices work in Southern cities, 2) the labor relations that support these operations, 3) the politics of infrastructure maintenance and repair, and 4) their socioeconomic and infrastructural outcomes.

Firstly, scholars have described how maintenance and repair practices are organized and implemented in various urban infrastructure networks in Southern cities (e.g., Baptista, 2019; Schubert, 2019; de Coss-Corso, 2020; Silver, 2014). These studies highlight the incrementality and ad hoc characteristics of maintenance and repair in cities, portraying them as contingent and situated socio-technical operations (Baptista, 2019; Anand, 2017; Wahby, 2021). In this view, scholars also agree that maintenance and repair practices entail adaptive patchwork, relying on the repair workers' knowledge and ability to improvise and invent creative local solutions (de Coss-Corso, 2020; Baptista, 2019). Indeed, the repair workers' knowledge of the city and its infrastructure conditions and

layouts becomes critical in maintenance and repair (Schubert, 2019) when considering that urban infrastructures are shaped by the urban contexts in which they operate (Anand, 2017). Some scholars equally argue that maintenance and repair practices often do not follow universal standards or guidelines but are instead based on what works and what does not work in each situation (Baptista, 2019; de Coss-Corso, 2020). Thus, every maintenance and repair work is unique, as it requires a distinct set of skills, knowledge, and adaptive practices. However, most of these studies focus on the maintenance and repair of infrastructure networks but neglect how existing sociotechnical arrangements in urban water supply shape maintenance and repair practices in these settings.

Secondly, some recent studies focused on the labor required to perform these operations and their crucial societal importance (e.g., Stoke and de Coss-Corso, 2023; de Coss-Corso, 2019; Anand, 2020; Ramakrishnan et al., 2021). These works have considered not only the bodily labor in the maintenance and repair of urban infrastructures (Stoke and de Coss-Corso, 2023), but also the role of human senses, such as sight, touch, intuition, and emotions, in the maintenance and repair of urban infrastructures (Anand, 2020; Ramakrishnan et al., 2021; Alda-Vidal et al., 2023). Even though repair work requires bodily labor, this sensorial dimension is necessary to enable the work to identify problems and implement appropriate fixes. Although critical and central to urban infrastructure operations in cities, scholars acknowledged that the value and importance of repair labor are often unrecognized and undervalued in society (Anand, 2020; Ramakrishnan et al., 2021). According to Anand (2020), the systematic subjugation and poor remuneration of maintenance and repair workers are partly linked to how this kind of labor is often called upon to act at night rather than during the day. He argued that conducting repair works at night reduces the impact of water infrastructure disruption on urban life and society, thereby consolidating the invisibility of repair work, helping to keep the value of this critical labor low. Thus, how maintenance and repair practices are organized and implemented reinforces the subjugation and low appreciation of repair labor and how people perceive, experience, and value it in society (ibid). Against this background, Ramakrishnan et al. (2021) indicated that it is vital for stakeholders to *care* for those (repair workers) who care for urban infrastructures. Such care, they argued, includes not only providing adequate remuneration for repair workers for their labor but also ensuring their safety at work sites.

Thirdly, the emerging literature also emphasizes the political dimensions of urban infrastructure maintenance and repair. For example, scholars have argued that the ultimate aim of maintenance and repair is not always to fix a technical problem

but, more importantly, to sustain the diverse socio-political aspirations and power relations that underpin technical artifacts (Ureta, 2014; Graham and Thrift, 2007). Others show that maintenance and repair practices can enact and sustain state political goals and interests tied to urban infrastructures (Barnes, 2017; Ureta, 2014). But those practices can also provide an avenue for various private actors to challenge the state's monopoly and control over urban infrastructures (Barnes, 2017; Wahby, 2021; Velho and Ureta, 2019; Graham and Thrift, 2007) and even the credibility of political authority (Ureta, 2014). For example, Barnes (2017) demonstrated how the state's political authority in Cairo was enacted and sustained through irrigation infrastructure maintenance and repair. At the same time, Wahby (2021) argued that the emergence of private actors in maintaining and repairing urban water infrastructures in gated neighborhoods in Cairo could/can challenge and potentially diminish state power and authority. In Santiago, Chile, Ureta (2014) demonstrated how maintenance and repair are called upon differently to 'repair' the state's credibility to restore confidence in a failing metro transportation system. Moreover, maintenance and repair decisions embody political logics, reflecting state priorities, values, and power dynamics (Anand, 2017). For example, resource allocation for maintenance and repair is a prime example, as it involves political choices about the allocation of public funds. Maintenance and repair can serve as a tool for political rhetoric and accountability, whereby the failures of infrastructures can be mobilized to question state power or demand accountability and justice from the state (Barnes, 2017; Wahby, 2021; Graham and Thrift, 2007). To a more significant extent, maintenance and repair intersect with broader policy agendas, such as environmental justice, sustainability, and economic development (Ramakrishnan et al., 2021). In sum, the political dimension of maintenance and repair is often overlooked, yet it significantly influences governance and state authority and is crucial for fostering an inclusive, resilient, and sustainable society.

Lastly, some other studies revealed the socioeconomic consequences of maintenance and repair, highlighting their role in increasing socio-spatial inequalities in cities and how they shape inhabitants' access to infrastructure services (Baptista, 2019; Alda-Vidal et al., 2018; Kjellén, 2009; Baptista, 2019). For example, by mapping the everyday maintenance operations of water networks in Lilongwe, Alda-Vidal (2018) showed that inadequate maintenance and repair can reinforce uneven access to the network water supply and consolidate pre-existing socioeconomic inequality in the city. Baptista's (2019) work in Maputo illustrated how maintenance and repair practices could exacerbate inequalities or enable access to formal electricity grids across socioeconomically different neighborhoods. Similarly, Kjellén (2009) demonstrated

that inadequate maintenance and repair practices can impact water quality and quantity availability for inhabitants, impacting urban sanitation and cost recovery.

The reviews above highlight three significant research gaps. Firstly, while existing literature extensively examines urban infrastructure maintenance and repair, there is a notable emphasis on the role and practices of public utilities engineers and technicians within centralized water networks. However, those implemented by private actors (plumbers and users) within and outside the public utility networks have hardly been discussed. Understanding maintenance and repair practices implemented by private and public actors inside and outside the networks is crucial for comprehensively assessing infrastructure management needs. Secondly, while the literature underscores the crucial role of human labor in maintaining and repairing infrastructure assets, it hardly reveals the diverse labor arrangements and relations involved in maintaining and repairing urban infrastructures within cities. Investigating the various actors and their labor relations is essential for understanding the dynamics that influence maintenance and repair outcomes. Thirdly, although various studies acknowledge the inherently political nature of maintenance and repair, they predominantly focus on the state's role and embedded political logic. However, there is a notable absence of research examining the influence of other significant actors, such as donors, whose political interests equally affect maintenance and repair practices. Studying donors' role and impact on maintenance and repair is crucial for revealing the multidimensional and diverse actors and their political interests shaping maintenance and repair. Despite the extant literature highlighting the crucial role of maintenance and repair practices in shaping urban infrastructure operations, there is no empirical study on how maintenance and repair practices influence the resilience of urban infrastructure. The next section will review the literature on urban infrastructure resilience to highlight the relationship between these important aspects of urban infrastructure.

1.2.4 The resilience of urban infrastructures

Over the last two decades, urban infrastructure resilience has gained significant attention in research and policy discourses as disaster risks continue to grow and manifest across cities in the global North and South (Meerow and Newell, 2019). Infrastructures such as water and electricity systems play a critical role in facilitating the smooth functioning of modern cities (Graham and Thrift, 2007). However, critical infrastructures also make modern cities more vulnerable to failures and disruptions (Monstadt and Schmidt, 2019), especially as these infrastructures are increasingly exposed to climate change impacts such as floods, droughts, and hurricanes (Huck, 2020; Campanella, 2016). Urban infrastructures in African cities are even more precarious because, in

addition to these external weather extremes, they face challenges of structural decay, aging networks, and fragmentation, further promoting infrastructural precarity, frequent breakdowns, and failures (Silver, 2015).

In various academic debates, urban infrastructure resilience has been defined as a system's capacity to resist, adapt, recover from shocks, and return to a prior state of functioning (Alexander et al., 2016; Balaei et al., 2018; Brassett and Vaughan-Williams, 2015; Gay and Sinha, 2013). This definition is sometimes referred to as capacity to 'bounce back' to a state of equilibrium after the disturbances (Hall et al., 2019). However, recent works on urban infrastructure resilience have shifted away from this conceptualization towards a framing that emphasizes the system's capacity to 'bounces forward' (Christmann and Ibert, 2012). In this regard, Meerow et al. (2016) defined urban infrastructure resilience as the capacity of a system to maintain or rapidly return to desired functions in the face of a disturbance, to adapt to change, and to quickly transform system components that limit current or future adaptive capacity. This shift in the focus on resilience is necessary because complex infrastructure systems do not necessarily 'bounce back' to their prior position of equilibrium (Monstadt and Schmidt, 2019; Folke, 2006; Christmann and Ibert, 2012) but could—and, arguably, should—also 'bounce forward' to new states of equilibrium that may be more resilient than before (Folke 2010). Herewith, change is necessary, and the capacities to learn, adapt, and transform are critical preconditions for enabling resilient systems (Folke et al., 2002; Folke, 2010).

In urban infrastructure resilience debates, scholars have pointed to what they call a "vulnerability paradox" (Eledi Kuusaana et al., 2023) to argue that cities with more reliable infrastructures tend to be more vulnerable to failures and interruptions because people hardly develop backup and alternative systems (Eledi Kuusaana et al., 2023; Folke, 2006; Graham, 2010). Conversely, they argued, cities that experience frequent interruptions and failures can be more resilient because users and service providers tend to develop adaptive capacities and coping mechanisms to mitigate societal impacts (Eledi Kuusaana et al., 2023). However, we know little about how this paradox plays out in maintaining and repairing urban water supply in African cities. The role of maintenance and repair in contributing to infrastructure resilience emphasizes this vulnerability paradox. A key assumption is that failures and breakdowns are inevitable in urban infrastructure systems (Graham and Thrift, 2007), and the goal of resilience should not be to prevent them but rather to learn how urban infrastructures can adapt to failures. In short, they emphasize the need for 'safe-to-fail' rather than 'failure-proof' systems (Ahern, 2011; Sharifi and Yamagata, 2018). Despite the extant

research on urban infrastructure resilience, the debates have so far focused on how socio-technical systems can withstand or respond to disturbances driven by climate change. However, those driven by internal systems dynamics (such as decay and aging networks) and the role of maintenance and repair in shaping infrastructure resilience have thus far been neglected. This focus is necessary because, in addition to climate change and demographic growth, urban infrastructures in African cities suffer from frequent breakdowns and failures due to decay and aging networks.

1.2.5 Summary of the research gaps

The literature review above has highlighted various research gaps this study seeks to address. First, the review has shown that critical studies have underscored the sociotechnical heterogeneity and hybridity of urban infrastructure arrangements, the coproduction of infrastructure services, and how these conditions influence access to and governance of infrastructures in these settings. However, the literature does not yet explain how socio-technical arrangements in urban water supply in and beyond the networks shape maintenance and repair practices and how those practices affect the resilience of water infrastructures. Addressing this research gap is necessary to move our understanding of the sociotechnical heterogeneity of urban infrastructures in the global South beyond discourses on provision and access to urban infrastructure toward the everyday practices of maintenance and repair that underpin infrastructures' functioning, sustainability, and resilience in the global South. Additionally, this insight will contribute to a better understanding of urban infrastructure maintenance and repair dynamics to develop more inclusive and responsive governance frameworks that account for the diverse stakeholders involved in water infrastructure maintenance and repair.

Second, although existing literature addresses the maintenance and repair of urban infrastructures in the global South, it predominantly focuses on the practices of public utility workers within centralized utility networks. The roles and practices of other private actors, including donors, plumbers, and users, in maintenance and repair are apparently neglected. It is critical to introduce the role of these various actors in the literature to move our understanding of maintenance and repair beyond the purview of the state and public utility companies toward collaborative labor relations between state and non-state actors or private and public agents. This shift can also broaden the debates on sociotechnical heterogeneity and hybridity into the maintenance and repair of urban infrastructure in the global South.

Third, whereas the literature widely acknowledges the crucial importance of maintenance and repair practices in supporting urban infrastructures' operations, access,

and sustainability in cities, there is a limited understanding of the role of maintenance and repair in shaping urban infrastructure resilience in African contexts. Exploring the role of maintenance and repair in shaping infrastructure resilience is critical because urban infrastructures in these settings are exposed to climate change risks and decay and aging infrastructure networks. This insight brings into the infrastructure debates an important but hitherto neglected aspect of urban resilience in the global south. This also expands the focus of urban resilience debates beyond climate change towards a position that emphasizes the system's internal dynamics.

A focus on the above research gaps will enable a better understanding of the relationships between socio-technical arrangements in urban infrastructure, maintenance and repair practices, and urban infrastructure resilience in African cities. By capturing the multiplicity of actors, practices, and labor relations that shape water infrastructure maintenance and repair in these settings, we can better explain how infrastructure services are coproduced and shaped through maintenance and repair and how practices work in the context of heterogeneous and hybrid infrastructure conditions. In short, researching these gaps can generate critical insight to enrich academic debates on socio-technical heterogeneity and hybridity and practical lessons for supporting urban water policy formulation on maintenance and repair and infrastructure resilience. In the next section, I will outline the study's aim and guide research questions from the above research gaps.

1.3 Research aim and questions

In response to the research gaps identified above, this section outlines the dissertation's main aim which is to develop a nuanced understanding of how socio-technical arrangements in urban water supply (in and beyond the network) affect maintenance and repair practices and the impacts of those arrangements and practices on the resilience of water infrastructures in Accra and Dar es Salaam cities. The dissertation responds to calls by scholars to interrogate to which extent sociotechnical heterogeneity and hybridity shape practices in the global South (e.g., Rateau and Jaglin, 2022; Baptista and Cirolia, 2022; Lawhon et al.,2018) and contributes to a better understanding of how maintenance and repair practices are organized and implemented in these settings and their implications for resilience (and sustainability) of water infrastructures. Against this background, the main research question that I analyzed in this study is: *How do socio-technical arrangements in water supply in and beyond the network shape maintenance and repair practices?*

With this overarching research question, I want to explore the complex structural arrangements and relationships in water supply and their impacts on social maintenance and repair practices. More specifically, this question addresses the sociotechnical arrangements in and beyond water networks in Accra and Dar es Salaam and focuses on the routine maintenance and repair practices by private and public engineers, technicians and repairers. The fundamental assumptions are that water supply systems are not constituted by technical artifacts alone but also by social elements such as human actors, institutions, and relations and that incrementally developed water supply beyond formal water networks is equally essential for understanding water supply systems in African cities as networked water supply by public utility companies (Tiwale, 2019; Monstadt and Schramm, 2017). These sociotechnical arrangements consist of situated and dynamic configurations of various artifacts and materialities which are interconnected to and shaped by social elements such as institutional arrangments, embodied knowledge, and discourses (Meilinger and Monstadt, 2022). The sociotechnical system view helps to better understand the complex relationships and interactions between technical and social components of the water supply systems. With such understanding, stakeholders such as policy makers and water managers can design comprehensive and more inclusive strategies and policies for enhancing resilience and sustainability in water supply.

The main research question will help us to understand not just the sociotechnical arrangements in water supply between the two cities but also more importantly what those arrangements mean for maintenance and repair practices in the two cities. The research question is further unpacked and discussed through three sub-questions discussed in Chapter 2-4, connecting maintenance and repair practices to labor relations, the role of donors, and infrastructure resilience.

RQ1: *How do labor relations among workers in water supply affect maintenance and repair practices?*

An important aspect of the sociotechnical arrangements in water supply is labor. The effectiveness of maintenance and repair operations depends on the labor relations among private and public repair workers. Labor relation in this context refers specifically to the 'everday' interactions and relationships between private and public repair workers in their attempts to maintain and repair the cities' water infrastructures. Factors such as worker cooperation, communication, job satisfaction, training, and organizational culture can impact the efficiency, safety, and quality of maintenance and repair practices. However, the extent to which labor relations among private

and public workers affect maintenance and repair practices is poorly understood. Against this background, this question interrogates the diverse labor arrangements and relations among repair workers operating within the two cities' water supply sectors, focusing on both private and public systems as well as networked and off-grid solutions. It explores the interactions between private and public workers and how their relations influence the organization, implementation, and governance of maintenance and repair practices in the two cities. The aim of this question is to understand the intersections between private and public labor and identify potential challenges and complementarities in maintenance and repair. This insight will expand the discourses and debates on the maintenance and repair of urban infrastructure in the global South beyond the state (or public utilities). It positions maintenance and repair within a context of hybrid labor arrangements between private and public agents in coproducing maintenance and repair. The question is addressed in Chapters 2 and 3.

RQ2: *How do donors' funding schemes in the water supply sector affect maintenance and repair practices?*

In the context of Africa, the role of donors and their funding schemes cannot be overstated in the urban water sectors. Donor funding schemes constitute a major source of investments in the construction and development of water infrastructures and play a crucial role in promoting technology transfer from developed countries to developing countries in the global South (El Khanji, 2022; Lu and Qiu, 2022). This research question delves into the complex relationships and implications of donors' funding schemes on maintenance and repair practices within the water supply sector of both cities. It unravels the multifaceted dynamics and institutional and political logics that underpin and shape development aid schemes and their deployment, and demonstrates how these complex sociotechnical arrangements affect maintenance and repair practices within water supply systems. This question contributes to the literature on maintenance and repair and urban infrastructure debates in the global South. This question is crucial because whereas the significance of donor funding schemes in constructing and developing technical water systems in African cities is widely acclaimed in development studies (El Khanji, 2022; Monney and Antwi-Agyei, 2018), the impacts of those funding schemes on maintenance and repair practices have hardly been explored. Thus, the question connects (indirect) donors' role to maintenance and repair practices, expanding the literature beyond local actors and contexts. The question is important because it emphasizes the need to anticipate maintenance and repair in donors' infrastructure funding schemes and technology

transfer arrangements to ensure resilience and sustainability. I address this question in Chapter 4 of this dissertation.

RQ3: *How do maintenance and repair practices affect the resilience of urban water infrastructure?*

This final question explores the linkage between maintenance and repair practices and water infrastructure resilience. It investigates how maintenance and repair practices (both formal and informal) might contribute to water infrastructure resilience capacities to resist, absorb, or adapt to infrastructure failures and breakdowns caused by internal systems dynamics such as material decay and aging networks. Thus, I recognize maintenance and repair practices as crucial preconditions for ensuring reliable and safe water supply. This focus on the role of maintenance and repair in building infrastructure resilience is particularly relevant in the context of African cities. Because, infrastructure systems' resilience in these settings is not only determined by climate change and weather events such as drought and floods (IPCC, 2021) but also by internal dynamics such as decay and aging material infrastructures. Yet, urban infrastructure resilience debates in these contexts rarely focus on the role of maintenance and repair and how they can contribute to infrastructures' resilience. This question seeks to contribute insight to this gap and is addressed in Chapter 5, drawing on empirical evidence and insights from Chapters 2-4.

After this outline, the next section presents the conceptual framework underpinning the study and how it will be applied to analyze the research questions.

1.4 Conceptual framework

This section outlines a conceptual framework to guide this dissertation, building on concepts in critical urban infrastructures studies. The conceptual framework (Figure 1) is underpinned by three main components, i.e, the sociotechnical arrangements in water supply, maintenance and repair practices and water infrastructure resilience. The conceptual framework explains how sociotechnical arrangements in water supply affect maintenance and repair practices through four main components i.e, materialities, institutions, knowledge and discourses, and the impacts of those practices on the resilience of water infrastructures.

Inspired by Science and Technology Studies (e.g. Smith et al., 2005; Meilinger and Monstadt, 2022), I define sociotechnical arrangements in water supply as a relatively

stable configuration of social and technical components, integrating artifacts, actors, institutions, techniques, and relations. With this understanding, I recognize the materialities, institutions, knowledge and discourses as critical to understanding the sociotechnical arrangments in water supply. This is because those four components are not only central to the design and functioning of the technical infrastructure but also the modes of organizing maintenance and repair practices and their governance in the city.

Figure 1.1 The relationship between socio-technical arrangements in water supply and maintenance and repair for water infrastructure resilience

Source: Author

I define materialities as the tangible components of the water supply system such as pipe networks, technologies, water plants, water resources and equipment (Tiwale et al., 2018). These elements can decay, break down, and fail due to wear and tear (Graham and Thrift, 2007; Tiwale, 2019). The institutions refer to formal laws, rules, policies, standards, and informal norms delineating roles and practices; providing regulatory frameworks within which actors operate (Tiwale, 2019; North, 1991). In other words, they provide the "rules of the game" within which actors operate. I define knowledge in relation to the technical 'know-how' required to implement maintenance and repair of various material artifacts in the system and encompasses the repair workers' knowledge of the local area (Anand, 2017; Anand, 2020). The local area knowledge is particularly crucial in African cities because it enables repair workers to navigate through the city and its diverse neighborhoods to identify various leakages and structural problems in the systems and implement maintenance and repair practices. Repair knowledge can be gained through both formal training and practical experience through "learning by doing' (Houston, 2019). The discourses refer to a discursive framing or how key actors portray and present specific water problems in their public and media narratives (Hajer, 1995). They can affect actors' and public attitudes, policy priorities, and resource allocations to maintenance and repair. Thus, discourses can affect how various actors in water supply (e.g., repair workers, users, donors) will approach, organize, and implement maintenance and

repair practices in urban water supply. The four dimensions enumerated above are interconnected in complex ways and their interplay influence the organization and implementation of maintenance and repair practices in water supply within the city. These practices include formal and informal activities as well as incremental and planned interventions organized and implemented by private and public workers in and beyond the networks (Baptista, 2019). Often, such practices do not follow strict standards and guidelines but are largely based on and shaped by workers' embodied knowledge, experience, and material configurations.

To systematically explain the main research question, I adopt a two-tier analytical framework that; (a) explains the maintenance and repair practices in water supply through materialities, institutions, knowledge and discourse dimensions of the socio-otechinical arrangements in water supply, and (b) explores how those maintenance and repair practices contributes to water infrastructure resilience capacities to resist, absorb, and adapt to failures and breakdowns. I hypothesize that water infrastructure resilience is a function of the maintenance and repair practices which are equally contingent on and shaped by the materialities, institutions, and knowledge and discourses dimension within the sociotechnical arrangements in water supply.

1.5 Research design and methodology

1.5.1 Qualitative research design

This thesis uses a qualitative case study—a research design that enables the exploration of complex social phenomena by analyzing different factors and practices interacting and shaping it in a real-life context (Yin, 2003; Flvybjerg, 2006; Epler, 2019). Numerous advantages of the qualitative case study design informed this choice. First, this research design enabled an in-depth exploration of the topics from multiple actors' viewpoints to gain a deeper understanding of the issues. Second, it enabled flexibility in the research because the researcher could ask further probing questions based on emerging information from the responses received from the interlocutors during field interviews (Giorgi, 2009). Hence, it is most suitable and preferred if the study aims to provide an in-depth explanation of *'how, what, and why'* questions relating to a social phenomenon (Creswell, 2014; Teherani et al., 2015).

The qualitative research design was chosen because it enabled me to explore maintenance and repair practices in-depth (Baskarada, 2014; Creswell, 2014) through the materialities, discourses, institutions, and knowledge dimensions of water supply systems in both cities. I analyze the maintenance and repair practices through these

four dimensions to identify and highlight their emerging differences, similarities, and broader patterns in relation to how maintenance and repair practices are conducted in each city. The differences identified help to understand how 'place-based' socio-technical arrangements in water supply shape and are shaped by maintenance and repair practices in different contexts. Those differences further generate empirical insights into the spatial dimension of maintenance and repair, the complex interactions in socio-technical systems, and the implications of maintenance and repair practices on urban water infrastructure resilience outcomes in African cities. Both deductive and inductive strategies were applied to analyze the data to generate insight for refining existing socio-technical systems theory and generating new assumptions that can be tested in further qualitative research. Deductive reasoning seeks to confirm or test existing theories and test hypotheses, and inductive approaches aim to develop new assumptions or refine existing theories based on empirical evidence (Azungah, 2018). Whereas deductive analysis entails identifying, coding, and interpreting the empirical data based on predetermined theoretical frameworks identified through literature reviews, inductive analysis is conducted based on emerging themes from the empirical data.

1.5.2 Comparative case study strategy

This research applied a comparative case study approach to explore and explain maintenance and repair practices through socio-technical arrangements in Accra and Dar es Salaam's water supply systems and how those practices affect water infrastructure resilience. More specifically, it analyses and compares actors' roles and practices in maintenance and repair, the respective maintenance and repair strategies and approaches, the impacts of donors' funding schemes on maintenance and repair practices across the two cities, and the impact of those practices on water infrastructure resilience. However, the comparison developed through this research is not a systematic but rather illustrative comparison (Epler, 2019). Thus, it highlights concrete examples from both cities (and their diverse neighborhoods) to illustrate their emerging differences, similarities, broader patterns, and relationships in maintenance and repair through the materialities, institutions, knowledge, and discourses dimensions (Yin and Davis, 2007; Kantor and Savitch, 2005). This comparative case study generates critical insight into situated and place-based maintenance and repair practices, yet it allows for building theories beyond localized contexts (Yin and Davis, 2007). The explanatory value of comparative case studies lies in their ability to provide nuanced, context-specific explanations for various phenomena, identify causal relationships, test and develop theories, and inform decision-making (Yin and Davis, 2007). Moreover, it provides an opportunity for sharing and learning lessons from successful cases, best practices, and failures from different contexts.

1.5.3 Rationale for selecting both cases

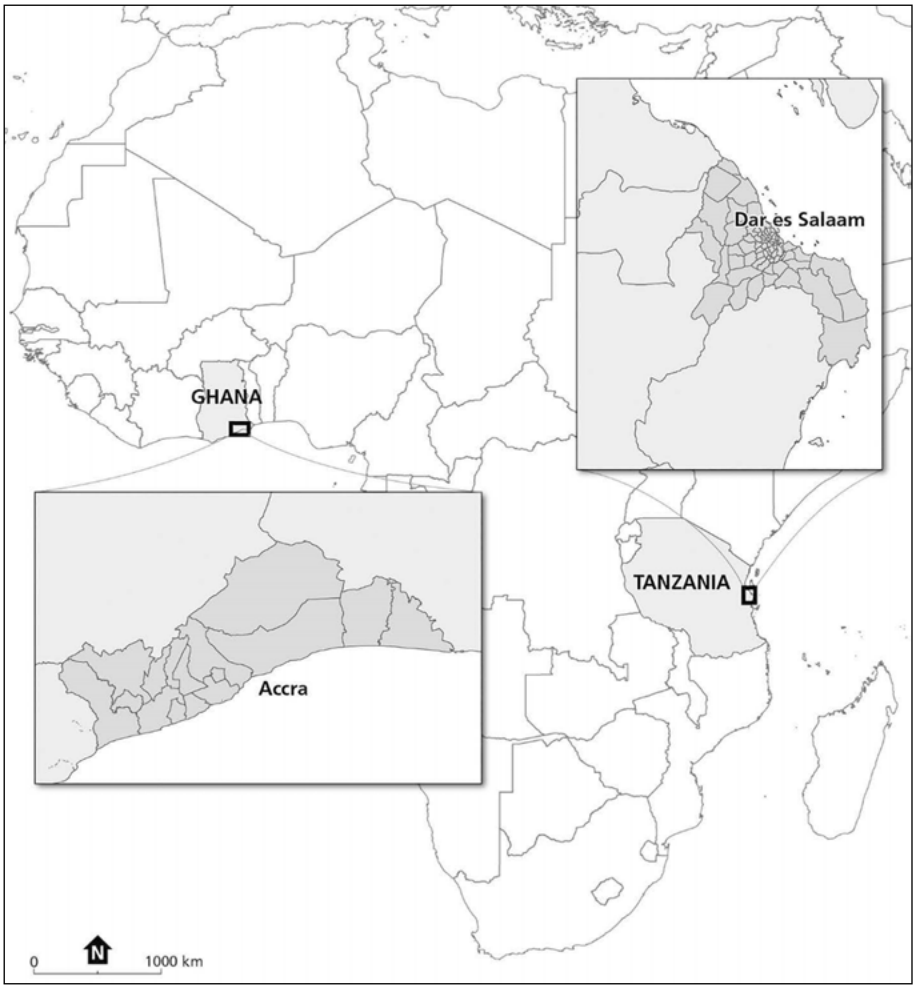
The two case study sites—Accra and Dar es Salaam—were selected because they are 'most similar' cases in terms of urban water problems, urban development, population growth, and their institutional arrangements in urban water sectors but differ significantly in terms of their maintenance and repair strategies and how they are organized and implemented in their respective water sectors. The most similar case strategy is adopted to analyze maintenance and repair practices across the two cities. The most similar case study approach involves analyzing a phenomenon across two or more cases with similar characteristics in many areas except for the variable of interest (Seawright and Gerring, 2008; Flvybjerg, 2006). The explanatory value of the most similar case studies approach relates to the ability to reveal context-specific factors that might have caused differences in maintenance and repair across two cases with similar characteristics (Seawright and Gerring, 2008). It is also valuable for explaining socio-technical relationships and the role of specific actors in shaping the outcomes of maintenance and repair in the two cities. Thus, most similar case studies can serve as benchmarks to explain how and why maintenance and repair practices and strategies differ in the two cities.

