WSUP
Water & Sanitation
for the Urban Poor

DISCUSSION PAPER

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How do improved services to slum areas impact water demand at the city level?

Modelling domestic water consumption in Nairobi and Accra

The Sustainable Development Goals (SDGs) set out the target of achieving universal access to a basic water supply by 2030. Coupled with explosive population growth in low-income urban areas, this will result in increasing pressure on urban utilities worldwide to enhance levels of access and service to low-income consumers. Alongside the urgent need for water service improvements delivered at scale, water resources in many regions are coming under ever-greater pressure from exogenous factors such as pollution and climate change, making it vital to understand the impacts that planned water supply improvements may have on city-wide water resources.

As part of its 2012-2015 DFID-funded research programme, WSUP aimed to strengthen the support available to utilities in this area by commissioning a modelling study. The study set out to quantify the relative impact of improved water service provision in slum areas within the context of a water basin serving a city. The resulting modelling tool is available on the WSUP website and provides a practical resource for utility managers in projecting the demand implications of specific service improvements in their city.

This Discussion Paper presents the context, methodology, results and conclusions of the study. The results suggest that significant service improvements and associated health benefits might be realised in slum districts with only minimal increases in city-wide water demand. The paper is based on the final report of the researchers from the University of Leeds.

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Study rationale

While hugely significant gains were made in levels of access to a safe water supply under the Millennium Development Goals (MDGs), an estimated 748 million people worldwide remain without an improved source of drinking water (WHO and UNICEF, 2014). The Sustainable Development Goals (SDGs) set out the target of eliminating this deficit by achieving universal access to a basic water supply by 2030. Coupled with continued explosive population growth in low-income urban areas, this will result in increasing pressure on urban utilities worldwide to enhance levels of access and service to low-income consumers. Alongside the urgent need for water service improvements delivered at scale, water resources in many regions are coming under ever-greater pressure from exogenous factors such as pollution and climate change, making it even more vital to understand the impacts that planned water supply improvements may have on city-wide water resources.

Informed by the above, this study aimed to address the following research questions: *If a city improves water services in slum districts city-wide, what will be the increased water requirement, and what is the magnitude of this increase relative to other competing demands? How will the net increase in water requirement be affected by different implementation scenarios?* The study had a very practical aim in mind: to support urban water utilities by developing a modelling tool that could project the impact of specific slum water supply improvements in their city.

Methods

The study is based on the concept that service can be improved both by bringing supplies closer to people's homes (*accessibility*) and by continuity of supply (*reliability*). As a first step, the researchers identified a two-dimensional matrix to describe existing and future service levels, shown in Table 1.

Table 1. Service levels (source: water@leeds, 2013)

Water supply is	Predictable		Unpredictable	
	Available > x days per week	Available < x days per week	Available > x days per week	Available < x days per week
At home	Highest level of service			
In the yard				
Delivered to home				
Carried to home				Lowest level of service

Increasing accessibility

Increasing reliability

In order to assess the impacts of service improvements in a given location, it is necessary to understand **a)** how the population of a city is currently distributed within the service levels presented in Table 1, and **b)** the expected changes in consumption when populations move between service levels. Fieldwork was conducted in the two case study locations – Nairobi and Accra – to obtain average per-capita water consumption values for different service levels in each city. The study combined existing data around water use patterns with purpose-designed surveys to explore usage and demand in slum areas. Using this data, a Microsoft Excel-based modelling tool was developed to test how specific service improvement scenarios in Accra and eastern Nairobi would impact on city-level water resources. Specific impacts to be considered for each scenario included the overall volume of water, energy use in water production and overall costs of production.

Results

The study found that simple improvements in services for those who currently do not have access to piped water can be expected to have little impact on overall water demand. Providing yard taps to 350,000 residents in eastern Nairobi who currently carry water to their home (or get it delivered) would increase total city-level water demand by only 0.6%, if the yard taps provide water for four days or less per week; or by only 3% if the yard taps offer a reliable seven-day service. Providing the equivalent upgrade (with a four-day service) to all consumers in Accra would result in only a 2% increase. In both locations, these figures represent a very small increase in city-wide demand relative to the level of service improvement and resulting health benefits which consumers would be expected to experience.

