# ANNEX 1: LAGOS

## *Introduction*

The pilot study was carried out in four Local Government Areas (LGAs) within the state of Lagos: Agege, Badagary, Epe, and Lekki (Figure A1.1).

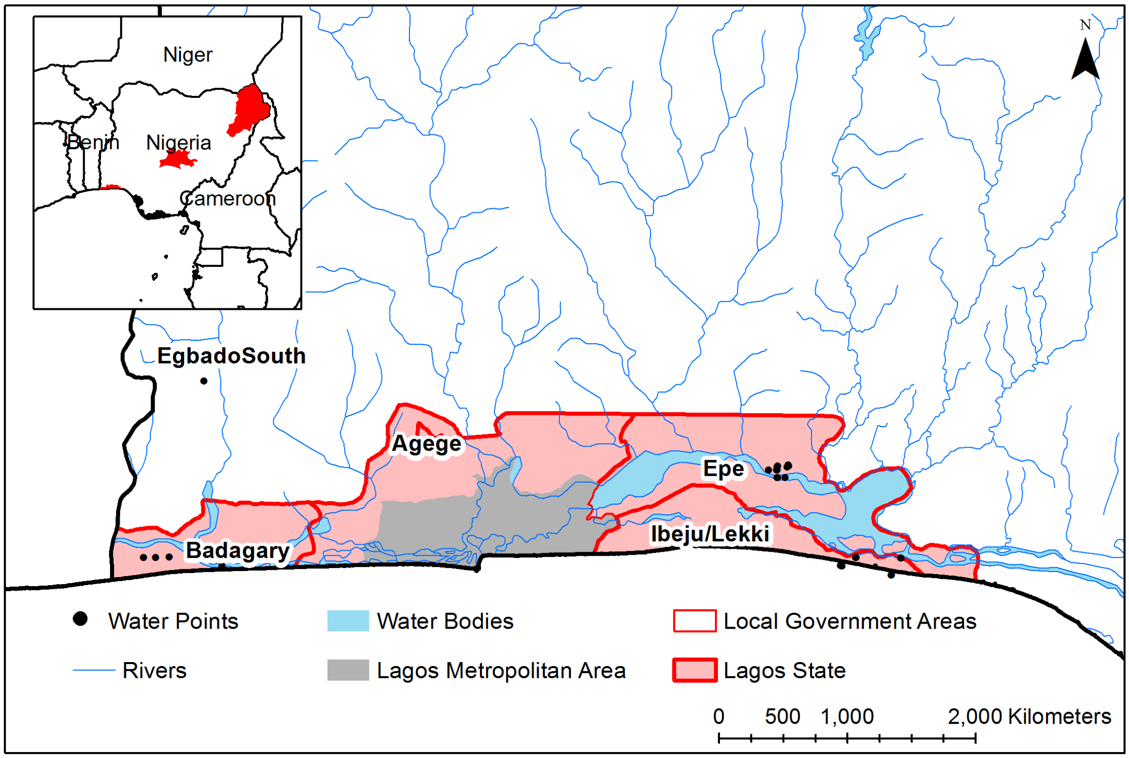



**Figure A1.1 Location map of four LGAs within the Lagos Pilot Study Area; inset shows the 3 pilot study regions in Nigeria**

This is a coastal region characterised by a number of environmental issues relevant to groundwater:

- High population density and urbanization with limited municipal infrastructure and associated poor land-use and infrastructural planning;
- Lack of central municipal sewage lines and waste treatment leading to discharge of household sewage in in-house septic tanks or direct to stream channels;
- Poorly controlled solid waste disposal systems with open dumping and incineration of refuse in un-engineered landfills, resulting in contamination of shallow groundwater systems;
- Widespread unregulated groundwater development with un-coordinated siting of boreholes and water points and poor hygiene and sanitation practices around well-heads;

- Incidences of flooding causing water point contamination and damage to infrastructure, as well as contamination from broken pipes in waste drainage channels, unplugged abandoned well / borehole points and contaminated drains / infiltrating pollutants.

The four LGAs in which the pilot study was undertaken are low- to middle-income urban and peri-urban settings with relatively high population density.

*Agege LGA* is considered a suburb of the Lagos metropolitan area, covering an area of approximately 17km$^2$. In 2006 the population of Agege was 1,033,064; this was projected to rise to almost 1.5 million in 2016[1] resulting in a population density of around 83,267/km$^2$.The economy is centred on trade (typical occupations of community members include water vendors, craftsmen, shopkeepers and labourers).The public water supply in this LGA extends to around 30% of the population, with the remainder largely reliant on boreholes and deep wells. Water is primarily used for domestic purposes (drinking, cooking, bathing and laundry), with some also used for irrigation for urban garden vegetables.

*Badagary LGA* constitutes a major coastal town and surrounding communities between the city of Lagos and the border with Benin. The LGA covers an area of around 443km$^2$ and had a population of 380,420 in 2006, projected to rise to 521,267 in 2016[1]. Population density is around 1,177/km$^2$, but is higher in the urban centre and lower towards the rural fringes. The economy of Badagary is centred on typical urban activities, as well as farming, fishing, border occupations and tourism. Water is primarily used for domestic purposes.

*Epe* is a town located on the north side of Lekki Lagoon. Although on the edge of the Lagos metropolitan area, it is an autonomous town with associated urban economic activities. The urban areas transition to lower density settlements where fishing and farming are also important. The population is currently around 443,457[1], as projected from the 2016 census, with an average density of around 480/km$^2$.There are strong development pressures in this LGA, where uncontrolled land reclamation is threatening protected wetland areas. Water is primarily used for domestic purposes and light commercial activities. Much of the public water supply infrastructure was damaged during construction of a major road and has not been repaired.

*Lekki LGA* constitutes a number of low-lying settlements to the east of the city of Lagos, forming a peninsula between Lekki Lagoon and the Atlantic Ocean. The economy is dominated by fishing and farming, but tourism, industry and logistics are becoming increasingly important with the development of the Lagos Free Trade Zone. The population is around 136,396[1]and is relatively low density (around 209/km$^2$), concentrated in linear settlements that are relatively isolated beyond the end of the highway. The primary use of water in this area is for domestic purposes.