Despite their locations in different countries, Accra and Dar es Salam have close similarities in their socioeconomic development and urban water sectors. Accra is Ghana's capital and largest city, and Dar es Salaam is the largest commercial hub in Tanzania (figure 2). Accra has about 2.6 million, compared to Dar es Salaam's estimated 5.4 million (URT, 2022; GSS, 2022). Both cities are fast-growing, with approximately 60% and 80% of Accra and Dar es Salam development described as informal (Dakyaga et al., 2022; Adams and Vásquez, 2019). Also, both countries' water sectors were structured and organized according to the World Bank/IMF-led structural adjustment program, which introduced neoliberal ideas in urban water supply (Pigeon et al., 2012; Ameyaw and Chan, 2013; Kjellén, 2006). These reforms have shaped both countries' urban water sectors to develop along similar structures, regulatory standards, and legislative frameworks.

However, the way the two cities organize urban water supply differs slightly. While the urban water supply in Accra is organized by a national water company (the GWCL), the water supply in Dar es Salaam is organized at the regional level by DAWASA. Both water companies have struggled to meet water demand in their respective cities, resulting in various informal, private water providers complementing residents' water needs (Monstadt and Schramm, 2017; Peloso and Morinville, 2014). A common problem facing the two urban water suppliers in both cities concerns structural

decay, aged water infrastructures, and inadequate maintenance and repair. This has resulted in approximately 50% of water losses in both cities (Kjellén, 2009; EWURA, 2018; GWCL, 2018). Examining the differences in maintenance and repair is relevant because African cities differ in terms of their socio-technical arrangements and the diversity of neighborhoods' water supply systems.

Figure 1.2 Map of Ghana and Tanzania showing Accra and Dar es Salaam cities



Source: author

1.5.4 Data collection methods

The empirical data for this study were collected between 2018 and 2021 in two research stays in each city. The sites and respondents were chosen through the purposive sampling technique—a non-randomized criterion prioritizing sites and informants with the most relevant characteristics for understanding a phenomenon (Robinson, 2014). The data were collected using various qualitative methods, including semi-structured interviews and direct field observations. These methods were triangulated with grey and secondary empirical literature analyses on urban water supply, infrastructure maintenance and repair, and resilience in the two countries, especially focusing on the two cities. In the following sections, I will first describe how the grey and secondary empirical literature analysis was conducted, followed by semi-structured interviews and field observations.

Grey and secondary empirical literature

As a first step, I analyzed secondary empirical and grey literature on both cities, focusing on urban water supply, policy frameworks, strategic plans, and annual reports of water companies and government ministries for water and infrastructure. Others include water sector legislations, newspaper articles on water supply, infrastructure development frameworks, and the discourses on non-revenue water in Ghana and Tanzania, focusing on Accra and Dar es Salaam. This analysis helped me to better understand the two countries' broader water sectors, focusing on urban water sector policy frameworks and institutional arrangements, their respective management approaches, national water agendas and priorities, and the key actors involved in each country's water sectors. I also gained a detailed understanding of the state of water supply, infrastructure constellations, and maintenance and repair arrangements in both cities. Ghana's water sector development policy and Tanzania's water sector development program documents were critical for me to understand the state policy aspirations in urban water supply and the financial schemes implemented by various international donors across both countries and cities. This method was pivotal for writing all the chapters in this dissertation and guided me to identify themes to be explored through semi-structured interviews.

Semi-structured interviews

Secondly, semi-structured interviews were a critical source of gathering empirical data for this study. The interviews were conducted in two rounds of field visits to Accra in 2018 and 2020 and Dar es Salaam in 2019 and 2021. A total of 75 interviews (39 in Accra and 36 in Dar es Salaam) were conducted and transcribed across the two cities (see list in Appendix 1). I interviewed respondents at various organizations and government

departments across the two cities. Specifically, I interviewed various repair workers and administrative managers of the Ghana Water Company Limited (GWCL) and Dar es Salaam Water and Sewerage Authority (DAWASA), private plumbers, individual users, and government administrators in both cities. I also interviewed representatives of various international donor agencies, Non-governmental Organizations (NGOs), local water experts, and civil society organizations across the two cities. The interviews were conducted using a semi-structured interview guide (Creswell, 2013), which was structured to explore various research themes. The themes include the types of urban water supply constellations, the diverse actors involved and their practices, the types of funding schemes by donors in water supply, the organization of maintenance and repair practices, their impacts on maintenance and repair practices, and urban water infrastructure resilience in the two cities. I explored these topics by developing several probing research questions to provoke open conversations with the respondents. These conversations enabled me to probe respondents further for more detailed accounts of specific issues based on their responses to the initial questions. All interviews were conducted in English. The data were recorded in detailed field notes, which I later compiled into field reports and interview transcripts for further analysis. This method was central to writing chapters 2 to 5 of this dissertation and provided me with some clues on the forms of maintenance and repair practices and issues I needed to explore further through direct field observations.

Direct field observation and conversations

Finally, I conducted several field trips to observe how repair workers implement maintenance and repair practices in real-life contexts across the two cities. I followed GWCL and DAWASA repair works and various private plumbers to different field locations to observe their routine maintenance and repair practices and operations in various urban water supply systems. This method enabled me to collect first-hand information about the everyday practices of workers relating to how they maintain and repair various urban water infrastructure artifacts in real life. It also helped identify their related challenges and how repair workers addressed them in their daily operations, including the forms of improvised and adaptive practices they implemented. Through informal conversations, I probed for more details about their everyday practices and experiences, delving further into specific findings that emerged from the semi-structured interviews that needed further clarity. Also, informal interactions with repair workers allowed me to develop personal relations with some workers and develop more trust, which I leveraged to support further conversations and data collection during the fieldwork. I also had the opportunity to capture various pictures and images of equipment and exciting maintenance and repair operations to enrich the data. This method was used

to collect data for writing chapters 2-5 of this dissertation. All the qualitative data were analyzed using various techniques discussed in the following section.

1.5.5 Data analysis

The grey and secondary empirical literature were analyzed using a content analysis strategy (Hsieh and Shannon, 2005). This involved reading through various texts in documents, identifying the key contents, categorizing similar contents, and interpreting their meanings and logic to explain my research topic. Moreover, all qualitative empirical data were analyzed using content and thematic techniques inspired by inductive and deductive approaches. The analytical units were the two cities, their diverse neighborhoods and heterogenous water supply systems, and the responses of various interviewees in the study. The data analysis involved describing, exploring, and interpreting direct quotes and interview transcripts to develop a meaningful interpretation of findings. The analysis focuses on socio-technical arrangements in water supply, how they shape maintenance and repair practices and how the maintenance and repair practices, in turn, affect infrastructure resilience. It also focuses on differences and similarities in how maintenance and repair are organized and implemented in the two cities. In sum, different qualitative analysis strategies were applied to the four research articles contained in this thesis. The interview data were transcribed, coded, and analyzed with four major topics consistent with the four research articles in this thesis (Chapters 2-5). These include (1) the maintenance and repair practices of utility employees and how they are organized and implemented differently in both cities, (2) how private plumbers' informal practices interplay with those of public utility employees in the maintenance and repair of water supply systems in and beyond the network, (3) the impact of donors funding schemes on maintenance and repair, and (4) the role of maintenance and repair practices in shaping water infrastructure resilience. The data were analyzed across these themes to identify emerging differences, similarities, and patterns across the two cities. Those differences and similarities were used to explain how socio-technical arrangements in water supply shape maintenance and repair differently in the two cities through the materialities, institutions, knowledge, and discourse dimensions and the implications of maintenance and repair practices on water infrastructure resilience in both cities.

1.6 Dissertation outline

This dissertation comprises six chapters combining this introduction (Chapter 1), three published journal articles (Chapters 2, 3, and 4), one submitted article (Chapter 5), and a conclusion (Chapter 6). Table 1 provides an overview and summary of the

journal articles, the chapters in which they can be found, and the specific research questions they addressed in this dissertation.

Chapter 1 lays the groundwork by introducing the central research problem focused on maintenance and repair practices within urban water supply systems in Accra and Dar es Salaam, emphasizing the intricate socio-technical arrangements that influence and are influenced by these practices. It underscores the involvement of diverse actors in urban water supply and the importance of studying the roles in shaping maintenance and repair. Chapter 2 delves into the specific practices of public utility workers within these systems, using a sociotechnical framework to explore how their routines interact with and are shaped by materialities, institutions, discourses, and knowledge. These four variables helped me to explain how maintenance and repair practices differ across the two cities and why they differ. By comparing these practices across the two cities, the chapter reveals the significant roles and involvement of various actors beyond public utility employees, such as local plumbers, users, and donors, and calls for the need to include these actors in maintenance and repair studies.

Table 1.1 Summary of thesis structure and publications

Chapter	Authors, the title of papers, and journal	Research questions addressed
Chapter 2	Jambadu, L., Monstadt., J and Schramm, S. (2022). Understanding maintenance and repair in networked water supply systems in Accra and Dar es Salaam. *Water Alternatives*, 15(2), 265-289, https://www.water-alternatives.org/index.php/alldoc/articles/vol15/v15issue2/661-a15-2-3.	MRQ and RQ1
Chapter 3	Jambadu, L., Pilo', F., and Monstadt, J. (2023). Co-producing maintenance and repair: hybrid labor relations in water supply in Accra, Ghana. *Urban Research & Practice*, 1-23, https://doi.org/10.1080/17535069.2023.2180325.	RQ1
Chapter 4	Jambadu, L., Monstadt, J., and Pilo', F., (2024). The politics of tied aid: technology transfer and the maintenance and repair of water infrastructures. *World Development*. 175(2024),106476, https://doi.org/10.1016/j.worlddev.2023.106476.	RQ2
Chapter 5	Jambadu, L., Hölscher K., and Monstadt, J., (2023). Enhancing infrastructure resilience through maintenance and repair? The case of water supply in Accra and Dar es Salaam. Unpublished manuscript under review.	RQ 3
Chapter 6	The conclusion synthesizes the study's key findings by revisiting and responding to the research questions. It also highlights the implications of the findings for shaping policy, future research, and water supply and infrastructure resilience.	MRQ

Chapter 3 builds on this insight further by examining the role of private plumbers and users in maintenance and repair practices, highlighting the hybrid nature of formal and informal practices and the interplay between private and public labor relations within the sociotechnical arrangement in water supply. The chapter emphasized the need to shift the analysis of maintenance and repair beyond the role of local actors such as plumbers and utility employees and called for the need to introduce the role of donors into the discourses on maintenance and repair and how their funding schemes affect practices.

Chapter 4 responds to the need to consider the impact of donors' funding schemes on maintenance and repair practices, arguing that while these schemes promote water supply expansion, they also introduce complexities and challenges to local expertise and financial capacity. This complexity challenges local experts' knowledge and their capacity to maintain and repair the infrastructures locally. The chapter concludes by emphasizing the need to critically explore the role of maintenance and repair and the need to better anticipate them in urban water infrastructure projects to enhance sustainability and resilience.

Chapter 5 explores infrastructure resilience in relation to maintenance and repair practices. It relies on empirical evidence and findings drawn from chapters 2-4 to explain the role of maintenance and repair in shaping urban water infrastructure resilience in Accra and Dar es Salaam. It examines how maintenance and repair practices by various actors shape urban water infrastructure resilience capacities to resist, absorb, and adapt to breakdown and failures caused by decay and aging systems and their implications on ecological, economic, and social sustainability outcomes. The chapter shows the vital role of maintenance and repair not solely in shaping water infrastructure resilience capacities but also in the infrastructure's sustainability outcomes. However, while maintenance and repair can enhance infrastructures' resilience capacities, the resulting capacities can harm the ecological sustainability of water systems. Therefore, maintenance and repair are vital in shaping not solely the technical infrastructures but also the socioecological systems in which they operate.

Finally, Chapter 6 concludes the dissertation by synthesizing the key insights and lessons learned to respond to the main research questions and open new questions about urban infrastructures, maintenance and repair, and resilience in African cities. The chapter draws on insights from chapters 2-5 to reflect on how socio-technical arrangements in urban water supply in and beyond the network shape maintenance and repair practices and how those practices shape water infrastructure resilience

in African cities. This dissertation generates insights to advance understanding in urban infrastructure studies through the lens of water infrastructure maintenance and repair in African cities. The chapter then recommends ways to support urban water policy formulation, planning practices, water management, and future research direction.

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CHAPTER 2

UNDERSTANDING MAINTENANCE AND REPAIR 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 socio-technical 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.

2.1 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 Dar es Salaam, Tanzania, is the decay of infrastructure networks. As a result of this decay, water supply in both cities is characterized 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 socio-material 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 into 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.

2.2 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 it (Barnes, 2017). Steven Jackson (2014) illustrates this crucial importance by emphasizing 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 breakdown and the resulting repair and maintenance work are thus characterized as transient, recurring, and dynamic (Ramakrishnan et al., 2020) and are 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 emphasize 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 socio-political and economic relationships surrounding them.

Despite the crucial importance of repair and maintenance, decision-makers 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 its 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 emphasizing 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).

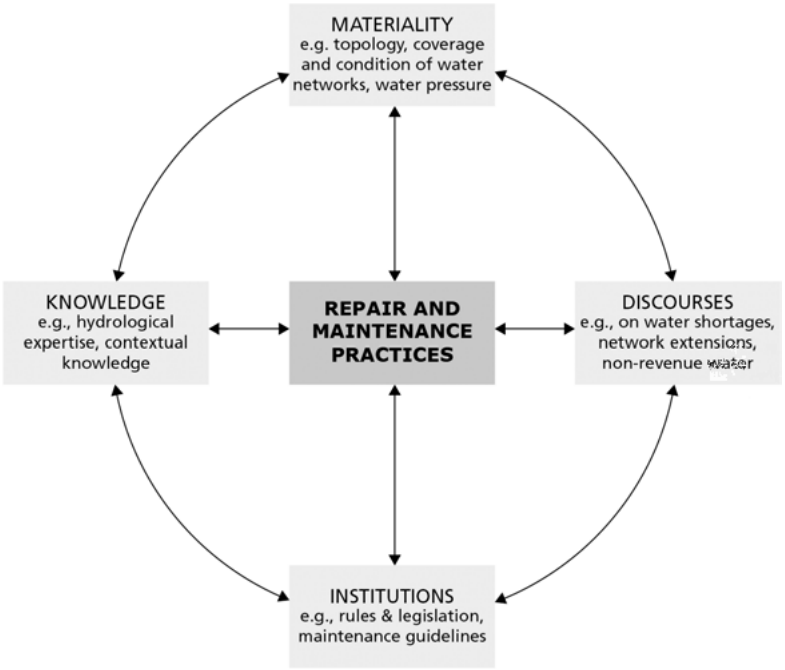
The above literature review shows that there is growing scholarly interest in studying infrastructure repair and maintenance. Previous studies, however, have mainly approached maintenance and repair in their situated contexts and have often focused on specific utilities. Our case study is thus a unique 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.

2.3 Conceptualizing 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 2.1).

Figure 2.1 Conceptualizing infrastructural repair and maintenance practices.



Source: Authors' construct.

In Figure 2.1, 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 labor to manipulate, tinker, adapt, or appropriate various artefacts in line with their

specific goals (Barnes, 2017). As different authors emphasize, 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 categorizations 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 organized and executed. At the same time, various informal norms and practical guidelines structure and regulate 'workplace order' during repair work in terms of labor 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 organization 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.

2.4 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 privatization of GWCL and DAWASA and subsequently to their Renationalization. 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, universalization 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 were aimed at studying their everyday practices relating to

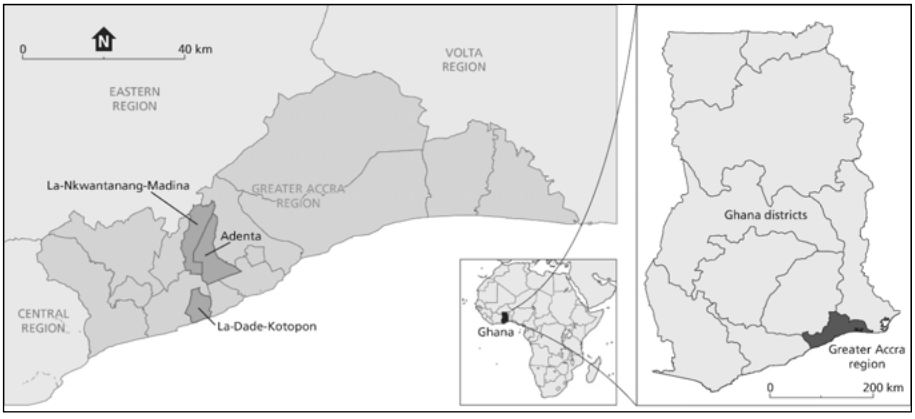
water infrastructure repair and maintenance. For two months in the respective cities, we followed repair workers around to different locations in order to observe their everyday practices as they fixed leaks and repaired broken equipment. This offered us opportunities to ask various questions for clarification 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.

2.5 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 km^2 of land (Addae & Oppelt, 2019). Accra city alone (Figure 2.2) 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 2.2 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 m^3 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 km^2 (Figure 2.3), 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 urbanization 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 the 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.

2.6 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 a loss of 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 2.4), repair and maintenance are hampered because engineers find it difficult to inspect networks and discover and repair leaks.

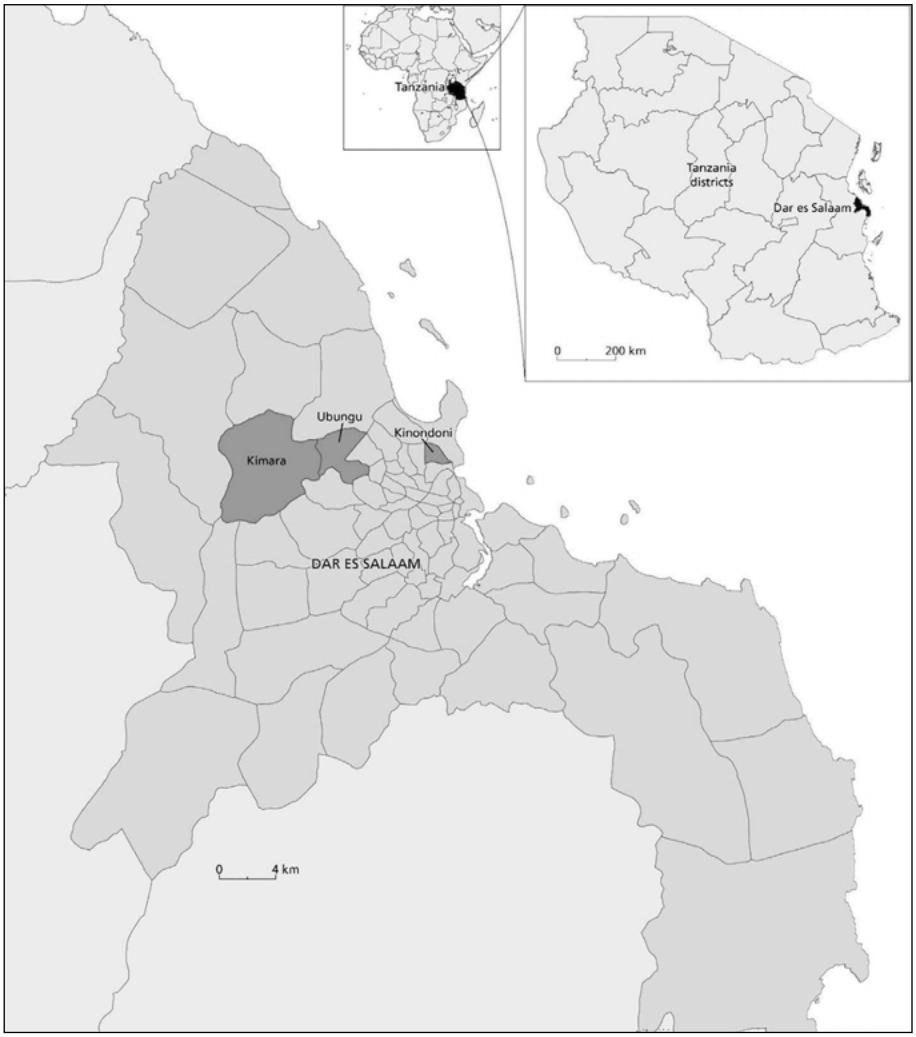
Hydraulic pressure differs between the GWCL and informal water systems. The GWCL's system, for example, suffers mostly from low-pressure problems because of limited natural gravity and because of the distance between the water source and the city. As a GWCL engineer explained it,

> *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

Figure 2.3 Map of Dar es Salaam, showing the districts in which data was collected.



Source: Authors.

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 a long time, 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 2.5). 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.

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 customized spare parts. Hence, rather than applying standardized, universal technical solutions, repair and maintenance personnel rely on tinkering with place-based configurations and with the local specificities of water infrastructure.

Figure 2.4: Pipelines under the frontage of a building in Dar es Salaam.

Source: Authors.

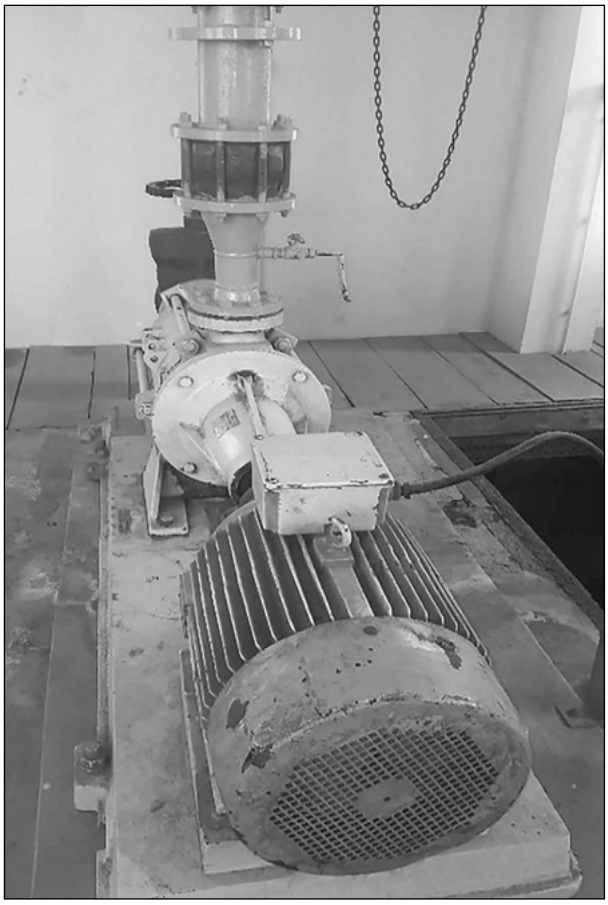
Discourses

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 universalization 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). Building on these institutional frameworks, various civil society groups hold the state responsible for universalizing water access, calling on it to prioritize 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 have 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.

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 emphasized as a key prerequisite for the universalization of water access and for sustainable water management (see, for example, World Bank, 2018). In both countries, water sector policies and programs 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

Figure 2.5: Malfunctioning booster pumps at Dodowa, Accra.



Source: Authors.

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 programs, 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, emphasize 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-emphasizes the crucial need for the state to invest in the 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 as 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 the 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 institutionalized. 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 operations 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 formalized 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 labor 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 labor 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 labor 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 prioritize those they consider to be major and more urgent. Figure 2.6, 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.

Figure 2.6 Leaking pipe in Dar es Salaam.

Source: Authors.

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.

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 emphasizes the vital role played by repair and maintenance in shaping learning, creativity, innovation and discovery in contemporary societies.

2.7 Discussion and Reflection

The analysis above highlights several important similarities and differences between the two cities; these are summarized 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 labor 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 centralized 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).

2.8 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 conceptualization 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 socio-spatial, 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 centralized and decentralized administrative management and geographical knowledge, and their working relations with the private sector. These observed differences emphasize 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 decentralize their 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 prioritize 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 centralized 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 localized 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 standardized protocols that could guide repair and maintenance practices by utility employees; on the other hand, it may inspire a rethinking of organizational matters, since more decentralized approaches to repair and maintenance may be advantageous, as the Dar es Salaam case indicates.

Table 2.1 Key differences and similarities in water supply in Accra and Dar es Salaam.

Dimension	Accra	Dar es Salaam
Materiality	· Networked infrastructure decay · Illegal booster pumps · Low pressure · Leaking networks	· Networked infrastructure decay · Illegal networks · High pressure · Leaking networks
Discourses	· Human right to water access · Cost recovery/affordability · Non-revenue water is attributed to network decay	· Human right to water access · Cost recovery/affordability · Non-revenue water is attributed to water theft
Institutions	· National water company · One maintenance team per district · GWCL's employees have conflictual relations with local plumbers	· Regional water authority · Several maintenance teams per district · Employees of DAWASA have cordial relations with local plumbers
Knowledge	· Employees of GWCL have limited knowledge of the local networks · Engineers rely mainly on approximations · Limited expertise on some equipment	· Employees of DAWASA have rich contextual knowledge of the systems · Engineers rely on approximation · Limited expertise on some equipment

Source: Authors.

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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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.

CHAPTER 3

CO-PRODUCING MAINTENANCE AND REPAIR: HYBRID LABOR RELATIONS IN WATER SUPPLY IN ACCRA, GHANA

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Abstract

Access to water supply is still a problem in African cities. This has sparked discussions about how small-scale private actors could collaborate with the state to improve water supply. However, scholarly discussions on water supply have hardly examined the role of such actors in maintenance and repair. This paper shows how water infrastructures are maintained and repaired through hybrid labor relations between private and public actors where formal and informal practices are combined. These findings allow us to shift conceptualization in maintenance and repair beyond the state and explain how private actors enact and challenge the state's power through maintenance and repair practices.

Key words: informality; repair; maintenance; water supply; infrastructure.

3.1 Introduction

Despite several years of interventions by international donors and national governments, access to water supply remains a significant concern in many African cities. Over the past 30 years, the persistence of the water supply challenge has sparked discussions among scholars and practitioners about the role of small-scale private actors in improving water access, as it has become clear that public water providers alone cannot meet the growing demand for water (Furlong and Kooy, 2017; Peloso and Morinville, 2014). The context of Ghana provides a concrete example of these

private actors' vital role in water supply. Here, urban water supply is the responsibility of the Ghana Water Company Limited (GWCL), a state-owned water provider (Bartels et al., 2018). However, in rapidly growing cities such as Accra, where rising water demand has outstripped GWCL's system's capacity, residents usually access water supply through a combination of public and various private providers such as vendors, tanker operators, and sachet water sellers (Peloso and Morinville, 2014; Bartels et al., 2018).

The role of private actors in water supply in the Global South has already been discussed extensively. However, the focus has been mainly on formalized public-private partnerships through management contracts (see Budds and McGranahan, 2003; Adams and Zulu, 2015; Dill, 2009; Twum and Abubakari, 2020) and how citizens informally collaborate with the state in co-producing water supply (Adams and Boateng, 2018; Bartels et al., 2018; Monstadt and Schramm, 2017; Moretto et al., 2018; Allen et al., 2006; Ahlers et al., 2014; Peloso and Morinville 2014). These studies have demonstrated the crucial importance of small-scale private actors in complementing water supply in the Global South, particularly in African cities. However, even though they are usually involved in maintenance and repair operations, these private actors' role in water supply systems maintenance and repair has rarely been examined. Instead, research on water supply has mainly approached maintenance and repair as a public task for which public utility providers are responsible (Alda-Vidal et al., 2018; de Coss Corzo, 2021; Anand, 2017; Jambadu et al., 2022). However, such conceptualization tends to neglect the vital role of private actors like users and plumbers in maintenance and repair operations (exceptions are Wahby, 2021; Sanchez et al., 2019). In this paper, we thus investigate the role of private plumbers and users in maintaining and repairing water supply in Accra, Ghana's capital and largest city. We aim to explain how these private agents' everyday practices complement public water providers' practices in co-producing maintenance and repair of urban water supply.

In Ghana's urban areas, the body responsible for the maintenance and repair of public water systems is the GWCL, but in rural and peri-urban areas, it is the Community Water and Sanitation Agency (CWSA) (Bartels et al., 2018). However, individual households are fully responsible for maintaining and repairing their private water systems, although that task is usually outsourced to private plumbers. This article shows the dependence of water infrastructure maintenance and repair on hybrid labor relations between public engineers and private plumbers in which formal and informal practices of all actors are combined.

This concept of hybridity enables us to advance three critical contributions in infrastructure maintenance and repair on the one hand and, on the other, private sector participation in water supply. First, by focusing on the role of private actors, we expand conceptualization in maintenance and repair beyond the state to emphasize the crucial role of users and private plumbers and how their practices routinely interplay with public utility officials in co-producing critical services. Second, we bring maintenance and repair into dialogue with the broader literature on infrastructure co-production in the Global South, which allows us to shift the focus of co-production debates away from infrastructure provision to maintenance and repair—an aspect of water supply that has often been overlooked in co-production literature. Third, the findings provide helpful empirical insights on hybrid labor relations in maintenance and repair that can guide public utility providers and policymakers in the governance of water supply.

The article is based on two case studies conducted in the neighbourhoods of Nima and Dodowa in the Greater Accra Metropolitan Area (GAMA). Accra was selected because research has shown that water scarcity is a significant stress on the city's resilience and its inhabitants' health and livelihoods (Adams and Vásquez, 2019). Nima is an informal settlement, while Dodowa is a peri-urban area with different infrastructural and socioeconomic conditions. Thus, studying these two neighbourhoods has enabled us to understand the spatial dynamics of maintenance and repair and how they work in different urban contexts.

The rest of the paper is structured as follows: section two discusses the role of private actors in water supply, focusing on formal public-private partnerships and informal co-production modalities. Section three discusses the concept of hybridity, and section four introduces our research methodology. Section five discusses the findings under four subsections to show how formal and informal practices of private and public actors interplay in water supply. Section six concludes that private actors are crucial not only for ensuring water supply but also for maintaining and repairing water infrastructure. We argue that the state should recognize the importance of the private sector in improving water supply in African cities.