By contrast, providing in-house connections to all consumers would have a significantly greater impact in the two locations. While a great deal of variability was seen within the household tap consumption category, providing residents currently without a formal connection (as well as those already using yard taps) with household connections was projected to increase overall city-wide water demand by 15% in eastern Nairobi; in Accra, providing a household connection to all consumers currently using yard taps would increase city-wide demand by 33% and providing *all* consumers in the city with a household connection would result in a 56% increase. Although these increases are clearly very significant, such scenarios represent service improvements for more than four million residents in the two cities, all of whom would a) gain access to piped water in their homes, and b) become paying customers able to contribute to improved cost recovery by the utility. Any change in demand would also be greatly reduced where the utility uses the extra revenue generated from new connections to reduce physical losses.

Limitations

WSUP believes the modelling tool developed under this project – free to download from the WSUP website – can be of practical use to water utilities. However it is important to stress a number of limitations: **i)** the project drew heavily on secondary data (the survey samples in Nairobi and Accra were relatively small and should not be considered statistically representative of the city as a whole); **ii)** the resulting modelling tool is highly dependent on the quality of input data (where detailed local data is not available only rough estimates at the city level can be made; to obtain realistic estimates of demand, fieldwork would need to be conducted in areas of the city that represent the range of service levels); **iii)** the tool does not assess feasibility of the various options for improving services (investment needs, land tenure and other issues that impact on service extension must be taken into account); and **iv)** in developing the tool, the research team gave only limited consideration to how price and other relevant factors might affect water demand (so while the simulations give a general indication of what changes are most likely to be seen in water consumption at a city level, at this early research stage this is a simplified model of water consumption behaviour change).

Conclusions

Urban water utilities are often unwilling to extend coverage to low-income areas in their cities. Some utilities believe that this would not be cost-effective; others are fearful of the strain that new connections would put on the city's already-pressured water sources. Notwithstanding the study limitations, this research indicates that **i)** the demand implications of improved water service provision can be modelled in a way that is genuinely useful, subject to availability of the required data, and **ii)** significant service improvements to slum areas do not necessarily translate to significantly higher demand on city-level water supply. Indeed, from a water resources perspective, it may be possible to realise large health benefits with only minimal increases in city-wide water consumption. The modelling tool designed by the research team could therefore be of real value to urban water utilities and city planners.

1 Introduction

1.1 Water supplies and services under pressure

Despite access to adequate amounts of clean water being crucial to health and development, there are still 748 million people worldwide without access to improved sources of drinking water (WHO and UNICEF, 2014). The Sustainable Development Goals indicate that improving access for these people is a global development priority. However, fresh water resources in many regions are simultaneously coming under increasing pressure from factors such as pollution, population growth and climate change (Khatri et al., 2009). Cities in the developing world in particular are growing rapidly while their infrastructure struggles to keep pace with the numbers of people it is required to serve. Furthermore, as economies grow and standards of living rise, increasing numbers of people are looking to improve their level of water access and obtain connections to piped water networks (Nauges and Whittington, 2010). According to the Joint Monitoring Programme (JMP), "approximately 70% of the 2.3 billion people who gained access to an improved drinking water source between 1990 and 2012 gained access to piped water on the premises" (WHO and UNICEF, 2014). There is also increasing pressure worldwide on city utility companies to improve their coverage and quality of service (Banerjee and Morella, 2011). As yet it is unclear what effect these changes will have on city water resources, however it is important that projections are made to anticipate and prepare for their results.

1.2 Researching the impact of improving water service provision

This research project aims to quantify the relative impact of improved water service provision in slum areas within the context of a water basin serving a city. Impacts for consideration include the overall volume of water, energy use in water production and overall costs of production. For the purposes of this analysis we are interested in the implications of supply changes in housing areas where regular utility water supplies piped to the home are not available – hence the scope lies beyond slums and may incorporate low-cost public and private housing with legal land tenure in addition to informal and unplanned settlements and temporary shacks. The research question is therefore the following:

If a city improves water services in slum districts city-wide, what will be the increased water requirement, and what is the magnitude of this increase relative to other competing demands? How will the net increase in water requirement be affected by different implementation scenarios?