Across the four LGAs, three fieldwork activities were undertaken:

[1] Lagos Bureau of Statistics, 2016

1. Household Surveys: to determine how different water sources are used at the household level and what users' perceptions of these sources are in terms of quality, reliability, and resilience
2. Water Point Surveys: water point description, water quality sampling, and vulnerability assessment
3. Community/Focus Group Discussions: to identify general perceptions and understanding of groundwater resilience

### *Geology & Hydrogeology*

Coastal aquifers play an important role in meeting local, urban, agricultural, and industrial water demands in the Lagos area. Groundwater use is widespread, although much of the extraction is from domestic hand dug wells and boreholes that are largely unmonitored, and the total volume extracted from the coastal aquifers is presently unknown.

Longe et al (1987) delineate three major regional aquifers, which form part of the Dahomey Basin in south-west Nigeria:

1. The uppermost Coastal Plain Sands Aquifer is characterized by interbedded sand and clay horizons
2. Below this is the confined Ilaro Formation Aquifer, described as a sequence of predominantly coarse sandy estuarine deltaic and continental beds (i.e. alternating sequences of sand and clay)
3. The Deep Confined Aquifer, which is the most productive, also consists of alternating sequences of sand and clay

In the Lagos study area the Coastal Plains Sands Aquifer is the most significant in terms water supply. Locally, it can be subdivided into three distinct aquifer units: a shallow unconfined unit, an intermediate semi-confined unit, and a deeper confined unit. The unconfined unit is exploited by hand-dug wells and shallow boreholes and is vulnerable to pollution from surface activities. At the coast, the semi-confined and confined units of the Coastal Plains Sand Aquifer occur at depths of 30-120m and 120-270m, respectively, while in the hinterland areas, the deeper confined aquifer occurs at depths of 30-150m. These semi-confined and confined aquifer units are exploited by boreholes, and are the basis of small water works in parts of Lagos State.

Saline intrusion has been reported to occur in the semi-confined units of the Coastal Plain Sands Aquifer in a zone stretching from Apapa (central metropolitan area on Figure 1) to Lekki (Oteri and Atolagbe, 2003). It occurs beneath a freshwater lens in a belt stretching inland from the coastline to a distance of about 5km in some places. Further east, freshwater layers in the Coastal Plain Sands Aquifer are sandwiched between saltwater-bearing sands.

## *The State of Play*

### Sources of water used in communities visited

The majority of domestic water comes from hand dug wells, boreholes, and sachet water, with little variation in the sources used throughout the year. Rainwater harvesting is occasionally used domestically for non-drinking purposes, and river/stream water is sometimes used for irrigation.

### Water source preferences

The household surveys and community discussions highlighted that the preferred water sources are motorized boreholes and sachet water, due to the positive perception of these sources in terms of water quality. Some communities use water from hand dug wells for washing and cooking, while sachet water and that from motorized boreholes are used for drinking purposes. In communities like Orile Agege where the hand dug wells are relatively deep, these are also used for drinking purposes.

### Trend to development of private domestic boreholes

The community discussions and household surveys point to a proliferation of private well and borehole development across Lagos State over the last 40 years. This is highlighted by the water point survey data (Figure A1.2): of the 41 groundwater sources examined, 80-100% of water points developed within the last 40 years were privately owned, compared to less than 50% of those developed more than 40 years ago.

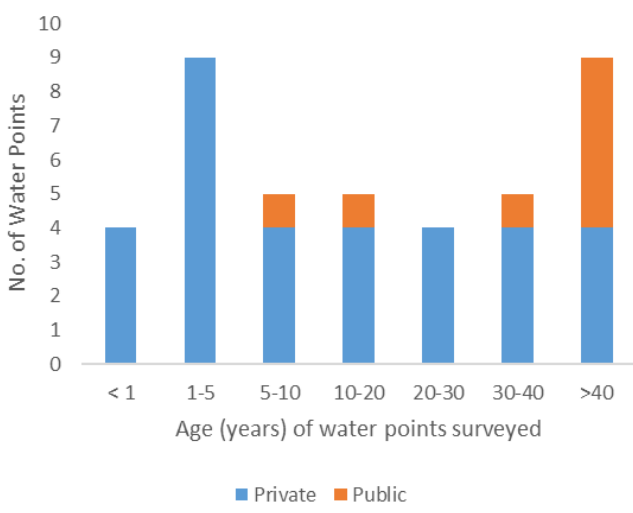



**Figure A1.2 Number of private and publically owned water points examined during the pilot study, disaggregated by the age of the water point**

Communities stated the main reasons for this trend as:

- The absence or unreliability of public (piped) water supply;
- The need to be self-reliant in response to failing public supply;

- The potential commercial gains of selling water to less privileged members of the community.

Details of sources tested

The following 47 water sources were examined in detail across the 4 LGAs:

- 21 hand dug wells (17 with extraction by rope and bucket, referred to herein as Hand Dug Wells; 4 with extraction by motorised pumps, referred to as Motorised Dug Wells)
- 19 boreholes (all with extraction by motorised pump, referred to as Motorised Boreholes)
- 1 pond
- 6 sachet water

The data collected are summarised in Table A1.1. Discounting the sachet water sources, 32 of the 41 groundwater sources (78%) were private (12 hand dug wells with rope and bucket extraction, 3 motorised hand dug wells, and 17 motorised boreholes), one was a commercial source, and the remainder were available for public use. Of the 32 private sources surveyed, permissions were not required for any of these to be developed and only seven are routinely monitored.

