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Understanding intra-urban inequality in networked water supply in Wa, Ghana

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Abstract Extant studies on urban water access in African cities have mainly explained inequalities from the socio-economic and political perspectives. However, the material dimension of water supply has received little attention in the literature, though it is central in urban water supply. This paper examined how physical infrastructure artifacts and properties shape water access in Wa, Ghana. To understand the spatial dynamics, the study applied intra-urban comparative approaches to systematically analyze and compare networked water infrastructure across four different socio-economic neighbourhoods within the city. Data were collected through document reviews, in-depth interviews with utility officials and customers of the water company in Wa. The study reveals important differences across the four neighbourhoods that were studied, in respect of the extent of physical network coverage and the technical qualities of principal mains. The study concludes that both the physical and technical properties of water supply networks influence the distribution of piped water supply in Wa. Our case study emphasizes the agency of material objects in shaping water access in cities, which thereby takes the analysis of inequalities in water access beyond simple socio-economic and political narratives.

Keywords Materiality · Infrastructure · Urban · Inequalities · Water supply · Ghana

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Introduction

Of all drinking water sources, centralised water supply delivered in homes through a network of pipes is most preferred (Galada et al., 2014). It is relatively safe, convenient and conveys ideals of progress and modernity (Monstadt & Schram 2017; Larkin, 2013; Keough & Youngstedt, 2014). Because of this, the networked water supply system has been promoted as the 'modern infrastructure ideal' (Tiwale, 2019) and a suitable pathway for achieving universal access to safe drinking water in African cities (Monstadt & Schramm, 2017). But unlike the Global North, access to networked water supply in many cities in Africa is often characterised by socio-spatial inequalities

(Schramm, 2018; Smiley, 2020; Tiwale, 2019; Tiwale et al., 2018).

Previous studies have linked these socio-spatial variations to colonial histories of racial segregations (Schramm, 2018; Smiley, 2020); socio-economic factors such as wealth and income (Adams et al., 2016; Mulenga et al., 2017); the spatial organisation of cities (Bakker et al., 2008; Kooy & Bakker, 2008; McFarlane & Rutherford, 2008) and political factors (Bapat & Agarwal, 2003; Meehan, 2014; Zérah, 2008). Although these perspectives have illustrated the intricate relations between society, technology and water supply, the agency of materiality in shaping networked water access is often overlooked in the literature (see exceptions; Tiwale, 2019; Tiwale et al., 2018). In light of this gap, urban and water governance scholars have called for a deeper engagement with water's materiality, to better understand urban water access and socio-spatial inequality beyond established notions of socio-economic and political explanations which so far have dominated the academic literature (Anand, 2017; Meehan, 2014).

Indeed, emerging evidence has shown that systematic study of the materiality of networked water infrastructure could provide a deeper and more nuanced understanding of the dynamics of water access and inequalities within and between cities in the Global South (e.g. Anand, 2017; Tiwale, 2019; Tiwale et al., 2018). For example, Anand (2017) in his study of Mumbai's water supply reveals how the everyday practices of water engineers, residents, and political actors' interplay and shape water supply, access and differentiated "citizenship" in Mumbai. Similarly, Tiwale's et al. (2018) analysis of networked water access in Lilongwe show that the technical properties of water infrastructure helped to divert 'extra-water'[1]—originally meant for low-income neighbourhoods—to boost supply in elite neighbourhoods that were already receiving better service.

In common with many developing countries, intra-urban inequalities in access to piped water are pervasive in Ghana, especially between high- and low-income neighbourhoods (Ainuso, 2010; Amankwaa et al., 2014; Bartels, 2016; Obeng-Odoom, 2012). Obeng-Odoom (2012) for example reports that access to piped water in low-income Ghanaian communities like New Takoradi, Kwesimintsim (in Sekondi-Takoradi), Sukura, Sabon Zongo, Old Fadama, Avenor, and James Town (in Accra) is far less than the national average of 30% for all urban areas. Even the few households with piped connections in low-income areas experienced erratic water supply (Osumanu et al., 2010). The underlying causes of the foregoing differences in water access as reported in the literature include; rapid expansion of urban development due to urbanisation, differential socio-economic status, and inefficiencies in the management of public utility water supply (Mosello, 2017; Peloso & Morinville, 2014). However, the literature is so far silent on how the material dimension of water systems could shape access in Ghanaian cities. This has the potential to limit our understanding of socio-spatial inequalities in urban water supply as well as interventions aimed at improving water supply in Ghanaian cities. Thus, to better inform interventions, policies and programmes in networked water supply and the theorisation of uneven access to water supply in African cities, this study examines how the materiality of networked water supply systems influence spatial inequalities in water access among inhabitants of four neighbourhoods in Wa, Ghana.

Inspired by science and technology studies, we hereby define materiality as the material elements, or artefacts, including their properties that constitute water supply systems in a place (Tiwale, 2019; Leonardi & Killinikos 2012; Leornardi 2012). In the context of materiality, inequalities can manifest both physically in the form of limited networked coverage and technically in terms of low-quality service delivery, e.g. low-pressure or quantity of water supply. Specifically, the study analyses the technical properties of principal feeder mains, including size, coverage, directions and lengths and their implications on water supply across the four neighbourhoods. The principal mains (also known as principal feeder mains) consist of large distribution pipes that convey bulk water supply from the service reservoir into demand areas or neighbourhood level for onward connection by households (Alan et al., 2000; Alda-Vidal et al., 2018; Kjellen, 2006).

The rest of this article is structured as follows: In section two, we reviewed the literature on the state of water supply in sub-Saharan Africa (SSA), with

[1] Tiwale and colleagues define extra-water as additional water resulting from addition expansion in the water supply system's capacity.

emphasis on urban access and issues of socio-spatial inequalities. Building on science and technology studies, we then conceptualised materiality to provide clarity of its meaning and operationalisation in this study. Following that, a brief overview of the study settings and research methods are presented in section three. The results of the study are presented in section four and discussed in section five, while section six captures the conclusions, where we situate the research findings in the extant literature on urban water access in Africa and the Global South more generally.

Overview on access to water supply in sub-Saharan Africa

The Sustainable Development Goal (SDG) target 6.1 seeks to achieve universal and equitable access to safe and affordable drinking water for all by 2030, with the indicator being the proportion of the population using safely managed water services [World Health Organization (WHO) and United Nations Children's Fund (UNICEF) 2018]. Six years into the SDGs, only 30% of the population in SSA has access to safely managed water services (WHO and UNICEF, 2021a). Of the remaining 70%, 35% has access to basic service, 13% has limited service and 22% still use unimproved/surface water (WHO and UNICEF, 2021a). Between 2015 and 2020, safely managed water coverage in SSA increased marginally by 3% (WHO and UNICEF, 2021a). Based on the current rate of progress, all SSA countries risk missing universal access to safely managed water services by 2030 (SDG target 6.1) unless the rate of progress is increased by at least 10× (WHO and UNICEF, 2021a).

