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Domestic Groundwater Abstraction in Lagos, Nigeria: A Disjuncture in the Science-Policy-Practice Interface?

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Abstract

The rapid development of groundwater systems as part of urban water supplies around the globe is raising critical questions regarding the sustainable management of this essential resource. Yet, in many major cities, the absence of an effective policy regime means that the practice of groundwater exploitation is driven by the actions of domestic households and drilling contractors. Understanding what shapes the decisions and practices of these actors, their understandings of the groundwater resource and the extent to which scientific knowledge shapes this understanding, is an area of critical importance that is currently under-researched. Using a mixed-methods methodology, the paper explores domestic practices of groundwater abstraction in Lagos, Nigeria. It finds that there is a disjuncture between the households who are actively shaping exploitation of the groundwater resource on a day-to-day basis and science and state actors. This disjuncture results in household decisions that are influenced by commonly held, but potentially outdated, perceptions of the groundwater resource rather than scientific evidence or policy instruments. The unseen nature of groundwater resources effectively renders the scale of changing groundwater conditions invisible to households and the state, adding to the challenge of influencing practice. Addressing this disjuncture requires not just more scientific knowledge, but also the active construction of interfaces with, and between, non-state actors through which knowledge can be confronted, discussed and shared.

1. Introduction

The role played by groundwater in urban water supplies is gathering more attention, particularly in low- and middle-income countries (Foster et al, 2018). Rising demand, coupled with threats of resource degradation, has focused attention on how policies and practice can support sustainable groundwater management (Famiglietti, 2014; IAH, 2015, Lapworth et al, 2017, Villholth et al, 2018). In many cities across low- and middle-income countries it is everyday non-state actors, such NGOs, households and firms, who are driving the rise in groundwater abstractions (WHO/UNICEF, 2016; IAH, 2015). These actors directly commission their own wells and boreholes, which operate alongside the formal state provision of water supply infrastructures but may not be subject to significant regulatory control. In practice, this gives rise to urban water infrastructures that are pluralistic and highly distributed, which we define as involving a myriad of individual actors with access to multiple options for the sourcing of domestic water supplies.

The proliferation of private wells and boreholes for domestic water consumption in cities raises important questions for the stewardship of groundwater resources by urban households, and the influence of science or state actors on the actions of these households, particularly in circumstances where the levels of understanding of groundwater resources, of both state officials and the public, may be low (Hoque et al, 2019; Lopez-Maldonado et al, 2017; Rajeevan and Mishra, 2019). Academic research into the stewardship behaviour of private well owners, and the factors that influence this, remains limited and tends to focus on rural areas and the global north (Gholson et al, 2018; Kreutzwiser et al, 2011; Ternes, 2019). These studies stress the limitations of policy approaches where the onus to act is on individual well owners and have found high levels of confidence and complacency in the quality of drinking water (Chappells et al, 2015; Imgrund et al, 2011) which may not concur with the actual quality of the water and associated health risk (Rowles III et al, 2018; Gholson et al, 2018). Water literacy can also be related to proximity to the groundwater resource (Ternes, 2019) and individuals' perceptions of local environmental problems (such as contamination) rather than their broader environmental awareness (Imgrund et al. 2018).

Previous research suggests that the role of policy, government officials and educational materials are less relevant in shaping water literacy than social norms, neighbourhood networks, previous education, social media and formal media (Chappells et al 2015; Kreutzwiser et al, 2011; Rajeevan and Mishra, 2019). However, studies in urban areas, particularly in Africa are lacking. For example, a recent review of global groundwater governance issues included nothing on the situation in urban Africa (Villholth et al. 2018) and little on the role of individuals. Therefore, by focusing on the situation of Lagos, Nigeria, arguably the largest and fastest growing city in sub-Saharan Africa, we introduce a new dimension to the existing literature.

In this paper we examine urban households' use of groundwater in Lagos, Nigeria - a strongly pluralistic and distributed waterscape within a limited policy environment. We explore three questions to help examine how practice has developed in the absence of policy or widespread scientific knowledge: (1) what are households' perceptions of the quality of available groundwater and how does this compare to actual water quality; (2) what are households' perceptions of the amount of groundwater available to them, now and into the future; and (3) what role is played by drilling contractors, as potential knowledge brokers or intermediaries, in providing the evidence to base practice on. We draw our findings together to consider whether a disjuncture in the science-policy-practice interface exists in the case of groundwater abstraction in Lagos, Nigeria and, if so, the reasons for this and its implications. We conclude by considering whether this is particular to the case of Lagos, or whether our findings have relevance more widely.

2. Water Supplies in Lagos

Lagos State is located on the Atlantic littoral of Nigeria. In 2016 the State had an estimated population of between 12.5 million and 21 million persons (United Nations, 2016; World Population Review, 2018), with population numbers projected to double to around 32 million persons by 2050 (Hoornweg and Pope, 2014). At the heart of Lagos State lies the metropolitan area of Lagos, the commercial capital of Nigeria and the largest city in sub-Saharan Africa. As Nigeria is a federal nation, responsibilities for the provision of services such as water supplies are devolved to individual States. Within Lagos State, responsibility for managing the supply of public potable water lies principally with the Lagos Water Corporation (LWC)[1]. It is regulated by the Lagos State Water Regulatory Commission, which is also responsible for the control of water pollution. In addition, the Lagos State Ministry of the Environment (part of the Lagos State Government) has a mandate for environmental quality across the State. Legal opinion as to who governs the right to access groundwater is currently contested, with some advocating the rights of individuals to unrestrained access to all waters within the boundary of their property and others advocating that it is a responsibility of federal government (Akpabio and Ekanem, 2009). At the State level groundwater management focuses primarily on issues of water quality and forms part of the activities of the Lagos State Environmental Protection Agency.