Of the non-private (or public) sources surveyed, most were constructed by NGOs, government agencies, politicians or affluent members of the community. However, many of these water points were found to be out of use (non-functional) during the fieldwork, mainly due to maintenance problems. Community discussions revealed that no plans or guidelines were put in place for the maintenance of public water points, and that a lack of ownership by the community has led to non-committed attitudes to maintenance.

| Source Type | Source Depth Measured /Known | Water Level Measured | Vulnerability Assessed | EC Measured | Nitrate Measured | Iron Measured | E. Coli Measured |
|---|---|---|---|---|---|---|---|
| Hand Dug Well (17) | 17 | 16 | 17 | 17 | 17 | 17 | 17 |
| Motorised Dug Well (4) | 3 | 2 | 4 | 4 | 4 | 4 | 4 |
| Motorised Borehole (19) | 6* | 2* | 18 | 19 | 19 | 19 | 19 |
| Pond (1) | n/a | n/a | 1 | 1 | 1 | 1 | 1 |
| Sachet (6) | n/a | n/a | n/a | 5 | 6 | 6 | 6 |

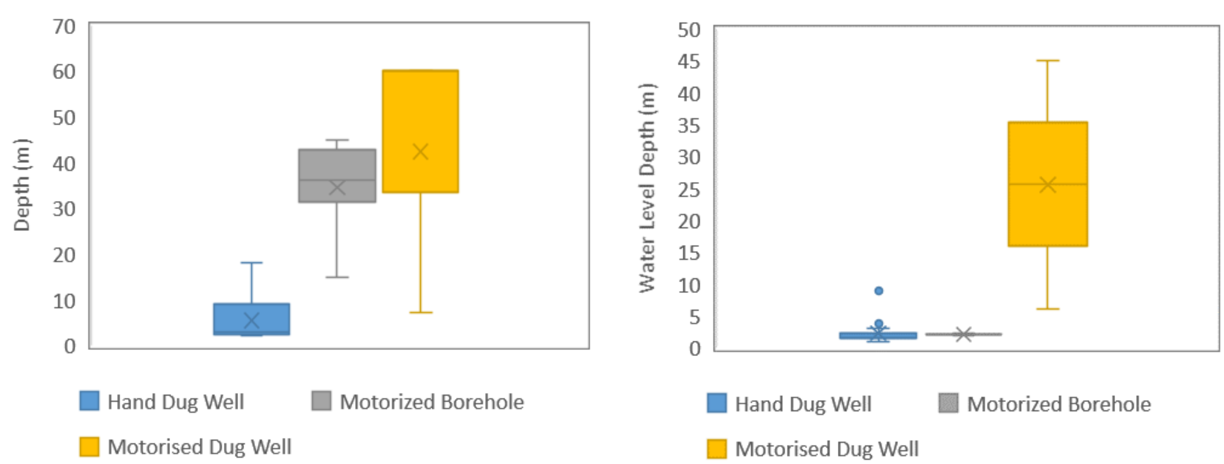
*note that water level measurements and depth values are for different sources

**Table A1.1 Summary of data collected for water sources in Lagos Pilot Study Area**

Where possible, the depth and water level of groundwater sources were measured using a dipmeter (Figure A1.3). Depth data was collected for almost all hand dug wells, but for only six of the 19 boreholes, many of which could not be accessed due to the head works. Figure A1.3 shows that the hand dug wells are all shallower than 18m, with the majority less than 10m deep. Groundwater levels in the hand-dug wells are generally very shallow, at depths of less than 3m.

One of the three motorised dug wells is also shallow (depth of 7.2m), while two extend to depths of more than 30m (the exact depth is not known but they are estimated to be between 30 and 60m deep; they are displayed on Figure A1.3a as 60m deep). These deep hand dug wells are both located in Agege LGA, which is further inland than the other study areas, and characterised by a thick laterite profile. Groundwater was measured in one of these dug wells at a depth of 45m.

Of the six boreholes measured, five extend to depths greater than 30m, with one at a shallower depth of only 15m.Water levels were only measured in two of the motorised boreholes, located close to the lagoon area in Epe LGA. Groundwater levels here were very shallow, at depths of less than 3m.However, in the absence of depth and water level data and construction details for the motorised boreholes, it is difficult to make general assumptions about the depth of groundwater these water points are exploiting.




**(a)** **(b)**

**Figure A1.3 (a) Known or measured source depth and (b) measured water level depths**

Each water point surveyed was subject to a vulnerability assessment, which provides a vulnerability score ranging from zero (low vulnerability) to seven (high vulnerability). The factors considered in the vulnerability score are summarised in Table A1.2.

| Factor contributing to vulnerability | Vulnerability Score |
|---|---|

| | |
|---|---|
| Presence of a pollution source within 10m of the water point:<br>No / Yes (at a lower elevation) / Yes (at a higher elevation) | 0 / 1 / 2 |
| Poor drainage around the water point causing ponding within 2m:<br>No / Yes | 0 / 1 |
| Concrete apron of radius > 1m:<br>Yes / Yes but damaged / No | 0 / 1 / 2 |
| Cover over the water point: Yes / No | 0 / 1 |
| Fencing around the source: Yes / No | 0 / 1 |
| TOTAL SCORE (sum of all scores above) | 0 to 7 |

**Table A1.2 Factors considered in the water point vulnerability assessment score**

Figure A1.4 shows that almost 50% of hand-dug wells are classified as highly vulnerable, compared to only 28% of boreholes. Only 6% of hand dug wells are considered to have low vulnerability, compared to 28% of boreholes.