Improvements of water supply services can be broken down into two main dimensions: accessibility (e.g. whether the water source is located inside the home, in the yard, or elsewhere) and reliability (e.g. whether water is available for more or less than a certain number of days per week or hours per day, and whether or not these can be predicted in advance). This can be visualised in Table 1, which was developed by water@leeds (2013) in order to portray different levels of water supply service and the steps that can be taken to improve them.

In most low-income rapidly growing cities in the global south the impact of such improvements is likely to be high, given that a significant proportion of the population reside in slums and informal and low-cost housing areas with very low levels of service. In Dhaka for example it is estimated that as much as 65% of the population within the utility service area do not receive piped water at home from the water utility. A recent review of water infrastructure in Africa estimated that typically utilities provide service in only about 70% of their service area and that demand-side constraints result in fewer than 45% of the population actually connecting (Bannerjee and Morella, 2011).

Within this context, the main objectives of this project are: firstly, to understand the resultant changes in consumption when populations move between cells in Table 1; and secondly, to find how the population of a city is distributed within Table 1 at the moment. The effects of moving the population of the city around on Table 1 can then be simulated, and the results shown in the context of the city's water balance. For this study, the cities of Nairobi and Accra have been selected for use as case studies to examine these objectives.

2 Background

2.1 Cities

2.1.1 Nairobi

Overview

Nairobi is the capital city of Kenya and the commercial, financial and diplomatic hub of East Africa (UN Habitat, 2006). The city began as supply depot in 1899 during the construction of a railway stretching from the coast to Uganda (NCC, no date (a)). Since then, the population has swelled to over 3.5 million people (NCC, no date (b)) and continues to grow at a rate of 2.8% per year (UN Habitat, 2006). The city employs around a quarter of the Kenyan work force and generates over 45% of the country's GDP, but it is also characterised by high rates of poverty, extreme inequality, poor health outcomes, significant levels of crime and inadequate provision of basic services (UN-Habitat 2006 p.4). While many of these problems have had a long history, rapid population growth in recent years has been an important exacerbating factor. It is estimated that up to 60% of the population reside in informal settlements, which cover just 5% of the city's land area (ibid). Nairobi employs 43% of all urban workers in Kenya, however the majority of employment is found within the informal sector (ibid).

Much of the population growth has been concentrated in large informal settlements and 60% of Nairobi's population now live in such locations (Crow and Odaba 2010). The informal settlements can have a population density 100 times as high as those of some of the wealthier neighbourhoods and many of their residents live below the poverty line (Graf et al., 2008; UN-Habitat 2006). The high rates of poverty are matched by poor provision of basic services including water, sanitation, electricity, waste disposal and health care, partly due to stretched capacity, partly due to poor urban planning, and partly due to the illegal status of many of the houses.

While the inadequacies of such provisions are especially stark in informal settlements, they are not exclusive to them. Water provision in particular has long been considered poor even in the more affluent areas of the city. A 2005 survey of 674 households from a cross section of residential settlements and socioeconomic groups found that – by a substantial distance – improving Nairobi's water supply was seen as the city's most pressing need (Gulyani et al. 2005b).

Institutional framework

The institution with responsibility for water supply in Nairobi is the Nairobi City Water and Sewerage Company (NCWSC), created after the Kenyan Water Sector underwent significant reforms in 2002 (NCWSC, 2011a). Major features of these reforms were corporatisation of water supply and the separation of policy-making, service delivery and regulation. Assets are owned by the Athi Water Services Board, while service delivery is carried out by NCWSC, a subsidiary of Nairobi City Council (ibid). The Water Services Regulatory Board (WASREB) was also set up as part of the 2002 reforms as an industry watchdog, and runs community-level Water Action Groups (WAGs) to assist customers in following up on unresolved water complaints (WSP, 2011).