Households account for some 70% of the demand for water supplies in Lagos (Balogun et al, 2017). At present there is an acknowledged gap between the public demand for water and the amount the State is able to supply (LSWC, nd; Punch Nigeria, 2017), with estimates of the proportion of the population served by piped municipal water supplies ranging from around 10% to around 30% (Aina and Oshunrinade, 2016; Healy et al, 2018; Omole et al, 2016). Public water supplies are also erratic and frequently subject to prolonged outages (Balogun et al, 2017). In the

[1] In rural areas the national Rural Water Supply and Sanitation Agency takes responsibility.

absence of reliable public water supplies, many households and businesses have turned to commissioning their own boreholes, via private contractors, in order to secure personal water supplies. This practice is facilitated by the hydrogeology of Lagos, which consists of a series of sand and gravel aquifers of varying thickness, interbedded with clay horizons, which occur between the ground surface and a depth of less than 200m (Longe and Malomo, 1987; Balogun et al, 2017; Yusuf et al, 2018). The Coastal Plains Sands Aquifer is the most significant in terms of water supply and is easily exploited by shallow hand dug wells or deeper manually drilled boreholes. Balogun et al (2017) note that public water supplies are usually obtained from aquifer depths of 40m-200m (see also Longe and Malomo, 1987). A deeper aquifer, at around 450m depth, is not widely exploited for water supply (Yusuf et al, 2018).

The proliferation of domestic boreholes in Lagos is widely acknowledged (Yusuf et al, 2018), although evidence on the true scale of development is elusive. The LWC estimates that there are up to 200,000 such boreholes across Lagos State[2]. Others argue that this may be an underestimate, with one report estimating "that private manually drilled boreholes provide the primary drinking water source for at least 5 million people in Lagos State", when supplies from water vendors are included (Danert et al, 2014 p.18). Population surveys suggest that boreholes are the source of water for around half of respondents (independent of income), with wells used by a further 15% (Omole et al, 2016). One reason for the uncertainty in the number of boreholes is that there is, at present, no requirement for the licensing or registering of boreholes, nor any process for monitoring or managing the quality or quantity of groundwater being abstracted.

As for many cities in sub-Saharan Africa, up-to-date and reliable groundwater data is lacking for Lagos State (Foster et al, 2018). Available studies focus on the shallow aquifer and present a mixed picture. Some studies report groundwater to be suitable for domestic use, with borehole water of better quality than that of hand-dug wells, whilst others report levels of dissolved solids (TDS) above the WHO recommended limit for drinking water in groundwater at very shallow depths (3m-13m) (Aina and Oshunrinade, 2016; Afolabi et al, 2012; Longe and Malomo, 1987, Yusuf et al, 2018). Yusuf and Abiye (2019) find that in the Lagos coastal zone there is evidence of anthropogenic contamination in the near surface aquifer and of saltwater contamination in the aquifer underlying this, with the extent of contamination recorded rising since earlier work reported in 2012. Evidence on residency times and recharge of the aquifers is limited, with science only gradually building an understanding of the complexity of the groundwater system underlying Lagos (Yusuf et al, 2018). In their work Yusuf et al (2018) find that the majority of groundwater in

[2] Reported by a Lagos Water Corporation official in the stakeholder event connected to this study.

the shallow aquifer systems underlying Lagos is renewable, derived from recent active recharge predominantly occurring during the wet season (Yusuf et al, 2018).

3. The Science-Policy-Practice interface

The persistent gap between science and practice is widely recognised, despite long-standing efforts to address this (Kettle et al, 2017; Vogel et al, 2007). One reason for the persistence of this gap is the tendency to regard the science-policy-practice interface as a linear or cyclical path where knowledge generated by science informs policy which then influences practice (Ward et al, 2009). A powerful critique of this perspective contends that it overlooks both the social dimension of the process of knowledge production, exchange and application and the fact that the various components of the science-policy-practice nexus are rarely organised in a linear fashion (Cash et al, 2003; Dilling and Lemos, 2011; Ward et al, 2009). Critiques of the linear model also highlight the significant role played by actors other than the state and professional stakeholders in shaping knowledge exchange and the practical application of knowledge, particularly civic society (Nowotny, 2003; Carayannis and Campbell, 2010).

Recent work by Cavallini et al (2016) suggests that the role of the state in knowledge exchange and learning is both more limited than often presumed, and that the capacity of a state to act declines with lower levels of economic development, whilst the role of civil society increases. Cavallini's perspective accords with new theorisations of the state that emphasise the role of multiple actors in shaping the production of urban space, highlighting how power rests with both state and non-state actors (Schindler, 2014). In areas where access to infrastructure is uneven and contested, state-led policy actions are just one shaper of practice (Cornea et al, 2017; MacFarlane and Desai, 2015).

In recognising the potentially decisive role played by non-state actors, such as individuals and households, in affecting the groundwater system, academic attention is increasingly turning to what shapes the decisions and actions taken by these actors. One key feature appears to be the perception of the nature of the groundwater resource held by communities. Once an issue is perceived or framed in a particular way it can provide a powerful shared narrative that can prove difficult to alter (Van Hulst and Yanow, 2016; Schön and Rein, 1994). In their work, Van Hulst and Yanow (2016) highlight how the framing of an issue is dynamically constructed through the interaction of different parties situated in both time and place. Where science and state actors are not strongly present, or the framing of an issue is contested, cultural memory, faith and informal institutions, such as the role of traditional leaders, all play a critical role in shaping collective framings, practice and perceptions of risk (Murphy et al, 2016; Douglas and Wildavsky, 1982).

The importance of knowledge generated by non-scientific means is increasingly recognised in the policy literature. The significance of traditional knowledge, practices and beliefs is now well-established (Gómez-Baggethun et al, 2012). Academics are also now recognising the role played by 'non-knowledge' and 'ignorance' (Nielson and Sørensen, 2015; Paul and Haddad, 2019). In this framing, ignorance, or the unknown, is no longer regarded simply as a residual to be overcome by increasing scientific enlightenment (Weiss, 1979) but as a powerful force in its own right which can be deliberately constructed. Writing on the 'unexpected virtue of ignorance', Nielson and Sørensen (2015) welcome the recognition of the role of the 'unknown' in decision-making processes, in so far as this shapes conscious and unconscious decision-making.