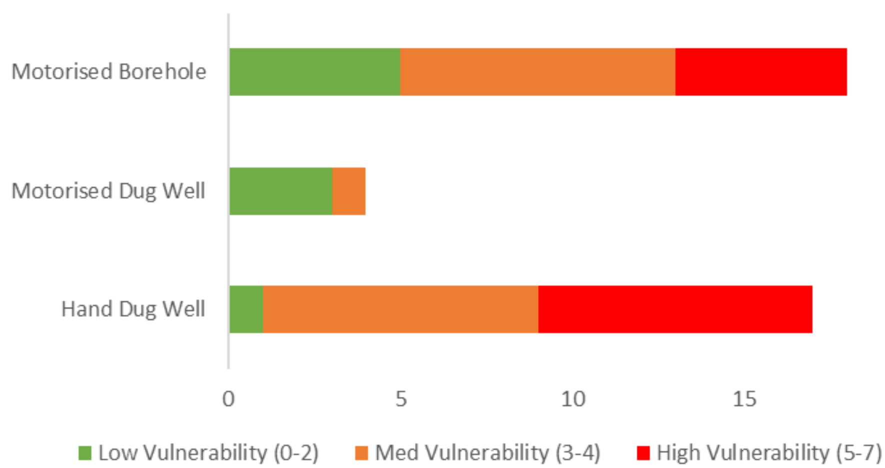



**Figure A1.4 Number of sources classed as low, medium and high vulnerability**

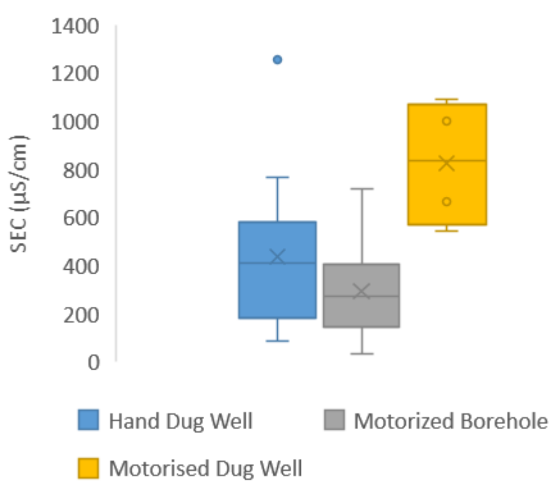
<u>Water Quality of Sources Tested</u>

Several water quality parameters were collected to determine the quality of groundwater from different source types across the Lagos Pilot Study Area: E. Coli concentration, nitrate, and specific electrical conductance (SEC). SEC gives a measure of the dissolved material in groundwater and can be elevated by natural or anthropogenic processes. SEC is often used in combination with other water quality indicators, such as nitrate and microbiological parameters, to indicate anthropogenic contamination. E. Coli is a coliform bacteria indicative of faecal contamination in groundwater, which is a known contributor to the diarrhoeal disease burden (Pruss-Ustun et al, 2014). The main source of faecal contamination in urban groundwater is municipal and domestic waste (e.g. pit latrines, septic tanks, sewer leakage, sewage effluent and sewage sludge), particularly where there is high population density and inadequate sanitation and sewage treatment facilities. The ability of these microorganisms to survive in the environment is determined by the characteristics of the organism and the properties of the soil, unsaturated zone, and aquifer (Pedley et al, 2006). Concentrations in groundwater are dependent on the pathway from source to receptor, and may be attenuated in deeper and/or lower permeability aquifers. Elevated nitrate is frequently associated with high counts of faecal indicator bacteria, although the evidence surrounding the disease burden associated with nitrate in drinking water is complex (Lapworth et al, 2017). Sources of nitrate in drinking water include municipal and domestic waste, as well as agricultural use of fertilisers and pesticides. Denitrification (the reduction of nitrate) can occur in the environment under low oxygen conditions.

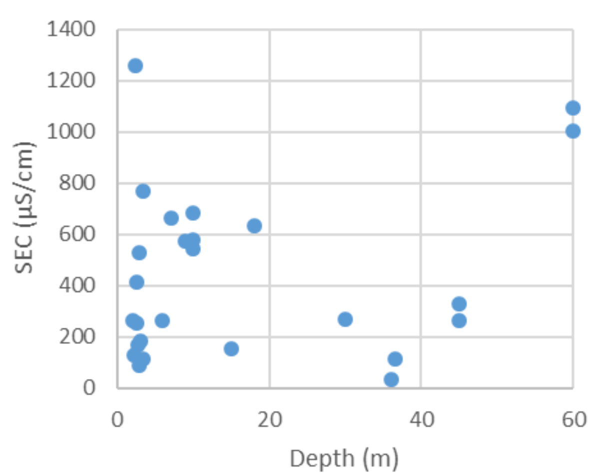
Figure A1.5 shows the results of the SEC, nitrate and E. Coli sampling for groundwater sources across the Lagos Pilot Study Area. SEC values are generally elevated in shallower sources, and are higher in the hand dug wells than motorised boreholes. Disaggregation of SEC results across the four LGAs shows that sources in Badagary, Epe, and Agege follow this trend; however the results from Lekki are reversed, with boreholes generally having higher SEC compared to the hand dug wells. This may be due to salinity caused by sea-water intrusion in the semi-confined Coastal Plain Sands Aquifer, rather than contamination from anthropogenic sources.

Elevated nitrate is also generally seen at shallower depths, however there are some shallow hand dug wells that show elevated SEC without elevated nitrate (Figure A1.6a). This may be due to reducing groundwater conditions leading to denitrification, also highlighted by elevated Iron in these shallow sources (Figure A1.6b), or elevated SEC being caused by saline intrusion rather than anthropogenic contamination.

Elevated nitrate and SEC are seen at greater depths in the two motorised dug wells (Figure A1.5 b and d), one of which has a nitrate concentration above the World Health Organisation drinking water standard of 50mg/l.