3.2 Private actors' participation in water supply and maintenance and repair in Africa

In many African cities, water supply usually entails a combination of public and various private infrastructure arrangements and systems (Allen et al., 2006). In current research and policy discourses, the involvement of private actors in water

supply has been discussed under two broad headings: public-private partnerships and co-production. Scholarly discussions since the 1980s have mainly focused on public-private partnerships (PPPs) and privatization schemes, highlighting how public water providers collaborate with private entities in urban water supply through formal management contracts (Budds and McGranahan, 2003; Monney and Antwi-Agyei, 2018; Twum and Abubakari, 2020).

Public-private partnership here means that the responsibility for water supply (initially taken on by the state) is outsourced to a private entity while the state remains the owner of the infrastructures and regulator of the service delivery (Allen et al., 2006). For a long time, the World Bank framed and promoted PPPs in Africa as the best way to improve cost efficiency in public water supply (Bakker, 2008; Budds and McGranahan, 2003) and implemented various PPPs across many countries. However, PPPs are often controversial and highly contested by civil society and human rights activists (Darmame and Potter, 2011; Mudege and Zulu, 2011). Indeed, most have been short-lived in Africa, with disappointing impacts on urban water supply (Allen et al., 2006).

The disappointing outcomes of PPPs have sparked discussions about other alternative models, such as co-production (Adams and Boateng, 2018). Co-production discourses mainly focus on the role of small-scale private actors and how they collaborate with the state in water provision (Ahlers et al., 2014; Bartels et al., 2018). Joshi and Moore (2004) define co-production in the context of long-term institutionalized collaboration between the state and organized citizen groups in public service delivery (Joshi and Moore, 2004), whereby both actors contribute substantial resources (see Moretto et al., 2018). From this definition, co-production might suggest a harmonious cooperation between state and non-state actors who work together to improve water supply. However, Ahlers et al. (2014) have cautioned that co-production is by nature characterized and shaped by tensions and conflictual relations between actors due to power asymmetries and divergent interests (Ahlers et al. 2014, 2). Also, co-production entails hybrid arrangements in which the interactions between actors shape and, in turn, are shaped by the socio-political, economic, biophysical, and infrastructural drivers, thereby constituting new practices (ibid.).

Therefore, co-production is often seen as a means to enable and deepen user participation in water service delivery and can empower local communities to take full responsibility for their water supply (Adams and Boateng, 2018; Moretto et al., 2018). However, Pilo' (2017) cautioned that in societies where state authority is weak, co-production could create ambiguous roles and responsibilities between state and citizens,

potentially challenging state power and authority. Despite being a powerful conceptual lens, co-production has not adequately explained the role of small-scale private actors in water supply because it has mainly focused on institutionalized or recognized group collaborations while often ignoring individual private actors. This has prompted some scholars (Ahlers et al., 2014; Peloso and Morinville, 2014) to discuss the role of private vendors and small-scale providers concomitantly with binary formal and informal categories. In these discussions, formality is usually linked to the state's centralized, networked infrastructure system, while informality is attributed to incrementally built systems (Maryati et al., 2018; Peloso and Morinville, 2014). Such conceptualization assumes that informal water supply systems have emerged due to failures of the formal supply systems and thus will disappear once the formal system becomes efficient.

However, Ahlers et al. (2014) indicate that such a notion is inaccurate because informal systems (e.g., illegal networks) can be found in the so-called formal networks (Misra, 2014), while formal systems also exist beyond centralized systems, e.g., water tankers operated by water utilities (Peloso and Morinville, 2014). In practice, the boundaries between formal and informal systems are often blurred and intertwined through the everyday practices of actors (Ahlers et al., 2014). Extending this line of scholarship to the practices of maintenance and repair, current research in the Global South has demonstrated how formality and informality interplay in the maintenance and repair of electricity services in Maputo, where infrastructures are "always in the making" through the constant work of maintenance and repair (Baptista, 2019). De Coss-Corzo (2021) built on similar thoughts to show that waterworks in Mexico City are often constituted and shaped by incremental patchworks of maintenance and repair—acts that are never based on standard rules or guidelines but instead are somewhat adaptive and ad-hoc improvisations that combine formal and informal practices.

In this sense, maintenance and repair work is neither fully formal nor completely informal but instead combines elements of both (de Coss Corzo, 2021). In Cairo, Egypt, Wahby (2021) shows how the public maintenance and repair system has increasingly been challenged (and could potentially be replaced by) community-led repair interventions in gated communities. She traces the emergence of "gehood zateya" (individual and community repair efforts) to neoliberal land reform policies in Egypt, which has shifted the responsibility for maintenance and repair from the state (public utility) to the private real estate companies, thereby setting the stage for private actors' participation in maintenance and repair in water supply. While studying irrigation infrastructure repair in Cairo, Egypt, Barnes (2017) contends that maintenance and repair works are not meant only to fix broken artefacts but also

to maintain state power and control over the infrastructures and the citizens who depend on them—a notion expressed earlier by Graham and Thrift (2007).

Despite growing interest in studying the maintenance and repair of water supply systems in the Global South, scholars have mainly focused on the practices of public utility providers, such as official engineers, while other private actors involved are usually neglected. A more precise conceptualization is thus required to explain maintenance and repair beyond the perspective of public utility providers that has dominated the literature to date. Building on these debates, we introduce the notion of hybridity in the next section to better explain how the everyday practices of private plumbers, users, and public utility officials interplay in co-producing maintenance and repair in the public water supply system.

3.3 Hybridity in maintenance and repair configurations

The concept of hybridity has been used to describe how different—i.e., networked and non-networked, public and private, formal and informal—infrastructure configurations work together in water supply (Furlong, 2014; Ahlers et al., 2014; Wahby, 2021; Cawood et al., 2022) or electricity supply (Rateau and Jaglin, 2022) in the global South and how these are governed (Yates and Harris, 2018; Furlong, 2014). Recently, Cawood et al. (2022) defined hybridity in water supply as an arrangement "in which formal and informal supplies and practices blur in residents' everyday lives as they negotiate to gain and maintain access to water" (ibid: 689). Unlike co-production, which focuses on relations and collaborations between state and non-state actors in service delivery (Rateau and Jaglin, 2022; Ahlers et al., 2014), hybridity is concerned with the resulting different infrastructure delivery configurations and how they function together or against each other in cities (Rateau and Jaglin, 2022; Cawood et al., 2022). In short, coproduction is often discussed in relation to the role of state and nonstate actors in the process of service delivery, while hybridity is discussed with reference to the diverse configurations resulting from the tensed and contested coproduction process (Rateau and Jaglin, 2022). However, both concepts usually describe how different service delivery modes work beyond the state, where service provision usually combines the characteristics of market logics and public services (Pestoff, 2014).

Although a robust explanatory framework, hybridity has been critiqued by scholars. For instance, Ahlers et al. (2014) argue that actors in water supply usually have multiple identities (which allow them to switch between public and private) simultaneously. This fluidity and plural identities create ambiguities in actors' roles, responsibilities,

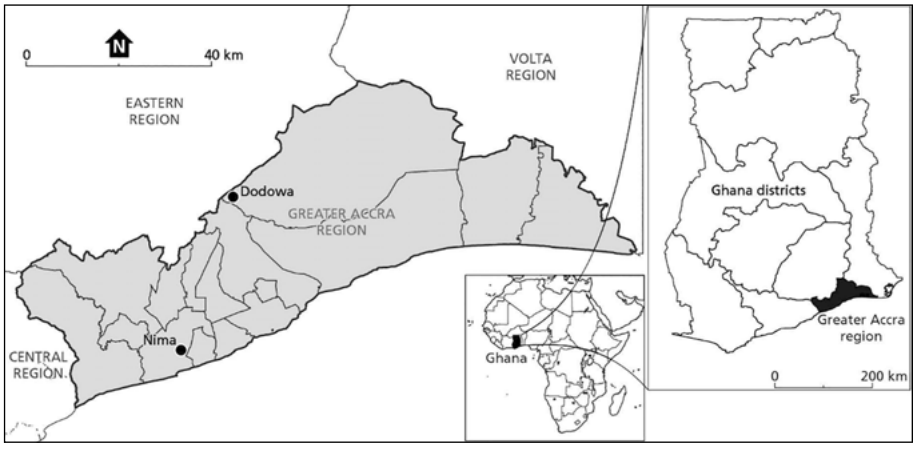
and limits (Furlong, 2014; de Coss Corzo, 2019). At the same time, the ambiguity could result in an "identity crisis", as it becomes difficult to differentiate the actors and from which position they operate at a specific time. Despite these critiques, hybridity remains a powerful conceptual lens through which we can move critical analysis of everyday practices in the global South beyond the binary of formal and informal or private and public to a "third space" (Sayegh, 2008) where the transactions of all actors in water service delivery can be fully accounted for without falling into the trap of fixity and absolute categorization (ibid). In this article, the concept of hybridity helps us to explain better how public and private repair configurations not only interpenetrate but are linked to each other in water supply and the resulting power relations from the interactions between the actors involved (Ahlers et al., 2014; Pilo', 2017). At the same time, it enables us to understand maintenance and repair beyond the state and explain how maintenance and repair are co-produced through the interaction between state and nonstate actors, where market-oriented logics interplay with public services interest.

Building on the above literature, we use hybridity to describe a form of maintenance and repair configurations in which public and private schemes operate simultaneously, and actors involved combine formal and informal practices in their everyday operations (see Wahby, 2021; Cawood et al., 2022). Thus, the resulting hybrid configuration is neither entirely public nor private but combines specific characteristics of both (e.g., actors, materialities, knowledge, and practices). Moreover, all actors involved have multiple identities and can substitute each other but sometimes work complementary in sustaining water supply (Wahby, 2021; Meehan, 2014). Furthermore, the everyday practices of actors interplay between formality and informality (Ahlers et al., 2014). In this context, the categories of formality and informality are described as contingent, intertwined, and continually shifting through the everyday practices and interactions between actors (Misra, 2014). We thus argue that although the formal and informal categories have analytical value, they are, in practice, often blurred and intertwined as a "series of transactions that connect different [maintenance and repair configurations] to one another" (Roy, 2005: 148). Furthermore, formality and informality are not synonymous with legal and illegal binaries (Ahlers et al., 2014). Rather, they describe slightly different urban conditions and practices. Thus, we argue that although the boundaries of these concepts often intersect in everyday urban practices (Roy, 2005; Ranganathan, 2014; Misra, 2014; Ahlers et al., 2014), they have different meanings. In this study, legality and illegality are used to describe practices or configurations that contravene or comply with water providers' laws and regulations. In contrast, formality and informality describe practices that conform (or do not comply with) technical standard operating procedures as defined by organizational guidelines (Ranganathan, 2014).

3.4 Case study sites and methods

For this qualitative study, two case studies were conducted in the neighbourhoods of Nima and Dodowa in the GAMA. Accra is particularly suitable for this study because acute water shortages have been identified as a significant stress on the city's resilience (Adams and Vásquez, 2019). The GAMA region (Figure 1) covers approximately 1585 km^2 and shares boundaries with the Eastern, Volta, and Central regions (Addae and Oppelt, 2019). Accra is the national capital and the most populous city in Ghana, with approximately 5.4 million residents in GAMA (Ghana Statistical Service [GSS], 2021). Its growth is, however, driven primarily by informal construction practices (Silver, 2014), and about 60% of the population lives in informal settlements (Adams and Vásquez, 2019). Accra's rapid growth means that peri-urban areas like Dodowa have become part of the urban agglomeration. This has brought together diverse neighbourhoods with different socio-spatial and political configurations and has reconfigured institutional and urban boundaries of rural, urban, and peri-urban spaces.

Figure 3.1 Map of Accra showing Nima and Dodowa, the case study locations.



Source: authors

In this study, we focus on the neighbourhoods of Nima and Dodowa because they differ appreciably in terms of socioeconomic, infrastructure, and urban conditions. For instance, Nima is a densely populated informal settlement (Owusu et al., 2008), while Dodowa is a rapidly expanding peri-urban area. Nima has about 80,000 inhabitants compared to 12,000 in Dodowa (Grönwall and Oduro-Kwarteng, 2018; Adams and Vásquez, 2019). Most inhabitants of Nima are classified as low-income, while those in Dodowa are regarded as middle- or high-income (Owusu et al., 2008; GSS, 2014).

Whereas most houses in Nima are in compounds and lack space for future expansion and infrastructure access, those in Dodowa are mainly constructed as semi-detached housing units intended for single families. These contrasting characteristics make it possible to understand the diversity of water supply systems and the hybrid labor relations and practices that underlie and shape their operations, repair, and maintenance in different urban contexts.

Empirical data for this study were collected through semi-structured interviews and field observations conducted in the two neighbourhoods between 2018 and 2020. We interviewed 48 respondents, i.e., GWCL officials, local plumbers, residents, owners of small-scale businesses, and representatives of government administrations. The interviews covered water supply, maintenance, and repair operations, the role of plumbers in repair, and their relationship with GWCL officials in their everyday operations. To better understand the practices of the actors, we followed private plumbers and GWCL engineers separately to different field operations to observe them while they were carrying out maintenance and repair in real-life contexts. This provided further opportunities to learn about their respective field operations and gain first-hand insight into their everyday practices on the ground and the underlying logics. During these field observations, we had informal conversations with repair workers to gather further information that might not have been captured in the semi-structured interviews. All qualitative interviews were transcribed, coded, and analysed through content and thematic analyses. They are presented below under three main themes: starting with an overview of water provision in the Greater Accra Metropolitan Area, followed by maintenance and repair of water supply, and the role of private plumbers therein. The empirical data was complemented by reviewing various academic literature and official policy documents on water supply and maintenance and repair in Ghana and African cities.

3.5 Water supply in greater Accra and its diverse neighborhoods

The provision of water supply in Accra follows the general framework for Ghana, structured along the lines of rural/urban categories (Bartels, Bruns, and Alba, 2018). In urban areas like Accra, responsibility for water supply rests with the GWCL, while in rural/peri-urban areas, it rests with the local assemblies and the CWSA. As a coastal city, seawater intrusion restricts groundwater use in large parts of Accra (Grönwall and Oduro-Kwarteng, 2018). This means that water supply is mainly provided through the GWCL systems and other intermediary configurations, such as sachet water sellers, tanker operators, and public vendors, who resell GWCL's water in various forms and

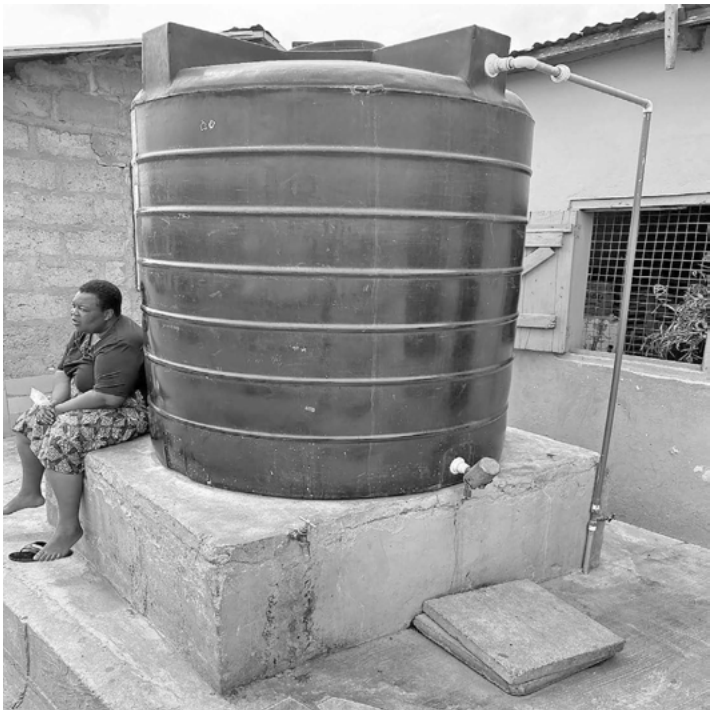
packages. GWCL's operation is regulated by the Public Utilities Regulatory Commission (PURC) and the Water Resource Commission (WRC), while the Ministry of Sanitation and Water Resources provides strategic leaders and policy direction (Government of Ghana, 2007; 2014). GWCL abstracts its water from the Volta and Densu rivers via the Kpong and Weija treatment plants. These plants are complemented by a seawater desalination plant, which mainly serves the Teshie—Nungua areas.

GWCL's water system's supply capacity is about 215 million gallons per day, but the current demand for water in Accra is approximately 273 million gallons per day (Jambadu et al., 2022). The demand gap is further widened by the considerable losses of up to 50% of all the water fed into the GWCL's distribution system due to technical leakages, water theft, illegal connections, and inadequate metering (Jambadu et al., 2022; Ghana Water Company Limited [GWCL], 2018; Effah-Ameyaw and Chan, 2013). Consequently, GWCL's centralized supply system meets only approximately half (50%) of the city's daily water demand, while the remainder of the population accesses water through various private arrangements, including small-scale vendors (Peloso and Morinville, 2014). GWCL's water supply is also erratic and intermittent due to rationing schemes (Effah Ameyaw and Chan, 2013): everywhere in the city receives water twice or three times per week (Afriyie and Ferber, 2018; Peloso and Morinville, 2014). The rationing timetables are not usually transparent to households and are often not adhered to by local pump operators. As a result, most households in Accra typically have backup plans, including storing water in various containers and developing multiple water infrastructure configurations (Bartels et al., 2018; Peloso and Morinville, 2014). However, the forms of infrastructure configurations in a neighbourhood depend on the prevailing socioeconomic, spatial, and urban conditions. Therefore, the inhabitants of Nima and Dodowa access water supply through different modalities and infrastructure configurations. In Nima, as in the rest of central Accra, underground boreholes and wells are not common because seawater intrusion makes water from these sources salty and unfit for human consumption. Hence, water supply is mainly provided through GWCL's centralized system and other intermediaries. Similarly, private water tanker operators are not common in Nima because the haphazard nature of the settlement makes it difficult for tanker trucks to navigate.

The GWCL has installed basic water infrastructure in Nima, i.e., main transmission lines, distribution networks, and subsidiary networks. However, only a few individual households have private connections, not because residents cannot afford to pay but mainly due to the haphazard nature of the settlement, which makes it impossible to extend the primary networks into individual households (Interview 1, 2020). As a

result of these challenges, illegal networks and water theft are more common in Nima than elsewhere in the city. Even if the GWCL could provide private connections to households, it would be difficult to ensure their maintenance and repair and to collect payment for water bills (ibid, 2020). Because of this challenge, the GWCL mainly promotes public standpipes and commercial stand-posts across the neighbourhood. Besides the GWCL networks, inhabitants also use sachet water, while those with private connections (Figure 2) often sell water to their neighbours (Adams and Vásquez, 2019; Bellaubi and Visscher, 2014).

Figure 3.2 Household selling GWCL water in Nima.



Source: authors

Dodowa presents a relatively different sociotechnical configuration in water supply. Unlike Nima, underground water sources such as boreholes and wells are common in Dodowa because it is about 30 kilometres from the Atlantic Sea, and therefore, the aquifer is generally free from seawater intrusion (Grönwall and Oduro-Kwarteng, 2018). Hence, about 78% of households' drinking water is sourced from boreholes (Grönwall and Oduro-Kwarteng, 2018). As Dodowa is a peri-urban area, the responsibility for its water supply officially falls under the mandate of the local assembly and

the CWSA. However, the GWCL has also installed its water supply systems in Dodowa (as in Figure 3), and they operate side-by-side with the decentralized systems installed by CWSA. The latter include communal boreholes, hand pumps, and shallow wells constructed by the local assembly and CWSA. In addition to these state-led systems, local entrepreneurs package and sell borehole or piped water to residents in various ways: tankers, vendors, and sachets (Grönwall and Oduro-Kwarteng, 2018).

Figure 3.3 Private water connection in Dodowa supplied by GWCL

Source: authors

Approximately 4,000 customers were officially connected to the GWCL's network in Dodowa in 2019 (Interview 4, 2020). This number was achieved after the water company had collaborated with residents to expand the primary networks into most parts of the city, making it possible for many households to connect. In this collaboration, the residents agreed to contribute to "self-finance" the primary network, even though the network is the responsibility of the GWCL (Interview 3, 2020). While this intervention expanded the network's coverage, it raised the initial connection cost by more than half, making it difficult for low-income households to afford it (Interview 3, 2020). Hence, those without private connections usually rely on their neighbours' pipes and other common sources, i.e., boreholes, wells, hand pumps, sachet water, public stand-posts, and private tanker operators (Foppen et al., 2020; Grönwall, 2016; Grönwall and Oduro-Kwarteng, 2018).

Table 3.1 highlights the different water infrastructure configurations in the two neighbourhoods. The key differences include the level of coverage by GWCL networks and the

diversity of other water supply systems, including boreholes and private tanker operators. In short, the water supply systems in Dodowa entail more diverse infrastructure configurations than in Nima. Thus, whereas inhabitants of Nima can access water supply mainly from GWCL's centralized system, their counterparts in Dodowa have various choices, including underground boreholes and tanker services, which are usually rare in Nima. The maintenance and repair of the abovementioned water infrastructures require differentiated expertise, knowledge, and labor relations based on the local context. The following sections explore these place-based specifics, starting with an overview of GWCL's public maintenance and repair system in Accra.

Table 3.1 Summary of water infrastructure systems in Nima and Dodowa

Variable	*Nima*	*Dodowa*
Typologies of water systems	Authorized GWCL connections Unauthorized networks Public standpipes Sachet water Neighbor's pipe	GWCL connections Boreholes/handpumps Public standpipes Tanker operators Water sachets Shallow well
Actors in water supply	GWCL employees Entrepreneurs/vendors Users/Residence Private plumbers	GWCL employees CWSA District Assembly Entrepreneurs/vendors Water and Sanitation Management Teams Users/residents Private plumbers

Source: Authors, based on fieldwork.

3.6 The maintenance and repair of Accra's centralized water supply system

The GWCL is the official maintenance and repair service provider for all public utility network infrastructures in Ghana. Within the GWCL, the actual task of maintaining and repairing water infrastructures is delegated to district-level offices across the city. The GWCL has about ten district offices in the GAMA region, which includes Dodowa and Nima. Each district has a maintenance and repair team of about 6–10 people (repairers, pipefitters, technicians, and supervisors). The everyday operation of GWCL's maintenance and repair teams is shaped by formal and informal rules, guidelines, and standard operating procedures developed by the company's management (Interview 5, 2020). Team members operate on the basis of their hydraulic knowledge, practical

experience, and contextual knowledge gained through many years of working. Before the repair teams embark on routine field operations, the team leader (the operation and maintenance manager) usually issues brief instructions, summarizes the tasks at hand and provides the necessary logistics and tools for carrying them out. He assigns specific tasks to members and supervises their work with the supervisors, whom team members refer to as *foremen*. The repair team usually works as a group (as in Figure 3.4) but is sometimes split into subgroups working in different locations.

Figure 3.4 GWCL's officials repairing a pipeline, Accra (December 8, 2018).

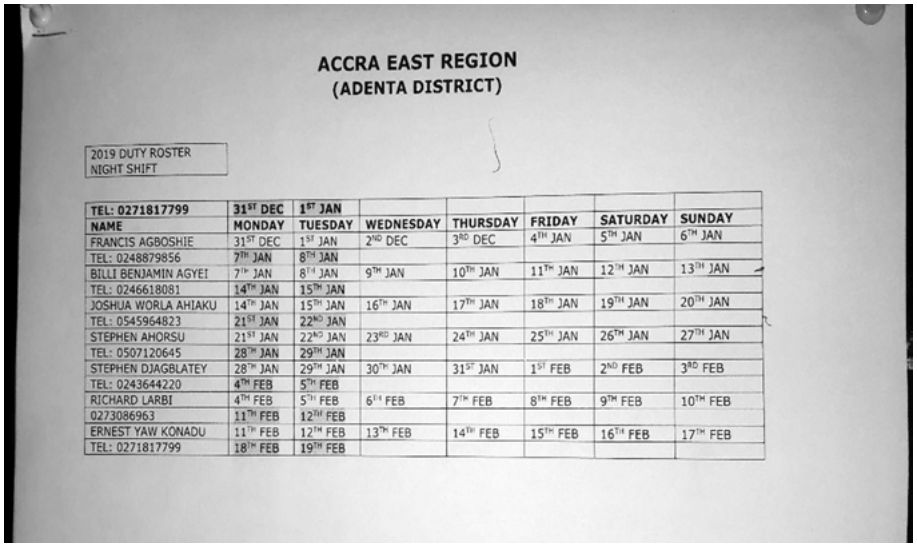
Source: authors

GWCL has no technology for discovering leakages and bursts in their networks. Instead, the repair teams often rely on principled residents' volunteering information. Anyone can report a leak or burst by calling a centralized call centre or walking into their district offices to complain. An engineer in the Dodowa office describes the situation as follows:

> *We do not have any technology to discover leaks. We rely upon people to report to us, or our engineers discover them during field operations. However, we have a call centre in the region that helps us to get reports from the public. When they call, we ask for the physical locations and directions using landmarks. I then dispatch my boys to go and check it up and close the valves first before we check about the repair (Interview 2, GWCL employee, 2019).*

This means that only those leaks and bursts that come to the notice of public utility engineers will be repaired; the unreported ones will persist unresolved. When leakages/bursts problems are reported, e.g., by phone, the team leader logs and profiles the problem for tracing and identification by field staff. A fact-finding team is usually dispatched to locate the spot, conduct a preliminary assessment of the extent of the fault, and report to their leader for instructions. One team leader disclosed that they usually prioritize major leaks and quickly close the valve on any leaking line to reduce further losses before they contemplate repairing the leakage (Interview 4, 2019). In addition to the core repair team, districts have parallel emergency teams that usually operate at night (see schedules in Figure 5) and are meant to provide quick solutions to repair needs, especially for critical infrastructures and services such as the airport and hospitals.

Figure 3.5 Duty roster for night shift maintenance and repair in Accra.



ACCRA EAST REGION
(ADENTA DISTRICT)

2019 DUTY ROSTER
NIGHT SHIFT

TEL: 0271817799	31ST DEC	1ST JAN					
NAME	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY	SUNDAY
FRANCIS AGBOSHIE	31ST DEC	1ST JAN	2ND DEC	3RD DEC	4TH JAN	5TH JAN	6TH JAN
TEL: 0248879856	7TH JAN	8TH JAN					
BILLI BENJAMIN AGYEI	7TH JAN	8TH JAN	9TH JAN	10TH JAN	11TH JAN	12TH JAN	13TH JAN
TEL: 0246618081	14TH JAN	15TH JAN					
JOSHUA WORLA AHIAKU	14TH JAN	15TH JAN	16TH JAN	17TH JAN	18TH JAN	19TH JAN	20TH JAN
TEL: 0545964823	21ST JAN	22ND JAN					
STEPHEN AHORSU	21ST JAN	22ND JAN	23RD JAN	24TH JAN	25TH JAN	26TH JAN	27TH JAN
TEL: 0507120645	28TH JAN	29TH JAN					
STEPHEN DJAGBLATEY	28TH JAN	29TH JAN	30TH JAN	31ST JAN	1ST FEB	2ND FEB	3RD FEB
TEL: 0243644220	4TH FEB	5TH FEB					
RICHARD LARBI	4TH FEB	5TH FEB	6TH FEB	7TH FEB	8TH FEB	9TH FEB	10TH FEB
0273086963	11TH FEB	12TH FEB					
ERNEST YAW KONADU	11TH FEB	12TH FEB	13TH FEB	14TH FEB	15TH FEB	16TH FEB	17TH FEB
TEL: 0271817799	18TH FEB	19TH FEB					

Source: authors

The GWCL finances its public maintenance and repair scheme through internally generated revenue. The regional offices organize all necessary materials, logistics, and equipment for onward distribution to district operations. Among the significant challenges affecting maintenance and repair operations in GWCL are inadequate financing, limited repair staff, and inadequate access to materials, logistics, and technical tools (interviews 2, 4, and 5 2020). As discussed in the next section, these challenges often undermine the public repair system and require private plumbers'

and users' informal interventions to fix maintenance and repair problems in public water supply systems.

3.7 The role of private plumbers in maintaining and repairing water systems

How the water supply systems in Nima and Dodowa are repaired and maintained in real life differs considerably from the ideal repair system described above. In practice, maintenance and repair entail private plumbers, users, and public engineers operating side-by-side and sometimes replacing each other. This section discusses how the practices of users and plumbers routinely intersect with GWCL's repair systems in the two sites.

Maintenance and repair in Nima

Under Ghana's water sector policies, households are responsible for maintaining and repairing their private water connections. However, that task is usually outsourced to private plumbers. The owner and commissioned plumber negotiate the cost, fees, and scope of maintenance and repair work. Private plumbers are mostly hired based on recommendations by friends and family members who have used their services and can attest to their competence. Whereas the maintenance and repair of legal private connections can be outsourced to any competent private plumber, illegal connections (which are common in Nima) are usually outsourced to the plumber who originally installed the network—a strategy that keeps the network a secret known only to the plumber and the owner(Interviews 10 & 11, 2020). To sustain this arrangement, the owner of the illegal networks occasionally rewards the plumber for his loyalty while the commissioned plumber repairs and maintains the systems.