This institutional framework was established in 2004, with Nairobi City Council having previously managed provision of water services in the city. The creation of the AWSB and NCWSC were part of an attempt by the government of the time to create a more commercially focused and financially sustainable water sector, free from political interference (Gulyani et al. 2005a). Prior to 2004, the financial and commercial management of water services had been criticised for its poor performance, and maintenance and capital expenditure had declined (Gulyani et al. 2005a; Werna 1997). By creating a water company autonomous from the council, it was felt that there would be a greater commercial incentive to improve efficiency, develop infrastructure and drive up service quality (Crow and Odaba 2010).

Water resources and system capacity

Nairobi sources the vast majority of its water from dams located up to 50km to the north of the city in other counties (NCWSC, 2011b). A small amount is also drawn from groundwater sources both within and outside the city boundaries (ibid). Since it was completed in 1994, the Thika Dam has been the city's main source, supplemented by water from the Sasumua and Ruiru Dams, the Kikuyu springs and several hundred of boreholes dotted around the city itself (NCWSC 2013). Supply is estimated at 580,000m^3 per day (Athi Water Services Board, 2006); however, NCWSC only receives revenue for around 60% of this amount (Ledant, 2011a). Around half of all water losses are estimated to be commercial losses while the other half are physical losses (ibid). Due to inadequacies in current monitoring methods, data on flows and usages is considered unreliable, making it difficult to precisely assess the losses or to trace them back to their origin (Gulyani et al., 2005a).

Supply does not meet demand, which is projected to increase over the coming years (Athi Water Services Board, 2006). Nairobi therefore employs a rationing programme, whereby water is rotated to different areas of the city on a weekly basis. A project of large-scale infrastructural investments to improve water supply is underway, with short-term demand expected to be met by around 2017 (ibid). However, this requires sourcing water from ever-further catchments.

The future of Nairobi's water supply from the stand point of resource availability is uncertain. Siltation of the reservoirs which currently act as the city's main source will gradually reduce existing capacity, while political factors and conflict are potential threats in the future.

Distribution sources

Basic services have struggled to keep up with the rapid population growth that has taken place in Nairobi. Nilsson and Nyangeri Nyanchaga (2008) indicate that this is probably one of the main reasons for the significant decline in service standards since the 1970s. While an estimated 64% of Nairobi's residents have direct access to piped water either through a yard tap or household tap, it is estimated that 80% of residents in informal settlements do not have any form of connection and must therefore transport water to their properties (Ledant, 2011a; UN Habitat, 2006). They source water from standpipes, kiosks and vendors using handcarts or tankers.

In Nairobi, households make use of an array of different water sources. A survey by Gulyani et al. (2005a p.1252) of households from three Kenyan cities, including Nairobi, reported that 46% of households use private in-house piped connections as their primary source of water, while 15% use yard taps. As the reliability and quality of the piped network tends to be poor and because large areas of the informal settlements are not served by the NCWSC's network, a number of alternative water sources are also widely used (Werna 1997).

In high and middle-income neighbourhoods, water trucks commonly supply households with water to supplement their piped service and a few thousand boreholes are operated by households, farms and businesses (Banerjee and Morella 2011; Gulyani et al. 2005a). In the informal settlements on the other hand, the primary source of water are standpipes and water kiosks. Although a number of community-based organisations also operate them, these kiosks and standpipes are mostly run by private vendors. They are often illegally connected to the NCWSC network and make a profit by reselling the water from the piped system for a higher price. It is believed that around 64% of slum residents rely on buying water from these sources, often using buckets or jerry cans to transport the water between the kiosks and their homes (Gulyani and Talukdar 2008 p.1922). Across all socioeconomic groups, there is a tendency to store large quantities of water in homes to safeguard against shortages and the irregularity of the supply (Crow and Odaba 2010).

The handling of water supply to informal settlements has long been an issue of debate. There has been reluctance within government agencies to allow investment in the slum areas for fear that it will signal tacit approval of the settlements which have often been built illegally (Werna 1997). Furthermore, the continuing threat of removal that many residents face from both the authorities and their landlords (only 8% of residents are owner-occupiers) with whom they often only have informal agreements, means they have little incentive to invest in their own units (Gulyani and Talukdar 2008 p.1920). There is also a belief that improving service provision will lead to gentrification in those areas affected, benefiting landlords but not the current tenants (Gulyani and Talukdar 2008).