**(a)**

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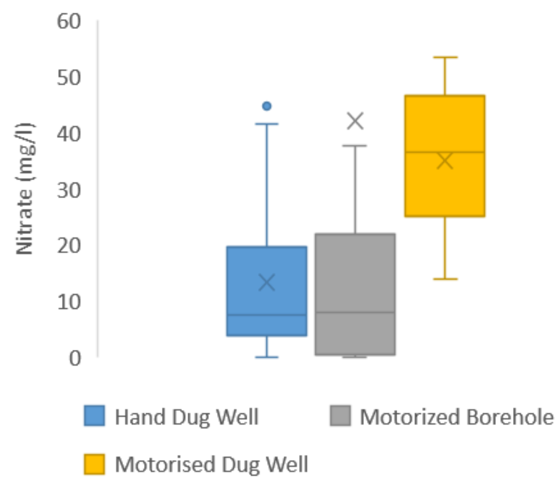
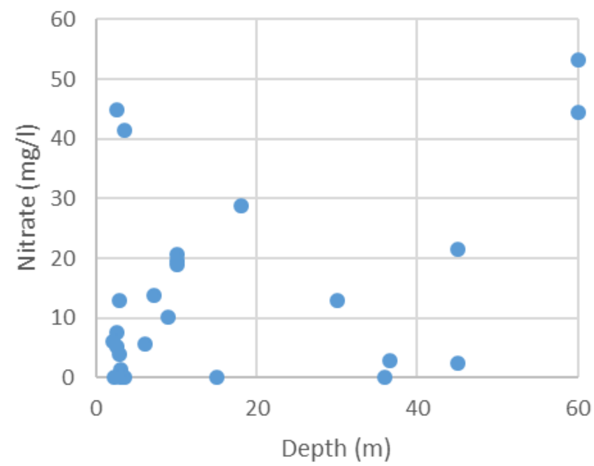
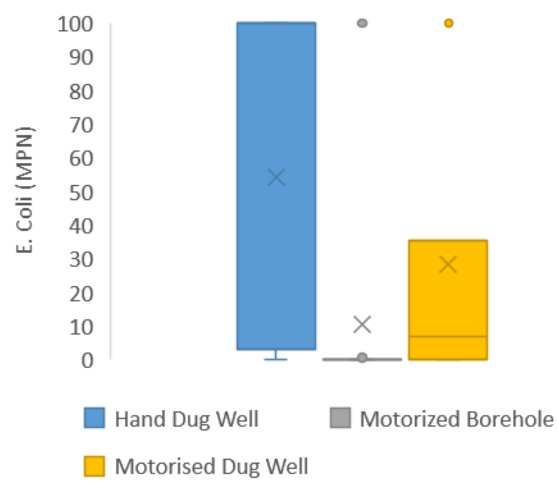
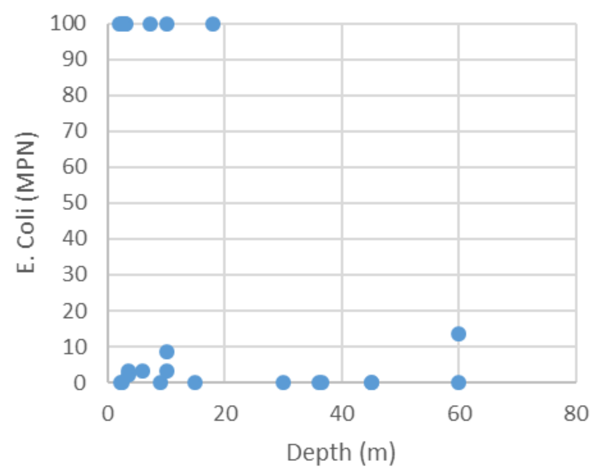


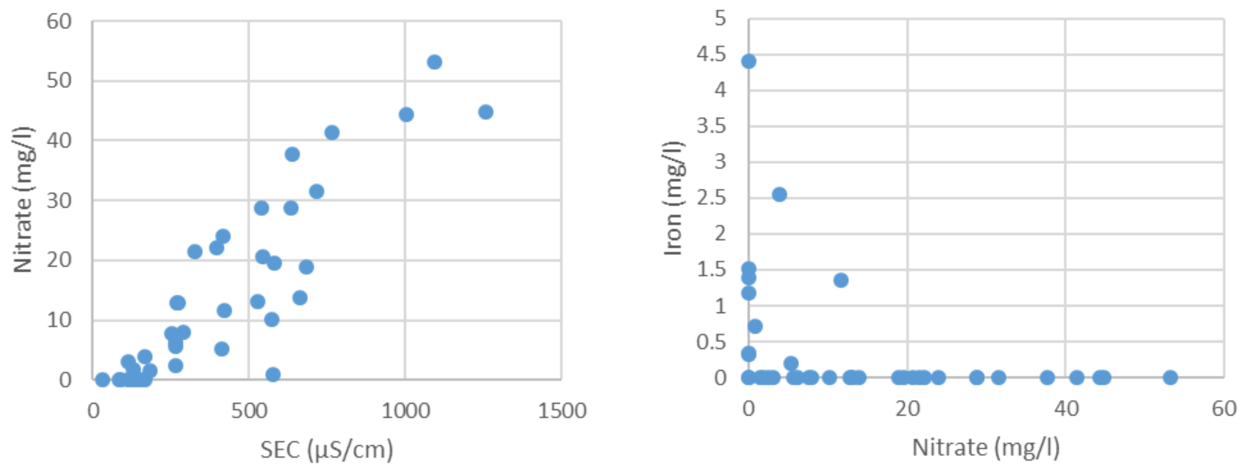

**(c)** **(d)**




**(e)** **(f)**

**Figure A1.5 SEC (a and b),nitrate (c and d), and E. Coli (e and f)results for sources across the Lagos Pilot Study area; note that figures (a), (c)and (e) contain data from 40 water points, while figures (b), (d), and (f) contain data from 26 water points due to missing depth data.**




**(a)** **(b)**

**Figure A1.6 Relationship between (a) SEC and nitrate, and (b) nitrate and iron for sources across Lagos**

E. Coli testing was undertaken at all 47 sources. According to the World Health Organisation, the safe limit for E. Coli in drinking water is 0 MPN/100ml (MPN: most probable number). An MPN of 1-10/100ml is classed as intermediate risk, 10-100/100ml as high risk, and >100/ml as very high risk. The results from the Lagos Pilot Study show:

- 27 sources were considered safe: all 6 sachet water, 17 motorized boreholes, 2 motorized dug wells, and 2 hand dug wells with rope and bucket extraction
- Six sources were considered intermediate risk: 1 motorized borehole and 5 hand dug wells
- One source was considered high risk: a motorized dug well
- 13 sources were considered very high risk:1 motorized dug well, 2 boreholes, 9 hand dug wells, and the pond

As for SEC and nitrate, elevated E. Coli numbers are generally seen at shallower depths and are much more common in hand dug wells compared to boreholes (Figure A1.5 e and f). Figure A1.7 shows that 84% of the boreholes tested were classified as safe or intermediate risk (according to E. Coli levels), compared to 50% of the motorised dug wells and only 18% of the hand dug wells with rope and bucket extraction. Over 50% of hand dug wells were classified as high or very high risk, compared to only 11% of motorised boreholes.

Although the results from the Lagos Pilot Study indicate that water quality is generally poorer at shallow depths and in hand dug wells, nitrate and SEC are not always indicators of faecal contamination. There are some safe sources, according to the E. Coli results, showing elevated nitrate and SEC, and some very high risk sources showing low SEC and nitrate concentrations. There is no obvious pattern dictating the sources with low E. Coli and elevated SEC/nitrate – they encompass boreholes and hand dug wells, deep and shallow sources, and occur across different LGAs. The sources showing high levels of E. Coli with low nitrate/SEC are generally shallow hand dug wells. It should be noted that microbiological indicators tend to show more temporal variation than nitrate and SEC and repeat water quality sampling of these sources would be useful to determine variations in faecal contamination indicators over time.