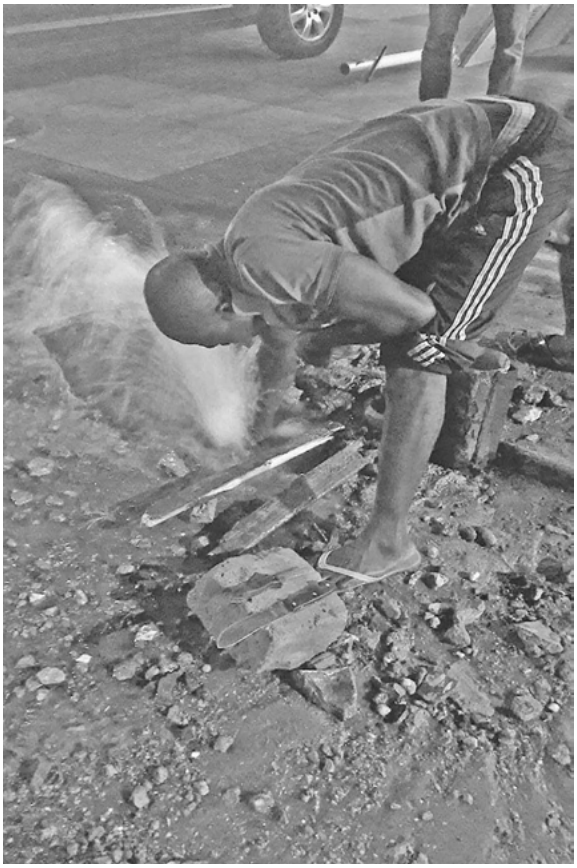
Since the GWCL's scheme for maintaining and repairing the public utility networks in Nima is generally ineffective, private plumbers and users are just as crucial for the maintenance and repair of these networks too. Nima's networked infrastructure's maintenance and repair is the responsibility of the Accra North district of the GWCL. However, because of the poorly planned nature of the settlement, GWCL's repair scheme has not been effective in Nima. An employee of GWCL indicated that:

> *"[maintenance and repair] is a problem in Nima because of the layout. We have few [legal] connections there, but [. . .] the challenge is how [utility officers can] navigate there to do maintenance and read water meters?" (Interview 1, GWCL employee, 2019).*

Our field observations in the area confirm that layouts are haphazard, with practically no space to install waterlines inside individual homes. Because of this situation, residents of Nima are notorious for their illegal water connections and often assault GWCL officials who visit there to disconnect illegal networks. An official of the water company said that:

> *"That place [Nima] is very problematic. They can beat you if you attempt to work there. I was once attacked when I supervised a disconnection exercise there. When they see our officers, they feel threatened that we are there to disconnect their illegal networks. Nowadays, when we are going there, we go with the police" (Interview 2, GWCL employee, 2020).*

Figure 3.6 Private plumber repairing a burst pipeline in Nima



Source: authors

GWCL's repair scheme is also challenged by inadequate repair workers. For instance, the Accra North district—which is responsible for Nima—has only 24 such workers. According to the company's district manager, this workforce is woefully inadequate, considering the district's size. Hence, the capacity of GWCL's repair workers is often overstretched, making it challenging to provide adequate and timely responses to maintenance and repair needs in all areas. These challenges often require private plumbers and users to intervene informally to sustain water supply in the public utility networks. For instance, it is common to see private plumbers repairing leakages in GWCL's public networks (as shown in Figure 6). A household or a group of residents who are affected by a leakage in the public system usually mobilize resources and hire private plumbers to fix the problem (Interview 3, 2020). Although the legality of these informal practices is often questionable, they are crucial for residents in areas like Nima that lack an adequate repair system, as they provide a way to ensure a reliable water supply.

Residents and local plumbers often justify these informal interventions by arguing that the GWCL staff are generally reluctant and inefficient, especially in Nima. A resident of Nima who sells water to residents from his private connection said that:

> *"If you call them [GWCL officers], they will not come. Sometimes, it can take them weeks to respond to the problem. So, if you need the water, you have to get a plumber to fix the problem because it affects you and not the company (Interview 6; Resident, 2020).*

Another interviewee added that whenever he reports a leak to the company, they are likely to close off the water supply to the entire area for several days before they resume supply. Hence, he feels that residents should mobilize and fix the problem themselves rather than report to the utility company (Interview 7, Resident, 2020). An employee of the GWCL, however, dismissed these claims, contending that:

> *The people [of Nima] are very smart. I can tell you they do self-repair to hide their illegal networks from our officers. They know we will discover some illegal networks if we go there[. . . .] (Interview 9, GWCL employee, 2019).*

These findings reveal the ineffectiveness of the GWCL repair systems and the fact that residents appear to have lost confidence in GWCL's systems and are taking measures to meet their water infrastructure maintenance and repair needs outside the public systems through private plumbers. More importantly, these findings point to a

clash between the logics of legality and necessity and indicate how the private repair systems can challenge the public utility's authority and power to carry out repairs. However, the divergent explanations by actors reveal different motives that often underlie maintenance and repair practices.

Maintenance and repair in Dodowa

The approach to maintenance and repair in Dodowa is somewhat different from that in Nima. Being a peri-urban area, the responsibility for maintaining and repairing water systems falls to the CWSA. That responsibility is delegated to Water and Sanitation Management Teams (WSMTs) at the community level. Each WSMT is a small group of 3–5 residents that is formed to oversee decentralized water systems' management, maintenance, and repair. The WSMTs are directly responsible for maintenance and repair operations to boreholes, hand pumps, and wells installed for the community by the district assembly and CWSA. The team usually collects payment of water bills from users (on a pay-as-you-fetch basis) and uses the funds to finance ongoing maintenance and repair (Government of Ghana 2014). This decentralized approach is in line with Ghana's community water and sanitation management strategy, which seeks to empower rural communities to handle their water infrastructure needs (Government of Ghana, 2014).

Although the WSMTs are usually trained in handling minor maintenance and repair, most still lack the necessary skills, expertise, and tools to maintain and repair major technical problems. Therefore, they usually outsource most of their major maintenance and repair needs to private engineers, commonly referred to as area mechanics[1]. As pointed out in the national community water strategy (Government of Ghana 2014), inadequate funding and lack of adequate expertise and skills are significant challenges that undermine water infrastructure sustainability in most peri-urban and rural areas where boreholes are common. The role of CWSA in maintenance and repair is to provide technical training and working tools for WSMTs members and connect them to appropriate markets for spare parts and professional experts whom they can rely on for major maintenance and repair needs. These community-based repair systems coexist with the GWCL repair systems and various independent private experts in Dodowa.

1 These are trained mechanical engineers/technicians who specialize in hand pumps and boreholes and usually operate in rural areas where these infrastructures are found.

3.8 Situating maintenance and repair in-between private and public labor relations

GWCL's repair system is more effective in Dodowa than in Nima. Hence, self-organized repair interventions by community members and local plumbers are rare in Dodowa. Instead, it is common to find GWCL employees doing maintenance and repair on people's private connections—a task not in their official remit—for extra income. The employees' primary justification for these "side jobs" is to earn extra income to support their families to help meet Accra's high cost of living. An employee of GWCL who also works as a private plumber revealed that he earns approximately 800 cedis [about 100 US dollars] per month from his side jobs and shares part of it with his two apprentices (not GWCL employees). He uses the remainder to supplement his regular income as a technician (Interview 12, personal communication, 2020).

Although the GWCL authorities do not encourage employees' "informal" practices, they do not see them as a challenge that must be addressed. For instance, one utility official considers such practices unofficial but legitimate private arrangements between individuals and, therefore, has no problem with them, as they take place outside the employee's working schedules (Interview 13, 2020). In short, maintenance and repair in Dodowa entail multiple actors and systems, including community-based systems, private repair systems, and public repair schemes, which operate together as a hybrid system in which formal and informal practices are combined. This further emphasizes the heterogeneous nature of water systems in Dodowa, which require different maintenance and repair systems to sustain. Private repairers' common challenges include limited access to working tools, inadequate expertise, and the lack of recognition by state water providers. These challenges undermine maintenance and repair and the full utilization of local resources for improving water supply.

The results above show that the actual maintenance and repair operations of water supply in both neighbourhoods entail hybrid labor relations between public and private engineers. In Nima, maintenance and repair are co-produced through the efforts of GWCL employees and private plumbers hired by residents. In Dodowa, however, they require the combined efforts of public utility employees, community-based actors, and private engineers. In such a hybrid repair configuration, the practices of all actors are intertwined and overlapping because actors routinely change positions or roles by moving in and out of the private or public systems at different times. As the case of Nima shows, residents frequently hire private plumbers to perform the roles

of public utility employees by fixing leakages in public utility networks, although this contravenes the water company's policies. Likewise, in Dodowa, GWCL employees sometimes operate as private plumbers by maintaining and repairing residents' private connections. Moving in/out of the different repair configurations is possible because all actors have similar expertise and competencies.

However, these constant fluxes by actors make it difficult to differentiate on the ground between formal/informal or legal/illegal acts and the boundaries between private and public repair configurations. This means that formal/informal practices transcend the categories of public and private repair configurations and can be described as a set of discursive framings of the practice that actors perform in their everyday repair operations. As Wahby (2021) showed in the case of Cairo, the intricate connections between the practices of private and public engineers on the ground make it difficult to draw boundaries between formal/informal or legal/illegal maintenance and repair practices by all actors. The situation is made more complex by the fact that all actors can function in the public and private sectors, compete for similar contracts in the private labor market, and use similar tools in their operations.

These findings show that no single maintenance and repair configuration can work for all types of water infrastructure. In most parts of Accra, where water supply systems are highly fragmented and shaped by heterogeneous configurations (i.e., networked and off-grid solutions, illegal connections, public and private connections), a single repair scheme cannot work. Instead, hybrid approaches that combine different repair systems and actors with different expertise and knowledge in different material configurations are required. Based on these findings, we contend that the private and public repair systems coexist as complementary service providers but sometimes act as alternative service providers because they can replace each other in the private market. Indeed, the fact that actors can change roles and operate on either side of the system indicates that the private and public systems are competitors rather than complementary systems, as often portrayed in the water provision literature (Kjellén, 2010). This is because private plumbers offer the same services as those provided by public utility officials. Hence, when they are hired to act in the position of public engineers, they not only replace the functions of the public repair systems but also inadvertently challenge the authority and power of the GWCL as the sole legitimate repair system in the city.

Nevertheless, their operations are vital in meeting maintenance and repair needs that cannot be met through the public systems alone. Many households prefer private

repair workers because their services are available and affordable and can also be negotiated and adapted to suit their specific financial and economic conditions. Because actors in the hybrid system offer similar services, users can choose to meet their maintenance and repair needs from either system. However, since actors tend to compete in the same market, their interactions often produce tensions and conflicts in different forms and magnitudes due to differences in competing interests. The case of Nima and Dodowa highlights different conflicts and how they work to enable and challenge the state's political authority. In Nima, neighbours often challenge GWCL workers and sometimes physically attack them because they see their presence in the neighbourhood threatening residents' water access. Hence, residents work to protect their interests by deploying informal and self-maintenance and repair tactics to prevent public engineers from visiting the area. At the same time, GWCL workers must reduce water (and revenue) losses by reducing water theft and leaks. These clashes of motives often result in conflict situations between residents and public engineers in Nima.

The case of Dodowa presents a quite different conflict situation involving different actors. Here, private and public repair workers compete in the private market for repair contracts from users, which often results in other forms of tensions and conflicts between them, although they are not as confrontational as in Nima. Various studies have explained such tensions as the results of power struggles and asymmetries between the state and non-state actors (Barnes, 2017; Graham and Thrift, 2007), portraying maintenance and repair as inherently political (Baptista, 2019). We have built on this line of scholarship to show how actors enact and contest the state's power through the maintenance and repair of the water systems.

3.9 Conclusion

This paper has analysed the maintenance and repair of water supply through the lens of hybridity, focusing on two case studies in Accra. An important insight from the results is that there is often a difference between how infrastructures are imagined to be maintained and repaired and how the maintenance and repair work is actually done. We mobilize the empirical insight from these case studies to put forward three salient contributions that advance debates in infrastructure maintenance and repair studies and debates on co-production in water supply. First, current research in water supply has often portrayed maintenance and repair as a public task handled solely by public utility engineers and showcases the public repair scheme as the ideal (Wahby, 2021).

Our case studies provide empirical evidence to challenge this notion by showing how maintenance and repair are co-produced through hybrid labor relations between private and public agents and users and how these actors negotiate maintenance and repair through the interplay of formal/informal practices in water supply. By deploying hybrid notions, we have shifted conceptualization in current research on maintenance and repair beyond the state by repositioning private plumbers and users as equally important actors in co-producing maintenance and repair in water supply systems. In practice, all actors involved can move in and out of the public or private systems, and their roles or positions can change (even if only temporarily). This is what hybrid maintenance and repair entail—a dynamic process "always in the making" (Baptista, 2019).

Second, our case studies further show how the state's power is enabled and sometimes challenged by private actors through maintenance and repair. The cases of Nima and Dodowa yield helpful empirical examples to demonstrate how residents and private plumbers subvert and contest the state's political authority (vested in the utility provider) and sometimes replace it with private and self-organized maintenance and repair. On the one hand, the water providers support the state's control and power by sustaining the water systems' function. On the other, this power is constantly challenged and subverted by residents and plumbers who bypass the GWCL authority to implement their informal and self-organized repair interventions in water supply. In this regard, citizens' active involvement in maintenance and repair could inadvertently challenge state power, as self-organized repair efforts replace or diminish the state's role and control over public infrastructure.

Finally, by demonstrating how public and private actors work side-by-side in sustaining water flow through maintenance and repair, we expand the debates on water infrastructure co-production and private actors' participation in the Global South to show how infrastructures are repaired and maintained through hybrid labor relations. Indeed, the Nima and Dodowa case studies have shown that residents are not passive recipients of water supply but are actively involved in shaping how the water supply system is repaired and maintained. However, further research is required to understand how maintenance and repair are governed in contexts where hybrid infrastructure systems operate and the institutional challenges therein.

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CHAPTER 4

THE POLITICS OF TIED AID: TECHNOLOGY TRANSFER AND THE MAINTENANCE AND REPAIR OF WATER INFRASTRUCTURE

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Abstract

In many African countries, international donor funding schemes contribute significantly to financing water infrastructures, especially for constructing new networks and water plants and upgrading existing ones. However, little is known about how these financial arrangements shape infrastructure maintenance and repair. This article explores the politics of tied water aid to show how international donors' technology transfer schemes and their associated funding conditionalities shape water infrastructure maintenance and repair. Empirically, this study builds on a qualitative study of the cities of Accra (Ghana) and Dar es Salaam (Tanzania), where the maintenance and repair of water infrastructures have been a persistent challenge. The article shows that the compulsory adoption of foreign technologies embedded in donors' funding schemes limits local capacity to properly maintain and repair water infrastructure. As maintenance and repair increasingly depend on imported expert knowledge, spare parts, and engineering services, donors' funding schemes undermine effective maintenance and repair in both cities. We argue that to make transferred water technologies work sustainably in recipient countries, funding schemes need to anticipate maintenance and repair by incorporating local capacity building and knowledge transfer to reduce import dependence.

Keywords: urban infrastructure; maintenance and repair; Africa; Accra and Dar es Salaam; technology transfer, tied aid.

4.1 Introduction

International donors play a crucial role in urban water supply in Africa, and Ghana and Tanzania provide helpful examples to illustrate their importance. In these countries, donor funding schemes significantly contribute to financing urban water supply. For example, external loans and donor grants contributed over 80% of the funding needed to execute Tanzania's National Water Sector Development Program (WSDP-II) between 2015 and 2020 (URT, 2020). Similarly, they contributed about 90% of Ghana's water sector budgets between 2013 and 2014 (Monney and Antwi-Agyei, 2018: 134). These funds were primarily invested in upgrading existing systems' capacity and developing transmission networks in Dar es Salaam (URT, 2020), while in Ghana, they have also financed the extension of distribution networks (Mansour and Esseku, 2017; Ameyaw and Chan, 2013) and the construction of a seawater desalination plant (Jambadu et al., 2022). These investments have undoubtedly improved these countries' urban water infrastructures and the residents' access to critical water resources.

Although the impact of donors and their funding schemes on infrastructure development has gained considerable attention in development studies (Mattlin and Nojonen, 2015; El Khanji, 2022; Quadir, 2013), we still know little about how such financial arrangements shape infrastructure maintenance and repair and their underpinning political logics and effects in African cities. Understanding this relationship is crucial because research on urban infrastructures in Africa and other parts of the Global South has identified inadequate maintenance and repair as a critical challenge facing externally funded infrastructure projects (Alves, 2022; Harvey and Reeds, 2004; El Khanji, 2022; Holcombe et al., 2017).

Recently, urban scholars have critically examined urban water infrastructure maintenance and repair in African cities and have emphasized the incremental and improvisational practices through which users, engineers, and plumbers tinker with, contest, and shape water networks (Alda-Vidal et al., 2018; Jambadu et al., 2022; Wahby, 2021). They have also highlighted how these actors' practices (re)shape power relations between the state and non-state actors (Barnes, 2017; Wahby, 2021; Alves, 2022; Jambadu et al., 2023). However, to date, no study has examined how donor funding coupled with technology transfer schemes affects infrastructure maintenance and repair and their underpinning political effects in recipient countries in Africa.

This article uses qualitative research to analyse how donors' tied water aid schemes affect infrastructure maintenance and repair in Accra and Dar es Salaam. The

objective is to provide a detailed account of how donor-tied water aid schemes affect the maintenance and repair of infrastructure in both cities. These cities were selected because of their dependence on donors' funding schemes in reforming their water sectors. Thus, they represent meaningful empirical examples to illustrate how these funding programs affect water infrastructure maintenance and repair in Africa. We systematically address two critical questions: (1) How does technology transfer embedded in donors' funding schemes affect water infrastructure maintenance and repair in Accra and Dar es Salaam? (2) What political implications and power relations do donor-funded technologies enact in water supply, and how do they affect water supply in recipient countries? Although donor funding schemes improve water supply, we argue that the contractual obligation to use highly complex and costly technologies and buy spare parts from donor countries makes maintaining and repairing water infrastructure strongly dependent on imports. While this reliance provides a market opportunity for donor countries to export their technologies and engineering services, it negatively affects the local capacity of recipient water companies to maintain and repair water infrastructure.

To explore this dynamic, we draw on the politics of tied aid and the politics of technology transfer to show how donors' tied water aid schemes affect maintenance and repair in Accra and Dar es Salaam through the interplay of their institutional conditionalities, technology, and local knowledge building. We argue that technology transfer provides a helpful conceptual lens for grasping the complex power relations within infrastructures (Lu and Qiu, 2022; Casadella and Liu, 2019) and we illustrate how specific political ideas become embedded in technological artefacts (Pilo', 2021). We further argue that technology transfer is not solely about implanting new technical artefacts; for transferred technologies to work sustainably in recipient countries, it is necessary to build the local knowledge and skills needed to maintain and repair transferred technologies. However, Science and Technology Studies (STS) research has shown that technology transfer is a highly complex and political process; even though technologies travel, they need to be adapted to connect with the contexts of their new settings (Behrends et al., 2014), whereas some knowledge does not travel but needs to be developed locally (Monstadt and Schramm, 2017).

This paper makes two specific contributions: First, it expands our understanding of water infrastructure maintenance and repair in the Global South beyond local actors (see, e.g., Jambadu et al., 2022; Wahby, 2021; Barnes, 2017) by explaining the crucial role of donors' funding schemes in the performance of these operations. Analysing donors' roles helps illustrate the multi-dimensionality and multi-scalarity

of maintenance and repair operations. Second, we introduce a new conceptual framework (Figure 1) to understand better the complex relations between donors' technology transfer and the political economics of water infrastructure maintenance and repair. This helps to reveal the ambivalent effects of donors' technology transfer schemes and how technological systems shape power relations and the (re)distribution of financial aid resources.

The remainder of the paper is structured as follows: Section two reviews the debates on development aid, technology transfer, and their relations to maintenance and repair. Section three describes the research methodology. Section four first provides an overview of donor funding schemes in Ghana and Tanzania's water sectors. Based on case studies on Accra and Dar es Salaam, we further explore the politics of tied water aid and how it affects maintenance and repair practices by assessing their institutional conditionalities and technology and local knowledge-building schemes. Section five concludes by calling for stakeholders to anticipate maintenance and repair in donor funding schemes and urban water policies in order to reduce the effect of import dependence and enhance infrastructure sustainability in Africa.

4.2 Literature Review

This section first introduces the debates on development aid and technology transfers and then discusses technology transfer in terms of its politics and its effect on maintenance and repair.

Development aid and technology transfer

Development aid generally refers to financial or technical assistance given to low-income countries to improve the living conditions of people (Apodaca, 2017). It entails bilateral and multilateral assistance schemes (Kim and Kim, 2016; Douch et al., 2022; Chen and Landry, 2018). The traditional donor countries include many European countries, the USA, Canada, Japan, and Australia, while China and India are often described as emerging donor countries (Mattlin and Nojonen, 2015; Chung et al., 2015). Donor aid can be tied or untied. It is called tied aid if the recipient country is required to fulfil specific conditionalities, but it is untied aid if no conditionalities are attached (Koeberle, 2005). Conditionalities refer to the actions and requirements the recipient country must satisfy to be eligible for donor aid or the set of principles and rules that guide the application of aid funds (Douch et al., 2022; Koeberle, 2005). Aid conditionalities vary substantially across different donor countries. For example, the USA and China often tie bilateral aid to the procurement of goods and

services from companies and contractors in their home countries (Morgenstern and Lawson, 2022; Mattlin and Nojonen, 2015), while other countries often stipulate anti-corruption policies, adherence to democratic or 'good governance' principles, free trade and liberalization policies, and private sector participation (Koeberle, 2005; World Bank, 2007; Douch et al., 2022). Depending on how policymakers in donor countries formulate these conditionalities, some scholars have argued that donors' conditionalities are a set of strategic tools to pursue and protect donor countries' foreign policy objectives in recipient countries (Apodaca, 2017; Douch et al., 2022; Dalgaard and Hansen, 2001).

Although the Paris Declaration on aid effectiveness of 2005 resulted in the share of untied aid from traditional donor countries increasing from 78% in 2005 to 84% in 2009 (Chung et al., 2016), recent studies show that in 2018 alone, the USA spent about 40% of its bilateral aid on procuring goods and services from USA-based companies and contractors (Morgenstern and Lawson, 2022). In the case of China, an explicit conditionality is for recipient countries to recognize China's political sovereignty over Taiwan (Mattlin and Nojonen, 2015; Oakes, 2021; Chen, Y., & Landry, 2018), but in addition, the Export–Import Bank of China (China Exim Bank) usually requires recipient countries to engage Chinese contractors and workers and to buy technologies made in China (Mattlin and Nojonen, 2015; Oakes, 2021; Tan-Mullins et al., 2010; Yang, 2022). According to some studies, these tied aid procurement practices can increase the cost of aid for recipient countries by 10–40%, as they deny them the opportunity to explore other sources that could offer the same services or products more cheaply (Chung et al., 2016; Kim and Kim, 2016; Morgenstern and Lawson, 2022).

Aside from direct monetary assistance, donor aid frequently transfers technologies from a donor to a recipient country, and the recipient countries tend to be in the Global South (Lu and Qiu, 2022; Li, 2016). Technology transfer is often seen as the precondition for rapid development, societal transformation, and modernity in the Global South (Lu and Qiu, 2022; Pandey et al., 2022; Watson, 2014). However, STS studies have shown that technology transfer is far more complex because it is not simply about 'implanting' new technologies in settings. Instead, it involves 'de-territorializing' technologies from their current settings and 're-territorializing' them in new contexts with distinct ontological and epistemological backgrounds, practices, knowledge, and institutional arrangements (Monstadt and Schramm, 2017; Behrends et al., 2014). This process of de/re-territorializing is highly political and place-based and thus has implications for the maintenance and repair practices in recipient contexts.

The politics of technology transfer and maintenance and repair

Technology transfer is an important aspect of international development aid and is vital for economic development and industrial transformation in the Global South (Casadella and Liu, 2019; Giorcelli and Li, 2021; Monson, 2009). For instance, it has been argued that donor technology transfer enables less resourceful countries to access advanced technologies that they otherwise may not be able to afford and that access to new technologies and innovations can fast-track economic development and industrial transformation and create new jobs in recipient countries (Giorcelli and Li, 2021; Li, 2016; Liu and Qiu, 2022).

Despite these merits, technology transfer is a highly complex political process, as it is driven and shaped by diverse interests and power relations (Pilo', 2021; Casadella and Liu, 2019; Watson, 2014; Li, 2016). Some scholars argue that current technology transfer practices bring about uneven power relations and create opportunistic relations between powerful donor countries and less resourceful recipient nations in the Global South (Casadella and Liu, 2019; Li, 2016; Monson, 2009). In the African context, postcolonial scholars contend that technology transfer reinforces colonial relationships by enabling imperial nations to maintain their presence in former African colonies and exert political influence over these countries' development (Li, 2016; Watson, 2014; Monsoon, 2006). Other scholars argue that donors' technology transfer conditionalities implicitly tie recipient countries' economic development to imported technologies, imported labor, and imported spare parts, which benefits the economies of donors' home countries (Mattlin and Nojonen, 2015; Pandey, et al., 2022; Mattlin and Nojonen, 2015; El Khanji, 2022; Quadir, 2013). This import dependence ends up suppressing local industrial growth in recipient countries because local firms cannot compete with imported goods, but it contributes to donor countries' industrial growth.

Beyond these explicit political considerations, STS studies have shown that technology transfer is far more complex than generally assumed and that even without these political rationalities attached to aid, it is still a highly political process because of the simplistic and diffusionist logics underlying aid and technology transfer. As many STS studies have shown (Monstadt and Schramm, 2017; Behrends et al., 2014; Lu and Qiu, 2014; Pandey et al., 2018), technologies are not simply 'implanted' into new settings but instead need to be adapted to connect with pre-existing materialities, knowledge, and institutional arrangements (Lu and Qiu, 2022; Monstadt and Schramm, 2017; Behrends et al., 2014). Therefore, technology transfer is not a 'copy and paste' process but requires 'place-based' adaptation, which is highly political and

shaped by local contexts and circumstances. For the new technologies to work in their new settings, they require specific "techniques of how to deal with a standardized model in place-based contexts" (Behrends et al., 2014:2).

These techniques consist of embodied knowledge that does not travel with the technological artefacts but needs to be reinvented in recipient contexts through improvised and experimental practices (Monstadt and Schramm, 2017:5). Another complex dimension of knowledge transfer relates to intellectual property rights that shape access to specific knowledge and also knowledge circulation and use (Lu and Qiu, 2022). The specific knowledge required to ensure specific technologies function is not universal, as it is usually owned by individual firms and manufacturers who control its distribution and use in society (Lu and Qiu, 2022). Hence, powerful manufacturers can use this monopoly power to their advantage but at the expense of maintenance and repair in recipient countries. In sum, knowledge cannot simply be transferred from one setting to another but needs to be developed from their situated contexts.

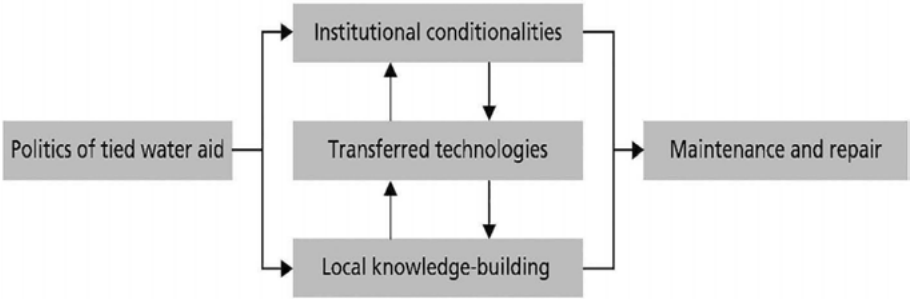
The complex political dimensions of technology and knowledge transfers affect maintenance, repair, and their role in shaping infrastructures in the Global South. Over the last decade, STS literature has increasingly focused on the maintenance and repair of urban infrastructure processes in the Global South (Graham and Thrift, 2007; Anand, 2017; Barnes, 2017; Baptista, 2019; Wahby, 2021; Ramakrishnan et al., 2021). In these publications, scholars have almost exclusively focused on the everyday practices of local actors (such as engineers, plumbers, and water users) and how they shape and, in turn, are shaped by urban infrastructure-making processes in cities. At the same time, Jambadu et al. (2022), Graham and Thrift (2007), and de Coss Corzo (2020) have pointed to the crucial importance of maintenance and repair in shaping the operation of urban infrastructures, with de Coss Corzo (2020) and Baptista (2019) also highlighting how maintenance and repair build and shape local knowledge and innovation through learning by doing improvisation, and ad-hoc tinkering practices.

All these authors have also shown how actors routinely mobilize these local adaptive practices to adapt and shape foreign technologies to work in certain ways that are often beyond how their original designers anticipated. De Coss-Corzo (2020) has argued, however, that such adaptive practices often do not follow any standardized guiding rule but can be considered to be "patchworks" that depend on what works and what does not work in each repair case. This means every repair work is unique and relies upon the repair workers' embodied expertise and experience (Björkman, 2018; Ramakrishnan et al., 2021; Graham and Thrift, 2007). While some scholars see

these local adaptive and improvised practices as manifesting local agency (Graham and Thrift, 2007; de Coss Corzo, 2020; Baptista, 2019), we frame them as the results of failures to align and situate foreign technologies to connect with local contexts and capacities. Despite the rich scholarly debates on urban infrastructure maintenance and repair and donors' technology transfer in the Global South, it is still poorly understood how donors' funding schemes conditioned on technology transfer affect maintenance and repair in recipient countries.

In this study, we draw on the literature on the politics of tied aid and politics of technology transfers to explain how donor-tied water aid schemes affect maintenance and repair practices in Accra and Dar es Salaam, using the lenses of institutional conditionalities, transferred technologies, and local knowledge-building. We argue that the politics of tied water aid influence these three variables, which, in turn, influence maintenance and repair practices in Accra and Dar es Salaam (Figure 1).