Access to safe water in SSA has received considerable scholarly attention in the past few decades. Scholars have analysed various aspects of water access, including water security, scarcity and service delivery quality (e.g. Ablo & Yekple, 2018; Bellaubi & Visscher, 2014), water quality and related health problems (e.g. Dongzagla et al., 2020); and heterogeneous and hybrid delivery configurations (e.g. Jaglin, 2015; Lawhon et al., 2018; Smiley, 2020). Others have also explored the political dimensions of water supply and access (Schramm & Ibrahim, 2019) as well as differentiated access by different socioeconomic groups across and within cities (Adams, 2018; Dongzagla, 2021; Peloso & Morinville, 2014; Tiwale et al., 2018). At the same time, these and many other studies have pointed out the challenges faced by urban authorities in an attempt to improve access to potable water supply in SSA.

One of the hegemonic models of urban water provision in cities in SSA (and the rest of the world) is the networked water supply system, which is variously referred to as the centralised water supply or piped water supply. This typology of water supply consists of diverse and multiple material artefacts and components (e.g. pipes, valves, reservoirs and plants) but also diverse social and institutional relations that underpin and shape their operations in a place (Lawhon et. al. 2018; Alda-Vidal et al., 2018). Due to their entanglement with society, Science and Technology Studies (STS) regards the networked water systems as "socio-technical systems" which emphasise the diversity of social, economic, political and technical variables that underlie and shape their existence and operations in society (Anand, 2017; Lawhon et al., 2018; Tiwale, 2019). In SSA cities, the networked water supply model has been criticised by many scholars, indicating that they tend to promote divisions, inequalities, and urban fragmentation rather than networking (see Jaglin, 2015; Furlong 2014; Smiley, 2020). In short, while some scholars and international development planning experts see the centralised systems as the best medium of networking and universalising water access in cities, others emphasise their potential for (de)networking, spatial segregations and splintering of cities in Africa and the Global South (Graham & Marvin, 2001; Bjorkman 2015; Tiwale, 2019; Anand, 2017; Jaglin, 2015). Another argument often made against the networked system is that, as planners and policymakers aspire to achieve universal network coverage in cities, the imperative of small-scale decentralised water supply systems (or off-grid alternatives) is often overlooked (e.g. Furlong, 2014; Furlong & Kooy, 2017; Jaglin, 2015)—even though they are the main water provision sources for the majority of poor inhabitants in African cities. In all these debates, scholars have framed access inequalities as the effects of socio-economic, historical and political variables (Adams et al., 2016; Schramm, 2018; Schramm & Ibrahim, 2019), with little attention given to the physical artefacts themselves. Hence until now, the debate has mainly focused on the social variables while the technical and physical dimensions of water supply are neglected. This is because many scholars tend to focus attention on water supply itself rather than on the infrastructure (Keough & Youngstedt, 2014). Yet, attention to water's materiality can reveal important insight relating to access, culture, gender, as well as spatial and temporal dynamics of inequalities that surround water access in African cities (Keough & Youngstedt, 2014).

Like many SSA countries, access to safely managed water services in Ghana is low. In 2020, the WHO/UNICEF Joint Monitoring Programme estimated safely managed water coverage in Ghana to be 41% and projected it to 85% by 2030 (WHO & UNICEF, 2021b). Of the 59% without safely managed water services, 44% have basic access, 7% have limited access and 8% still use unimproved/surface water (WHO & UNICEF, 2021b). Disaggregated data by the elements[2] of safely managed water services in the 2017/18 Ghana Multiple Indicator Cluster Survey (MICS) report shows that Ghana has made significant progress in the area of access to sufficient quantities of drinking water at source (88.3%) but lags in the areas of accessibility to drinking water sources on-premises (23%) and access to faeces-free water at source (51.7%) (GSS, 2018). Faecal contamination of drinking water sources in Ghana is mainly attributed to high open defecation, poor management of water infrastructure and proximity of drinking water sources to pit latrines (Ahiabor & Amoako, 2016; Dongzagla et al., 2020). Low access to drinking water sources on-premises on the other hand stems from limited piped water coverage, due to financial constraints on the part of water utility companies and households, inaccessibility of housing units to physically connect to the water networks, bureaucratic administrative procedures involved in securing new connections and ill-suited housing arrangements (Ablo & Yekple, 2018; Kumasi, 2018). Some studies linked limited financial constraints on the part of water utility companies to low central government funding, low tariffs, uncollected revenues and high water loss (Kumasi, 2018; Monney & Antwi-Agyei, 2018; Nedjoh & Esseku, 2016). In addition to low coverage, piped water systems in Ghana are characterised by intermittent flows in water supply (Tutu & Stoler, 2016). This implies that access to piped water systems does not necessarily mean that a household would have access to sufficient quantities of water from the system. With access to water on premises being a key indicator of safely managed water services, this study interrogates how the materiality of the networked water supply system in Ghana might affect water access on premises in different neighbourhoods, using Wa as the empirical case study. The next section provides literature on the concept of materiality to clarify its meaning and application in this study.

Conceptualizing materiality and water access in cities

The concept of materiality can be traced back to the 1950s when it first emerged from the field of organizational studies. Since then, the concept has evolved and proliferated across different fields of studies, including STS, and information, communication and technology studies (e.g. Bijker, 1995; Orlikowski et al., 1995). In the field of organisational studies, materiality is often used to emphasise the role of "material objects" (but also digital technologies such as software) in the operation of organisations (e.g. Volkoff et al., 2007; Faraj & Azad 2012). In STS, materiality is often used interchangeably with related concepts such as "socio-materiality", sociotechnical systems or technology, although these terms themselves have slightly different meanings (Kallinikos, 2012; Leonardi, 2012). In this study, we stick to the term materiality. Leonardi et al., (2012) define materiality as the material or physical elements that constitute the technology, including their technical properties (such as form and size) which are more intrinsic to the artefacts and do not change over time (Leonardi et al., 2012). For Kallinikos (2012), materiality refers to the physical constitution of technological objects and the implications of such constitutions for the design, making, and use of objects. This conceptualisation frames material objects as configurations of form, function, and matter, and thus entail much more than their material constitution (ibid: p.69).