Water consumption

Per-capita water consumption in Kenya is notably low. A survey by Gulyani et al. (2005a p.1252) found that water use averaged about 40 litres per-capita per day (lpcd) with a median value of 30 lpcd for the three cities in their study. In Nairobi, the mean consumption was found to be 37 lpcd while the median was 30 lpcd. These figures are low not just compared to other countries, but also compared with previous consumption in Kenya. Gulyani et al. (2005a p.1252) report that in 1967 consumption was at 105 lpcd, which means a significant decline has taken place.

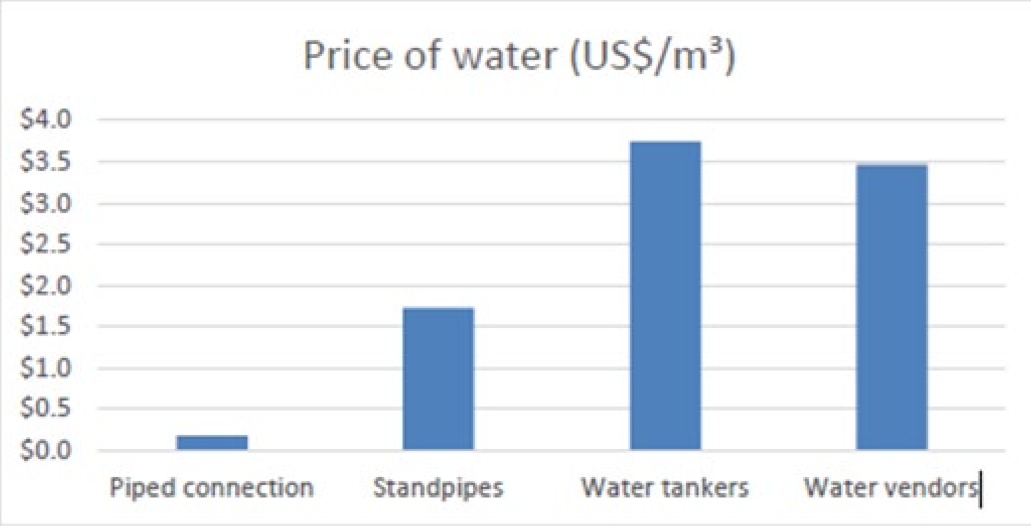
Perhaps unsurprisingly, there is inequality in water use between socioeconomic groups, though it is not as great as might be expected. The survey by Gulyani et al. (2005 p.1254) found that individuals from poor households use an average of 33 lpcd compared with 44 lpcd for the non-poor. Consumption amongst the wealthiest 11-12% of households is around 30% of the total domestic water supply, showing the disparity in regards to water consumption (UN-Habitat 2006 p.4). It should be recognised that all of these figures are now several years old so changes to consumption patterns might have taken place in the intervening years.

Core issues

Poor reliability, high prices and time spent on collecting water are three of the main problems affecting Nairobi's residents above and beyond issues relating to access to the piped network (Gulyani et al. 2005a). Poor reliability and occasional shortages characterise the piped water supply. Gulyani et al. (2005a p.1262) report that '36% of the households with private connections, 36% of those relying on kiosks and 47% of those with yard taps report that water is available for less than 8 hours per day'. Indeed, only a minority of households with private connections receive water for more than 16 hours a day. In informal settlements like Kibera, water is often completely unavailable on certain days making storage essential (Crow and Odaba 2010). Reservoir shortages can lead to even more reduced service.

The second issue is cost. Although it should be recognised that these figures can fluctuate seasonally and according to supply, Banerjee and Morella (2011, p.166) report that households buying water from water vendors or tankers pay about 20 times more for water than those with private connections, as shown in Figure 1. The poor service provision by the utility is therefore forcing households from all socio-economic groups to purchase water at significantly higher prices than they could have if the quality, reliability and accessibility of the piped network were improved.