Figure 4.1 Tied water aid and its effects on maintenance and repair



Source: authors

We define institutional conditionalities as the rules and policy requirements defining the procurement rules and how water aid funds should be used. These variables affect maintenance and repair because they influence the technology choices and their underlying technical and regulatory standards relating to the quality of infrastructure. Transferred technologies here refer to specific material artefacts being transferred to recipient countries through water aid. They include water plants, equipment, pipelines, and their associated spare parts. This aspect of technology transfer is vital in shaping maintenance and repair because they define the system's complexities, cost, technical properties, the knowledge required, and ease of accessing necessary spare parts. The 'local knowledge-building' dimension pertains to the knowledge required to maintain and repair specific technologies: such knowledge is often imported and

added to the local knowledge base and may also be adapted and enriched with existing local knowledge in order for the maintenance and repair to be effective. We argue that in both cities, the politics of tied water aid shape maintenance and repair through the interaction between these three dimensions.

4.3 Research Methodology

This article is based on qualitative research conducted in Accra and Dare es Salaam on the effect of donors' funding schemes on water infrastructure maintenance and repair. Using the analytical lenses of institutional conditionalities, transferred technology, and local knowledge-building in the two cities, we applied an illustrative case study approach (see Epler, 2019; Yin, 2009) to explain how the politics of tied water aid affect the cities' infrastructure maintenance and repair. The illustrative case study is especially useful because it allows us to explain in detail "what is happening and why it is happening" in the two cities (Hayes et al., 2015:8).

Recently, Cawood et al. (2022) used this approach to explain how water access, maintenance, and repair are organised across different cities in the Global South. Our illustrative case study allows us to mobilize concrete examples from both cases to vividly describe the role of donors and how their tied water aid schemes affect maintenance and repair in two different African cities with distinct political, socio-economic, and institutional arrangements in water supply. To this end, we aim not to systematically compare the two cities but to provide an in-depth account of the effects of donors' tied water aid on maintenance and repair, using concrete examples from the two cities. However, we also highlight a few differences, similarities, and patterns that emerge from our analysis of the institutional conditionalities, transferred technologies, and knowledge transfer across the two cities. A detailed analysis of donors' role in water supply is especially relevant because African countries rely heavily on donor aid (Monney and Antwi-Agyei, 2018; Pigeon, 2012), and the two cases provide a broader insight into the impacts of donor aid on maintenance and repair in Africa. It also enables us to understand how differentiated donor conditionalities, transferred technologies, and local knowledge-building might shape maintenance and repair practices differently in African countries.

Rationale for the selection of the case studies

The case cities of Accra and Dar es Salaam were selected because they share many development challenges, yet each of them represents a unique context. Despite their difference in population size (the population of Dar es Salaam is more than double

that of Accra), their political structures and institutional arrangements in water supply are similar, which can attract similar donor countries. Secondly, both cities have undergone World Bank structural reforms in their urban water sectors, which has paved the way for introducing neoliberal ideals in their respective water sectors (Pigeon, 2012; Ameyaw and Chan, 2013; Kjellén, 2006). Third, while both cities still depend strongly on donor funding schemes for financing water infrastructure (Monney and Antwi-Agyei, 2018; URT, 2020), water challenges persist as residents rely on private providers for water supply (Bartels et al., 2018; Dakyaga et al., 2022; Jambadu et al., 2022). All these characteristics make both cities suitable to study in order to learn about the effects of tied water aid on maintenance and repair and their implications for water supply in Africa.

Data collection and analysis

The empirical data for this study was gathered between 2018 and 2021. We paid two fieldwork visits to each city and used three methods to gather data from various respondents and sources. First, we analysed official water policy documents, reports, laws, and water supply regulations and examined various academic literature relating to Accra and Dar es Salaam in order to obtain a broad understanding of the policy and institutional contexts of water supply and donor funding schemes across the two cities. Second, we conducted semi-structured interviews focusing on how donor funding schemes operate in the water sectors of the two countries. Two different interview guides were used, depending on the interviewees. When interviewing government officials, international donors/development partners, NGOs, and local research institutions, we explored issues related to urban water supply, infrastructure financing, key actors and their responsibilities, specific donor funding schemes, institutional conditionalities, and the technologies donors fund in the two cities. When interviewing GWCL (Ghana Water Company Limited) and DAWASA (Dar es Salaam Water and Sewerage Authority) officials (administrators and managers), we focused on the maintenance and repair of water infrastructure, exploring the specific maintenance and repair challenges, their financing, and local experts' knowledge and capacity. In total, 46 interviews were conducted across the two cities. Analysis of these interviews clarified our understanding of broader policy issues relating to water supply, infrastructure maintenance and repair, and their relations with donors' funding schemes in the two cities.

The third method entailed making observations in the field and holding informal conversations with various utility engineers, technicians, and repairers across the two cities. We visited field locations to observe repair workers operating maintenance and

repair in real-life contexts (Yin, 2009). We visited various water plants and observed how GWCL and DAWASA official engineers and technicians maintained and repaired equipment and water networks in both cities. These observations yielded critical empirical data on the everyday practices of maintenance and repair, the challenges involved, and the innovative practices repair workers use to solve repair and maintenance needs in water networks. The first author conducted 41 of the field interviews in person; the remaining five were conducted online due to COVID-19 restrictions. Ethical approval for the study was obtained from our university's ethics board, and we also implemented all the university's standard protocols and guidelines for responsible research conduct. The empirical data was analysed through thematic analysis strategies, which included coding the data according to four major themes: the donors' funding schemes, their institutional conditionalities, transferred technologies, and transferred knowledge. We have used examples from both cases to illustrate how these dimensions affect maintenance and repair in the two cities.

4.4 Results and Discussion

Below, we first present an overview of the urban water sectors of Ghana and Tanzania before going on to demonstrate how the politics of tied water aid in the two cities affect maintenance and repair through conditionalities, transferred technologies, and local knowledge-building

Donor funding schemes in Ghana and Tanzania's water sectors

Accra is the largest city in Ghana and the country's national capital. Its population is approximately 2.5 million (Ghana Statistical Services, 2021). It is the headquarters of all the country's political administrations and governance institutions and hosts the country's most crucial trade infrastructure, such as Tema Harbour. Similarly, Dar es Salaam is Tanzania's largest and most important city. Its estimated population was 5.4 million in 2020, and it is the fastest-growing city in East Africa (Dakyaga et al., 2022). Although Dar es Salaam is not the capital city, it has remained the commercial hub and headquarters of Tanzania's most important political institutions and commercial infrastructure (URT, 2021).

In both cities, the stakeholders critical for urban water supply are the central governments (including the water ministry[2]), various state regulatory agencies and

2 The Ministry of Sanitation and Water Resources in Accra and the Ministry of Water and Irrigation in Dar es Salaam.

municipalities, civil society organizations, water providers, users, and various international donors. These actors play specific roles and responsibilities stipulated in the water legislation and national water policies. For example, the central government in both countries is ultimately responsible for urban water provision and infrastructure financing (Monney and Antwi-Agyei, 2018; Ameyaw and Chan, 2013; URT, 2020), while the Ministry of Water is responsible for developing water policies, regulations, and legal frameworks for the water sectors (URT, 2019; Fuest et al., 2005), and the urban water supply companies are responsible for infrastructure maintenance and repair (Kjellen, 2006; Bartels et al., 2018).

The water sectors of both countries are governed through slightly different institutional arrangements. In Ghana, the Statutory Corporations (Conversion to Companies) Act 461 (1993) established the GWCL as a state-owned limited liability company and redefined its mandate as the sole urban water supply provider in Ghana (GWCL, 2017). Act 522 (1996) established the Water Resources Commission to regulate water resource use in Ghana (Fuest et al., 2005), while Act 538 (1997) established the Public Utilities Regulation Commission (PURC) to regulate urban water tariffs and service quality (Fuest et al., 2005; Jambadu et al., 2023). Ghana's national water aspirations are articulated in the national water policy developed in 2007, which recognises basic water access as a fundamental human right for every citizen (MWRWH, 2007).

An integrated legal and regulatory framework governs Tanzania's water sector. The Water Resources Management Act (No. 11) of 2009 regulates water resource use and gives residents the right to drill private boreholes for domestic purposes (URT, 2009; Dakyaga et al., 2022). The Water Supply and Sanitation Act (WSSA 5) (2019) established the DAWASA and mandated it to supply water and sanitation services in Dar es Salaam (URT, 2019). The act also reaffirms the regulatory authority and responsibilities of the Energy and Water Utilities Regulatory Authority (EWURA) concerning tariffs and the issuance of operating permits to various regional water authorities (URT, 2019). Tanzania's first national water policy was developed in 2002 (URT, 2002). The WSSA regards basic access to safe drinking water as a fundamental human right (URT, 2019: 12).

Although they do not have explicit responsibilities in water supply in either country, international donors play a critical role in financing water infrastructure. For instance, in Ghana, donors contributed about GHS 174 million (about USD 14 million) out of the GHS 260 million (about USD 24 million) budget for the Ministry of Water and Sanitation Resources in 2019 alone (MSWR, 2020). This figure translates

to approximately 67% of the ministry's budget. Similarly, about 57% of Tanzania's water sector budget in 2019 came from donors, who also funded up to 84% of the entire budget for WSDP-II (URT, 2020:103). Key donors for water supply in Ghana include the World Bank, China, the USA, and Canada (Ghana Ministry of Finance, 2020), while in Dar es Salaam, they include India, the World Bank, and the African Development Bank (URT, 2020:104). Table 4.1 presents some major water projects funded by donors in Accra and Dar es Salaam.

Table 4.1 Selected infrastructure projects funded by donors in Accra and Dar es Salaam

City	Description of project	Amount (USD)/m	Donors /Funders
Accra	Construction of a new seawater desalination plant at Teshie-Nungua	126	World Bank/Standard Charted Bank of South Africa
	Extension of distribution and sewer networks in the Greater Accra Metropolitan Area	150	World Bank
	Upgrading of Kpong Water plant	273	China Exim Bank
	Upgrading of Weija Water plant	22	World Bank/IMF/Dutch government
Dar es Salaam	Upgrading of Upper Ruvu plant	178	India Exim Bank
	Upgrading of Lower Ruvu water plant	46	Millennium Challenge Corporation
	Construction of a new 56.7 km long transmission network from Lower Ruvu River to Dar es Salaam township	59	Government loan from World Bank
	Water resource management, operational efficiency, and sanitation infrastructure	230	World Bank

Source: authors, based on policy documents and literature

Table 1 shows that donors' loans and grants mainly supported the construction of large-scale water infrastructure, such as new water plants, the upgrading of existing systems, and desalination systems and transmission networks. These large-scale infrastructure projects have undoubtedly improved water supply in both cities, although they presented different challenges in water maintenance and repair.

Unpacking the politics of tied water aid and its effect on maintenance and repair

Below, we examine the politics of tied water aid through the lenses of institutional conditionalities, transferred technologies, and local knowledge-building to reveal how these politics affect maintenance and repair in the two cities.

The institutional conditionalities

Conditionalities are an essential dimension of tied water aid in both cities. Our research revealed that donors' funding conditionalities vary slightly across the two cities. A typical conditionality in Accra and Dar es Salaam relates to hiring foreign contractors for donor-funded infrastructure projects. In Accra, this concerns the upgrading of the Kpong water plant, while in Dar es Salaam it applies to rehabilitating the Upper Ruvu water plant. However, China's Exim Bank funded the Kpong project in Accra (PUWU, 2019), while India's Exim Bank funded the Upper Ruvu plant in Dar es Salaam (Interviews 1, 2, 3, & 4, 2018/2021). Yet both projects were tied to foreign contractors from the donor countries. The USD 273 million Kpong water project was awarded to China Gezhouba Group Corporation (CGGC) (Interviews 3, 4, & 5, 2018), while the USD 178 million Upper Ruvu plant was given to India's construction giant, WABAG group (Kiganda, 2016). Both were turn-key projects, meaning the same contractors handled the design, construction, and equipment installation (Interviews 2, 5, 6, & 7, 2018/2019). The foreign contractors also used foreign technologies and engineers to design and build both water systems, while the GWCL and DAWASA engineers conducted monitoring and periodic checks to ensure compliance with agreed quality and technical standards (Interviews 2, 7, 8, 9 & 10, 2018/2019).

These findings show that local experts were not directly involved in the construction and installation of equipment because turn-key projects give the contractors full responsibility to design, construct, and install technical equipment in line with agreed international standards specified by donors. This bound the contractors to use foreign technologies and experts to ensure the quality and standards that they had agreed with donors. Using quality materials and complying with quality standards in infrastructure construction can enhance the systems' durability, prolong their lifespan, and reduce technical breakdowns (Ramakrishnan et al., 2021), which brings the benefits of lower short-term maintenance and repair costs. However, it also limits local agencies, especially regarding how local actors can influence technical standards and technologies that were agreed in contractual agreements with donors, even if these are unsuitable for the local context (Pandey et al., 2019). Moreover, implementing foreign standards in local contexts can be seen as an attempt to impose certain

technical principles as 'universal standards' across different contexts without considering that they need to be adapted to fit each locale's 'place-based' circumstances, and pre-existing knowledge, institutions, and materialities (Behrends et al., 2014; Monstadt and Schramm, 2017). The end result will be that donors' home standards and knowledge become the universally accepted standards and are placed above all others in conducting maintenance and repair everywhere.

The second conditionality relates to open and fair completive bidding for donors' infrastructure projects. This conditionality applies to upgrading the Lower Ruvu water plant in Dar es Salaam. The USA funded the USD 46 million water project through its Millennium Challenge Corporation (MCC, 2021) (URT, 2011). The critical procurement conditionality required the government of Tanzania to implement free and fair bidding for the project, and to engage only competent and qualified contractors (URT, 2011). Degremont and Spencon Services Limited (a French construction company based in Kenya) subsequently won the contract and handled the system's design, construction, and installations (ibid).

While competitive bidding has significant merits in terms of competence, quality, and cost-effectiveness (Interviews 11, 12, 13, 14, 15, 2018/2021), it can also restrict local firms' participation in constructing large-scale infrastructure because they usually have insufficient financial and technical capacity to be able to compete with foreign contractors for such projects and hence, even if the tender process is open, local firms are implicitly left out of the construction projects (Interview 11, 2021). This presupposes that competitive bidding creates an opportunity to enlist foreign firms in local infrastructure projects in both cities, laying the basis for the water system's dependence on imports. In this sense, technology transfer conditionalities implicitly tie water system development in the two cities to imported technologies, imported labor, and imported spare parts (Mattlin and Nojonen, 2015), a situation that increases the cost of maintenance and repair and hampers the long-term sustainability of infrastructure.

The two examples discussed above illustrate different conditionalities informed by different political considerations. The cases of the Kpong and Upper Ruvu water plants demonstrate donor state economic protection policies and the need to promote their domestic industries (Morgenstern and Lawson, 2022). That is why China's eight principles for providing loans to other countries prioritize China's public enterprises and contractors in implementing all external infrastructure projects financed by China's public funds (Li, 2016). However, the case of the Lower Ruvu water plant in Dar es Salaam illustrates the need to ensure cost-efficiency, fairness, and transparency in

the application of donor funds, all of which are also consistent with the USA's foreign policies relating to the promotion of anti-corruption, transparency, and democratic principles in the application of public funds (Morgenstern and Lawson, 2022). However, both conditionalities limit local agency in the construction process and produce highly complex and costly systems, as discussed in the following sections.

Transferred technology

Our interviews and analysis of official reports revealed that donors funded slightly different water infrastructures in Accra and Dar es Salaam. For example, in Accra, China Exim Bank funded the Kpong water plant upgrading project, while the World Bank also funded a novel but controversial seawater desalination technology (see Table 1). The USD 126 million reverse osmosis desalination plant was developed by Befessa Aqua of Spain in 2015 and is funded through a private-public partnership (PPP) arrangement (Interviews 14 &16, 2020). The PPP entails a 25-year lease agreement in which Befessa is permitted to design, build, and operate the plant and transfer it to the state-owned utility (GWCL) after the contract expires (PURC, 2018). The desalination plant enables seawater to be converted into drinking water for residents of Accra. The plant can produce about 60,000 m^3/day (Interview 5, 2020). Under the contract agreement, the private operator must sell treated water to the GWCL, which, in turn, sells it to its customers (PURC, 2018).

The contractual agreement means that although the GWCL does not manage the desalination plant, its operation affects GWCL's financial capacity to conduct major structural maintenance and repair of its water infrastructure. For instance, the Public Utilities Workers Union (PUWU) contested the desalination plant in 2019, arguing that a desalination plant was "technically and financially flawed" and that there were cheaper alternative technologies that should have been adopted (PUWU, 2019:1). Many GWCL officials also argued that a desalination plant is expensive to operate and puts a financial burden on the company, making it difficult to finance critical infrastructure maintenance and repair (Interviews 5, 17 & 18, 2018/2020). The consequence is that GWCL cannot raise funds to maintain and repair its water systems due to its debt obligations to private operators (PUWU, 2019). These opinions show that the desalination plant can be considered to be inappropriate technology because it is sophisticated and expensive.

In Dar es Salaam, donors mainly funded the upgrading of technical systems and expansion of existing plant capacity in the Lower and Upper Ruvu water plants and developed additional transmission mains to convey water from the two plants

to Dar es Salaam city (URT, 2020; Kiganda, 2016; URT, 2011). Both plants comprise conventional water treatment systems using standard filtration, chlorination, and clarification technologies (Interviews 19 & 21, 2019). The latter two interviews revealed that the rehabilitation projects involve installing additional water pumping mains, disinfection and filtration equipment, and clean water tankers to store the water for onward distribution. This means old pumps and equipment have been replaced with new and modern systems, and other new technologies and equipment have been added to the existing systems. After the upgrading, the Upper Ruvu system's capacity increased to about 200,0000 m^3/day (EWURA, 2018), while according to the interviewees, the Lower Ruvu system went up to 270,000 m^3/day. Several kilometres of new transmission mains were also installed.

The water supply systems in both cities are large-scale, complex, and costly to maintain and repair. As indicated earlier, this complexity results from using foreign contractors, who usually use foreign technologies and equipment to construct water systems to comply with donor countries' quality and regulatory standards. These standard compliance requirements technically bind water systems to imported spare parts, expertise, and engineering services after the contractors leave. As many development scholars have shown (Mattlin and Nojonen, 2015; Kim and Kim, 2016; Yang, 2022), importing these spare parts and expert services will benefit the donor countries' domestic economies in terms of providing a market for their industrial products and technology services.

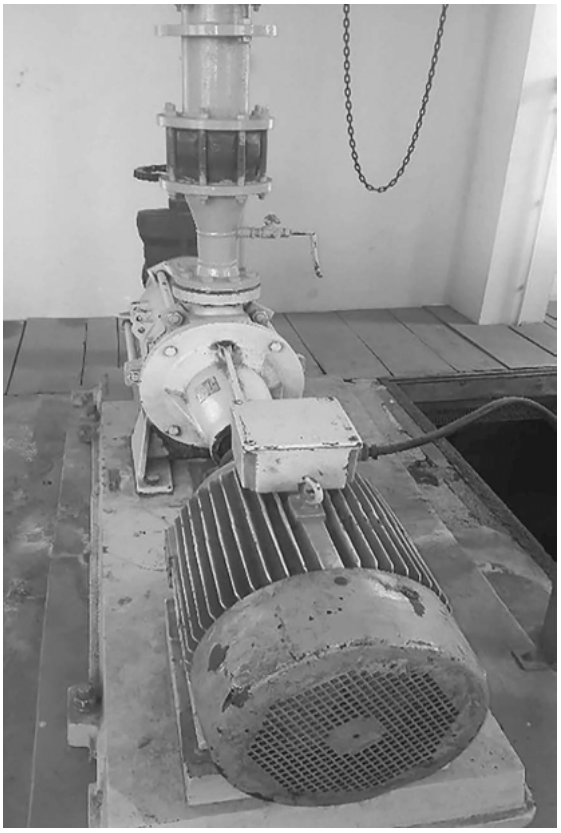
However, strong reliance on imports affects maintenance and repair in the two cities in two main ways. The first is the high cost of imported spare parts and materials, which makes them unaffordable for utility companies (Interviews 7, 10, 19 & 20, 2018/2019). For example, a GWCL official in Accra indicated that

> "*one of our major problems is the cedis depreciating so fast against dollars. When we budget for materials and spare parts at the beginning of the year, the cost will increase by more than half in the middle of the year due to depreciation. This always pushes our budgets off-track. We often have to cut down the quantities and buy what we can"* (Interview 5, 2020).

In practice, these constraints mean doing without critical equipment and spare parts needed for maintenance whenever possible and otherwise only using the bare minimum. In some situations, maintenance and repair needs (e.g., network maintenance) must be suppressed in order to be able to import critical spare parts, or else the equipment is abandoned because there are insufficient funds to import the correct spare

parts (Interview 3, 2018). For example, Figure 1 shows a dysfunctional booster pump that has been abandoned at one of GWCL's water stations in Accra. The site engineer revealed that the equipment had developed a technical fault a few years previously, but the company was unable to import the correct spare parts. The pump was thus left to deteriorate further to the point that repairing it would cost more than buying a new one (Interview 21, 2018).

Figure 4.2 An abandoned booster pump in Accra.



Source: Authors

Second, importing spare parts causes delays in maintaining and repairing water systems. An official of DAWASA in Dar es Salaam revealed,

> "*We import most of the plant/equipment from South Africa or India, which causes many delays. Sometimes we don't have the experts and must bring down experts from the manufacturers, which takes much time*" (Interview 7, 2019).

Getting equipment or spare parts to Ghana from distant places like China can take an especially long time—up to three months (Interview 21, 2020). And meanwhile, the malfunction may worsen, pushing up the repair cost considerably (Jambadu et al., 2022) or even leading to it being abandoned, as in the case of the pump shown in Figure 1.

The DAWASA company has decided to foster local solutions by producing certain basic spare parts locally to reduce dependence on and the challenges associated with imports. A company official disclosed that they usually engage local artisans (blacksmiths) to improvise or reinvent some of the essential spare parts and equipment it frequently uses, thereby enabling them to reduce the costs and delays associated with importing spare parts (Interview 7, 2019). These local adaptive practices show how utilities cope with the challenges of foreign technologies by adapting and appropriating them to connect with their local contexts and circumstances (Monstadt and Schramm, 2017). Other scholars (Mattlin and Nojonen, 2015; Chung et al., 2016; Pandey et al., 2018) have also shown that technology transfer and the associated import dependence benefits donors' domestic economies in terms of exports and employment creation but can come at the expense of maintenance and repair and long-term sustainability of technologies in recipient countries.

Local knowledge-building

Making technologies work in local contexts depends on the recipient organization's capacity to reinvent and adapt existing knowledge to connect with the new expertise it needs to use to maintain and repair the foreign systems (Monstadt and Schramm, 2017). Our research findings show that local experts in GWCL and DAWASA have limited knowledge of the new technologies and systems transferred by donors, and therefore, their ability to maintain and repair complex water technologies is restricted. For instance, although engineers and technicians of both companies in Accra and Dar es Salaam could handle most of the everyday maintenance and repair problems at the various water plants and networks, they struggled to deal with more complex issues, such as troubleshooting malfunctions of certain electro-mechanical equipment at the water plants (Interviews 7, 8, 9 & 21, 2018/2019).

A system technician stationed at the Kpong water plant in Accra revealed,

> *"we can handle most of the common problems if the correct spare parts are available. But when there are complex issues we cannot handle, we report to the headquarters for higher expertise. Even for them [the headquarters], there are some issues they*

cannot also handle. In that case, they have to hire a specialist from abroad" (Interview 23, 2018).

Similarly, a technician at the Upper Ruvu water plants in Dar es Salaam reported that

"sometimes when new equipment is imported, we do not have the expertise immediately to operate, repair, or maintain them. So we have to do our research to learn about them. The company does not have money to sponsor training abroad" (Interview 24, 2019).

These statements show the limits to the knowledge of utility engineers and technicians and reveal the multi-scalar nature of maintenance and repair knowledge in technical systems. In the case of more complex technological systems such as the desalination plant, no GWCL engineer has the necessary maintenance and repair expertise, even though the plant is to be operated by the company after the lease contract expires (Interviews 5 and 17, 2018). These interviews revealed that GWCL officials were also unsure if there were plans or arrangements to build up their knowledge and skills, so they could operate, maintain, and repair the systems after the foreign contractors leave.

The opinions noted above indicate that building local knowledge and capacity for maintenance and repair have been poorly anticipated in the donor-funded technology transfer schemes for the two cities. This accounts for the persistent knowledge gap in both companies and their limited capacity to handle the complex maintenance and repair of imported technologies. It seems probable that donors often consider such capacity building and training of local experts to be a core task of the utility companies that are responsible for maintenance and repair (Alves, 2022). This conception can also be interpreted as the negative consequence of tying water aid to foreign contractors and complex technologies and the resulting ripple effects that further consolidate import dependence in both cities' water systems (Mattlin and Nojonen, 2015).

These findings highlight an important political dimension of knowledge. The knowledge and skill set required to maintain, and repair specific infrastructure is not ubiquitous (Houston, 2019; Jackson et al., 2011) but instead is limited and controlled by a handful of foreign manufacturing firms who also control their production, use, and distribution through intellectual property rights (Lu and Qiu, 2022). Therefore, building local knowledge and capacity for maintenance and repair in recipient

countries will reduce dependence on foreign experts and engineering services and destabilize these firms' power and monopoly over using and distributing such knowledge. Thus, transferring technologies without building local knowledge protects the monopoly power but at the expense of maintenance, repair, and sustainability.

Local experts in both cities thus compensated for the above knowledge shortcomings by frequently improvising, learning, and tinkering with various infrastructure artefacts to find local and place-based solutions to maintenance and repair needs. For example, the interviews revealed that without formal capacity building and training opportunities, many technicians in both cities conduct personal research online by watching free videos and reading manuals and other resources to learn about new technologies and techniques so they can experiment with maintaining and repairing new equipment and that some technicians use personal knowledge and experiences to tinker with various material artefacts to solve diverse maintenance and repair problems, even if such solutions are temporary (Interviews 7, 9, 19, 20, 23, & 24, 2018/2019).

These tinkering and improvisation practices often do not follow prescribed technical standards or guides but are instead based mainly on individual experience and knowledge (De Coss-Corzo, 2020). Therefore, they can also pose additional risks to the system's functionality. For instance, although we observed that some experiments at maintenance and repair succeeded, interviewees reported that many have failed, further damaging the faulty equipment (Interviews 7 & 21, 2018/2019). However, as many STS studies in the Global South have shown (Graham and Thrift, 2007; Jackson, 2019; Baptista, 2019; De Coss-Corzo, 2020), the everyday acts of tinkering and improvising also stimulated an environment of ongoing learning and innovation among local engineers and technicians. These acts not only enable local experts to appropriate foreign technologies to work under conditions of resource poverty but can also be interpreted as acts of resistance that challenge foreign technologies, the universalization of repair knowledge, and standardization.

4.5 Conclusion

This article has investigated the politics of donor funding schemes in water supply and how they shape infrastructure maintenance and repair in Accra and Dar es Salaam—two fast-growing cities in sub-Saharan Africa. To illustrate how tied water aid practices affect maintenance and repair practices in both cities, we relied on the politics of tied aid and technology transfer and the analytical lenses of donors'

institutional conditionalities, transferred technologies, and local knowledge-building. We have unpacked the complexities of the politics of tied water aid through these analytical dimensions to show how donors' funding schemes have had ambivalent effects on maintenance and repair in both cities but can positively impact donor home countries' economies in promoting exports and employment. Although donors funded slightly different technologies in the two cities and imposed different conditionalities, their effects on maintenance and repair were generally similar: i.e., delays and costly spare parts that are difficult or impossible to obtain and expensive to import. Moreover, these imposed technologies challenge local experts' knowledge and skills.

In general, donor conditionalities have imposed complex and costly technologies without considering the need to build local knowledge or to provide appropriate foreign technologies to connect with the local contexts and their situated materialities, knowledge, and institutional arrangements (Behrends et al., 2014). This misalignment has resulted in tension because local experts lacked the knowledge required to handle the maintenance and repair of complex systems. Both utility companies also struggled to afford imported spare parts, facilitate local knowledge-building, or hire foreign experts to handle complicated maintenance and repair problems. Thus, although donor-funded technologies have improved water supply infrastructures in both cities, their long-term sustainability is problematic because donors poorly anticipated the maintenance and repair possibilities in recipient countries. Overall, the case study has illustrated the crucial importance of donors in maintenance and repair and the need to address their role more systematically in the study of maintenance and repair in Africa and, more broadly, in the Global South.

Our case study contributes critically to infrastructure maintenance and repair literature and the politics of tied aid and technology transfer in the Global South in several ways. First, by investigating the role of donors in water infrastructure maintenance and repair, the paper has illustrated the multi-scalarity and multi-dimensionality of infrastructure maintenance and repair. We have shown how different aspects of technologies (i.e., actors, artefacts, knowledge, institutions, and political rationalities) interact at different scales in shaping maintenance and repair practices. This insight also shows that even though maintenance and repair involve practices of local actors such as utilities, engineers, plumbers, and users (Wahby, 2021; Alda-Vidal et al., 2018; Jambadu et al., 2022), they are simultaneously shaped and driven by the political rationalities, decisions, and agencies of international donors. Second, we have demonstrated that the impact of development aid goes beyond the time of the

infrastructures' construction and installation (past decisions) and their operations (present-day) and extends far into the long-term maintenance and repair (future). This has practical implications and relevance for shaping policy formulation and international donor funding programs in Africa. We argue that there is a need for donors and national governments to anticipate the maintenance and repair of infrastructure more systematically by incorporating local knowledge and capacity-building programs in donor-funded infrastructure projects in order to reduce import dependence and enhance long-term sustainability.