The challenge of the 'unknown' is particularly pertinent in the case of groundwater, which is frequently described as a hidden resource. In such circumstances, academic writers stress the role of the mass media in bringing issues into existence for the public and acting as brokers of knowledge, dialogue and policy (Ravetz, 1987; Nisbet and Fahy, 2015). However, Nielson and Sørensen (2015) caution that the media operates according to its own logic of gathering audiences and advertisers, which may affect its ability to act as an effective broker in specific instances. Unpacking the role of the media as an actor in the science-policy-practice interface is critical when considering how science and policy affect practice (Eberth et al, 2014), always recognising that the media can be partial in its reach.

One of the challenges for understanding the science-policy-practice interface is that environmental problems, such as water management, are neither straightforward nor solely technical in nature (Swatuk, 2005; Pahl-Wostl et al., 2012; Welp et al, 2006). Referring to Garrison and Greer-Wooton (2000), Welp et al (2006), point out that as environmental problems tend to be subject to both factual uncertainty and conflicts over values, they are particularly difficult to frame in any meaningful way, leading to their description as 'wicked problems' (Newman and Head, 2017). In such cases there is the risk that actors speak past each other rather than engage in meaningful dialogue, a version of Van Eeton's 'dialogue of the deaf' (1999) where fundamental differences in underlying beliefs and values complicate learning across the science-policy-practice interface. Newman and Head (2017) argue that rather than trying to reduce 'wicked' problems to their technical components, the real challenge is to untangle the values-based discourse that shapes decision-making.

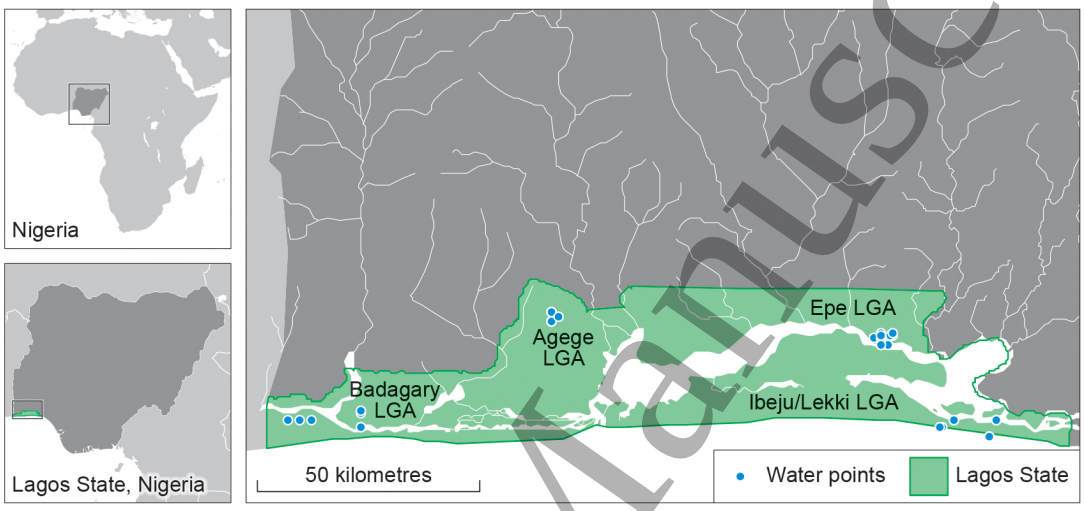
A non-linear conception of the Science-Policy-Practice interface (Carayannis and Campbell, 2010) brings the role of households and other non-state actors to the fore, particularly in circumstances where the state is a weak or ineffectual actor. In such situations, the decisions, values and understandings of non-state actors can play a decisive role in shaping practice. In the case of urban groundwater in Lagos, the limitations of current scientific knowledge further points to the need to better understand the multiple, lay and often localised and socially-contingent knowledges

shaping actions and perceptions of risk within lived communities (Capstick, 2013; Howell et al, 2016; Moran, 2016).

4. Method

The research focuses on Lagos State in Nigeria (Figure 1). Permission for the research was granted by the Lagos State Ministry for the Environment and was undertaken in the Local Government Areas (LGAs) of Badagary, Epe, Agege and Ibeju/Lekki (Figure 1). The methodology comprised four principal elements:

Figure 1 Study area and waterpoint testing locations



1. A one-day introductory stakeholder event (SE) held in March 2017, consisting of 44 invited community leaders, government officials, academics, private drilling contractors and other stakeholders, served to introduce the purpose of the project and to secure the support of community leaders for the research to take place in their communities. This event was complemented by a closing event to share the findings of the study in July 2017.

2. A Waterpoint Survey of 40 wells and boreholes (broad locations set out in Figure 1) across the four LGAs provided information on groundwater availability and quality. A mix of shallow wells (typically hand-dug) and motorised boreholes (typically manually-drilled) were surveyed providing, where possible, source depth and depth to water table measurements, water quality parameters, including specific electric conductance (SEC, a measure of the salinity of water), nitrate levels, and E. Coli concentrations (measured in terms of Most Probable Number (MPN) of coliforms), and a water point vulnerability score based on a sanitary inspection of each water point (WHO, 1997). Where users of each waterpoint were present at the time of testing they were asked for the history of the waterpoint, their perceptions of water quality and any observed seasonal variations in water availability and quality. In addition, a more detailed semi-structured face-to-face interview was

undertaken with representatives of sixteen households who were available at the time their waterpoint was being surveyed and agreed to a more in-depth interview (Household Interviews). The interviews were administered in Yoruba (the local language) by local academics and considered the use of the water drawn from the water source, perceptions of the groundwater resource, the governance of the resource and concerns for the future held by the household. Questions were open-ended with no prompts.

3. An online survey of 539 individuals living in Lagos State provided a broader contextual analysis of the factors promoting or constraining the proliferation of domestic boreholes at the household level. The survey was targeted at individuals with the means to develop their own boreholes (based on income assumptions) and administered using existing survey panels organised by the market research company Qualtrics. The survey was conducted in English as is standard in the use of these survey panels. Quota sampling was utilised in order to obtain as representative a sample as possible in terms of age and gender.