Building on these conceptualisations, Tiwale (2019) defines materiality as the "objective property" of technology that does not change over space and

[2] Access to drinking water source on premises, access to sufficient quantities of drinking water at source when needed and access to faeces-free water at source.

time and is (theoretically) available for all in a similar fashion (Tiwale, 2019). From this perspective, Tiwale (2019) then makes a distinction between "materiality" and "material agency": Whereas the former refers to the material elements themselves, the latter relates to the functions to which these material elements could be applied (Tiwale, 2019). In all these definitions, three key dimensions of materiality have been emphasized including; *matter* (physical structures); *form* (shape, or order) and *functions* (or purpose/use), which in themselves are interlinked.

In the context of this study, we used materiality in relation to the material dimension of piped water systems (cf: Tiwale, 2019). The networked water supply system is made up of a variety of materials or matter (e.g. pipes, pumps, reservoirs, valves, metres). These artifacts, which play specific roles in the water delivery system are arranged and ordered in a particular *form* or design to enable them to *function* efficiently in water supply. Thus, our conceptualization of materiality includes the *matter* and its properties (such as form, order, shape, sizes, length, coverage, etc.) that work together to perform its envisioned *function* (cf: Kallinikos, 2012). For Ramakrishnan and colleagues, infrastructure's materiality is central to understanding the production of social differences (e.g. in gender, race, caste, class, and sexuality), power relations and access to and distribution of resources (Ramakrishnan et al., 2020:2).

One of the important material components of the water distribution system is the principal feeder mains, which carries water supply from the main reservoirs to the various neighbourhoods for onward distribution to users. As the main channel for conveying bulk water supply to the neighbourhoods, the properties of principal mains are the primary determinants of the quantity, quality, volume and pressure of water supply to various demand areas (Alan et al., 2000). Against this background, the study focused particular attention on the principal feeder mains. For Tiwale et al. (2018), key questions relating to "where", "whom" and "what quantities" of water that can be supplied to a neighbourhood or demand area can best be explained through the materialities of the principal water distribution mains. Hence, focusing attention on principal mains can help us to better understand differentiated access to piped water supply both at the neighbourhood level and urban scale. While the concept of materiality is central in this study, it is important to indicate that this paper does not intend to contribute to the ongoing conceptual debates on materiality. Instead, we simply apply the concept as a heuristic tool to explain how and why certain neighbourhoods might have better access to piped water supply than others.

Taking material artefacts as the entry-point, our case study advances a better understanding of uneven water access by situating inequality within the material artefacts. Through this, we expand conceptual debates on uneven water access beyond socio-economic and political explanations by emphasizing how material elements re/produce landscapes of differentiated water access. We emphasize that if the goal is to achieve a nuanced understanding of the dynamics of water access in African cities, a materialistic lens offers a useful conceptual corridor for theorizing intra-urban disparities. Not least because, the materiality framework embraces both the *physical and technical* dimensions of water access, an important aspect of water supply that is often missed by other analytical approaches and frameworks. Here, the *physical dimension* of water access refers to the availability of the water infrastructure and its proximity to users. Holding all other factors (such as price) constant, this aspect merely concerns the question of whether there is a functional water distribution infrastructure in the neighbourhood. On the other hand, the *technical dimension* of water access is concerned about the "quality" of material artefacts that are used for water supply in a particular neighbourhood. These include the size of the principal feeder mains, the direction and number of people they serve, and the length and extent of their coverage but also the level of hydraulic pressure they contain. In short, we argue that both the physical and technical aspects of water access must be taken into consideration when analyzing inequalities in networked water supply in cities. In this context, inequality is defined in terms of the spatial variations concerning physical water accessibility by inhabitants of various neighbourhoods within the city.

Study context and methodology

Study area

This study was conducted in Wa, the administrative capital and most urbanised city in the Upper West

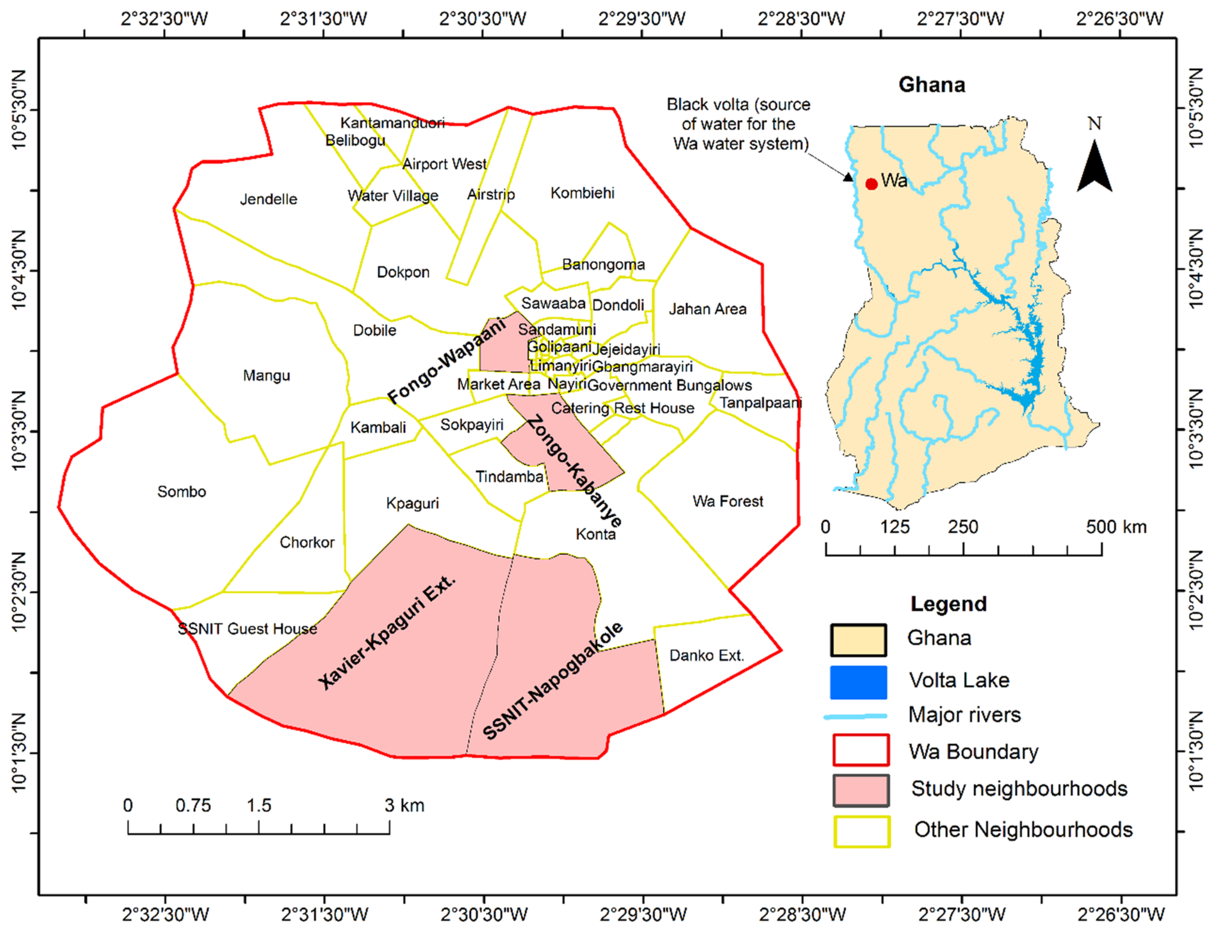

Fig. 1 Map of Wa showing locations of the study neighbourhoods. *Source* Authors' construct (2020)