Figure 1: Price of water by water source, Nairobi (Bannerjee and Morella, 2011)



Theoretically, the poor are eligible for a subsidised tariff from the piped network, but because so few have a private connection, they in fact end up paying some of the highest rates of all by having to buy from kiosks. Gulyani et al. (2005a p.1247) found that kiosk operators commonly charge 18 times the price they pay for water. While Crow and Odaba (2010) attribute some of this mark up to the high capital costs traders can incur by laying pipes, buying storage tanks and, often, paying bribes to plumbers and officials for connections to the piped network, substantial profits are still thought to be made. The opening of NGO-run kiosks has apparently put downward pressure on water prices in the areas where they operate (Gulyani et al. 2005a p.1267). However, there remain significant barriers to entry for those looking to set up competing kiosks and other water retail operations in the informal settlements as a substantial proportion of the vendors currently act as a cartel and have sought to protect the exclusivity of their trade (Crow and Odaba 2010 p.741).

The final major issue is the time water collection can take. Again according to the survey by Gulyani et al. (2005a p.1259), households spend an average of 30 minutes a day collecting water. The time spent was found to be 15 minutes for the non-poor and 42 minutes for the poor. Women or children are primarily responsible for the task of collecting water. They can spend an hour or more walking to the vendor, queuing, collecting the water and returning home, often with very heavy loads (Crow and Odaba 2010). Collecting water can consume even more time when additional water is needed for laundry or other uses, and this often limits what else these people can do during the day.

These issues have substantial repercussions for Nairobi's residents. For many people paying for water accounts for a significant portion of their wages, while washing clothes, showering and the number of meals cooked can be curtailed when water is not available or too costly, and disease can spread much more easily when access to water is difficult (Crow and Odaba 2010). For example, diarrhoea among children younger than three is around three times more prevalent in Kibera than in Nairobi as a whole (Graf et al. 2008 p.337)

Future

There is significant scope for improving water supply for many of the residents of Nairobi. This need, however, exists against a background of rapid population growth, poor revenue recovery due to high water losses and water scarcity. The organisations involved in delivering water to the people of Nairobi face a significant challenge in their attempts to improve access to and quality of the service. There also appear to be clear lessons for the providers to learn and important debates to be had, especially when it comes to how water provision should be handled in the informal settlements where a major part of the city's population lives.

2.1.2 Accra

Overview

Accra is the capital and largest city of Ghana. The Greater Accra Metropolitan Area had a population of 4 million in 2010 and that figure is expected to double by 2030 (Government of Ghana, 2012; Adank et al., 2011). Accra's neighbourhoods are marked by economic and ethnic segregation (Agyei-Mensah and Owusu, 2010), which are important to any consideration of service and infrastructure disparities across the city (Lundehn and Morrison, 2007).

Ghana has been called a "model for democracy" in Africa by Barack Obama (Karimi 2012), and in recent years the country has also made significant economic strides. In 2012 its GDP growth rate was 7.4% (Ghana Statistical Service, 2013). Recently, Ghana declared success in halving the proportion of its population without access to improved water sources, in advance of the 2015 Millennium Development Goal target date (National Development Planning Commission, 2015). The country has abundant water resources which when managed properly could provide adequate water supply for its people. However, despite those abundant water resources, many cities including Accra experience chronic water shortages due to uneven distribution of rainfall, prolonged drought, and poor water resource management (Nsiah-Gyabaah, 2001).

Water sources and infrastructure

Accra is supplied with potable water from two water treatment plants (WTPs): the Kpong WTP (supplying the eastern peripheries) which receives water from the Densu River; and the Weija WTP (supplying the western peripheries) which receives water from the Volta River. Accra's municipal drinking water system is run by the Ghana Water Company Limited (GWCL). However, the supplies are inadequate to meet the demand, both with regard to quality and quantity (Adank et al., 2011). The water supply system in Accra is overwhelmed by population growth. Adank et al. (2011) reported that the water supply system in Accra was capable of meeting only 71 to 81% of demand in 2007. Piped network supplies reach about half of Accra's residents directly (Van-Rooijen et al., 2008; Ainuson, 2010), while the remaining population depends on intermediary providers such as water kiosks (Adank et al., 2011). Water shortages are not driven by lack of surface or ground water, but are attributable to production and distribution limits, poor governance and improper resource management (Nsiah-Gyabaah, 2001). The rate of non-revenue water in Accra is as high as 60% (Fichtner et al, 2010), with approximately half of these losses occurring through leakages (Abraham et al., 2007).