4. Wider qualitative data on use, perceptions and understandings of the water resource, was collected through:
   a) Four community-based focus groups (CFGs), with one held in each LGA. Total participation comprised 58 persons with a broad gender balance. Each CFG was led by a local academic using a common semi-structured framework and was undertaken in Yoruba. The CFGs considered the main sources of water used by those communities, recent trends in the development of water sources, governance arrangements for private wells and boreholes, understanding of water quality and resource availability and questions around common perceptions of community attitudes towards groundwater. Attendance at the CFG was based on invitations from community leaders.
   b) A focus-group of professional drilling contractors was attended by six drillers (Drilling Contractors). The discussion was undertaken in English and utilised a similar semi-structured schedule to the community focus groups, with a stronger emphasis on the group's understanding of trends in the development of domestic boreholes and groundwater conditions.
   c) Semi-structured interviews with two journalists, to assess the nature of the media's coverage of groundwater extraction by domestic households. The journalists were identified through a review of published articles on groundwater and domestic water supplies.

Fuller details of the methodology are available in Annex 1.

5. Results

5.1 Access to boreholes

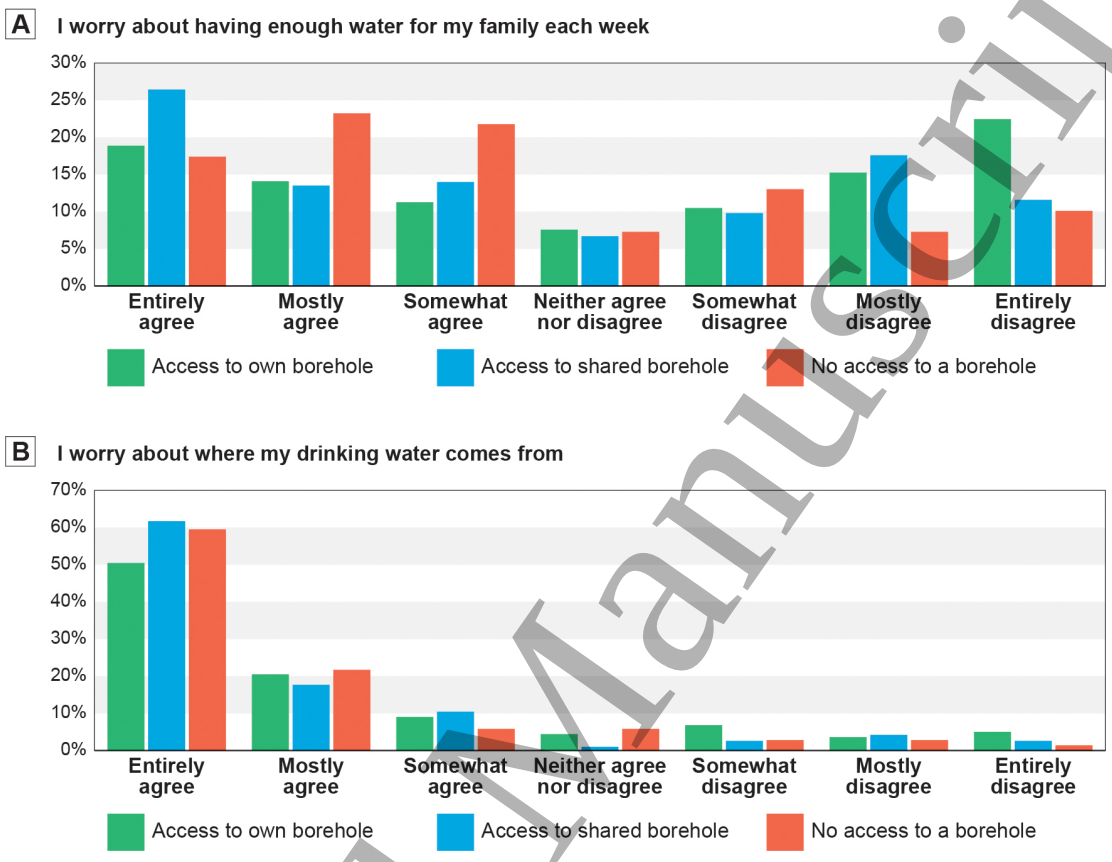
The study findings confirm the significance of domestic boreholes as a source of domestic water supply in Lagos State. Slightly over half (51.3%) of the respondents to the online survey reported that they had access to their own borehole, with a further third (35.9%) reporting access to a borehole shared with neighbours. Just 12.8% of online respondents reported that they had no access to a privately-owned domestic borehole. The Drilling Contractors and the four CFGs all endorsed the significance of private borehole development in Lagos for domestic water supplies. In common with findings from other studies (Nauges and Whittington, 2010), the online survey found that households tend not to rely on one water source but make use of multiple sources depending on availability and planned use. The online survey found that bottled and sachet water tends to be most commonly reported as a drinking water source (used weekly by 85% of respondents), followed by private boreholes (72% reporting that they use a private borehole at least weekly).

5.2 Confidence in water supplies

According to participants in the CFGs and the SE, one of the major drivers for the commissioning of private domestic boreholes is to increase the security of household water supplies. Participants in the CFGs and the SE highlighted the fact that the public water infrastructure does not extend to all communities and that where it does, supplies are often erratic, with multiple reports of frequent water outages. As one SE participant memorably put it: "we don't want plans in the pipeline, we want water in the pipeline!". The 16 Household Interviews further support this perspective with 87.5% describing public water supplies as 'inconsistent', 'erratic' and 'unreliable'; significantly outweighing the next most frequent descriptions of public water supplies: good quality and cheap cost (cited by 37.5% and 18.75% respectively).

A lack of confidence in available water supplies is also evident in responses to the online survey (Figure 2). When asked whether or not they worry about having enough water for their family each week (Figure 2a), around one third of survey respondents agree that they do (36.3%). Post-hoc comparisons treating the agree-disagree responses as a seven-point scale (one-way ANOVA: $F(2, 535) = 4.92$, $p=.008$) indicate that survey respondents with their own borehole are less worried about having enough water than survey respondents with shared boreholes (mean difference=.52, SD=.21, p=.04) and that survey respondents with their own borehole are less worried than survey respondents with no regular borehole access (mean difference=.75, SD=.30, p=.04). In contrast, three-quarters of online survey respondents (75.7%) agree that they worry about where their drinking water comes from (Figure 2b). Again, post-hoc comparisons (one-way ANOVA: $F(2, 536) = 3.99$, $p=.02$) show that survey respondents with access to their own borehole are less likely to worry about their water source than are survey respondents who access a borehole shared with others (mean difference=.39, SD=.15, p=.03). Indicative of the wider concern regarding water quality is the finding from the online survey that most respondents (82%) treat their drinking water, regardless of source.