Region of Ghana (Fig. 1). The population of Wa grew exponentially from 21,393 in 1970 to 66,441 in 2000 (Ahmed et al., 2020; Korah et al., 2018) and further up to 143,358 in 2021 (GSS, 2021). In 2016, the built-up area of Wa was estimated to be 29.2 km^2 standing for an increase of 97.3% if compared to the year 2000 (14.8 km^2) (Korah et al., 2018). This rapid expansion could partially be explained by the establishment of a new campus of the University for Development Studies in 2002. Most inhabitants of Wa derive their livelihood from trading activities, with a few of them into agricultural, civil, public and social works (GSS, 2014).

Like other parts of Northern Ghana, Wa experiences two main seasons—wet and dry seasons. The wet season spans from April to October with the peak rainy months being August and September, followed by a long dry season spanning from November to March. The mean annual rainfall varies between 840 and 1400 mm (GSS, 2014). The main drainage systems of Wa are the Sing-Bakpong and its tributaries to the south and Billi and its tributaries to the north (GSS, 2014). The predominant geology of Wa and its environ is a mixed of Pre-Cambrian, granite and metamorphic rocks with the major soil types being laterite and the savannah ochrosols (GSS, 2014). These rocks have well-developed fracture systems with a good borehole success rate.

Most of the houses are concentrated around the city centre, but progressively dispersed at the urban fringes (Ahmed et al., 2020). At the city centre, the houses are largely unplanned and built haphazardly in the form of compound houses. Most houses were built using local materials such as mud and cement blocks and roofed with corrugated iron sheets. Wa can be divided into three zones, comprising the inner zone, middle zone and outer zone/urban fringe. The inner city comprises of neighbourhoods like Zongo, Kabanye, Tendamba, Wapaani, Market, Nayiri, Limanyiri, Suuriyiri, Tagrayiri, Degu and Dondoli (Fig. 1). These areas are usually considered traditional settlements, with high population density and low incomes (Wa Municipal Assembly, 2018). Notable neighbourhoods in the middle zone are Waapaani, Fongo, Kabanye Kpaguri, Dokpong, Dobile, Mangu, Airstip, Kumbiehi, Napogbakole, Kambali, Juderiyiri and Tampalpaani (Fig. 1). At the outer zone/urban fringe, where new development is actively taking place, there are mostly semi-detach and luxury self-contain apartments, which are mainly owned and inhabited by relatively wealthy elites: upper- and middle-income classes (Wa Municipal Assembly, 2018). Areas like Xavier, Kpaguri, Napogbakolee and SSNIT residential areas can be found in these peri-urban spaces (Fig. 1). Like most Ghanaian cities, Wa has pre-existing settlement layout plans and maps, but the actual development hardly conforms to them. Because housing development is mostly shaped and driven by individual taste and preferences rather than state planning regimes.

In common with many rapidly expanding cities in Africa, the inhabitants of Wa depend on heterogeneous water supply systems and sources for their water needs. Broadly, these sources can be classified into piped networks (household connections and public taps/standpipes) and non-piped systems such as boreholes, wells, tanker supply, sachet water and bottled water. These heterogeneous systems co-exist side-by-side, and users may depend on one or a combination of multiples of them for meeting their 'everyday' water needs. Households' dependence on any particular system (or a combination of systems) is contingent on several factors, including the availability of the water infrastructure, the cost of accessing it and convenience. In the results section, we discussed into detail households access to piped water system in Wa.

Research methods

Situated in the qualitative research paradigm, this paper applies an 'intra-urban' comparative case study design (McFarlane et. al., 2017), which involves a systematic comparison of a phenomenon across different neighbourhoods or groups of populations in the same city (Smiley, 2020). This approach can be useful as it provides a situated lens to better understand localised and place-based dynamics, factors, and conditions that underlie and shape piped water access in different parts of the city. With intra-urban comparison, the city is hereby seen, not as a 'singular space' but a space that consists of *'multiple urban worlds'* (Smiley, 2020) with localised urban conditions, challenges and water infrastructure specificities.

The empirical materials for this case study were gathered from four neighbourhoods in Wa. We purposefully selected Wa for two main reasons. First, the authors have lived in the city before, and thus, appreciate the local challenges confronting residents in piped water supply and accessibility. Further, our lived experiences helped us to better understand the state of water supply in the city; such as the extent of coverage, limitations, and challenges. Secondly, one of the authors works with the utility company (the Ghana Water Company Limited) in the Wa office, which is the focus of the study. This helped us to have easy access to the necessary spatial data for our analysis.

The data collection was organised at three levels, using different methods: literature reviews, semi-structured interviews, focus group discussions and field observations. This is useful for triangulation of data sources (Creswell, 2009). First, we carried out an in-depth literature review and official document analysis about water supply in Ghana and the Wa water supply system in particular. The review involves reading, classifying and interpreting meanings from various documents, official reports, maps and the water system's profiles. Issues such as network water coverage; connection rates; the number of customers served; service delivery quality; systems capacity and geospatial data relating to the networks as well as their operational challenges were studied. This initial review helped us to gain a deeper understanding of the state of literature in water supply and the research gaps, especially regarding issues of access, inequality and the role of materiality in water supply.