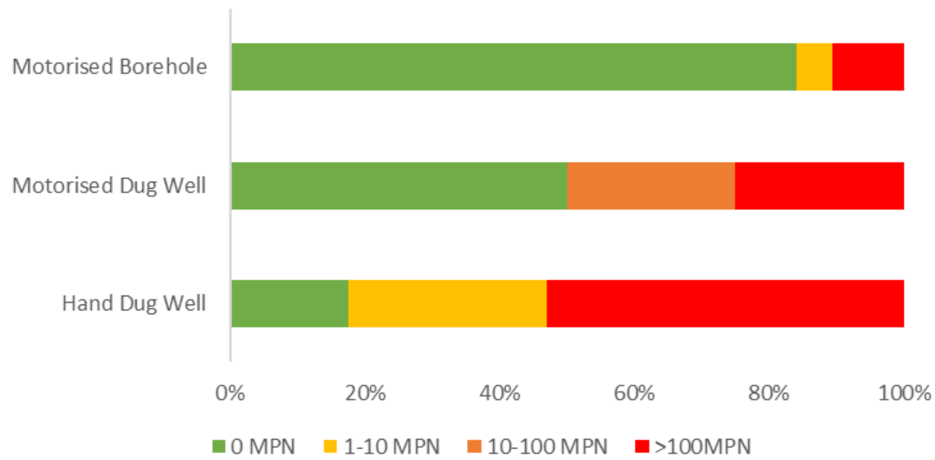
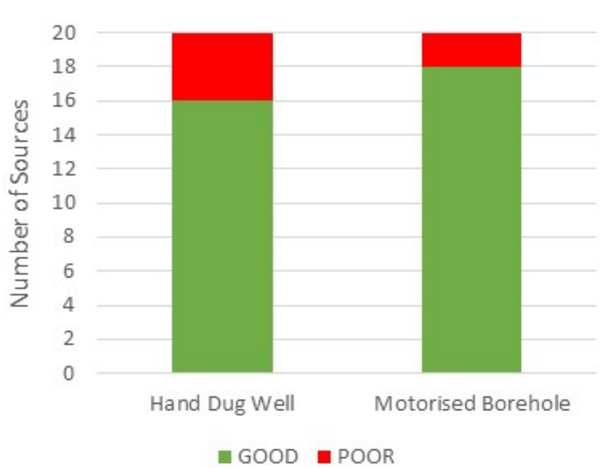


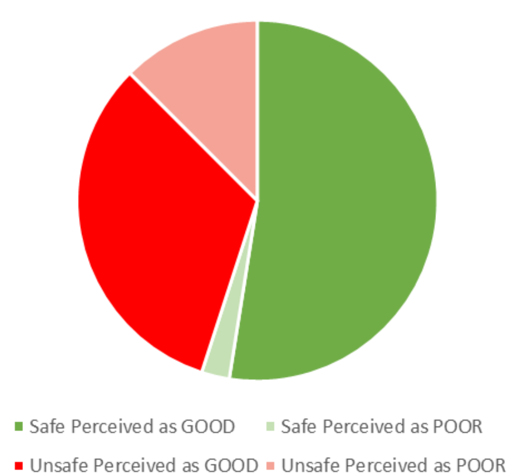

**Figure A1.7 Source risk as indicated by E. Coli MPN method and World Health Organisation classification from their Guidelines for Drinking Water Quality**

Comparison of the E. Coli results with the vulnerability score, shows that 10 of the 14 sources classed as high or very high risk (according to E. Coli levels) had a pollution source within 10m of the water point, lacked a concrete apron with a radius greater than 1m, and were uncovered. A further three had covers that were damaged. As expected, this suggests a clear correlation between unsanitary conditions around the wellhead and the prevalence of E. Coli.

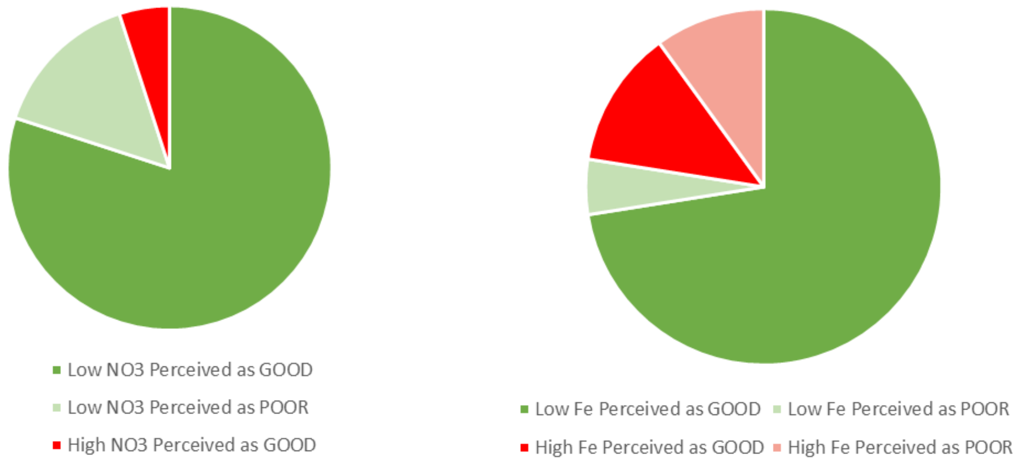
Perceptions of Sources Tested

The household surveys provide information on peoples' perceptions of different source types in terms of the quality of water they provide. For 40of the groundwater sources tested, users were asked whether they perceived the quality of water as good or poor. The results show that 90% of boreholes and 80% of hand dug wells (including motorised dug wells) are perceived as good quality (Figure A1.8a).