Figure 2 Results of the online survey of individuals showing the percentage of respondents that agreed with the statements: [A] I worry about having enough water for my family each week and [B] I worry about where my drinking water comes from.



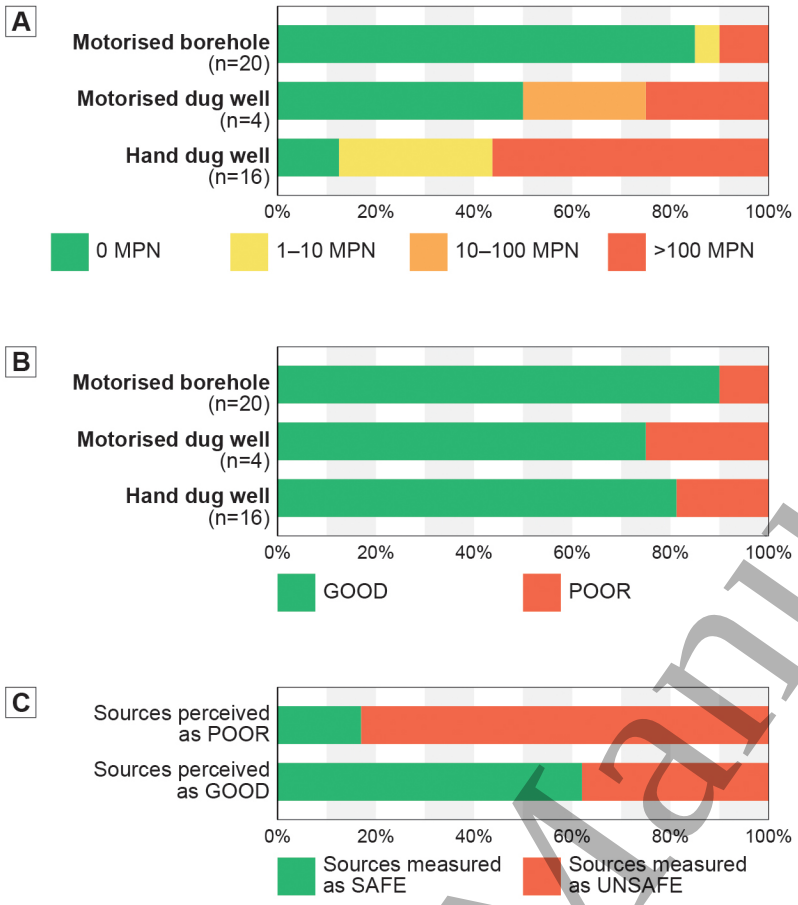
Source: Online survey

5.3 Perceived vs actual water quality

Findings from the Waterpoint Survey highlight the variation in water quality between boreholes and hand dug wells (Figure 3a). 82% of shallow wells recorded E. Coli levels greater than 1-10 MPN which poses an intermediate, high or very high risk to human health (according to World Health Organisation guidelines for safe levels of E. Coli in drinking water). Deeper wells and boreholes are less likely to demonstrate levels of E. Coli posing a risk to human health, but some still recorded levels that WHO regard as high or very high risk. SEC and nitrate levels were generally within WHO drinking water guidelines and are not illustrated here, although two deep (60m) hand-dug wells returned elevated levels of both SEC and nitrate that exceeded WHO drinking water guidelines.

Figure 3 The quality of water from different source types in the survey within Lagos: (a) E-Coli (MPN) measured from different sources; (b) households'

perceptions of water quality; and (c) comparison of measured water quality with perceptions of water quality.



Source: Waterpoint survey

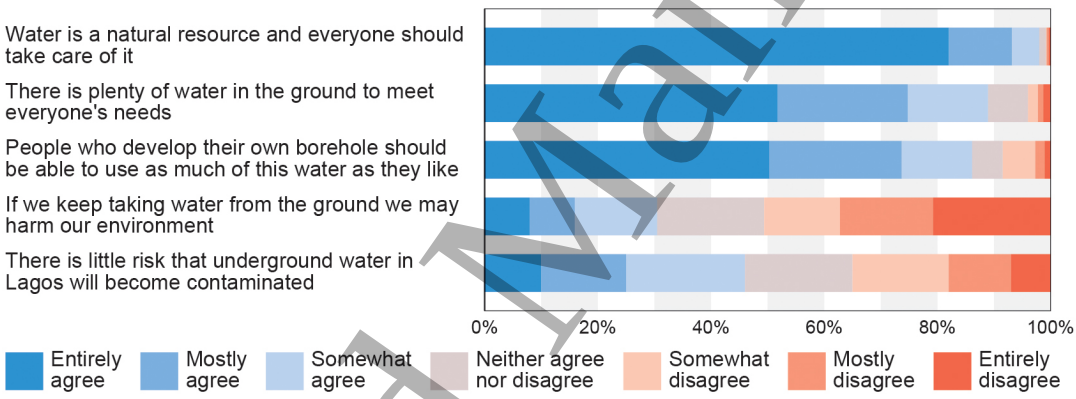
Waterpoint users reported that 90% of the boreholes and 80% of the hand dug wells provided water supplies they regarded as being of 'good quality' (Figure 3b). Figure 3c compares the findings of the waterpoint survey E. Coli tests for the 40 waterpoints based on a comparison of the responses provided by the users interviewed at each waterpoint and the recorded water quality data. Of those waterpoints perceived as good quality, almost 40% displayed unsafe levels of E. Coli according to WHO drinking water guidelines (MPN > 1). Most of these are hand dug wells and it should be noted here that not all of these sources were being used for drinking purposes.