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5. Engineer, GWCL-ATM, Accra, March 20, 2020
6. DAWASA Regional manager, Dar es Salaam, February 18, 2019
7. Technician, Lower Ruvu plant, Dar es Salaam, March 1, 2019
8. Technician, Upper Ruvu plant, Dar es Salaam, March 4, 2019
9. Technician, Weija water plant, Accra, March 26, 2018
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CHAPTER 5

ENHANCING INFRASTRUCTURE RESILIENCE THROUGH MAINTENANCE AND REPAIR? THE CASE OF WATER SUPPLY IN ACCRA AND DAR ES SALAAM

Jambadu, L., Hölscher, K. and Monstadt, J., (Unpublished). Enhancing infrastructure resilience through maintenance and repair? The case of water supply in Accra and Dar es Salaam (unpublished manuscript).

Abstract

Infrastructure resilience to ensure sustainable water supply in African cities is challenged not only by weather extremes but also by internal technical breakdowns and failures resulting from decay and ageing infrastructures. Drawing on qualitative studies of water supply in Accra (Ghana) and Dar es Salaam (Tanzania), we explore how maintenance and repair shape water infrastructure resilience capacities to resist, absorb, and adapt to decay, breakdowns, and failures and how these capacities, in turn, shape the ecological, economic and social sustainability of water supply systems. The findings demonstrate that maintenance and repair are important to enable the continuous regeneration of water infrastructures, yet in both cities, they are hindered by insufficient prioritization, investment, knowledge, and staff. Capacities to resist are low, and capacities to absorb are modest, but the capacities to adapt to infrastructure disruptions are comparatively high across both cities. We show that understanding urban infrastructure resilience through maintenance and repair enables appreciation of dynamic, ongoing practices and processes shaping resilient urban water supply. We conclude that incorporating maintenance and repair in urban infrastructure resilience policies and plans and allocating more financial and organizational resources are critical for enhancing infrastructure resilience and sustainability.

Keywords: Infrastructure resilience; water supply; maintenance and repair; global South; cities.

5.1 Introduction

Urban infrastructure resilience has attracted increased attention from scholars and policymakers due to the need to protect critical urban infrastructures from frequent man-made and natural disasters linked to climate change (Silver, 2015; Huck et al., 2020; Balei et al., 2018; Teen, Roberts and Challies, 2020). In Africa, these external threats add to existing challenges facing urban infrastructure systems, which are characterized by highly uncertain, unsafe, and inequitable service provision due to everyday technical breakdowns and failures connected to infrastructure decay and ageing systems (Bartels et al.,2018; Alda-Vidal et al., 2018; Kjellén, 2009). Moreover, infrastructure resilience in these contexts is complex because infrastructure systems usually involve hybrid socio-technical configurations of centralized and decentralized systems (Coutard and Rutherford, 2015; Monstadt and Schramm, 2017) and hybrid labor relations and practices of private and public actors (Cawood et al., 2022). Urban infrastructure resilience in African cities thus needs to be approached as a continuously evolving socio-technical system's property—enabled through multiple socio-technical configurations and practices—that is able to resist, absorb and recover from, and adapt to, the everyday technical breakdowns and failures arising from infrastructure decay and ageing systems.

Much infrastructure resilience research focuses on building resilience against external shocks and disasters—such as floods and droughts—but mitigating failures internal to infrastructure systems has attracted less attention. Here, our premise is that maintenance and repair are particularly important practices to preserve infrastructures' functioning, help regenerate systems and restore functionality after breakdowns or failures (Jackson, 2012; Graham and Thrift, 2007; Ramakrishnan, O'Reilly and Budds, 2021). In addition, maintenance and repair practices harbour innovation potential to adapt infrastructure systems to anticipate and prepare for future developments and risks (Graham and Thrift, 2007; Jackson, 2019; Ramakrishnan et al., 2021).

This paper aims to explain how maintenance and repair shape the resilience capacities of urban water supply systems in Accra (Ghana), and Dar es Salaam (Tanzania) and how these capacities, in turn, affect these cities' sustainability. Although there is an extensive scholarly discussion on urban infrastructure resilience (Balaei, 2018; Sweya, Wilkinson and Kassenga, 2021; Eledi Kuusaana, Monstadt and Smith, 2023) and on maintenance and repair in the global South (Graham and Thrift, 2007; Jackson, 2019; Ramakrishnan, et al., 2021; Alda-Vidal et al., 2018), how maintenance and

repair shape infrastructure resilience and sustainability has so far received insufficient attention.

We argue that the maintenance and repair of water systems is critical to achieving water infrastructure resilience in both cities (and, more broadly, in African cities). For instance, about 50% and 48% of the treated water supplied by the Ghana Water Company Limited (GWCL) and the Dar es Salaam Water and Sanitation Authority (DAWASA), respectively, are classified as nonrevenue water, i.e. water "lost" before it reaches consumers (EWURA, 2018; GWCL, 2017). A major reason is leaking networks (ibid.), resulting in overexploitation of scarce water resources and amplifying water scarcity in the city. Limited access to water, in turn, stimulates residents to drill more private boreholes, thereby undermining sustainable water resource management in cities (Teen, Roberts and Challies, 2020; Aina, Thiam and Dinar, 2023).

In this article, we analyse the relationship between water infrastructure resilience and sustainability through maintenance and repair in two steps. First, we analyse how maintenance and repair practices contribute to water infrastructure resilience capacities to resist, absorb and adapt to breakdowns and failures; second, we assess whether and how these capacities affect the ecological, economic and social sustainability of water supply systems. While the first step yields insights into maintenance and repair as processes shaping infrastructure systems' abilities to continue or restore functioning in the face of decay, breakdown and failures, the second step assesses three key dimensions of sustainability, focusing on ecological, economic and social outcomes. Our two-step analytical approach connects an assessment of infrastructure resilience capacities (system properties) to that of sustainability (outcomes), and how both are shaped by maintenance and repair. We respond to a critical question concerning whether infrastructure resilience also enhances social, economic and environmental sustainability (Meerow and Newell, 2019; Elmqvist et al., 2019). The article contributes to understanding in urban infrastructure resilience and sustainability through maintenance and repair in African cities where urban water supply systems are shaped by splintered and hybrid configurations.

The remainder of this paper is structured as follows: Section two presents our conceptual approach to analyse how maintenance and repair contribute to three resilience capacities, and how they are connected to ecological, economic and social sustainability dimensions. Section three introduces the research methodology, including the rationale for selecting the two case studies and how data was collected and analysed. Section four presents how maintenance and repair practices contribute to the

three resilience capacities in Accra and Dar es Salaam. Section five discusses the key lessons for improving infrastructure resilience through maintenance and repair, particularly in view of the impacts on the sustainability of water supply. Section six concludes with the overall insights and value of the case studies for informing urban infrastructure resilience debates, policies and practices in the two cities and other cities in the global South.

5.2 Understanding urban infrastructure resilience through maintenance and repair

This section presents our conceptual approach to analysing the relationship between maintenance and repair and urban water infrastructure resilience.

Urban infrastructure resilience capacities and maintenance and repair

Urban infrastructure resilience has received massive attention from policymakers and scholars in the last two decades (e.g., Balaei, 2018; Sweya et al., 2021; Taysom and Crilly, 2017). This attention is driven by growing concerns about the increasing impacts of climate change, natural disasters, rapid and unplanned urban growth, and environmental pollution and the associated impacts on cities, people, and infrastructures (e.g., Huck et al., 2020; Folke, 2016; Campanella, 2006). From this perspective, infrastructure resilience is generally defined as the capacity of urban infrastructure systems to remain functional and deliver services in the face of external shocks or disturbances (Alexander et al., 2016; Folke, 2016; Campanella, 2016; Darkwah, Cobbinah and Anokye, 2018). Urban infrastructure resilience can be assessed in terms of the socio-material, political, and technical configurations and interrelations embodied in socio-technical infrastructures (Sweya et al.,2021; Hall et al., 2019; Taysom and Crilly, 2017) and how these manifest in resilience capacities to ensure safe water quality, sufficient quantities, social equity, and environmentally sustainable service provision in cities (Satur and Lindsey, 2020).

Drawing on resilience literature, we distinguish three resilience capacities, i.e. to resist, absorb and adapt (Table 1; Balaei et al., 2018; Sweya et al., 2021; Taysom and Crilly, 2017), through which maintenance and repair can shape water infrastructure resilience. Accordingly, this study posits maintenance and repair as crucial for mitigating the impacts of material infrastructures' decay and wear and tear (Graham and Thrift, 2007) and as mechanisms that continually restore infrastructure systems after breakdowns (Jackson 2012) and provide opportunities to continually innovate ways to readjust the system to improve its functionality and

reduce risks of failure (Graham and Thrift, 2007; Ramakrishnan et al., 2021; Baptista, 2019).

The *capacity to resist* refers to an infrastructure system's ability to prevent or mitigate the risks or likelihood of disturbances or failures (Balaie et al., 2018). Maintenance and repair enhance this capacity by facilitating early detection of decay in infrastructure systems and identifying potential risks of failure in technical systems (Graham and Thrift, 2007; Ramakrishnan et al., 2021). Accordingly, preventive measures provide the opportunity to detect risks early and fix minor faults in the systems (e.g., leaks, decay, or worn-out parts) before they escalate into breakdowns and failures. This capacity is shaped by existing policies, rules, and regulations for ensuring repair workers adhere to a preventive maintenance and repair culture. These workers' detailed knowledge about the infrastructure systems and their vulnerability hotspots also facilitates easy and early detection of risks in the networks (Anand, 2020; Jambadu, Monstadt, and Schramm, 2022).

The *capacity to absorb* refers to an infrastructure system's ability to accommodate or tolerate some disturbances or shocks by facilitating coping and recovery practices (Satur and Lindsay, 2020; Meerow and Newell, 2019; Pahl-Wostl et al., 2013; Balaei et al., 2018). It is activated when infrastructures experience breakdowns or failures, which can disrupt critical urban services (Graham and Thrift, 2007). Here, maintenance and repair ensure that by detecting faults in the systems early and proactively responding to them (Baptista, 2019; Jackson, 2012) and ensuring that disrupted infrastructures can quickly "bounce back" after breakdowns (Jackson, 2019). For example, detecting network leaks and bursts early using GIS and GPS technologies facilitates prompt responses to infrastructure maintenance and repair needs (Whittle et al., 2013).

The *capacity to adapt* refers to the system's ability to continually adjust and reorganize to accommodate undesirable consequences in the long term (Balaei et al., 2018). Adaptive capacity is progressive and seeks to improve the system through re/self-organization. It minimizes adverse consequences in the long term, particularly when the system's capacity to resist and or absorb adverse consequence shocks is exceeded (Pahl-Wostl et al., 2013; Alexander et al., 2016; Eledi Kuusaana et al., 2023). Adaptive capacity is based on continuous changes, learning, and self-organization (Folke, 2010; Alexander et al., 2016), which resonates with maintenance and repair being seen as dynamic processes involving continuous learning, innovation, and improvisation (de Coss Corzo, 2021; Baptista, 2019; Jackson, 2019). In global South cities, in particular,

improvisation and tinkering practices are needed to circumvent complex technicalities and material constraints (Schubert, 2019), e.g., to innovate local solutions and material resources for maintenance and repair (Baptista, 2019; Barnes, 2017). These low-cost solutions introduce new technologies into existing infrastructure and are vital to ensure uninterrupted infrastructure functioning.

Table 5.1 Resilience capacities and relations to maintenance and repair

Resilience capacities	**Link to maintenance and repair**	**Examples of practices**
Capacity to resist: the ability to prevent or mitigate risks and service disruptions	To mitigate infrastructure decay and failures, to ensure continuous service delivery.	Preventive maintenance and repair to renew worn-out parts Identifying vulnerability hotspots Developing detailed knowledge about infrastructure systems to recognize risks early
Capacity to absorb: the ability to cope with and recover from service disruptions	To accommodate breakdowns and failures by quickly restoring disrupted or broken systems.	Routine maintenance and repair of leaks, bursts, and equipment Emergency maintenance and repair schemes to enable fast response to critical repair needs Easy access to private plumbers for fast response to maintenance and repair needs
Capacity to adapt: the ability to adjust and reorganize in response to short-term and long-term service disruptions	To facilitate innovations and learning to develop and integrate new technologies and practices in existing infrastructure systems.	Innovating and improvising (local) solutions Ongoing learning about how to improve infrastructure systems (e.g., new technologies)

Source: authors

Sustainability and resilience capacities through maintenance and repair

Debates on urban infrastructure resilience have thus far neglected the importance of sustainability (Ayyub, 2020; Elmqvist et al., 2019), and the relationship between these important dimensions of urban infrastructure is rarely explored. Scholars emphasize the need to connect resilience to questions of „what, to what, and for whom?", which also recognize undesirable resilience, such as traps and maladaptation, and inequitable distribution of benefits (Simon, Griffith and Nagendra, 2018; Meerow, Newell and Stults, 2016; Bahadur and Tanner, 2014). The World Commission on Environment and Development (WCED) defined sustainable development as meeting „the needs of the present without compromising the ability of future generations to meet their own

needs" (WCED, 1987, p.16). It also introduced the commonly used three pillars—social equity, environmental protection, and economic development—to further describe and assess sustainability. The New Urban Agenda (UN-Habitat, 2016) identifies sustainable infrastructures as a core component of sustainable cities and as needing to be designed, maintained, used, and operated in a way that minimizes strain on resources, the environment, and the economy while contributing to public health and welfare, social equity and diversity. Furthermore, the New Urban Agenda employs the notion of „just sustainability" to emphasize environmental issues alongside economic, social welfare, and justice ones.

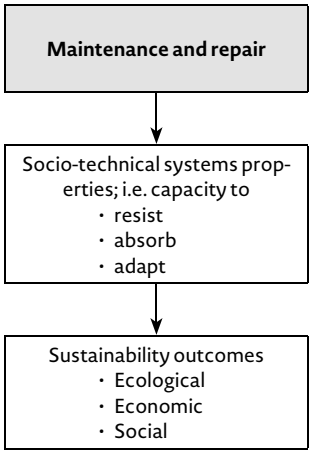
We employ sustainability of urban water infrastructures to mean infrastructures' ability to ensure safe and reliable water supply without compromising environmental integrity, social equity, human well-being, and economic feasibility now and in the future (cf. Kaur and Garg, 2019; Ayyub, 2020). The ecological dimension refers to whether infrastructures preserve, restore, and integrate the natural environment, including efficiently using natural resources and minimizing pollution. The economic dimension relates to the financial and cost implications: for instance, if infrastructures generate a positive net economic return over their lifecycle. The social dimension concerns equitable access to water resources and the health implications in society (Kaur and Garg, 2019). The maintenance and repair of water infrastructures for resilient water supply impact all three sustainability dimensions. For instance, severe water losses in networks due to insufficient maintenance and repair can reduce water supply, exacerbating urban water crises and impacting public health (Kjellén, 2009; Boztaş et al., 2019). Large volumes of water loss lead to high levels of nonrevenue water, which impacts water supply systems' economic viability and cost recovery (Jambadu et al., 2022). Also, severe water crises in cities can provoke high reliance on private boreholes and sachets and bottled water to maintain supply, which generates negative externalities on the ecological systems (Morinville, 2017; Peloso and Morinville, 2017).

A two-step assessment framework for resilience capacities and sustainability

We employ a two-step assessment framework that connects infrastructure resilience capacities to sustainability outcomes and illustrates how both are shaped by maintenance and repair (Figure 5.1). We conceptualize maintenance and repair as influencing infrastructure resilience capacities in terms of infrastructure systems' abilities to continue or restore functioning in the face of decay, breakdown, and failures. We also include an assessment of whether and how these resilience capacities affect the sustainability

of water supply to address concerns and questions about the ecological, economic, and social desirability of enabled resilience (Elmqvist et al., 2019; Ayyub, 2020). Linking resilience and sustainability enables us to discuss not just their relationship but also the opportunities and trade-offs arising from that relationship and how they are shaped by everyday maintenance and repair practices in water supply. Our two-step conceptualization (re)positions urban infrastructure resilience beyond the capacity to respond to external shocks and stresses (e.g., linked to climate change) by demonstrating how infrastructure resilience is connected to sustainability through maintenance and repair. However, this conceptualization also emphasizes the socio-technical nature of infrastructure resilience by highlighting how people's everyday maintenance and repair practices affect and are affected by technical systems' functionality (Tiwale, 2019). For instance, maintenance and repair depend highly on workers' embodied expertise, creativity, practical knowledge, and prior material configurations as embedded in a particular time and place (de Coss Corzo, 2021; Anand, 2020).

Figure 5.1 Conceptualizing infrastructure resilience and sustainability through maintenance and repair



5.3 Research methodology

We draw on a comparative qualitative case study to develop a nuanced understanding of how maintenance and repair shape resilience capacities and urban water infrastructure resilience in Accra, Ghana, and Dar es Salaam, Tanzania. A comparative case study approach helps highlight the key differences, patterns, and similarities across the two cases (Kantor and Savitch, 2005), revealing how maintenance and repair

affect the three resilience capacities and assessing how, in turn, these capacities affect the ecological, economic and social sustainability of water supply. Below, we describe the rationale for selecting both case studies, the data collection, and the analysis.

Rationale for the case selection

Whereas Accra is the largest and capital city in Ghana, Dar es Salaam is the commercial centre and largest city in Tanzania. We selected these cities as case studies for two main reasons. First, they share many water supply challenges. Approximately 64% of Accra's population has access to a piped water supply (Tetteh et al., 2022), compared to about 86% in Dar es Salaam (EWURA, 2021). Both cities rely on decentralized systems such as vendors, private boreholes, tankers, and sachet and bottled water to compensate for the splintered character of water networks and the frequent interruptions to networked water supply (Jambadu et al., 2022; Smiley, 2020; Peloso and Morinville, 2014). Secondly, water infrastructure networks in both cities are decaying and leaking, resulting in significant losses and a high share of nonrevenue water, which are related to insufficient maintenance and repair by service providers. The cities organize the maintenance and repair of water infrastructures differently. Urban water supply is organised through the national water company (the Ghana Water Company—GWC) in Accra but by a regional water authority (the Dar es Salaam Water and Sanitation Authority—DAWASA) in Dar es Salaam. The differences and similarities provide a concrete basis to ascertain how maintenance and repair are enacted and their implications on water infrastructure resilience in different contexts.

Data collection and analysis

The data for this study were collected between 2018 and 2021 through semi-structured interviews, direct field observations, informal conversations, and literature reviews. The aim was to investigate maintenance and repair strategies and practices in both cities, whether and how they manifest in the three resilience capacities, and to identify challenges and barriers.

First, we analyzed official water policy documents, reports, regulations, and secondary empirical literature across the two cities in order to understand national water policies and strategic water frameworks, the state's priorities in water supply, the organization of maintenance and repair in water supply and infrastructure resilience strategies in the two countries. Second, we conducted forty-eight semi-structured interviews across the two cities with public utility officials (n=22), private/informal plumbers (n=8), government officials (n=4), residents (n=10), and businesses/local entrepreneurs (n=4). The interviews focused on maintenance and repair strategies and

practices in water supply in centralized and decentralized systems, how maintenance and repair are organized and implemented in the two cities, and the practices of private and public utility employees in the different systems. Other topics the interviews covered include challenges and opportunities in maintenance and repair for resilience, the policies and regulations of maintenance and repair practices in centralized and decentralized systems, and the impact of all of these on water systems' resilience capacities and outcomes. Thirdly, we conducted field observations, including informal conversations with utility repair workers and private plumbers across the two cities, to ascertain how these workers maintain and repair water systems in real-life contexts. We visited various water plants and observed how employees of GWCL and DAWASA and private plumbers conducted maintenance and repair there and in the networks. Ethical approval for the study was obtained from our university's ethics board, and we also implemented all the university's standard protocols and guidelines for responsible research conduct.

The empirical data were analysed using our two-step analytical framework (see Figure 1). First, the data were labelled, coded, categorized, and analysed based on three resilience capacities: the capacity to resist, absorb, and adapt to breakdowns and failures. To this end, we analysed whether and how maintenance and repair manifest in the three resilience capacities, including identifying capacity gaps, barriers, and opportunities. The unit of analysis is informal and formal repair workers and their situated practices of maintenance and repair in centralized and decentralized systems across the two cities. Second, we assessed how these three capacities affect the sustainability of water supply, focusing on its ecological, economic, and social dimensions. This analysis was not to systematically assess sustainability but rather to illustrate emergent implications helpful when discussing resilience capacities vis-à-vis sustainability.

5.4 Building infrastructure resilience by maintenance and repair

We first describe Accra and Dar es Salaam's water supply systems and infrastructure maintenance and repair and then how these practices shape these cities' three infrastructure resilience capacities.

Water infrastructure maintenance and repair in Accra and Dar es Salaam

The centralized and decentralized water infrastructures in both cities are partially obsolete and decaying. However, Dar es Salaam's centralised water infrastructure

networks appear slightly better than Accra's since DAWASA recently carried out major renewal and rehabilitation across the networks (Interviews 4, 5, and 6, 2019). Nonetheless, in both cities, the infrastructure networks' state and inadequate maintenance and repair contribute to the public utility companies' massive water losses of approximately 50% and 48% of nonrevenue water from leaking networks in GWCL and DAWASA, respectively (EWURA, 2018; GWCL, 2018; Nganyanyuka et al., 2014; Jambadu et al., 2022).

Although both cities organise and enact maintenance and repair similarly, there are also important differences, especially concerning the maintenance and repair of the centralized systems. For example, Ghana's water policy framework emphasises full cost recovery in urban water supply for sustainability and recognizes the need to ensure affordability for people experiencing poverty (MWRWH, 2006). Under its cost-sharing arrangement, user fees cover the full cost of routine maintenance and repair plus a contribution towards the renewal of infrastructures, whereas the GWCL (in collaboration with the government) covers major rehabilitation and renewal costs (MWRWH, 2006). Tanzania's water sector policy framework emphasizes maintenance and repair as critical to infrastructure sustainability by advocating for full cost recovery through user fees (URT, 2002). Water tariffs should, therefore, be sufficient to offset the cost of routine operations, maintenance, and repair, including renewal of decaying water infrastructures.

Both countries' water infrastructure maintenance and repair policies mainly focus on the centralized systems while neglecting the decentralized ones. This neglect is attributable to their planning aspirations to achieve the "modern infrastructure ideal" (Graham and Marvin, 2001) and their practice of focusing publicly funded maintenance and repair solely on centralized systems. In both cities, private and public sector regulations, standards, and guidelines are insufficient, and workers rely on personal knowledge and experience. Within the centralized system, although the GWCL and DAWASA claim to have formal maintenance and repair rules, guidelines, and policies, their enforcement is problematic, and worker adherence to standards is low due to limited supervision by managers (Interviews 1, 7, and 16, 2018/19). In the private sector, the situation is even worse because no clearly defined rules, policies, standards, or regulations have been defined by the water companies or any state agency. Therefore, private plumbers often do not follow standards but instead base maintenance and repair on personal knowledge, experience, and users' preferences. The lack of rules and standards affects all three resilience capacities: flexibility promotes creativity and innovation in maintenance and repair, which enhances adaptive capacity, while the

lack of standards and poor compliance can lead to the use of inferior spare parts, which undermines quality and contributes to lowering the resistance and absorptive capacities.

The GWCL and DAWASA companies are responsible for implementing and regulating maintenance and repair practices in the two cities' centralized systems. GWCL and DAWASA follow different approaches to maintaining and repairing the centralized water infrastructures. GWCL's maintenance and repair operation in Accra is organized centrally at the district level. Each district has a maintenance and repair team comprising 6-10 workers (Interview 1, 2018), which may be split into several smaller groups when necessary (Interview 2, 2018). Districts also have parallel emergency teams to maintain and repair critical infrastructures at night and in specific priority locations such as the international airport, the presidential palace, and major hospitals (Interview 3, 2018).

By contrast, DAWASA's water infrastructure maintenance and repair approach is more decentralized to the neighbourhoods and zonal levels. Each district has multiple smaller teams (about 3-4 members) operating in specific zones. They can operate in specific locations for some time before being reassigned (Interviews 4 and 5, 2019), which enables them to develop in-depth knowledge of the infrastructures, including the vulnerability hotspots. Despite adopting different approaches, common challenges restricting maintenance and repair operations in both cities include inadequately skilled and too few repair workers, high costs for importing technical parts, high levels of informality, and insufficient financial resources (Interviews 1, 2, 5, 6 and 7, 2018/19). These challenges limit maintenance and repair in the centralized systems in both cities, rendering it incremental and primarily oriented towards responding to breakdowns rather than proactively addressing the systems' material decay and renewal needs (Jambadu et al., 2022). One way to address the staffing shortage in both cities is to hire private plumbers to help maintain and repair the centralized water infrastructures. DAWASA occasionally collaborates with private plumbers to increase the workforce for maintaining and repairing networks (Interviews 5, 11, and 12, 2019). Although the GWCL does not collaborate with private plumbers in Accra, residents often hire them to carry out maintenance and repair in public networks informally if GWCL employees fail to respond in time (Interviews 13 and 14, 2018).

Individual owners are responsible for ensuring the maintenance and repair of decentralized water infrastructures in both cities. They may hire private plumbers or public utility employees (who act as private plumbers) to fix maintenance and repair

problems in their private facilities. The owners usually negotiate the maintenance and repair project with the plumbers, including the cost and materials (Interviews 8, 9, and 10, 2018/19). Accessing the services of private plumbers is easy in both cities, and they respond more quickly to maintenance and repair needs than public utility officials. However, some plumbers are inadequately trained and thus lack the expertise to implement high-quality maintenance and repair (Interview 14, 2019). For instance, some plumbers use inferior materials and often do not adhere to technical maintenance and repair standards (Nganyanyuka et al., 2014). In short, maintenance and repair in both cities can be framed as a hybrid labor configuration that blurs the boundary between centralized and decentralized systems. This hybridity enhances infrastructure resilience by creating redundancies in maintaining and repairing water infrastructures, as the private and public actors complement and substitute each other at different times. Thus, users can use any of these actors for maintenance and repair if others are unavailable or too costly.

How maintenance and repair shape water infrastructure resilience capacities

Below, we first discuss maintenance and repair's contribution to the capacity to resist, the capacity to absorb, and the capacity to adapt.

Maintenance and repair and the capacity to resist

The capacity to resist describes the system's ability to prevent or minimize risks of infrastructure breakdowns and failures. It is enhanced by anticipating and proactively addressing risks related to material decay and replacing obsolete components. Overall, our assessment reveals that the infrastructures' capacity to resist breakdowns and failures in both cities is low, which is visible in ageing infrastructures that are insufficiently addressed by the maintenance and repair of centralized and decentralized systems. Maintenance and repair focus on responding day-by-day to actual breakdowns and failures instead of proactively addressing their risks to prevent or reduce their occurrence. Hence, water supply is generally erratic, and the water quality of centralized and decentralized systems is limited due to many network leaks and bursts.

A primary reason for the relatively low level of resistance capacity in both cities is that maintenance and repair are somewhat ad hoc and typically oriented towards responding to breakdowns and failures rather than proactive risk prevention in water systems. One respondent in Accra described the detrimental state of water infrastructures as: '*Our major challenge is the old pipes. Over 80% of the district's network*

is overaged and needs to be replaced, but we do not have the money to do so' (Interview 3, 2018). GWCL and DAWASA's water networks are postcolonial and need renewal, but they are only incrementally renewed by replacing critical sections of the networks or those irreparably broken (Interviews 5 and 15, 2019). This has not only increased the water losses through leaks and bursts in both cities but also contributed to a backlog of infrastructure renewal needs, thereby increasing the infrastructure's susceptibility to breakdowns and failures. The root causes of the unsatisfactory situation are underfunding and the shortage of skilled repair workers.

DAWASA's decentralized approach to maintenance and repair contributes to the somewhat better resistance capacity in Dar es Salaam because repair workers tend to have detailed knowledge of the infrastructures they are responsible for, including the vulnerability hotspots. This promotes early and easy detection of risks and decaying infrastructures and, thus, timely maintenance and repair to prevent breakdowns or failures (Interviews 5 and 15, 2019), which in turn provides opportunities to address minor problems and risks to avoid them becoming significant problems requiring more funds to fix (Interview 16, 2019).

In Accra, a GWCL employee indicated that routine daily checks by repair workers in the water plants help to identify problems early for attention:

> Daily inspections in the plant are very critical here. Every morning, we check the plants and listen to the machine's sounds. You can tell if something is not working well if you hear unusual sound changes in the system. Sometimes, the sounds can tell you the exact problem, whether a component needs to be replaced or is broken (Interview 17, 2018).

This also highlights the critical importance of repair workers' knowledge of the infrastructures and vulnerability hotspots for detecting risks in time and reducing risks of significant breakdowns and cascading impacts that could disrupt water supply.

The state of maintenance and repair of decentralized systems is even worse than that of centralized systems. Private owners maintain and repair these systems themselves; neither the public utility companies nor any other state agency takes responsibility. In general, private owners or operators only call private plumbers to fix maintenance and repair problems when the infrastructure breaks down or has developed a major fault (Interviews 10, 13, and 14, 2018/19). Thus, maintenance and repair in the private sector are generally reactive and oriented towards fixing critical problems rather

than preventing risks. But some private plumbers are inadequately trained, and their practices are neither regulated nor standardized. This promotes shoddy maintenance and repair, increasing risks of infrastructure breakdowns and failures (Interview 14, 2019). For instance, it was reported in Accra that some private plumbers use inferior spare parts for maintenance and repair (Interviews 1 and 9, 2018/19), while in Dar es Salaam, a respondent opined that '*[S]ome of the plumbers are not good. If you get an unqualified plumber, they can fix your pipe today, and it will break down a few days later'* (Interview 9, 2021). Plumbers' inadequate maintenance and repair practices thus contribute to lowering the infrastructures' resistance capacity by increasing the risks of breakdowns and failure rather than reducing them.