(a) (b)




(c) (d)

**Figure A1.8 (a) Number of sources perceived as good and poor quality by users; (b) perceptions of safe (MPN: 0/100ml) and unsafe (MPN: >0/100ml) sources according to the E. Coli results; (c) perceptions of sources with low (<50mg/l) and high (>50mg/l) nitrate concentrations; (d) perceptions of sources with low (<0.3mg/l) and high (>0.3mg/l) iron concentrations.**

However, Figure A1.8 indicates that people's perceptions of water quality from a source do not necessarily reflect the safety of the water for drinking. Of the 34 sources perceived as good quality, 13 (almost 40%) are classed as unsafe for drinking, according to the measured levels of E. Coli (Figure A1.8b). The majority of these (12 out of 13) are hand dug wells. 15% of the sources perceived as good quality have elevated levels of iron (above 0.3mg/l), most of which are boreholes, while the deep hand dug well with elevated nitrate (above 50mg/l) is perceived as being good quality. Of those perceived as poor quality, a cloudy appearance was the main reason given, indicating that perceptions of water quality seem to be based on the physical appearance rather the chemical or microbiological quality of the water.

Information on the functionality of groundwater sources highlighted that 38 of the 40 points surveyed are reported to provide water all year round. The two sources that do not provide adequate water all year are hand-dug wells. Five of the 40 water points were reported to have broken down in the last year (two motorised dug wells and three motorised boreholes). Four of these were private sources and were repaired within days.

Issues with annual water availability and drought were reported for five of the 40 sources, while users of the remainder of the water points either reported no experience of drought, or drought frequencies of >10 years. There were several observations of droughts becoming less frequent and only one report of drought frequency increasing. These general perceptions are related to the study area's location within the coastal and rainforest belt of Nigeria, which is characterised by high rainfall.

## *Developing boreholes (Underlying Drivers of Disaster Risk)*

### Reasons for sinking boreholes

The primary reasons for the proliferation of private borehole development, as highlighted by the household surveys and community interviews relate households seeking to strengthen their sense of water security and self-sufficiency. For many households, the lack of piped public water provision means that they are forced to find their own solutions. Commissioning their own borehole is often the more economical means of doing so, especially given the sense of control this presents over their water future. This sense of self-reliance in terms of water supply, particularly among better-off members of the community, was a strong theme.

Even where public water supplies were available to the household, the regular failure of such supplies and general sense of unreliability of the public water supply system (mainly due to power outages) led many households to commission their own borehole.

Boreholes were also commissioned (over cheaper shallow wells) as this allows households to access deeper groundwater. The shallow aquifers typically exploited by hand dug wells are of poor quality in most parts of Lagos.

### Perceptions of public supply

The main perceived risks associated with uncontrolled borehole development, as highlighted by the community discussions, are saline intrusion and subsidence. For most of the communities in Lekki, Epe and Badagry, saline water intrusion is seen as a major risk of uncontrolled borehole development and increasing abstraction, which is already evident in many parts of Lagos. A number of the household and community interviews also revealed subsidence as a possible risk in the face of uncontrolled borehole development and over abstraction. However, many households stated a belief that there is no risk whatsoever due to the perception of abundant annual rainfall and unlimited groundwater to meet demand.

### Risk perceptions/problems identified of borehole development

The main perceived risks associated with uncontrolled borehole development, as highlighted by the community discussions, are saline intrusion and subsidence. For most of the communities in Lekki, Epe and Badagry, saline water intrusion is seen as a major risk of uncontrolled borehole development and increasing abstraction, which is already evident in many parts of Lagos. A number of the household and community interviews also revealed subsidence as a possible risk in the face of uncontrolled borehole development and over abstraction. However, many households stated a belief that there is no risk whatsoever due to the perception of abundant annual rainfall and unlimited groundwater to meet demand.

### Choice of contractors

For those developing private boreholes, the available contractors generally include professional drilling companies or manual (semi-professional) borehole drillers. The choice of contractor usually depends on a number of key factors:

- Geology and nature of the aquifer: for example in areas like Lekki and Badagry, the friable shallow Coastal Plain Sands Aquifers are suitable for manual drilling, therefore semi-professional manual drillers are the primary choice of contractor in these areas
- Cost: where geology permits, the lower cost of manual drilling make it more attractive to most communities or private borehole owners
- Groundwater quality: in areas where the shallow upper aquifers are already contaminated (largely due to saline intrusion), corporate entities and government agencies or NGOs employ professional drilling companies to tap the deeper unpolluted aquifers
- Recommendations: in some cases the choice of contractor is dictated by recommendations from neighbours

Taken together, this is giving rise to a prevalence of low-cost, semi-skilled drilling contractors. In many cases, these contractors have learnt their trade 'on-the-job', which means that they tend to mimic observed practices. This provides a standardised approach which is rarely adapted to suit different geologies. As cost is a strong driver for many households, it means that more professional contractors are at risk of being squeezed out of the market. It also presents risks in terms of the quality of constructed boreholes.

### Treatment practices

The majority of private borehole owners do not, or rarely, treat their water but will occasionally clean storage tanks, usually when there is pump failure. There is a strong and widely-held perception that groundwater is of good quality and is not in need of treatment. Hand dug wells are not usually treated but are sometimes maintained by excavating debris or deepening during severe dry seasons.

Commercial borehole owners stated that boreholes are usually airlifted once or twice per year and chlorine may be added for disinfection. Water storage tanks may also be cleaned one to two times per year.

## *Differential (dis)incentives for action*

### What influences choice of water source

The principal determining factors influencing the choice of water source is availability, followed by cost and accessibility (convenience). Aesthetic influences can also play a role, particularly taste and temperature. Some residents reported a preference for water from a shallow well rather than an overhead tank (via a motorised borehole) owing to the coolness of the water drawn from the well. Similarly, refrigeration and availability/convenience of sachet water tended to provide a strong impetus to its demand as a drinking source. Whilst many households trusted the quality of sachet water (and so preferred it as a source of potable water) examples were given of how some brands were more trusted than others.

For those choosing to develop private groundwater supplies, there is generally a choice between exploiting the shallow unconfined, semi-confined, or deeper confined units of the Coastal Plain Sands Aquifer. Water from the deep confined aquifer is generally better quality (less vulnerable to pollution from the surface and saline intrusion), but the cost of drilling and pumping is higher. The household surveys indicate that most boreholes are drilled without detailed hydrogeological studies, resulting in a large number of wells and boreholes with poor design and completion having brackish water and being abandoned after a relatively short period of use.