5.4 Perceptions of the groundwater resource

Existing studies have found that households decide between alternative water sources based on their relative merits (Nauges and Whittington, 2010). The 16 Household Interviews demonstrate how households elect to use borehole water based on a decision-matrix that includes their perceptions of water quality (87.5%); proximity to the water source (87.5%); convenience of the water source (25%) and, to a lesser extent, affordability (6%). It is striking that unprompted responses from the household survey make no reference to their expectations of groundwater futures.

The lack of reference to future groundwater resources in the household surveys may signify a collective confidence in the availability and quality of groundwater. The online survey demonstrates a prevailing belief that the quantity of groundwater available for abstraction is sufficient for everyone's needs and that domestic borehole owners should be allowed to abstract as much water as they wish (Figure 4). Whilst nearly all respondents to the online survey agreed with the statement that water is a natural resource and that everyone should take care of it, there was much less consensus around the suggestion that if groundwater continues to be abstracted then this might harm the environment. Results from the Household Interviews support this finding, with 13 of the 16 interviewees describing the amount of water available as 'abundant' or 'infinite'. The remaining three stated that only 'God' can tell whether there is/will be enough water. Similarly, all four of the CFGs stated that there is enough water in the ground for all (with no dissenting voices). A typical phrase used was to liken the source to 'an underground river' or to make reference to a 'sea of water'.

Figure 4 Strength of agreement with different perspectives on the groundwater resource (%, online survey respondents)



Source: Online survey

Households' views as to the potential for groundwater in Lagos to become contaminated in the future are more mixed. Around a quarter of respondents to the online survey entirely agreed or mostly agreed that there was little risk of groundwater in Lagos becoming contaminated with almost a fifth entirely or mostly disagreeing with this (Figure 4). Most respondents fell in the middle three categories (57%).

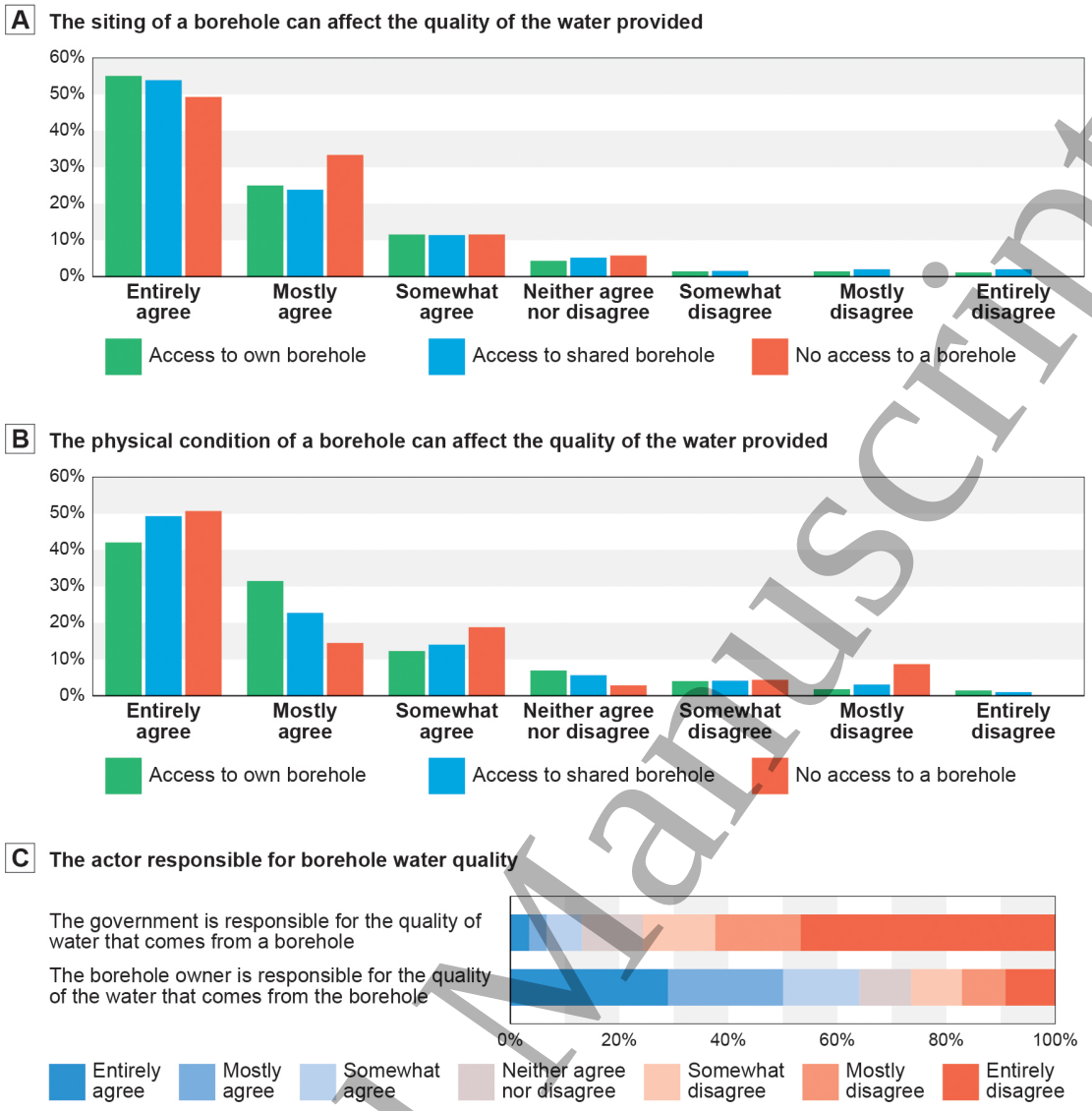
Based on their practical experience, the Drilling Contractors are less sanguine regarding both levels of abstraction and water quality. They claim that over-abstraction has led to water tables falling by some tens of metres over the course of the past two decades, particularly in areas with high concentrations of boreholes. Drilling Contractors report finding increasing incidences of saltwater intrusion and anthropogenic contamination of the aquifer. The Drilling Contractors also argue that the government has not been listening to their concerns or their expertise, with one

Drilling Contractor stating "We've been talking about this. But the government seems not to be … ready. They're [the Government] not taking us seriously. They acknowledge that there is a problem there but they're not doing anything".