The second stage involves the conduction of focus group discussions (FGDs) with utility officials: water engineers, technicians, GIS specialist and water managers. In fact, focus group discussion was not initially intended for the study. However, when we started to conduct semi-structured interviews with specific engineers, we encountered conflicting opinions. In order to address this challenge, we decided to conduct

FGD with all targeted utility officials to clarify conflicting responses. The FGDs enabled us to consolidate information and clarify conflicting issues relating to the networks. For instance, new networks that were developed recently, but not yet captured in the hydraulic maps were reconciled by local engineers and the GIS specialist. Three rounds of FGDs were held with six members each. In each session, discussants were purposively selected based on the subject under discussion. All FGDs were facilitated by the authors using a guide developed in English. The medium of communication was English since all participants were literates. From the FGD sessions, we collated and analysed various data: such as spatial distribution maps, layout plans, customer locations data, system's profile data, etc., and explored the opinions of engineers and administrators about the networks; to understand the water distribution system and its diverse materialities: configurations, sizes, directions, and pressure. Through these meetings, we co-developed a map that shows the sizes, location and number of customers on each of the principal feeder mains taking bulk water supply from the main reservoir to the four neighbourhoods involved in the study (Fig. 4).

The above-mentioned data collected from the FGDs with the utility officials helped us to further narrow down the analytical scope of the study to focus on four neighbourhoods: SSNIT-Napogbakolee, Xavier-Kpaguri Extension, Fongo-Wapaani and Zongo-Kabanye, as shown in Fig. 1. The first two areas (SSNIT-Napogbakolee, Xavier-Kpaguri Extension) were selected because they are located on the urban margins. Moreover, both neighbourhoods are fed by the same size of principal feeder mains (with a diameter of 225 mm). The other two communities (Fongo-Wapaani and Zongo-Kabanye) were selected because they are located in the inner/middle part of the city, with the largest number of customers and also fed by principal feeder mains of similar size in diameters (110 and 160 mm respectively) (Fig. 4).

Finally, the third stage of the data collection involves the conduction of semi-structured interviews with engineers and customers of the GWCL. To validate our preliminary findings, we conducted four semi-structured interviews with the scheduled water engineers of the sampled four neighbourhoods to have an in-depth discussion about water pressure, leakages, illegal connections and new connection fees. We also conducted semi-structured interviews with 20 randomly selected customers of the GWCL (i.e., five in each study area). The rationale of these interviews was to further understand specific issues relating to water pressure, rationing, etc.from customers experiences, and to compare and contrast that with the opinions of engineers. All interviews were conducted in English and local language (where necessary), using an interview guide.

All qualitative data were analyzed using thematic analysis, which combines both indicative and deductive approaches. This approach basically involves a detailed examination of transcripts, labelling of key findings, sorting of findings and coding them around five main themes—network coverage, length, size, and density of pipes, with cross-cutting issues such as capacity and pressure. The data were presented both in the form of direct quotes (where necessary) and paraphrased sentences and interpretation of the findings. The spatial data were analysed using GIS and Microsoft software, and presented in simple maps, figures and charts.

Ethical clearance was obtained for the study. First, we sought clearance from the water company (GWCL office in Wa) before the interviews were conducted. Also, consent was sought from all participants. As part of the process of seeking informed consent, the purpose of the study, uses of data and pictures to be taken were made known to the participants. Participants were also assured of maximum confidentiality and anonymity with regards to the information they will provide. All of them understood and voluntarily consented to participate in the study before they were interviewed.

Results

Access to networked water supply in Wa

The history of piped water supply in Wa is scanty. But available information suggests that the first borehole systems were drilled around the late 1940s as part of a nationwide water and sanitation sectors development programme pursued by the British colonial rulers, which aimed to provide portable water supply to inhabitants of larger communities (Bohman, 2010). Towns such as Tamale, Yendi and Wa benefited from this programme (Fuest, 2005). Those boreholes later became the nucleus of piped water development in the city around 1993, when the GWCL took over urban water management in Ghana. The GWCL subsequently increased the number of boreholes and constructed storage reservoirs to distribute piped water supply to residents of the city.

Our interaction with officials of the GWCL revealed that by 2015 the water system comprised of about 17 boreholes; two reservoirs and several kilometres of pipe networks, configured into the hydraulic system (Interview 2, 2021). The boreholes pumped water directly into two reservoirs—located at the Eastern and Western sides of the city—for onward delivery to consumers. Originally, the system operated at about 17 hours per day, with an average supply capacity of 1,300 m^3 per day (Interview 2, 2021). However, towards the end of 2015, this capacity dropped drastically, due to aquifer depletion and deterioration of wells (ibid.). At the same time, the city's population rapidly increased due to an influx of students from the University for Development Studies, Wa campus. This created a huge supply deficit in the city and led to severe water rationing by utility managers, in order to manage the challenges (Interview 3, 2021). Some excerpts from officials of the GWCL on the borehole-based network system are captured as follows; *until 2017, the water supply system in Wa was dependent on boreholes…water was pumped from these boreholes into our reservoirs for treatment before we supply to our customers. As at 2017 when we switched to the Jambusie water system* (a surface water source system)*, we were having 17 boreholes with an average daily supply capacity of 1,300m*^{3}*…. The daily supply capacity was less than demand so we had to do rationing*. (We probed further on why GWCL didn't drill more boreholes to increase supply and end the rationing?). *Is true we could have increased capacity by drilling more boreholes but that comes with cost, and we were not having the money to do that. However, any time we got little money we added some boreholes; that's how come we increased the number of boreholes to 17 before Jambusie came. With Jambusie, we no longer have problem with supply capacity and we are not doing rationing* (Interview 3; Engineer, 2021).

At the peak of the rationing scheme in 2015, Kosoe and Osumanu (2015) reported that residents had water supply once every four days. Our interaction with the officials of the GWCL further reveals that while the utility had a rationing schedule, it was hardly followed by pump operators, because water supply was often strongly shaped by situational basis, depending on the 'everyday' exigencies of water demand and supply and the state of infrastructure (Interviews 2 and 3, 2021). This created considerable uncertainties in the city's waterscape and compelled residents who relied solely on the utility grid, to develop additional configurations outside the utility network to complement their water demand. For those who had financial resources, private mechanized boreholes became handy, while piped water served as a supplementary channel.

In 2017, an additional water supply system based on surface water resources from the Black Volta was developed and commissioned by the state to boost networked water supply in the Wa Township and beyond (Ghanaweb, 2017; Interviews 2 and 3, 2021). Located at *Jambusie*—a farming community about 30 km from Wa—the new system currently has about 15,000 m^3 daily water supply capacity with an expandable capacity of about 20,000/day (Interview 4, 2021). Technically, this capacity far exceeds the city's average daily water demand—which is about 4,000 m^3 per day at peak demand in the dry season and about 3,000 m^3 per day in the wet seasons (Interviews 4 and 5, 2021). An official of the GWCL stated that: *the Jambusie system brought a sigh of relief to us and our clients. As I said earlier, we no longer do rationing. If a household tap is not flowing then it could be due to maintenance work or extension work going on somewhere. As it stands, daily supply capacity is far above demand. Daily water demand is about 4,000 m*^{3} *while supply capacity is around 15,000 m*^{3} *daily. But for financial constraints, we can extend water to all households in Wa… we are mobilizing resources to extend our network to all areas* (Interviewer 4, 2021).