There is a suggestion amongst some respondents that status and reputation drives some households to invest in boreholes. However, amongst very high status individuals examples were also given where sachet and bottled water was used for drinking and cooking purposes rather than borehole water.

### Patterns of water use

During the pilot study it was observed that most households and communities have hand dug wells, however, the preferred source for drinking water is boreholes. Many use these conjunctively, with water from hand dug wells used for other domestic purposes. Many households and communities also use sachet/bottled water as an alternative drinking water source. While this may have obvious impacts on household finances, it is a clear indication of the value placed on water quality. In some communities/households the cost of water also determines the pattern of use, for example while borehole or sachet water is preferred, the high cost to develop or buy this results in the use of water from hand dug wells instead, particularly in low-income communities.

Overall, households and respondents reported that overall demand for and use of water is rising as its accessibility increases. Those with access to private boreholes were reported to have higher water use, as it was less costly to collect. Most households with private boreholes have limited storage capacity, leading to a strong on-demand culture. This often meant that tanks would be allowed to overflow as power supplies were simply left on (to operate when there was an electricity supply) unless powered by a standalone generator. Respondents reported a strong myopic tendency with users believing that water supplies were infinite.

### Effects on adaptability

Owing to the presence of multiple alternative sources of domestic water supplies the main effects of access to household boreholes is in terms of convenience and, to a lesser extent, personal security. Some time savings were reported to result from not needing to visit a communal water point, although these were not substantial unless significant queuing had been involved. Households also reported increased safety through not having to cross busy roads carrying water.

However, the public perception of an unlimited supply of groundwater (and its assumed quality) may limit adaptive capacities in the face of future environmental hazards. This is due to the lack of consideration of proactive planning and strategies for coping and/or adaptive measures.

#### Attitudes to water resources

The attitudes expressed towards water as a resource were largely determined by the source of water used, its availability, and the cost, i.e. if water is readily available within a household and free to use, occupants will tend to use more. This was highlighted by households using the bath more than once a day when water is supplied by a private borehole or motorised well with gravity supply from storage. Conversely, where households are required to travel to retrieve water, or they pay for their water, they will tend to conserve water and manage its use.

There is a widely held belief that groundwater resources are not subject to scarcity and will be available in perpetuity. Any future issues, in so far as these might be arise, will be dealt with in the future, suggesting a degree of myopia or a strong sense of confidence.

### *Role of governance*

Groundwater governance in Lagos is limited. There are currently no clear policies from central or local government related to the development of groundwater – permissions are not required to drill a new borehole and abstraction is not licensed or controlled. There is also a lack of groundwater monitoring, in terms of both quality and quantity, to feed into water management policy.

An important governance challenge for groundwater, and water more generally, in Nigeria is the unclear distinction between state and federal government jurisdiction. There are several government agencies involved in water resource management at different levels of government (e.g. Nigeria Hydrological Services Agency, Nigeria Integrated Water Resources Management Commission, State Ministries of Water Resources and their Rural Water Supply and Sanitation Agencies, and River Basin Development Authorities). However, the roles and responsibilities of these bodies are unclear and often overlapping, resulting in either a duplication of effort or a case of “everybody’s business is nobody’s business”.

The new National Water Bill is currently being debated at the National Assembly in Abuja and it is hoped this will address current conflicts within water governance structures and help improve water resource management across Nigeria.

### *Role of communication*

In the Lagos Pilot Study, the media was found to play little or no role in promoting sustainable groundwater development and use. The media tends to report issues of acute water shortage, flooding or health related matters (and the role of household water treatment).

Family and friends were cited as the most common sources of information. Community groups tended to report role of community leaders – many of whom are articulate and aware of issues in borehole development.

### *Conclusions*

- Lagos is a coastal region characterized by high population density (high domestic demand for water) and limited or unreliable public water supply provision
- This has led to a proliferation of private water source development, with the majority of domestic water coming from hand dug wells, boreholes and sachet water (boreholes and sachet water are preferred for drinking)
- Lagos is underlain by the Coastal Plains Sands Aquifer which can be subdivided into: (1) an upper unconfined unit, which is mainly exploited by hand-dug wells and vulnerable to contamination from surface activities; (2) a semi-confined unit which is vulnerable to saline intrusion; (3) a deeper confined unit, which is better quality than the overlying units but more expensive to exploit
- Groundwater quality is generally poorer, showing elevated SEC, nitrate, and E. Coli concentrations, in shallow hand dug wells compared to deeper boreholes; however, there are exceptions to this:
    - the deep hand dug wells often used for drinking in inland areas (Agege LGA) show the highest nitrate concentrations observed across the whole study area
    - boreholes close to the coast show high conductivities, most likely related to saline intrusion
- People's perceptions of water sources seem to be based on physical rather than chemical or microbiological quality
- People's perceptions do not always correlate to observed water quality, although there seems to be some appreciation of the relative quality of water from shallow hand-dug wells compared to boreholes as water from boreholes is preferred for drinking
- Water treatment is not common practice, which highlights the need to communicate potential risks of poor water quality
- Water quality, rather than quantity, appears to be the key issue in Lagos, with limited reporting of issues related to water availability and a general stated belief that there is unlimited groundwater to meet demand; however this highlights a need to communicate potential consequences of uncontrolled borehole development in terms of groundwater availability
- Poor siting and construction practices often lead to poor water quality and sources being abandoned

### *Future Research Questions*

- How does chemical and microbiological contamination vary over space and time?

- What are people's perceptions of water quality based on and how do they rate the quality of different sources relative to each other?
- Is the perception of abundant groundwater availability justified – how sustainable are rates of abstraction relative to recharge (also taking into account saline intrusion)?
- How does the 3D architecture of the Coastal Plains Aquifer influence borehole success – a better understanding in terms of quality and quantity is required to inform borehole siting, design and construction to improve borehole functionality – and how is this best communicated to practitioners involved in siting and drilling?
- How can governance structures be improved/streamlined to control or manage private groundwater source development in Lagos?
- What are the health and livelihood impacts of water quality and availability across Lagos?

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