Water supply infrastructure in Accra has not been significantly expanded since the 1980s, despite considerable population growth. As a result, water rationing began when Ghana Urban Water Ltd. (a subsidiary of the GWCL) instituted a program for water distribution within city limits (Van-Rooijen et al, 2008). Water rationing varies by neighbourhood both geographically and socio-economically with users receiving water for five days a week on average (Stoler et al 2012).

Due to water rationing and lack of direct connections, a large portion of Accra's population rely on alternative sources of drinking water such as vendors or tankers (Stoler et al 2012). Harris and Morinville (2013) examined a low-income neighbourhood in Accra, and reported that 47% of households access water in this way. Only 4% of households in these areas were reported to have an in-home water connection, while 16% of households accessed water from an in-yard connection (Harris and Morinville, 2013).

Future

There is considerable scope for improving the quality, quantity and equity of water supply services in Accra. However, the sustainability of any such improvements within the constraints of the city's water resources requires careful attention.

2.2 Measuring and predicting household water consumption

The quantity of water available to a person has a greater impact on their health than the quality of that water (Howard and Bartram, 2003), and it is therefore commonly accepted that providing adequate quantities of water should be prioritised over water quality. While utility companies often use broad figures to allocate water to various segments of a population (usually depending on housing size or neighbourhood type), corresponding real-world consumption in these areas can be very different. Some groups may consume more, and others less, than their allocated amounts. In Nairobi, for instance, 40% of the total water is used by 7% of the population, while 45% of the population consume only 15% of the city's water (Ledant, 2011a). Although the determinants of water consumption are not fully understood, they can be theorised to result from levels of accessibility and reliability of a water service. Understanding the water demand implications of changing levels of accessibility and reliability is therefore fundamental to carrying out good planning and equitable allocation of water resources (Briand et al., 2009; Nauges and Whittington, 2010). This becomes even more important in water-stressed countries.

Although many studies have been produced concerning household water demand in high-income countries, the corresponding body of work for low to middle-income countries is significantly smaller (ibid). One of the factors that make this work particularly challenging is the complex way in which many households in low to middle-income countries access water. Unreliable municipal supplies may lead households to utilise a combination of different sources, service providers, and technologies (ibid). For example, a household that receives water unreliably from the network may also opt to purchase groundwater from kiosks or neighbours at times when mains piped water is not accessible, or if the quality is perceived to be unsuitable for drinking. This makes analysing household water demand in these circumstances a far more challenging task than for users who generally access water from the network of one sole provider (Mu et al., 1990).

Another complication is the mismatch between demand and consumption when water supply falls short of requirements. In high-income countries, for the most part, demand equals consumption. However, a large number of cities in low to middle-income countries lack the water resources and/or infrastructural requirements to transfer an adequate amount of water to their population in order to meet total demand (Khatri et al., 2009). Water might therefore be rationed, and distributed to various different parts of the city on a daily or weekly basis. Consumption may consequently be different to demand if households lack the ability to store enough water for periods when the networked supply is not available. For unconnected households, other factors such as distance to source, queuing time, and inflated kiosk prices may result in a household's water consumption being less than their ideal water demand (Olajuyigbe, 2010). If these factors are altered so as to improve the accessibility of a water supply, we might expect consumption to then rise to meet demand.