From official data provided by the GWCL, the total number of official piped connections on the public utility network in Wa as of 2021 is about 7000. Of this, 190 are public standpipes; 40 are institutional or government department connections; 290 commercial connections, and 6480 are household connections. Proportionally, household piped water coverage in Wa as at 2021 stands at 18.6%—an increase of 3.4%

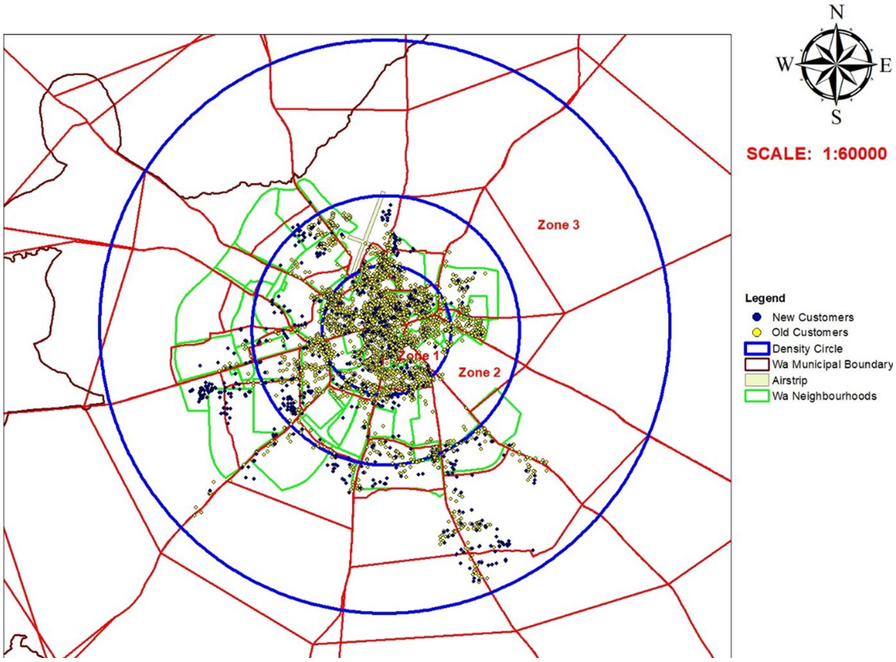

Fig. 2 Spatial distributions of household connections. *Source* Author's construct (2020)

since 2010 (GSS, 2014). Due to the low piped water coverage, a majority of households in Wa are dependent on other water sources (like boreholes and tanker supply) outside the utility network. This is particularly so in the peripheral zones (i.e., Xavier/Nakore and SSNIT/Napogbakolee extension) where the GWCL's network's coverage is comparatively limited (as shown in Fig. 2).

Physical access to piped water system

The first layer of our materiality analysis focuses on physical access, which critically examines the availability, proximity and extent of principal feeder main coverage in Wa with a focus on the four sampled neighbourhoods. Physical access to principal feeder mains by users is a precondition for gaining access to the piped water supply. In this context, physical access refers to users' proximity to a functional utility feeder main, which enable them to develop subsidiary networks to their dwellings. Geospatial data of customers' locations were used as proxy indicators of physical access to principal feeder mains. Our mapping analysis of customers locations shows that piped network coverage is densely populated at the city centre (Zone 1) but progressively becomes dispersed towards the urban peripheries (Zones 2 and 3) (Fig. 2). Notable neighbourhoods in Zone 1 are Zongo, Kabanye, Tendamba, Wapaani, Market, Nayiri, Limanyiri, Suuriyiri, Tagrayiri, Degu, Dondoli, and Fongo. Zone 2 comprises of Kpaguri, Dokpong, Dobile, Mangu, Airstip, Kumbiehi, Napogbakole, Kambali, Juderiyiri and Tampalpaani while Zone 3 is made up of Sombo, Xavier, Kpaguri Extension, Darko, Bamahu, Chorko, Kpalsaga and Nakoripaani.

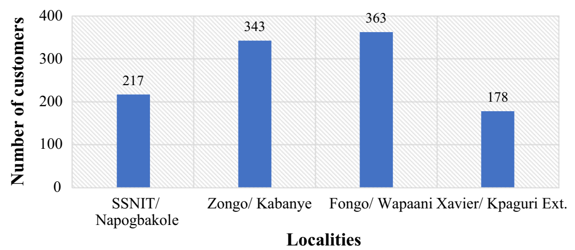

Fig. 3 Customers' distribution across the four study neighbourhoods

Of the four study areas, Kabanye/Zongo and Fongo/Wapaani, which are located in the inner city, appear to have wider network coverage than Xavier/Kpaguri Extension and SSNIT/Napogbakolee, which can be found at the urban fringes (Fig. 2). From Fig. 3, official data provided by the GWCL shows that there are more customers in Kabanye/Zongo

Table 1 Differences in the properties of principal feeder mains in four locations. *Source* Ghana Water Company Limited, Wa, December 2020

Neighbourhood	Size (mm)	Length(mm)	Est. design capacity (no. of connections)	Actual no. of connections
Fongo/Wapaani	110	5124	200	363
Zongo/Kabanye	160	6555	250	343
Xavier/Nakore	255	4651	500	178
SSNIT/Napogbakole	255	11,178	500	217

(343) and Fongo/Wapaani (363) than in Xavier/Kpaguri Extension (178) and SSNIT/Napogbakolee (271). These numbers support Fig. 2 which indicates wider network coverage in the inner city than in the peripheries.

Most of the new connections were developed in the outskirt of the city (Zone 3), following the commissioning of the Jambusie water system in 2017 (Fig. 2). This is indicative of GWCL's commitment to extend water to all parts of Wa. However, it was uncovered that households now bear the full cost of water connection (both subsidiary and main lines) because the GWCL has inadequate funds to undertake major expansion works. This means that households' proximity to the principal feeder main has a direct influence on the first service connection fees charged by the water company, which covers the cost of pipe materials, meters, valves and labour. According to officials of the GWCL, the lowest cost of the first connection is about 1,000 Ghana Cedis (approximately 200 US dollars). However, this amount progressively increases as the distance between the household and the principal feeder mains widens.