Maintenance and repair practices and the capacity to absorb

The capacity to absorb defines the system's ability to accommodate breakdowns and their impacts by enabling quick recovery (or restoration of service) through maintenance and repair. We found that the overall absorptive capacity of the centralized water systems in both cities is enhanced by private plumbers' informal labor. Due to the shortage of repair workers, inadequate funds, and the massive scale of network decay, neither public utility company can fully handle all maintenance and repair needs, so they only address urgent cases. These constraints result in similarly limited and ad hoc approaches to maintenance and repair, aimed at responding to critical breakdowns and failures rather than comprehensively addressing the systems' maintenance and repair needs. Thus, water systems always have unmet maintenance and repair needs at any given time.

However, maintenance and repair appear to contribute differently to absorptive capacity in Dar es Salaam and Accra. One key reason for this is their different approaches to maintenance and repair in the centralized systems: GWCL's is a centralized approach, but DAWASA's is more decentralized. Both approaches enable absorptive capacities but in different ways. Thus, DAWASA's decentralized approach enhances absorptive capacity by allowing repair workers to develop in-depth knowledge of the systems, which facilitates monitoring and identifying leaks and bursts early for timely maintenance and repair. Early discovery and maintenance of leaking networks can reduce the risks of interruption and water contamination and mitigate the likely impact of leakages on the city while reducing DAWASA's water losses. By contrast, the GWCL's centralized approach enhances flexibility, efficient coordination, and effective use of limited resources to ensure efficiency and quality in maintenance and repair. For instance, the maintenance teams can easily be split into many ad-hoc teams to attend to multiple emergencies and critical maintenance and repair needs occurring concurrently at different locations

(Interviews 1 and 2, 2018). This flexibility enhances absorptive capacity because maintenance teams can quickly attend to the system's most critical needs, especially in priority areas such as airports and major hospitals (Interview 2, 2018).

A major barrier to maintenance and repair for absorptive capacity in centralized systems is the costly import of spare parts and experts' services. Both utility companies spend a significant fraction of their budgets on imports, which reduces their ability to address other critical maintenance needs (Interviews 16, 20, and 21, 2018/19). Additionally, importing spare parts can significantly delay maintaining and repairing water infrastructures, resulting in delays in restoring the broken equipment or systems and thus disrupting water services (Interview 21, 2020).

As indicated earlier, informal labor is critical in maintaining and repairing the functionality of formal systems since both water companies have insufficient staff to handle maintenance and repair needs. When centralized networks malfunction, most residents call private plumbers to fix the problem as they respond faster to residents' calls than utility officials and, in most communities, are available and easily accessible (Interviews 17, 18, and 19, 2020/21). Private plumbers' availability and easy accessibility enhance absorptive capacity because they enable quicker response to maintenance and repair needs in centralized systems, and these plumbers are the main labor force sustaining decentralized water systems. Hence, informal labor contributes to promoting timely attention to maintenance and repair and restoration of the water supply after a breakdown.

Accra residents said that they turned to private plumbers so often because GWCL responded to maintenance and repair requests late or never (Interviews 8 and 18, 2020). Although illegal, these informal practices by plumbers and users enhance the capacity to absorb failures in the system because they help ensure residents' water supply. Some GWCL officials contend that maintenance and repair are inadequate because of the haphazard layout of some places, especially in informal settlements like Nima: repair workers have difficulty navigating such areas to conduct maintenance and repair (Interview 2, 2018). In Dar es Salaam, DAWASA relies directly on private plumbers to address maintenance and repair needs, as stated by a DAWASA official:

> *We collaborate with the fundis [private plumbers] only when we have a lot of repair work and we need their support. Usually, after work, we pay them their wages, and they leave. Some of them are very good on the job, and they often come around to ask if we have contracts for them. But the problem is that some are not*

trusted because they can steal our materials and make illegal connections (Interview 6, 2019).

These informal collaborations enhance absorptive capacity by supplementing the water company's workforce and technical ability to respond adequately and in a timely manner to network infrastructure maintenance and repair needs. Also, private plumbers are a cheap source of labor for DAWASA to exploit for its maintenance and repair instead of hiring professional employees at a much greater cost. The importance of informal labor for enhancing resilience is even more apparent, given that neither the GWCL nor DAWASA includes decentralized systems in their official maintenance and repair schemes. Therefore, most maintenance and repair needs in the private sector are handled by private plumbers. However, as indicated earlier, private plumbers usually have limited expertise, which further contributes to lowering the absorptive capacity for resilience because unqualified plumbers use inappropriate spare parts and practices, which exacerbate infrastructures' likelihood of malfunctioning or breaking down within a short period. For instance, using substandard pipes and spare parts for maintenance and repair can lower the hydraulic pressure in the water networks (Interview 1, 2018). In Accra, it was reported that private plumbers often install new networks without putting valve chambers in the distribution lines (Interview 1, 2018). GWCL employees, therefore, often have to correct such defective networks, as if leakage occurs, it will be difficult to shut off the water in order to be able to do maintenance and repairs (Interview 1, 2018). These corrective operations divert funds and employees from dealing with other critical maintenance and repairs.

Maintenance and repair practices and the capacity to adapt

The capacity to adapt is a system's ability to continually adjust and reorganize to accommodate change in the long run. Overall, the adaptive capacities of water infrastructures in both cities are higher than the other capacities, as multiple backup systems (water tanks and informal delivery constellations) exist that make water accessible, and repair workers routinely innovate and improvise local solutions for everyday maintenance and repair needs to keep water infrastructures functioning. However, the adaptive capacity is mainly oriented to finding solutions to existing problems of decay and breakdown rather than experimenting with "forward-looking" solutions to improve overall infrastructure resilience in the long term.

Water utility companies' employees and private plumbers use various alternative techniques, materials, and spare parts to overcome the often-limited access to spare parts (e.g., due to delayed imports) and the inadequate financial resources for maintenance

and repair. For instance, local blacksmiths in Dar es Salaam have fabricated essential spare parts and materials (e.g., nuts, bolts, valves, and shafts), which DAWASA regularly uses for maintenance and repair (Interview 11, 2019). Also, the GWCL and DAWASA repair workers have frequently learned new solutions and techniques from online sources and applied them to various equipment (Interviews 16 and 22, 2018/2019). In Accra, private plumbers improvised valve washers from old car tyres (Interview 18, 2020). These local creative practices increase adaptive capacity because they stimulate ongoing learning, innovation, and self-organization in the systems to cope with everyday maintenance and repair challenges.

However, this adaptive capacity is mainly oriented towards responding to the short-term needs of the systems, ignoring the need for solutions that can improve infrastructure resilience in the long term. For example, repair workers usually improvise and experiment with various low-cost solutions and quick fixes that address specific needs or challenges (e.g., lack of material resources) in maintenance and repair instead of improving the systems' general functionality. Thus, the adaptive capacity represents a means to cope with immediate needs but does not necessarily lead to long-term system improvement.

Another factor that increases the adaptive capacity is that maintenance and repair provide an opportunity to further improve the systems by integrating new technologies into existing systems to upgrade and enhance their efficient operations and quality of service delivery. For instance, both cities usually replace broken or burst PVC pipelines with high-density polyethene (HDPE) pipes, which are the latest technology and more durable than other PVC pipes (Interviews 1, 2, and 5, 2018). An official of the GWCL disclosed:

> *What we are doing now is to replace the very old pipes from the systems gradually. Whenever a pipe bursts or breaks down, we usually replace it with HDPE pipe, which is very strong (Interview 1, 2018).*

These incremental adjustments lead to upgrading old water systems to newer and more efficient technologies that ultimately enhance the system's adaptive capacity and overall resilience. However, introducing new technologies such as HDPE can also challenge the existing knowledge and expertise in maintenance and repair because new skills and tools, such as welding machines and electricity (or generators), are needed to install them (Interviews 4 and 5, 2019). These new challenges sometimes limit local experts' ability to ensure timely maintenance and repair (Interview 1, 2018).

5.5 Situating maintenance and repair within urban infrastructure resilience and sustainability

Our assessment shows the importance of considering maintenance and repair when aiming to understand urban infrastructure resilience. The three resilience capacities enabled through maintenance and repair differ in degree across both cities. Overall, however, insufficient maintenance and repair manifest in limited resilience capacities and, ultimately, in reduced or infrequent water supply. Notably, capacities to resist are low in both cities due to inadequate routine checks and renewals of worn-out parts, while capacities to absorb only encompass critical maintenance and repair operations and often fail to respond early to leakages, bursts, and infrastructure decay. The capacity to absorb largely depends on informal laborers who fill the gaps left by formal maintenance and repair operations, yet this is problematic due to their limited knowledge and technical skills. The somewhat higher levels of adaptive capacity further illustrate the crucial roles of repair workers, who, through innovation and improvisation, can ensure water infrastructure functions. However, this type of adaptive capacity can be characterized as mostly ad hoc and born out of need—for instance, to replace missing technical parts—rather than to facilitate forward-looking maintenance and repair to "bounce forward".

The results also highlight the crucial roles of local knowledge and flexibility in maintenance and repair and how they shape urban infrastructure resilience as a continuously evolving property. Whereas the criticality of repair workers' detailed local knowledge in building urban infrastructure resilience is showcased through Dar es Salaam's more decentralized approach, the importance of flexibility is highlighted in Accra's more centralized approach. The results highlight how these types of knowledge and flexible responses facilitate early risk detection, preparedness, and quicker response to infrastructure maintenance and repair needs. Other scholars have also emphasized the importance of local knowledge in maintaining and repairing urban infrastructure (Anand, 2020; Baptista, 2019; de Coss Corzo, 2021), as well as how community and local resilience (e.g., social memory and learning, flexibility, and self-organization) contribute to urban resilience (Choudhury et al., 2021; Folke et al., 2010).

The differentiated levels of resilience show varying impacts on the ecological, economic, and social sustainability of water supply in both cities. Regarding ecological sustainability, the low resistance and moderate absorptive capacities lead to severe water losses in water networks due to persistent leaks, bursts, and material decay. This state of infrastructure accounts for the loss of roughly 50% of water resources

in both cities, which not only reduces the quantity of potable water left for residents' use but also contributes to the overexploitation of scarce city water resources. But, the somewhat higher adaptive capacities coupled with water scarcity in both cities have created high reliance on groundwater resources through the drilling of private boreholes and buying of sachets and bottled water to meet water needs (Smiley, 2020; Peloso and Morinville, 2014). However, overexploitation of groundwater resources can lower groundwater levels and increase the salination of groundwater in coastal aquifers (Aina et al., 2023; Mtoni et al., 2013). And reliance on the sachet and bottled water generates massive amounts of plastic waste (Morinville, 2017), which, if not collected, can choke open gutters and drains, thereby aggravating flooding risks (Gronwall and Oduro-Kwarteng, 2018; Morinville, 2017).

The low levels of resilience capacities through insufficient maintenance and repair also limit the economic sustainability of water supply. In both cities, high shares of water losses translate into high shares of nonrevenue water and economic losses in water supply. Severe water losses through leaking networks in the cities' centralized systems represent not only actual water losses but also lost revenue to the utilities, leading to a vicious circle of cost-recovery problems and limited budgets for maintenance and repair (Jambadu et al., 2022): Neither company can hire enough repair workers and procure the spare parts and materials needed for everyday maintenance and repair. Moreover, inadequate financial revenues cause critical maintenance and repair to be deferred, resulting in a backlog of maintenance and repair needs. This further increases maintenance and repair costs in the future and further undermines full cost recovery and financial sustainability in water supply.

The importance of maintenance and repair for sustainability is further underscored when looking at how inadequate resilience capacity exacerbates social inequality and public health risks in both cities. For example, leaking networks can result in contaminated water and water-related illness, especially among people who cannot afford sachet and bottled water (Kjellén, 2009), while severe water shortages can result in poor sanitation and serious public health risks (Sippy, 2021; Monstadt and Schramm, 2017). Moreover, in both cities, the groundwater resources, which are a major source of drinking water, are becoming increasingly polluted due to waste disposal and splintered and insufficiently maintained sewerage (Mato, 2004; Hagan et al., 2022; Foppen et al., 2020).

The somewhat higher adaptive capacities in both cities also deepen social inequality. Wealthy residents can afford to drill private boreholes and buy sachet and bottled water

to obtain good water quality by drilling (Uitermark and Tieleman, 2020), whereas the poor remain dependent on inadequate water supply systems. Since wealthy people pay higher tariffs than the poor, losing their custom further impacts cost recovery in water supply and the quality of service provided by utilities. The inequality problem is even greater, given that publicly funded and organized maintenance and repair in both cities are only implemented in the centralized systems (Alda-Vidal et al., 2018), while the rest of the city, i.e., all decentralized systems and residents not connected to the centralized system, have to organize maintenance and repair themselves. In short, although the adaptive capacity enabled through maintenance and repair is higher, it is not always desirable for ecological, economic, and social sustainability. In general, the adaptive capacity enabled through maintenance and repair is oriented towards responding to specific short-term needs rather than to the need to be more "forward-looking" to make the infrastructure more resilient against future risks and shocks (Jackson, 2019).

5.6 Conclusion

This article examined water infrastructure resilience through the lens of maintenance and repair in Accra and Dar es Salaam—two fast-growing cities in sub-Saharan Africa. Highlighting the importance of maintenance and repair is necessary for understanding and strengthening urban infrastructure resilience, particularly in African and global South cities facing inevitable technical breakdowns and infrastructure failures (Graham and Thrift, 2007). Our assessment revealed a differentiated picture of how maintenance and repair contribute to the three resilience capacities. While the capacity to resist is low in both cities, absorptive capacity is moderate, and adaptive capacity is comparatively high, largely due to the availability of multiple decentralized water alternatives and the ability of informal repair workers to innovate solutions to everyday problems to maintain water supply. However, these alternative systems come with severe social, ecological, and economic trade-offs. We argue that improving infrastructure resilience requires anticipating future risks, developing preparedness strategies, and promoting effective response strategies through early warning detection, flexible responses, and reliance on local knowledge for quicker attention to maintenance and repair. This future-oriented perspective provides a concrete example of "bouncing forward" through maintenance and repair.

This article advances three important contributions to urban infrastructure resilience and sustainability studies in the global South. Firstly, while infrastructure resilience and sustainability debates have both received significant attention from scholars, the relationship between these normative concepts has not been explored. Thus,

our article is an important contribution to the urban resilience debates by introducing a novel assessment framework that connects urban infrastructure resilience to sustainability outcomes through maintenance and repair. We argue that resilient infrastructures may not necessarily enable sustainability, considering that adaptive capacity enhanced through maintenance and repair resulted in ambivalent impacts on the ecological, economic, and social sustainability outcomes. Secondly, our article approached infrastructure resilience from within the sociotechnical system—focusing on risks arising from internal systems dynamics—rather than external ones. This has enabled us to broaden the conceptualization of urban infrastructure resilience beyond the capacity to withstand or recover from external shocks, including the system's ability to resist, absorb and adapt to internal breakdowns and failures through maintenance and repair. Third, focusing on how maintenance and repair contribute to urban water infrastructure resilience enables us to reposition resilience as a sociotechnical property of a system continually shaped through everyday maintenance and repair practices. These results thus highlight the critical importance of maintenance and repair for enhancing infrastructure resilience and sustainability in the global South. We conclude by calling for maintenance and repair to be prioritized in urban resilience policies and agendas and for allocating more financial and organizational resources to improve infrastructure resilience and sustainability in cities.

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CHAPTER 6

CONCLUSION

6.1 Introduction

This dissertation questions the role of maintenance and repair in responding to chronic water problems faced by inhabitants of African cities, building on the cases of Accra and Dar es Salaam. It particularly explores the sociotechnical arrangements in water supply that sustain and shape these operations and proposes a conceptual framework to better explain the complexities in maintenance and repair and how they are organized and implemented in those cities.

The challenge of ensuring reliable access to safe water supply in African cities has persisted for many decades, raising concerns that countries in these settings might not achieve the United Nation's Sustainable Development Goal 6.1, which seeks to ensure universal access to safe and reliable water supply by 2030 (WHO and UNICEF, 2021; WHO et al., 2022). In most policy discourses and technical reports by donors and development agencies, the water challenges in African cities are portrayed and discussed as the result of climate change impacts and population growth (IPCC, 2021; WHO et al., 2022). At the same time, critical debates on urban infrastructures link the water problems in African cities to more profound governance challenges. For instance, some scholars argue that states' water policies and visions in these contexts explicitly profess the modern infrastructure ideal as a solution to water problems but tend to ignore persistent sociotechnical heterogeneity and hybridity in water infrastructure constellations (Smiley, 2020; Monstadt and Schramm, 2017; Peloso and Morinville, 2014).

To improve water supply in these settings, therefore, some scholars emphasize the need for a policy shift to recognize and integrate prevailing realities of multiple delivery channels and the organization of water infrastructures (Jaglin, 2014; Monstadt and Schramm, 2017; Dakyaga et al., 2023). Although these governance challenges have profound implications for maintenance and repair of water infrastructure in African cities, only a handful of empirical studies (e.g., Alda-Vidal et al., 2018; Wahby, 2021) have drawn attention to the role of maintenance and repair in shaping water

supply. Yet maintenance and repair are important because they affect water systems' reliability, quality, and public health. Hence, focusing on maintenance and repair can generate insight to (re)position the water challenges in African cities through the lens of structural decay and aging infrastructure networks—an important but often overlooked aspect in the water infrastructure debates.

This dissertation responds to the above research gap by investigating how water infrastructure maintenance and repair practices could contribute to tackling the chronic water problems in African cities. It argues for the need to engage with infrastructure maintenance and repair as a crucial starting point to address the water problems and enhance water infrastructure resilience in African cities. To this end, the dissertation aims to understand and explain how sociotechnical arrangements in water supply systems in and beyond the network shape maintenance and repair practices and how those practices affect water infrastructure resilience in the two cities.

I applied a two-step analytical framework to systematically analyze the main research question by investigating (a) how sociotechnical arrangements affect maintenance and repair and (b) how those practices and arrangements influence the resilience of water infrastructures. In the first step, I developed a conceptual framework based on materiality, institutions, knowledge, and discourses and used it to explore the sociotechnical arrangements in water supply and their implications for maintenance and repair practices in both cities. I applied this framework to identify the key differences and similarities in the sociotechnical arrangement in the two cities and how they organize and implement maintenance and repair practices in their respective water supply systems (chapter 2). This conceptual framework enabled us to understand and explain how and why maintenance and repair practices differ in different places and the contextual conditions that shape practices in each city's networks. Chapter 3 builds on the understanding developed on the sociotechnical arrangements in water supply systems in chapter 2 to explore further the labor relations between repair workers and how their maintenance and repair practices intersect in the sociotechnical arrangements of water supply systems in and beyond the networks. That chapter revealed that the conduct of maintenance and repair in both cities involves hybrid labor relations and integrates formal and informal practices. Against this background, chapter 4 moved the discourse further beyond local actors by engaging with the role of donors and their funding schemes within the sociotechnical arrangement in water supply and how these affect maintenance and repair practices in both cities. It explored the relationship between donors' funding schemes and maintenance and repair, focusing on the role of technological artifacts, institutional arrangements,

and embodied knowledge, and how these interplay and influence maintenance and repair practices in water supply. In the second step, I used the practices to explain how maintenance and repair can contribute to water infrastructure resilience. This final empirical chapter links maintenance and repair practices to the concept of infrastructure resilience. It explains how private and public workers' maintenance and repair practices can contribute to the two cities' water infrastructure resilience capacities to resist, absorb, and adapt to failures and breakdowns and the implications of those capacities for sustainability.

This dissertation pushes forward four salient contributions to advance practical lessons for supporting policy formulation on urban water supply. The study also advances theoretical debates on urban infrastructures, their maintenance and repair, and infrastructure resilience. Specifically, this dissertation advances the conceptual discourse on urban infrastructure maintenance and repair in the global South by conceptualizing maintenance and repair as deeply intertwined with sociotechnical heterogeneity and hybridity (referenced in chapter 2). Through this, the dissertation sheds light on the complex relationship between sociotechnical arrangements in water supply and how those arrangements affect maintenance and repair practices in African cities. Beyond that, the dissertation contributes to ongoing discussions on hybrid infrastructure delivery in the global South by challenging the traditional binary perceptions of formal versus informal maintenance and repair practices (explored in chapter 3). The study reveals the interconnectedness and dynamic practices and labor relations in maintenance and repair and how those arrangements affect water supply in the city. This insight emphasizes the need to move infrastructure maintenance and repair debates beyond the absolute categorization of practices into formal and informal binary, or private versus public labor. This contribution expands on emerging conceptual debates on the global South that emphasize hybridity and hybrid configurations rather than absolute categories (e.g., Rateau and Jaglin, 2022; Jaglin, 2014; Wahby, 2021). This understanding also shifts maintenance and repair discourses beyond the role of the state and public utilities and foregrounds the role of private actors as equally important in the provision of maintenance and repair services in African cities.

The dissertation expands on the discourses and literature on urban infrastructure maintenance and repairs by underscoring the significant yet often neglected role of donors and their funding schemes in maintaining and repairing water infrastructure (discussed in chapter 4). Connecting the role of international donors and development aid to maintenance and repair provides a broader empirical lens to understand the

multifaceted and multi-scalar nature of maintenance and repair while highlighting the broader impact of donors beyond merely financing infrastructure projects in Africa. Lastly, the dissertation links the role of maintenance and repair to concepts of urban infrastructure resilience and sustainability (outlined in chapter 5). The research demonstrates how maintenance and repair practices enhance or degrade infrastructure resilience capacities to resist, absorb, and adapt to failure and breakdowns. This insight underscores that maintenance and repair efforts are not solely reactive measures to technical failures but rather are crucial ongoing processes that are pivotal in enhancing the infrastructure system's resilience and sustainability at all times. This understanding challenges the notion that maintenance and repair only become important when infrastructure breaks down. The insight shows that these practices are always important for resilience and sustainability, even when the infrastructures are functioning properly.

The remainder of this conclusion reflects on the study's key findings, to connect them to debates on urban infrastructures in the global South (section 6.2). Section 6.3 concludes the thesis with recommendations for future research and policy formulation.

6.2 Summary of key findings and theoretical reflections

This section presents and reflects on the study's key findings as captured in chapters 2–5. The findings are summarized under four main themes: (i) Sociotechnical arrangements in water supply systems and their impact on maintenance and repair, (ii) The role of workers' labor relations in maintenance and repair, (iii) the impact of donors' funding schemes on maintenance and repair, and (iv) maintenance and repair and the resilience of water infrastructure. Reflecting on these themes is helpful to respond to the overarching research question and generate key lessons to be learned for improving water supply in African cities.

6.2.1 Sociotechnical arrangements in water supply and maintenance and repair

This section highlights the differences and similarities in the sociotechnical arrangements in the water supply system in the two cities and how those structural differences impact maintenance and repair practices, organizational modes, labor relations, and implementation approaches between the two cities. This focuses on the technological arrangements within the water supply systems, the organizational structures and managerial strategies, the key actors, and labor relations that underpin maintenance and repair in both cities.

To begin with, the two cities vary slightly regarding the material characteristics of their water supply systems and the underlying technologies. For example, Accra's system comprises conventional water plants and a desalination plant integrated into the piped networks. Those in Dar es Salaam consisted mainly of conventional water treatment plants and a limited number of mechanized boreholes configured into the piped networks. The network coverage in Accra is relatively lower than Dar es Salaam, but both cities are splintered and shaped by formal and informal networks, incremental networks, and high levels of illegal connections. While Accra's water networks experience persistent low-pressure problems, those in Dar es Salaam suffer from frequent breaks and bursts due to high pressure in the water plants. The chronic low-pressure problems in Accra's networks provoked the installation of illegal "pressure-boosting" pumps in the networks by wealthy individuals in their quest to increase water flows. In Dar es Salaam, however, high pressure in the networks has led to frequent bursts and leaks, increasing workload and demand for repair labor by residents. The state of utility networks and water infrastructures in both cities requires that residents compensate their water needs through reliance on various informal solutions and decentralized systems. These include boreholes, tankers, and sachet water (in the case of Accra).

A common structural characteristic of the sociotechnical arrangements in both cities' water supply sectors is the heterogeneity of actors, technologies, and the hybridity of centralized and decentralized constellations, modes of organization, labor arrangements, and practices. For instance, water supply systems consist of multiple technologies involving centralized and decentralized solutions and formal and informal networks integrated in the water supply system. These heterogeneous and splintered sociotechnical arrangements are directly or indirectly interconnected through their materialities, technologies, or functionality and, therefore, need to be viewed as complex and dynamic sociotechnical arrangements. The interconnectedness and interdependencies between these constellations complicate their vulnerability, as disruption in one system can quickly cascade through other interdepending arrangements, leading to a deeper crisis within the water supply system.

The conclusion yielded by my research is that sociotechnical arrangements in water systems profoundly influence infrastructure maintenance and repair in terms of technological artifacts, spare parts requirements, repair procedures, and standards. For example, the skills, expertise, and standards that guide maintenance and repair in centralized networks are different from those that underlie and shape practices in decentralized systems, such as boreholes and sachet water infrastructure. A key aspect

of the sociotechnical arrangement in water supply in both cities is the diversity of actors involved in organizing and implementing maintenance and repair of water infrastructure. The key actors identified include public utility workers, private contractors, informal repair technicians, international donors, and international engineering firms. Each of these actors brings unique skills, knowledge, practices, and aspirations to the maintenance and repair processes and operations. The coexistence of multiple actors, practices, and labor relations in the system can enhance maintenance and repair but can also lead to challenges in terms of coordination, communication, and accountability, particularly when roles and responsibilities are not clearly defined. For instance, this dissertation shows that the roles and practices of private and public workers in maintenance and repair are dynamic and intertwined, such that it is difficult to differentiate their boundaries or limits because all actors can switch roles and practices at different times. This interchangeability and dynamic character make it difficult to hold actors accountable for their practices and responsibilities in the systems.

The findings presented in chapters 2–4 show how the complexities of sociotechnical arrangements in water supply led to differentiated modes of organizing and implementing maintenance and repair, labor relations, and practices in Accra and Dar es Salaam. For example, the GWCL adopted a centralized approach in organizing and implementing maintenance and repair of their water networks, while their counterparts in DAWASA adopted a decentralized approach. The GWCL's centralized approach enables them to have separate (or parallel) maintenance teams that respond to all emergency problems in their water networks, especially at night. In contrast, DAWASA adopts a decentralized approach that integrates emergency response into the various maintenance teams operating at the neighborhood levels. These two approaches affect maintenance and repair practices differently, as well as their effectiveness and the labor relations involved in their organization and implementation.

6.2.2 The role of workers' labor relations in maintenance and repair

This section discusses the role of workers' labor relations in the sociotechnical arrangements and their implications on maintenance and repair practices in water supply. The sociotechnical arrangements in water supply equally influence the workers' labor relations, and these relations affect maintenance and repair practices. These labor relations encompass a wide array of dynamics, including the roles and responsibilities of workers, the relationships between different labor categories, and the interactions between workers and other stakeholders within the system. Chapters 2 and 4 showed that maintenance and repair of water supply in both cities are coproduced through the interplay of private and public labor. The diversity of practices in maintenance

and repair (i.e., formal and informal, incremental and planned, legal versus illegal) intertwines and changes over time, with repair workers capable of switching between formal and informal roles in maintenance and repair. This complex dynamic is linked and influenced by sociotechnical heterogeneity and hybrid constellation in the cities' water supply systems. The coexistence of formal and informal practices in the system, the ability of public and private workers to operate in both private and public networks and the centralized and decentralized systems highlights their adaptability and versatility within the water supply sector. This flexibility allows workers to navigate diverse contexts and address a range of maintenance and repair needs, contributing to the overall resilience and efficiency of the water supply infrastructure.

The relationships between different categories of repair workers—whether public or private, formal or informal—varied significantly, depending on factors such as power dynamics, competition for contracts, and professional norms. In some cases, public and private workers collaborated closely (as in the case of Dar es Salaam), sharing expertise and labor to ensure efficient and effective maintenance and repair of formal water networks. Collaboration between public and private workers enhances effective responses to maintenance and repair needs. In other instances (as in the case of Accra), conflicts arose between private and public repair workers in maintenance and repair due to competition for jobs in the private market, unclear boundaries, and struggle over access and control of the public networks. The diversity of workers and interchangeability of their labor within the system pose challenges for regulation and standardization of maintenance and repair practices. This further underscores the need for customized approaches to adequately address localized infrastructure needs within the systems, as the workers and their labor within the sociotechnical arrangement come with varying technical requirements, standards, and organizational structures. Overall, repair workers' labor relations constitute a vital dimension of the sociotechnical arrangements within water supply systems, influencing the organization, execution, and outcomes of maintenance and repair activities. Recognizing the diverse roles, relationships, and interactions among repair workers and other stakeholders is essential for developing strategies to address the complex challenges facing urban water infrastructure and to ensure the resilience, reliability, and sustainability of water supply systems in the long term.