5.5 Construction and siting of boreholes

Drilling Contractors contend that poor quality borehole construction and the prevalence of abandoned boreholes is contributing to increased contamination of groundwaters. The online survey demonstrates a strong awareness amongst respondents that both the siting of a borehole and the quality of its construction can affect the quality of the water abstracted, a finding that was strongly supported in the Household Interviews and CFGs. Figure 5a demonstrates the strong agreement of respondents to the online survey that the siting of a borehole can affect the quality of water available and, in Figure 5b, that the physical condition of a borehole also affects the quality of water provided. Post-hoc analysis of the online survey finds little evidence that ownership of a borehole is a relevant factor for these findings, suggesting that this belief is widely held amongst the broader population.

Figure 5 Results of the online survey of individuals showing the percentage of respondents that agreed with the statements: [A] the siting of a borehole can affect the quality of the water provided; [B] the physical condition of a borehole can affect the quality of the water provided; and in [C] described the actor they thought responsible for borehole water quality.



Source: Online survey

In practice, however, the Drilling Contractors report that many of the boreholes constructed for households are of poor quality and that many are abandoned as a consequence. Drilling Contractors attribute the poor quality of construction to an influx of poorly trained and unqualified drillers who are able to undercut the prices of professional drillers. This influx of low-cost, unqualified, drillers is enabled by the ease with which groundwater can be accessed across much of Lagos using manual drilling techniques, and is exacerbated by a lack of regulation. As one driller put it, there is: “No regulation, you don’t need to know anything, it’s a business the ordinary plumber, the ordinary trader can do. You just tell people you can do it and off you go”.

According to the Drilling Contractors, these low-cost drillers replicate the same technique across all ground conditions and complete works at a lower standard, such as using cheaper casings to line the borehole. As the Drilling Contractors are unable to compete with low-cost drillers on price, professional drillers now rarely undertake

work in the domestic borehole market, focusing instead on corporate sectors and more technical hydrogeologies, where low cost competition is less prevalent. Drilling Contractors report that households lack the knowledge to judge the quality of constructed boreholes but also pressurise drillers to reduce their prices, which encourages cost-cutting. The limited choice of sites available for locating a borehole on a householder's property can also negatively impact on the quality of constructed boreholes.

5.6 Perceived responsibility for groundwater

One of the striking findings of this study is the extent to which households regard responsibility for groundwater quality as an individual's responsibility and how few regard it as a government responsibility. This perspective is clearly displayed in the findings from the online survey (Figure 5c). This perspective was also echoed by the four CFGs, one of which stated that there was no management of boreholes in practice, and the other three reported that it was the responsibility of individual owners or the local community organisation if they were the operator of the borehole.

The limited role played by government in the management of the aquifer, and the effects of unregulated development, are causing concern amongst the Drilling Contractors. They feel that the proliferation of low-cost drilling and the lack of regulation combines to the effect that "now nobody is looking after what we are doing to the aquifers. (There is) no monitoring. A couple of individual studies here and there (is all there is)". Drilling Contractors also described a lack of understanding and awareness as a key challenge inhibiting the development of better groundwater practices, and advocate education to improve levels of understanding.

5.7 Information channels

In the absence of scientific data, the question arises as to what sources of information shape individual decisions on groundwater and borehole development in Lagos. Responding to this question (unprompted with multiple responses possible), three of the CFGs reported on the significance of family and friends; two CFGs referenced the role of non-governmental organisations and of radio, and in one CFG the role of television was mentioned. No CFG mentioned the role of government. Overall, the CFGs reported that media coverage of groundwater and borehole development is limited, with all CFGs also commenting on the limited reach of newspapers and of television. One reason for the reported lack of media coverage of groundwater is that the topic is regarded as unremarkable and of limited news value. Boreholes are borne out of necessity, rather than by choice. "Media don't really cover domestic boreholes," one journalist remarked. "When people are boxed into a corner they don't really have a choice about what they can do. They just dig their own borehole to get water." Moreover, in the absence of choice, concerns over possible water contamination fail to claim significant purchase in news reporting, unless there is an immediate health impact.

Whilst boreholes have historically not received much media coverage, there are signs that concerns regarding the quality of the available groundwater are beginning to surface in government. In official speeches, the Lagos State Government now highlights the risk posed to groundwater sources by the quantity of domestic boreholes, allied with poor construction quality, as they provide 'a window to the aquifer' (Lagos State Government, 2017; Lagos Water, 2017). Yet, this alternative discourse has still to gain traction with the public. As an example, a suggestion that the Lagos State Government planned to require the licensing of private boreholes in the State generated significant adverse coverage in the media, illustrated by headlines such as "Dig a Borehole and Go To Jail" (Aina, 2017). The headlines prompted the Lagos State Governor to issue a rebuttal stressing that any legislation would apply only to private boreholes that were commercially operated, not to domestic boreholes (Vanguard, 2017). Such examples illustrate the difficulty of challenging accepted practices, particularly where reliable alternative water supplies are limited.

6. Discussion

Public water supplies in Lagos have been unable to keep up with the rapid growth of the city. To secure their domestic water supplies households have invested in their own wells and boreholes, to the extent that households are now one of the principal drivers of borehole development in the city. These boreholes are unregulated and are not subject to monitoring by the state yet, collectively, form a major part of the domestic water supply for the city. Currently, there is no public support to introduce registration or licensing for domestic boreholes and at least half of the population believes that the quality of borehole water is the responsibility of the individual borehole owner. Overall, the population thinks that the owner of a borehole should be able to use as much groundwater as they wish. The result is a complex reality for groundwater governance, one that has not yet been fully considered by scholars in this field. Whilst Neves Alves (2019) suggests that the blurring of state-society boundaries in everyday water practices highlights the importance of previously hidden actors, such as households, our findings about boreholes in Lagos State sheds new light on the nature and scale of the part played by households in everyday groundwater management practices in cities such as Lagos. Current literatures on groundwater management underplay the fundamental role played by these actors, which is an important omission given the significance of in-situ self-supply from groundwater in cities across Africa (Foster et al, 2018).