Technical access

Our second level of materiality analysis focuses on the technical properties of principal feeder mains. These pipes are important because they convey water supply directly from reservoirs to the neighbourhood level for onward connection by residents. As the main conveyor of bulk water, the technical properties of principal mains—size and length—have a direct influence on water pressure as well as the quantity and quality of piped water supply to various neighbourhoods in the city. Our analysis shows that the size (diameter) and length of principal feeder mains differ considerably across the four neighbourhoods that were studied. For instance, the size of the principal feeder main that conveys bulk water supply to Xavier/Kpaguri Extension and SSNIT/Napogbakolee is 225 mm, which is about two times bigger than the one sending water supply to Waapaani/Fongo (110 m) and Kabanye/Zongo areas (160 m) (Fig. 3). If the size of water pipes is directly proportional to the quantity of water they convey, it means that areas like Xavier/Kpaguri Extension and SSNIT/Napogbakolee will receive more water supply than their counterparts in the Waapaani/Fongo or Kabanye/Zongo. If this is the case, and water quantity is the indicator, it means that despite having wider network coverage, the residents of Waapaani/Fongo and Kabanye/Zongo would have limited water access compared to their counterparts in the outskirts.

Secondly, the size and length of principal feeder mains affect the water supply system's carrying capacity, which refers to the highest number of connections that the principal feeder main can support without undermining its functionality and operational efficiency (Interview 5, 2021). The system's design capacity can be determined by system's engineers using hydraulic models, based on several factors such as size, length, elevation and others (Interviews 1 and 4, 2021). From Table 1, the results show that principal feeder mains in Waapaani/Fongo and Kabanye/Zongo areas have exceeded their respective design capacities, at least by more than half (50%). For instance, Waapaani/Fongo has an estimated design capacity of 200 connections but it currently serves about 363 customers, representing 82% more. Similarly, Kabanye/Zongo with a capacity of 250 customers is currently connected by 343 customers, roughly 37% more than its planned capacity. In contrast, the feeder mains serving water to Xavier/Kpaguri Extension and SSNIT/Napogbakolee are yet to reach their installed capacities. In fact, both neighbourhoods have only utilized less than half of their carrying capacities, which emphasizes the fact that they are relatively new networks, which are still expanding (Fig. 4).

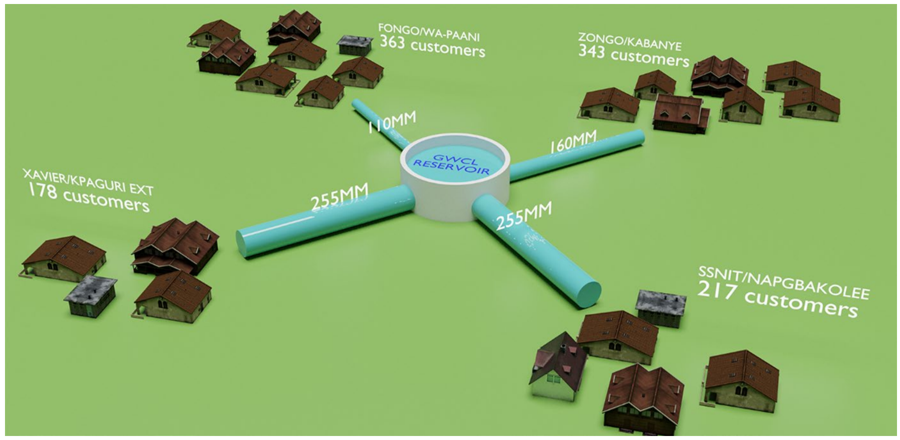

Fig. 4 Skirt of water distribution networks showing unequal sizes of principal mains across the four neighbourhoods

According to utility engineers, if a network exceeds its carrying limit, that line is likely to experience low pressure. One of the Engineers stated as follows; *If the mainline exceeds its carrying capacity, households at the end of the line may experience low pressure, especially when they are located on a highland* (Interview 5, 2021). This may well explain why some residents in Waapaani/Fongo and Kabanye/Zongo areas said they occasionally experience low-pressure than their counterparts at the outskirts. The qualitative interviews with residents confirmed that the quality of water service delivery in the inner city neighbourhoods is generally low. About three out of 10 customers we interviewed in Zongo/Kabanye and Wapaani/Fongo areas indicate that they experienced low pressure occasionally, which becomes more frequent in the dry seasons (Interviews 8, 9 and 10, 2021). Responses from some customers in Zongo/Kaabanye and Wapaani/Fongo on the pressure level of their taps are captured as follows; *my pressure is not good. I heard that we are many on this line and I am at the end of the line. So when all those before me open their taps, the pressure is usually bad for me. The pressure is only good when it is only a few households that have opened their taps* (Interview 11, Zongo, 2021). *The pressure is generally ok. It is only a few times that it goes low* (Customer 2, Kaabanye, 2021). *The pressure is good, except that when the water starts flowing, the pressure is usually low at the beginning. It takes about 10 min for the pressure to pick up* (Interview 8, Wapaani, 2021). In contrast, only one out of the 10 customers interviewed in Xavier/Kpaguri and SSNIT/Napogbakolee residential areas reported occasional low-pressure experience.

Though this survey is not comprehensive in coverage, the results suggest that, although physical access in terms of coverage is relatively low in urban fringes, residents of those areas appear to be enjoying high-quality water service delivery than those at the centre where coverage is relatively high. This is a result of pressure on networks, leading to low pressure in supply. Endemic low-pressure manifests a form of material inequality that is often overlooked in the urban water debate. However, the persistence of low-pressure may be localised or more specific to particular neighbourhoods, due to local factors such as illegal connections by users and the elevation of the natural terrains (Interview 5, 2021). Moreover, the network in SSNIT/Napogbakolee is disproportionally higher than the rest of the neighbourhoods, representing almost the same length as those in Waapaani/Fongo and Kabanye/Zongo areas put together (Table 1).

Discussions

From the results, piped water coverage in Wa is low. Only two out of every 10 households in Wa are connected to the piped water system. A majority of households therefore depend on non-piped systems for their household water needs (GSS, 2014). Similarly, Peloso and Morinville (2014) found that a majority of residents in Ashiaman (Accra) rely on various water sources other than the GWCL's networks for their water needs. Also, Alba et al. (2019) in their study observed that mobile tanker delivery services is an important source of water supply in Accra; not only for residents who are not connected to the utility grid, but also those who are connected but experiencing erratic water supply. These 'off-grid' sources often tend to cost between 2–5 times higher than the average public utility service, although they also have the lowest water quality (see Peloso & Morinville, 2014; Alba et.al. 2019; Schramm, 2018). Thus, high dependence on off-grid sources could expose the population to higher risks of contracting water-borne diseases. Between 2010 and 2020, households piped water coverage in Wa increased marginally by 3.4%. This translates into an annual growth rate of about 0.34%. With access to water on premises (mainly piped water connections in the case of Ghana) being one of the elements of safely managed water services, Wa risks missing universal access to safely managed water services by 2030.