6.2.3 The impact of funding schemes of donors on maintenance and repair

This section reflects on the role of donors in the sociotechnical arrangements of water supply systems. It extends the discourses on maintenance and repair to

connect with the role of international donor agencies and their funding schemes—an aspect that has often been overlooked in the mainstream literature and debates on maintenance and repair of infrastructures. This dissertation shows that international donors are an integral part of the sociotechnical arrangement in water supply systems and their funding schemes significantly affect maintenance and repair in different ways. For example, chapter 4 demonstrates how donors' funding schemes led to the introduction and circulation of new technologies, artifacts, and complex socio-political and economic relationships in the water supply systems of both cities. These sociotechnical arrangements involve institutional conditionalities, technology transfer, and imposition of specific standards and knowledge, which influence the organization and implementation of maintenance and repair practices in the water supply system.

One of the ways through which donors' funding schemes influence maintenance and repair practices is through the conditionalities attached to the aid. As chapter 4 shows, donors' funding requirements led to the imposition and adoption of specific technologies in water supply, the implementation of certain policies, and the adherence to international standards. While these conditionalities are often intended to promote transparency, accountability, and efficiency in the disbursement and use of aid, this study shows they also introduce unintended challenges and constraints for local capacity to maintain and repair the complex infrastructure systems. For example, both cases show that the application of donor conditionalities in both cities' water sectors led to the transfer and installation of highly complex foreign technologies. The transfer of highly complex foreign technologies usually requires extensive training and capacity-building efforts to ensure effective operation and maintenance. The requirements for a high level of specialist knowledge and expertise for maintenance and repair can increase maintenance and repair costs and deepen dependence on external experts and foreign engineering firms. This can lead to inadequate maintenance and repair practices in the system if the water company cannot afford the requisite knowledge and experts. At the same time, the finding shows that donors' home country standards were often promoted to recipient countries as universally accepted standards and principles for maintaining and repairing those infrastructures without recognizing the need to adapt them to local contexts and needs. The application of donors' home country standards and principles as the universal standards for maintenance and repair practices is predicated on the assumption that maintenance and repair are only implemented in the formal network system. However, this assumption tends to ignore the fact that many other sociotechnical configurations exist outside the networks.

Another way by which donors funding schemes affect maintenance and repair is by tying aid funds to the procurement of goods and services from specific firms and subcontractors from the donor home country. These include the procurement of materials, spare parts, and technologies. The findings in chapters 2 and 4 show that, in some instances, these restrictions result in delays, cost overruns, and logistical challenges for maintenance and repair. The reliance on imported spare parts and consumables also introduces vulnerabilities and interdependencies in the systems that transcend the boundaries of the recipient country. This makes it difficult to ensure an effective and timely supply of spare parts and materials and further exposes the system to external shocks, such as the high cost of imports. Thus, it is unsurprising that both water companies struggled to meet their water systems' maintenance and repair needs at most times. These interdependencies also restrict the capacity of the water company to respond quickly to maintenance and repair needs, undermining the system's resilience.

Finally, donor funding schemes affect maintenance and repair by introducing institutional reforms in urban water management in both cities. These reforms introduced performance-based contracting models and public–private partnerships (PPPs) arrangements, which shifted the roles and relationships between the state and private sector in water supply and maintenance and repair of infrastructures. Through these reforms, the state's role is increasingly restricted to regulation and standards, while the private sector's role is increasing to include organization and management of water supply, which encompasses maintenance and repair of infrastructure. These findings show that donor funding schemes have far-reaching implications for maintenance and repair practices and should be taken seriously in urban infrastructure planning. The key lesson is that stakeholders (i.e., donors, governments, and water companies) need to anticipate maintenance and repair in water infrastructure funding schemes by promoting capacity-building programs alongside new infrastructure constructions and adopting technologies that can be supported locally.

6.2.4 Maintenance and repair and the resilience of water infrastructures

This study's findings contribute to urban infrastructure resilience debates by providing a better understanding of the linkages between maintenance and repair and infrastructure resilience in the global South. The findings reveal that maintenance and repair practices are necessary preconditions for enhancing water infrastructure resilience capacity to withstand and recover from interruptions and failures caused by technical breakdowns and structural decay. Thus, through maintenance and repair

practices, we can enhance internal system resilience, which is especially crucial for building the overall system's resilience in the face of climate change. The key insight of this study thus lies in establishing a strong relationship between maintenance and repair practices and the resilience of urban water infrastructure. The insight proves that maintenance and repair practices are crucially important for continually enhancing the resilience of water infrastructure systems. Thus, rather than climate change alone, this dissertation argues for the need to build internal system resilience through maintenance and repair as preconditions for enhancing the system's resilience against climate change. However, it is important to note that the resilience capacity enhanced through maintenance and repair can contradict long-term sustainability goals and principles.

In the context of African cities, maintenance and repair are enabled and supported through heterogeneous and hybrid labor relations and practices. The coexistence of heterogeneous actors and labor relations (i.e., private plumbers, local contractors, public utility officials, and residents) and hybrid practices in maintenance and repair promotes resilience in the water supply system. This is because the interplay of private and public labor and practices in maintenance and repair creates some redundancy in the system, which ensures that water systems could still be repaired and maintained to continue functioning even if the actions of an agent are insufficient or inappropriate. This redundancy enhances the system's overall absorptive and adaptive capacities, which act as "shock absorbers" in the face of failures. In infrastructure resilience debates (e.g., Hall et al., 2019; Eledi Kuusaan et al., 2023), redundancy is seen as a critical mechanism for enhancing resilience in the system because it creates backups or alternatives to keep the system functioning in the absence or failures of others, thereby mitigating the impacts of failures.

Beyond complementing each other's labor and practices in maintenance and repair, private and public workers can replace each other in maintenance and repair because their skills are similar or identical. This replaceability of labor provides backups and alternatives for users when deciding about implementing maintenance and repair. This enhances individual users' adaptive and absorptive capacities to cope with interruptions and failures in the system. At the same time, the approach adopted by the two water companies for responding to emergencies also impacts the system's resilience. For instance, whereas the GWCL adopted a centralized approach, their counterparts in DAWASA applied a decentralized approach. On the one hand, having a separate maintenance team for responding to emergencies (as in the case of GWCL) promotes quicker response and preparedness in responding to maintenance and repair

needs in the systems. On the other hand, integrating emergency response in the various maintenance teams prepares all team members for a holistic and systematic response to emergencies in the systems at all times, which enhances overall resilience.

This dissertation shows that the repair workers' knowledge of the city and its infrastructure vulnerability is vital for building system resilience through maintenance and repair practices. On the one hand, local knowledge of the city and its infrastructure conditions is crucial for promoting early and efficient leak discovery and timely response to maintenance and repair needs in the systems, which contributes to enhancing resilience. On the other hand, the repair workers' local knowledge of the system's conditions enhances preparedness and planning for maintenance and repair, enabling workers to adjust and adapt to anticipated risks and failures and labor and resource requirements. This enhances the system's absorptive and adaptive capacity for resilience because it ensures responsiveness and preparedness for emerging infrastructure needs and changing sociotechnical conditions at all times. It also promotes effective and efficient use of limited resources for resilience, especially in contexts where resources are limited. The role of local knowledge and flexibility in building local resilience in socioecological systems has been documented (e.g., Choudhury et al., 2021; Ayyub, 2020; Elmqvist et al., 2019). The importance of these characteristics in building infrastructure resilience in African cities is even more critical given that urban infrastructures in these settings work are processes always in the making (Baptista, 2019). In such contexts, flexibility and local knowledge are vital for adjusting and making infrastructures work best in conditions of precarity.

6.3 Theoretical reflection

The key findings in the previous sections contribute insights to debates on urban infrastructures, maintenance and repair studies, and infrastructure resilience debates in the global South. This section further reflects on the key findings in relation to current research and debates on the maintenance and repair of urban infrastructure and infrastructure resilience studies.

This study builds on sociotechnical heterogeneity, hybridity, and co-production debates in the global South to push forward conceptualization in maintenance and repair beyond the role of the state and public utilities. It emphasizes how those processes and practices are coproduced through hybrid labor relations between public and private actors. Infrastructure scholars have underscored the crucial roles of public engineers and repair workers in urban water supply (e.g., de Coss-Corso,

2020; Anand, 2017; 2020). However, these studies have advanced an understanding of maintenance and repair in a way that tends to overlook or ignore the plurality of actors and labor arrangements in maintenance and repair (Barnes, 2017). This thesis extends the debates on maintenance and repair by revealing the heterogeneous actors and hybrid labor relations underlying maintenance and repair in African cities and how these sociotechnical arrangements shape water supply in and beyond the network. This conclusion resonates with recent calls by some scholars to rethink urban infrastructure maintenance and repair beyond the "repair ideal" (Wahby, 2021) or, more broadly, the state's role (Barnes, 2017; Björkman, 2018). This understanding can help us shift toward a broader conceptualization of maintenance and repair as collaboration and co-production arrangements in which the private and public sectors play equally important roles. "Thinking" maintenance and repair operations through co-production highlights the limits of the state or public utilities and the possibilities and potential inherent in the private sector, which we could harness for effective and efficient maintenance and repair (cf. Misra, 2014; Schramm, 2018; Coutard and Rutherford, 2015). Exploring how diverse actors and practices interplay in coproducing maintenance and repair offers a more comprehensive understanding of the dynamics and contested labor relations and practices that shape urban infrastructure delivery in African cities through maintenance and repair.

Beyond revealing the interplay of heterogeneous actors in maintenance and repair, the thesis contributes to deconstructing the "perceived binary" between formal and informal practices in maintenance and repair. In previous studies, some scholars have distinguished between formal and informal practices in maintenance and repair (e.g., Barnes, 2017; Baptista, 2019; Wahby, 2021), with the "formal" often broadly associated with public utility while the "informal" is linked to the private sectors. While these distinctions still have analytical value, their portrayal of how urban infrastructures are maintained and repaired in African cities tends to be inaccurate and incomplete. This thesis has shown that, in reality, all actors' maintenance and repair practices are intertwined as a hybrid—with all actors shifting between formal and informal roles at different times. Thus, maintenance and repair practices are neither fully formal nor informal (see chapter 4). This thesis takes accounts of a better conceptualization of the realities of maintenance and repair in African cities and enriches the ongoing debates on hybrid urbanism in the global South (e.g., Jaglin and Rateau, 2022; Gribat, 2021; Acuto et al., 2019).

This thesis extends the current body of research on maintenance and repair by examining the significant role played by donors in shaping these processes. While existing

studies on water supply acknowledge donors' involvement in infrastructure financing and technology transfers (e.g., Alves, 2022; El Khanji, 2022), they often fail to explicitly address their influence on maintenance and repair activities. This oversight may lead to the misconception that maintenance and repair practices are exclusively guided by local entities and agents such as public utility engineers, users, and private plumbers, thereby overlooking the equally vital role of international donors. By highlighting the critical role of donors in shaping maintenance and repair practices, this thesis expands the conceptualization and understanding of these processes. It underscores the complexity and diversity of actors involved, both locally and internationally, whose decisions and actions impact maintenance and repair operations. This theoretical advancement challenges the traditional view of maintenance and repair as solely localized transactions (Graham and Thrift, 2007; Anand, 2017), emphasizing instead the broader socio-economic and political influences introduced by donors. By shedding light on these dynamics, the thesis calls for broadening existing frameworks, advocating a more nuanced understanding that considers the intricate interplay between local workers and international donors. Ultimately, the study suggests that donors' engagement in water supply entails socio-political and economic dimensions that significantly shape maintenance and repair practices.

Finally, this thesis introduces a new perspective into the discourse on infrastructure resilience by emphasizing the pivotal role of maintenance and repair in fostering resilience in urban infrastructure systems. By demonstrating that maintenance and repair practices are not merely operational necessities but integral components of urban resilience, the thesis unveils a critical dimension that has often been overlooked in the resilience debates. This insight is critical for shifting conceptual and theoretical conversations on urban infrastructure resilience toward a position where we can recognize the multifaceted and multidimensional nature of infrastructure resilience (Chelleri et al., 2022). This conceptual shift is necessary because previous studies on urban infrastructure resilience (e.g., Alexander et al., 2016; Eledi Kuusaana et al., 2023; Balaei et al., 2018; Campannella, 2016; Meerrow et al., 2016) have mostly focused on the systems' capacity to adapt, resist or recover from shock and disruption (Walker et al., 2006), while often ignoring the everyday maintenance and repair processes and routines that continuously enhance this capacity. This thesis highlights the interconnected nature of resilience and those maintenance and repair processes that enables the capacity to adapt, absorb, and resist technical breakdowns and failures. This contributes to a more holistic understanding of urban infrastructure resilience and sustainability in African cities. Furthermore, this thesis highlights the need to expand current theoretical and conceptual lenses that traditionally explored

and analyzed infrastructure resilience within the context of natural disasters and disruptions linked to climate change (e.g., Folke et al., 2010; Andersson et al., 2022; Campanella, 2016) to include the system's internal dynamics, such as decay and aging networks (Ramakrishnan et al., 2021). This shift is crucial because maintenance and repair are not isolated tasks but are embedded in the larger context of urban infrastructure functionality, resilience, and sustainability. This holistic perspective enriches theoretical debates and refines conceptual frameworks, particularly in the global South. In regions where the risks of infrastructure failures and breakdowns stem more from decay and aging networks than from natural disasters, this comprehensive understanding becomes particularly relevant.

6.4 Recommendations for research and policy

This section discusses avenues for future research and policy recommendations based on the findings above. These recommendations can help shape future research directions and support infrastructure development and policy in Accra and Dar es Salaam and many other African cities. I will first discuss avenues for future research, followed by the recommendations for policy formulation.

6.4.1 Future research

This thesis highlights key recommendations for future research on maintenance and repair, water supply, and urban infrastructures in the global South. These recommendations enhance our understanding of maintenance and repair in terms of propositions to broaden the empirical basis of research by looking at different domains and geographies and introducing mechanisms to improve funding for maintenance and repair.

Firstly, this comparative case study has proven effective in revealing the complex relations that underlie and shape maintenance and repair practices within water supply systems in African cities and has yielded novel framework for understanding maintenance and repair practices through materialities, institutions, knowledge, and discourse dimensions. Nonetheless, there are still avenues for further comparative studies to broaden the empirical basis in order to understand the dynamics in maintenance and repair further. To this end, future research could test this novel framework by comparing maintenance and repair practices in different infrastructure domains at neighborhood level. Comparisons of different infrastructure domains across different neighborhoods in the city are rare in infrastructure studies but can reveal a better and situated understanding and geographies of maintenance and repair within

African cities. The following questions could guide future research: What are the unique challenges and strategies associated with maintenance and repair in different infrastructural domains? How do organizational structures and standards influence the effectiveness of maintenance practices in various infrastructure systems? Intra-urban comparative analysis is even more useful in the context of African cities because infrastructure constellations and practices that underpin them are not homogenous across all neighborhoods (Smiley, 2020; McFarlane et al., 2017; Koepke et al., 2022). Intra-urban comparison could broaden the focus of urban infrastructures studies from broader city levels to neighborhood scales where context-specific insights could be generated. This insight can then be used by utility companies, policymakers, and urban planners to develop more targeted and effective strategies for tackling maintenance and repair needs in urban infrastructures.

Secondly, future research is needed on the schemes for funding maintenance and repair. This study briefly touched on the funding schemes and modalities for maintaining and repairing urban water supply and identified significant funding challenges in both cities. However, there is a need to delve deeper into the funding models and financing mechanisms for the maintenance and repair of urban infrastructures deployed by municipalities and public utilities (Wall, 2021; Corning-Padilla and Rowangould, 2020). For example, potential research questions could explore why and how these funding challenges exist and how they could be addressed and what innovative approaches can be explored to secure additional funds for maintenance and repair. Further research also needs to engage with the key question of cost recovery through the broader political economy of maintenance and repair financing. This could explore the financial mechanisms and incentives that result from cost recovery pressures and the excessive debts of many utility companies and states that make investment in maintenance and repair difficult. How do the complex interplay of state political interests, economic conditions, and institutional frameworks shape cost recovery and how do they affect maintenance and repair? This focus is important because the sustainability of water supply systems hinges on cost recovery recouped through user fees, tariffs, or taxes levied on consumers. However, achieving full cost recovery is a major challenge for many water companies in Africa, especially because affordability, poverty, and inequality are already prevalent. Exploring these questions can reveal interesting insight into maintenance and repair financing in water supply and generate key lessons for guiding policymaking for the sustainability of water supply systems.

Finally, this dissertation highlights some shortcomings in relation to the coordination of formal and informal practices in maintenance and repair within public policies and

programs in both countries. Future research is needed to explore how the roles and practices of private and public workers in maintenance and repair can be harmonized and integrated into policies to ensure coherence. Further research could explore the legal and regulatory frameworks, focusing on the barriers that prevent informal water service providers from operating within formal frameworks. This includes examining the licensing and permitting processes and the enforcement mechanisms for ensuring compliance with regulations. Other studies could also focus on exploring the capacity building and support needed to enhance informal water service providers in terms of technical skills, business management, and health and safety practices, or by identifying innovative policy solutions that recognize the contributions of informal water service providers while ensuring the provision of safe, reliable, and affordable water services to urban residents. Addressing this research gap would contribute to improving water service provision in African cities and promote inclusive and sustainable water governance that addresses the needs of all urban residents, particularly those living in underserved areas.

6.4.2 Future water policy and maintenance and repair

In addition to the above research directions, this thesis offers some practical recommendations and suggestions for urban water policies on maintenance and repair in the two cities and similar contexts in the global South.

First, the findings of this study show that governments and public utility companies in both cities have no explicit and well-established maintenance and repair policies. Without clear policies, there may be a lack of systematic and proactive approaches to maintenance, which explains the high levels of deterioration and increased instances of leaks, breakdowns, and failures in water supply systems in both cities. Also, the absence of detailed maintenance and repair policies can lead to inconsistent practices across different regions and districts and create disparities in service delivery quality and access levels among residents. Thus, explicit and well-developed maintenance and repair policies are needed. For example, policies that specify quality standards and those that draw more attention to proactive maintenance rather than reactive repair approaches are critical for enhancing water infrastructures' resilience, efficient resource management, and long-term sustainability.

Second, this thesis highlights inadequate funding as a critical challenge that is undermining effective implementation of maintenance and repair practices in both cities. This challenge arises from the inability of both public water suppliers to mobilize sufficient financial revenues and the fact that maintenance and repair are not the

institutional responsibility of donors. At the same time, it is generally more attractive to build new infrastructures than to repair existing ones, further pushing maintenance and repair needs down the scale of companies' priorities. The situation is even more complicated, considering that urban water companies often prioritize expanding infrastructure networks and upgrading water systems capacities over maintaining and repairing existing networks (Matlin and Walnycki, 2020). In order to address this challenge, this study recommends that urban water managers dedicate some percentage of their revenues to maintenance and repair needs. For example, DAWASA has allocated about 10% of its revenues to the maintenance and repair of networks. These allocations can make more financial resources available for the maintenance and repair of water infrastructures while minimizing the risk of diversion maintenance and repair funds to support other expenses.

The uneven investment structure has led to a situation whereby the capacity of technical systems and network coverage have increased, but the maintenance and repair of existing water networks have deteriorated. This neglect can affect the sustainability of the water supply systems funded by donors and undermine the impacts of donors' aid in recipient countries. To address this structural problem, this study recommends that donors and national governments' water infrastructure funding schemes promote the construction of infrastructures in tandem with maintenance and repair of existing networks. Also, donors' water infrastructure funding schemes should anticipate maintenance and repair by investing more in the capacity building of local experts and engineers to ensure effective maintenance and repair. This is even more crucial because the findings of this study show that public utility engineers struggled to maintain and repair some technical systems, and access to spare parts was also challenging. These limitations can severely impact infrastructure sustainability and resilience in donor-recipient countries (Mattlin and Nojonen, 2015; El Khanji, 2022). Building local capacity for maintenance and repair can reduce import dependence, enhance repairability in the system (Lu and Qiu, 2022), and improve the overall water supply in cities. At the same time, donors should also consider adopting and transferring familiar and context-appropriate technologies for which technical spare parts and local experts can support their maintenance and repair.

Considering both cities' heterogeneous and splintered water infrastructure constellations, maintenance and repair must adopt more decentralized strategies that fit "place-based" constellations and situations. Such decentralized approaches are more responsive to the local contexts and, thus, more effective in addressing localized infrastructure maintenance and repair needs. The case of DAWASA provides a practical

example to show that decentralizing maintenance and repair to neighborhood level can enhance effective operations. This decentralized approach is effective because the repair workers can develop detailed knowledge of the city and its infrastructure networks, including their vulnerability hotspots, which aid in their ability to repair and maintain leaking networks efficiently and on time. Other water supply companies in similar contexts can adopt this decentralized approach to enhance the effectiveness of maintenance and repair in water supply systems. At the same time, Accra's centralized approach is cost-effective and adaptable because maintenance teams and resources can easily be reorganized into smaller teams to attend to maintenance and repair needs in different places. This adaptability and flexibility in maintenance and repair is especially appropriate for contexts where infrastructure services are considered to be precarious achievements (Baptista, 2019).

Finally, this study reveals that the private sector plays a significant role in facilitating the maintenance and repair of water supply systems. These findings show the private sector does valuable work and that public and private companies should collaborate in maintenance and repair for improved and timely response to maintenance and repair. However, such collaborations should be implemented with some level of regulations and standards, to ensure minimum quality in maintenance and repair practices. Integrating the private sector in maintenance and repair and water policies can enable us to exploit the full benefits of the private sector for enhancing urban water supply and infrastructure sustainability. For example, private plumbers could be engaged as local vanguards of the water networks in their neighborhoods and given specific roles in maintaining and repairing networks, with the water company remunerating them for their labor. The case of DAWASA shows that such collaborations can allow public utilities to harness the cheap labor of private plumbers to enhance maintenance and repair. The collaboration between DAWASA and private plumbers has proven effective in supporting maintenance and repair in their networks, and other water companies have also learned from their own experience in enhancing maintenance and repair. It is important to note that privatization only works if local governments/utilities build up the capacity to control the private contractors and if clear standards exist and compliance can be safeguarded.

6.5 References

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APPENDIX

LIST OF RESPONDENTS

1. Director of Water Supply, DAWASA, Dar es Salaam, 28 February 2019
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
12. GWCL district manager for Accra North, January 8, 2019
13. GWCL district operations maintenance engineers, January 12, 2019
14. Local plumber 1, Nima. February 3, 2020
15. Local plumber 2, Nima. March 4, 2020.
16. Resident 1 in Nima. March 12, 2020
17. Resident 2 in Nima. March 8, 2020
18. Resident 3 in Nima. March 10, 2020
19. GWCL District Manager, Dodowa. January 2, 2020
20. GWCL Operations & Maintenance Foreman, Dodowa, January 20, 2020
21. GWCL technician, Dodowa, February 15, 2020
22. GWCL District operations manager, Dodowa, February 5, 2020
23. Personal interactions with a technician and an employee of GWCL, March 3, 2020.
24. GWCL Management official, Accra East region, April 5, 2020.
25. Official at Ministry of Sanitation and Water Resources, Accra, December 17, 2018
26. Chief engineer, GWCL projects, Accra, December 20, 2018
27. Engineer, GWCL-ATM, Accra, March 20, 2020
28. Technician, Lower Ruvu plant, Dar es Salaam, March 1, 2019
29. Technician, Upper Ruvu plant, Dar es Salaam, March 4, 2019
30. Technician, Weija water plant, Accra, March 26, 2018
31. Regional Chief Engineer, GWCL-ATM, Accra, April 29, 2020

32. Researcher, Tanzania Water Institute, Dar es Salaam, August 23, 2021
33. WASH specialist, UNICEF Tanzania, Dar es Salaam, February 19, 2019
34. Government official, Tanzania ministry of water and irrigation, February 19, 2019
35. Technical officer, WaterAid Ghana, Accra, December 14, 2018
36. Consultant, World Bank Accra, December 18, 2018
37. GIZ official, Dar es Salaam, Dar es Salaam, July 5, 2021
38. WASH specialist, UNICEF Ghana, Accra, December 14, 2018
39. Chief manager, GWCL, Accra East, Accra, December 20, 2018
40. Distribution manager, Accra East region, Accra, March 26, 2018
41. DAWASA Manager, Kinondoni region Dar es Salaam, February 22, 2019
42. Manager, Weija water plant, Accra, March 26, 2018
43. Technician, Dodowa booster plant, Accra, December 12, 2018
44. Technician Kpong water plant, Accra, December 17, 2018
45. Manager, Upper Ruvu plant, Dar es Salaam, February 21, 2019
46. GWCL operations manager, Adenta district, Accra, December 20, 2018
47. GWCL manager, Accra North district, Accra, December 20, 2018
48. GWCL official, Accra East region, Accra, December 18, 2018
49. DAWASA operations manager Temeke, Dar es Salaam, February 20, 2019
50. DAWASA regional manager for distribution Dar es Salaam, February 18, 2019
51. DAWASA operations manager Kimara, Dar es Salaam, February 8, 2019
52. GWCL engineer in charge of project, Headquarters Accra, December 14, 2018
53. Resident and Borehole owner, Dar es Salaam, August 7, 2021
54. Private plumber in Accra, March 25, 2020
55. Private plumber 1, Dar es Salaam, July 20, 2021
56. Private plumber 2, Dar es Salaam, July 11, 2021
57. Private plumber 3, Dar es Salaam, July 10, 2021
58. Private plumber 4, Dar es Salaam, July 27, 2021
59. DAWASA operations manager, Kinondoni, Dar es Salaam, February 21, 2019
60. DAWASA manager Temeke, Dar es Salaam, February 24, 2019
61. Residents of Nima1, Accra, April 18, 2020
62. Residents of Dodwa, Accra, February 8, 2020
63. Residents of Dodowa, Accra, April 15, 2020
64. Residents of Nima2 Accra, April 8, 2020
65. DAWASA engineer, Lower Ruvu River, Dar es Salaam, 18 February 2019
66. Residents of Dar es Salaam, Dar es Salaam, July 17, 2021
67. Private plumber 5, Accra, April 5, 2020
68. Private plumber 1, Accra, April 2, 2020
69. Private plumber 2, Accra, April 20, 2020

70. Private plumber 3, Accra, April 3, 2020
71. Private plumber 4, Accra, April 21, 2020
72. Private plumber, Dar es Salaam, July 25, 2021
73. DAWASA system engineer, Dar es Salaam, February 21, 2019
74. GWCL chief engineer at ATM region, Accra, March 17, 2020
75. GWCL engineer at water plant at Kpong, Accra, December 21, 2018

PROFILE OF THE AUTHOR

Lazarus Jambadu was born in Kojokperi, a village in the Upper West Region of Ghana. He started his education from there and proceeded to the University for Development Studies to pursue BA (Hons) Integrated Development Studies (2012). He also obtained an MPhil Environment and Resources Management from the same University in 2016 and went on to pursue a *Joint PhD in Human Geography and Spatial Planning* from Utrecht University, Netherlands and TU Darmstadt, Germany. His PhD was funded through a full scholarship by the DAAD with financial support from Utrecht University and the DFG. Inspired by science and technology studies, his PhD research explored urban water infrastructure maintenance and repair practices in Accra and Dar es Salaam. He has produced four scientific articles as part of his PhD thesis. He has experience in conducting field research and comparative studies in the context of African cities. Aside from academics, he has consulted widely for various NGOs and international development organizations on issues of Water, Sanitation, Hygiene as well as gender and social inclusions in the context of African cities.

List of publications

Jambadu, L., Monstadt, J. & Pilo', F., (2024). The politics of tied aid: Technology transfer and the maintenance and repair of water infrastructure. *World Development*, *175*, 106476.

Jambadu, L., Pilo', F., & Monstadt, J. (2023). Co-producing maintenance and repair: hybrid labor relations in water supply in Accra, Ghana. *Urban Research & Practice*, 1-23.

Jambadu, L., Monstadt, J., and Schramm, S., .(2022). Understanding repair and maintenance in networked water supply in Accra and Dar es Salaam. Published in Water Alternatives, 15(2), 265-289.

Jambadu, L., Dongzagla, A., and Kabange I., (2022). Understanding intra-urban inequality in networked water supply in Wa, Ghana. Published in GeoJournal, Springer Nature: 1-17.

Korah, P. I., Jambadu, L., & Nunbogu, A. M. (2022). Mapping spatial and temporal dynamics in urban growth: The case of secondary cities in northern Ghana. *Journal of Urban Affairs*, 1-17.

Derbile, E. K., Dakyaga, F., Dakuu, G., and Jambadu, L. (2016). Exploring social outcomes of interactions between University Students and Waala Communities in the Wa municipality, Ghana. Published in Ghana Journal of Development Studies, 13(1), pp. 63-79.

In this study, Lazarus Jambadu examines the maintenance and repair practices of water supply systems in the rapidly growing African cities of Accra and Dar es Salaam. These cities face significant challenges in water access, quality, quantity, and reliability, largely due to inadequate maintenance and aging infrastructures.

Jambadu's research focuses on how sociotechnical arrangements, both within and beyond formal water networks, influence maintenance and repair practices. The study highlights the dynamics of labor relations between public and private workers, the impact of donor funding schemes, and how these factors collectively affect the resilience of urban water systems. A key insight from this study is the contrast between Accra's centralized approach and Dar es Salaam's decentralized approaches to maintenance and repair in terms of their organisation and implementation. However, both cities struggle with a dependency on expensive imported parts and inadequate maintenance practices due to the effects of donor funding conditionalities. The study concludes that both maintenance and repair are essential not only for technical functionality but also for the sustainability and resilience of urban water systems. He advocates for policy reforms that combine centralized and decentralized approaches, promote collaboration between public and private sectors, and encourage decentralized strategies to enhance the effectiveness of maintenance and repair in African cities.

This book provides essential insights for academics, policymakers, and practitioners working towards sustainable and resilient urban water solutions in Africa and other regions of the Global South.

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