In common with the findings of literature from elsewhere in the world, households in Lagos regard groundwater as a trusted and dependable source of supply. Those who own their own borehole are less worried about the quantity and quality of their water supplies than those who have access to a shared borehole or have to rely on non-borehole water supplies. This finding may suggest that perceptions of risk are relative to the form of access rather than the groundwater itself, a finding that merits further investigation. Our analysis provides some evidence that this confidence may be

misplaced or only partly merited. Waterpoint testing demonstrated that whilst boreholes generally provide water that meets WHO drinking water quality guidelines, shallow wells often demonstrate unsafe levels of E-Coli. Yet, many users regarded the water from these wells and boreholes as 'good' quality. Anecdotal evidence provided by Drilling Contractors, and some isolated groundwater studies, also report falling water tables and increasing incidences of contamination of the groundwater. Further research systematically testing for changes in groundwater quality and levels is essential, particularly in light of the significance of the groundwater resource in Lagos.

The implications of the extensive development of the groundwater resource in Lagos is not subject to significant levels of debate. Householders have a sanguine view of the future based on their past experience and the state is not actively introducing policies to affect the actions of householders across the city. The media does not perceive the topic to be newsworthy and professional drillers, who raise concerns based on their observations, claim that they are not listened to. The collective conviction in the health of the groundwater resource is at least partly sustained by the lack of robust and contemporary empirical data on groundwater conditions, both in terms of water quality and the level of net abstraction. In the absence of information to the contrary, households fall back on their existing knowledge developed through neighbourhood and kinship networks and based on prevailing social norms. Our finding suggests that 'proximity' to groundwater alone does not necessarily confer greater levels of water literacy, as intimated by Ternes (2019), and lends weight to the calls for more research into urban groundwater conditions (Foster et al, 2018).

Our findings support the broader contention of Cavallini et al (2016) that, at least in the case of groundwater in Lagos, the potential role of the state to safeguard groundwater can be over-emphasised. However, we also illustrate how state actors can influence practice even where they lack the ability, capacity or will to formulate and implement explicit policies (Neves Alves, 2019). By their actions, or in this instance inactions, state actors in Lagos have fundamentally shaped groundwater practices in the city. Local institutions have filled the gap created by the limitations of state-led activity and, through the individual actions of households, created a pluralistic and distributed water infrastructure where private provision sits alongside public provision. Whilst this highlights the critical role that non-state actors, such as households and drilling contractors, can play in the exploitation and stewardship of groundwater resources, our findings also emphasise the challenge of raising the knowledge base of such an abundance of non-state actors. In the case of Lagos, the easily accessible hydrogeology exacerbates the situation, as the ease by which new boreholes can be drilled is leading good quality drilling contractors to exit the market, due to the prevalence of low cost, but less qualified, competitors.

Our consideration of the exploitation and management of groundwater resources in Lagos suggests that there is a disjuncture in the existing science-policy-practice

interface. At one level, our work illustrates the limited connectivity between the worlds of science, policy and practice in the case of groundwater management. In the absence of an effective interface households base their decision-making on inherited knowledge and potentially outdated, or imperfect, information. Our work also highlights a disjuncture in the framing of the groundwater issue. It is apparent that the prevailing narrative in Lagos State concerns the contemporary demand for water security by households and that other narratives, such as that of a potentially deteriorating water resource, fail to gain traction. The fact that groundwater resources are hidden from sight serves to bolster this process as it limits the opportunities for alternative perspectives to be formed, and there are few mechanisms in practice that make the resource visible to households. This leaves groundwater as a prime example of the power of the 'unknown' where 'non-knowledge' holds sway. Addressing this disjuncture requires not just more scientific knowledge but the active construction of interfaces with and between non-state actors through which knowledge can be confronted, discussed and shared. Such interfaces may include school-level educational resources, training for non-qualified drilling contractors and science-based outreach and media events. The important role of social spaces, including social media, should also not be overlooked.

An outcome of the absence of effective policies governing groundwater management by the state in Lagos has been the emergence of an individualised water supply infrastructure, where the onus for groundwater stewardship is on the domestic borehole owner. Our findings reinforce the existing literature that highlights the challenge this reliance on individual action presents to policy-makers tasked with managing groundwater resources. Crucially, though, our work extends that literature into a major, and rapidly expanding, urban agglomeration in sub-Saharan Africa. Here the sheer scale of activity by non-state actors lends an urgency to the need to explore new institutional approaches to governing groundwater commons. Our work has demonstrated the political resistance faced by state actors seeking to exert control over an established system of domestic self-supply, suggesting that future arrangements for governing the aquifers underlying Lagos will need both the consent of residents and their active engagement if the current disjuncture in the science-policy-practice interface is to be overcome.

7. Conclusions

The case of Lagos highlights the critical role non-state actors can play in effecting changes in the groundwater system, and the apparently limited role of the state and of science in everyday practice. It forms an important example of the expansion of urban self-supply across urban areas in Africa, giving rise to the phenomenon of the 'off-grid' city. This increase in groundwater self-supply raises critical questions for understandings of the science-policy-practice interface, the application of knowledge, and the governance of groundwater stewardship practices.

Our study provides important insights into the factors that influence the exploitation, and depletion, of groundwater resources by households in urban contexts where scientific knowledge is limited and policy lacking. Significantly, the potential for a professional drilling community to act as informed knowledge intermediaries to the State's policy-makers or to households is not being realised, because policy-makers appear reluctant to act on the knowledge of the drillers, and households tend to commission low-cost drillers. Taken together, this not only highlights the disjuncture in the science-policy-practice interface in the case of Lagos, but also opens questions as to the framing of groundwater stewardship in situations of rapid urbanisation and where public water supplies are erratic or non-available.

Whether households are right to be confident in their future supplies of groundwater requires further research, but evidence from other African cities highlights the risk that water quality will deteriorate, and water levels fall (Lapworth et al. 2017, Foster et al. 2018). Our work reinforces the message that where the responsibility for groundwater stewardship effectively rests with individual borehole owners, mechanisms are required to build shared understandings of the groundwater resource that directly engage neighbourhood and kinship networks; that are responsive to changing groundwater conditions, and that boost a collective management of the groundwater commons.

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Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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