In terms of physical access to network infrastructure, we found that areas classified by the municipal authorities as low-income areas in the inner-city rather have wider network coverage than high-income areas at the outskirt of the city. This could be explained by the fact that water network's development in Wa started in the inner city before extending to the outskirts. Also, as a rapidly expanding city, the peripheries are developing faster than the rate of network expansion. In Ghana where centralized networks' development is often led by the state, and thus strongly shaped by financial resource limitations, it is expected that urban margins will experience limited connectivity compared to the inner city. These findings are not unique to only Wa. For example, Uitermark and Tieleman (2020) in their study of water supply in Accra, found that the public utility network coverage tends to be limited at the peri-urban areas than in the centre. Though these findings may be uncharacteristic of African cities, they highlight the fact that sociotechnical systems (such as water systems) are products of their local environments. Limited network coverage at the outskirt of the city reflects the case whereby urban growth appears to be outpacing networked infrastructure provision, which is mostly state-led.

The study also identified financial constraint as the main factor inhibiting network expansion by the water utility company. Similar observations were made by Ablo and Yekple (2018) in Ashaiman. Inadequate financial resources compelled the water utility company to rely on "co-provision" arrangement with residents, whereby residents agree to pay for the full cost of materials and connections fees. This means that households that are closer to the principal feeder main will pay less for water connection than those farther away. This could undermine physical access by poor residents at the outskirts, where extension of principal main is still ongoing. In Accra, Uitermark and Tieleman (2020) observed that connection fees charged by GWCL has stimulated the growth of private boreholes, which are relatively cheaper options, especially for those residing in peri-urban areas.

Furthermore, the case study has shown that physical access to water infrastructure does not guarantee access to sufficient quantities of water at all times. Equally important are the technical properties of the water infrastructure. The results of the study showed that although Waapaani/Fongo and Kabanye/Zongo (in the inner city) have wider network coverage compared to Xavier/Kpaguri and SSNIT/Napogbakolee (in the outskirt), occasional cases of low pressure were widespread in Waapaani/Fongo and Kabanye/Zongo than in Xavier/Kpaguri and SSNIT/Napogbakolee. This is because the size of the principal feeder mains in Waapaani/Fongo and Kabanye/Zongo were not only small but exceeds their carrying capacity whiles the principal feeder mains in Xavier/Kpaguri and SSNIT/Napogbakolee are yet to reach their carrying capacity. Occasional low pressure in the inner city including Waapaani/Fongo and Kabanye/Zongo can limit the quantity and quality of water households collect for consumption. These findings are in line with earlier studies conducted by Tiwale et al. (2018) and Tiwale (2019) in the case of water access in Lilongwe. What these findings mean is that merely having access to a waterline is not sufficient to conclude that an area (or household) would have better access to piped water supply; equally important is to know the material properties of the various water mains.

In sum, the study reveals considerable intra-urban variations in access to piped water supply among inhabitants of the four neighbourhoods. These findings are consistent with several studies across various African cities. For instance, various studies by Adams et al. (2016); Bellaubi & Visscher (2014) and Peloso & Morinville (2014) found that there are considerable disparities in piped water access between inhabitants of low-and high-income areas in Accra, Ghana. However, while these authors generally associate these disparities with socioeconomic variables such as income, wealth and education, the findings of the study also show that spatial disparities in water supply correlate with the materiality of the network. The paper argues that, aside socioeconomic and political variables, the material properties of water infrastructure is an important predictor of people's accessibility to improved water service delivery. Hence, knowing the material properties of piped water systems can be a useful entry point for understanding intra-urban disparities in water access. Elsewhere in Malawi, similar conclusions were reached by Tiwale et al. (2018). They argue that material elements and properties of water systems such as reservoirs, tanks and pipelines (including their properties such as direction, shape, sizes) play a central role in shaping where, how much and to whom piped water supply benefited in the city.

Conclusions

This article analysed how the material dimension of water systems shapes intra-urban inequalities in networked water access, using Wa as the case study. Two aspects of materiality were analysed; (1) physical access to the principal feeder mains with the indicator being customer locations, and (2) material properties (size and length) of the principal feeder mains. The study uncovered technical variations across these infrastructure, which we argued shape intra-urban disparities in water supply across the city. First of all, mapping of customers' locations shows that piped water system coverage is densely populated in the city centre but progressively dispersed towards the urban peripheries. This is because principal feeder mains are more accessible to households in the inner city than the outskirts. Furthermore, our analysis of the material properties of the principal feeder mains in the four study neighbourhoods revealed that physical access to a water network is not a sufficient condition in explaining households' water access. Equally important are the material properties of the water infrastructure. Thus, without quality infrastructure, people may have physical access to water systems but hardly receive quality water services.

The article contributes to debates in urban water research, in particular, inequality in urban water access. It does so by bringing in the often-neglected lens—materiality—to explain how and why inhabitants of different parts of the city might experience disparities in access to piped water supply. We demonstrated that intra-urban inequality in water supply is partly due to variations in the physical and technical properties of the material systems of the networks. The study points to the need for a rethinking of the conceptual notion of what 'water access' means, and how it should be measured and evaluated across different contexts, especially if the goal is to understand intra-urban disparities. Beyond academic debates, it provides empirical insights for shaping urban water policy and programmes and emphasizes the importance of the material dimensions of technical systems in water access. Thus, we call on urban and water scholars, practitioners and policymakers to give serious consideration to the material dimension of water systems in their analysis, theorization and measurement of urban water access in African cities.

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Data availability All data for this article is available. However, public disclosure is not permitted due to data protection polies. To access the data, please contact the first author.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Informed consent All of the interviewees who participated in the study did so voluntarily and with informed consent. Their names were not published in order to protect their privacy.

Appendix 1: Interviews cited

1. Informant interview, GWCL official, February 4, 2021.
2. Interview, GWCL official, December 10, 2020.
3. Focus Group Discussion, GWCL official, December 20, 2020

4. Interview with Engineer, GWCL official, February 5, 2021
5. Focus Group Discussion, GWCL official, December 20, 2020
6. Interview with Technician, GWCL, March 2, 2021
7. Resident of Wapaani, March 10, 2021.
8. In-depth interviews, GWCL customers, Wapaani, March 2021
9. In-depth interviews, GWCL customers, Zongo, March 2021
10. In-depth interviews, GWCL customers, Kabanye, March 2020
11. In-depth interviews, GWCL customers, Zongo, March 2020

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