3 Methodology

3.1 Secondary data review

Censuses

The Kenyan National Census was most recently produced in 2009 by the Kenya National Bureau of Statistics (KNBS) and the Ministry of Planning (KNBS, 2014). The Ghana Population and Housing Census was most recently produced in 2010 by the Ghana Statistical Service. The Kenya census covered a total of 909,589 households across Kenya, is available to download and can be disaggregated to sub-location level. The Ghanaian census data is publicly available and can be disaggregated to a number of municipal and metropolitan areas making up the Greater Accra Metropolitan Area. In both censuses, households are asked to identify their main source of water from a number of options. This data, together with Demographic Health Surveys, was used to populate the simulation spreadsheet (described in Section 3.4) with the numbers of people using certain water access categories at district level.

Demographic Health Surveys

The Demographic Health Survey (DHS) is designed to monitor health and population issues, and was most recently carried out in Kenya in 2008-09 (KNBS and ICF Macro, 2010) and in Ghana in 2008. A total of 1108 households were surveyed within the urban areas of Nairobi region and 1481 households were surveyed in the Greater Accra Metropolitan Area. As part of the surveys, respondents were asked to specify their drinking water source, household-use water source, and the time taken to collect water (ibid). Micro-data can be disaggregated to household level and sorted by region. This data was used to triangulate water access patterns from census data and gain further information on access categories which were not covered in the census, such as water delivered by handcarts or collected in sachets.

Access to Water in Nairobi: GWOPA and IFRA

The Global Water Operators' Partnerships Alliance (GWOPA) and the French Institute for Research in Africa (IFRA) Nairobi carried out a study in 2011 with the goal of mapping inequality in water and sanitation access at a sub-city level (Ledant, 2011a). This involved splitting Nairobi's neighbourhoods into a number of residential categories, which were then representatively sampled by household questionnaire (Ledant, 2011b). Residential categorisation was done using high-resolution satellite imagery and computer algorithms which grouped similar areas based on characteristics such as: plot size, ratio of public to private space, population density, and tree cover (ibid). Household questionnaires covered information on: household water source and consumption, cost per litre of water, percentage of household income spent on water, and sanitation type. Over 800 households were interviewed and the raw data was very kindly made available for use in this project. This data was used to select fieldwork sites so as to cover a wide range of water access patterns.

3.2 Fieldwork

Fieldwork was carried out in Nairobi for three weeks in April 2014 and in Accra for three weeks in March 2014 by researchers from the University of Leeds and a number of Kenyan and Ghanaian partners with local expertise and data collection experience. The purpose of the fieldwork was to ground-truth secondary data on spatial access patterns, and gather average consumption information and demographics for different water access categories. Fieldwork techniques included: household questionnaires, water point observations, focus groups and expert interviews. Sample sizes were not large enough to be statistically representative of the entire city due to time and resource constraints. However, the results are still of indicative value and can be used to show trends as well as patterns in the data.

3.2.1 Household questionnaires

Table 2: Residential characteristics of study sites in Nairobi

Neighbourhood name	Residential typology	Characteristics
Mukuru **Mathare** **Tassia**	Areas characterised by high density, unplanned, low-quality housing	Roof cover >85% corrugated iron sheet Tree cover <3% Built-up space >37% Public space <20%
Mowlem	Area characterised by low denisty, low-quality housing	Roof cover >85% corrugated iron sheet Tree cover <3% Built-up space >37%
Kaloleni	Area characterised by collective housing with open access	Tree cover >3% and <13.5%
Kayole	Area characterised by high density, low-quality, planned housing	Roof cover >85% corrugated iron sheet Tree cover <3% Built-up space >37% Public space >20%
Eastleigh	Area characterised by high density multi-storey buildings	Tree cover <3%
Buru Buru Phase 3	Area characterised by dense, individual housing	Tree cover >3% and <13.5% Plot size >190m^2

Source: Ledant, 2011B, modified by authors.

The neighbourhoods in Nairobi were selected using data gathered by the GWOPA and IFRA study, and aimed to represent maximum diversity in terms of access to water. A variety of other residential characteristics were also displayed, such as: population density, piped water and sewer access, average income, plot size, average water consumption and average water cost. All eight neighbourhoods were chosen from the eastern part of Nairobi, as shown in Figure 2, as this was identified to be the part of the city showing the greatest diversity in terms of these characteristics. Figure 3 shows the location of the neighbourhoods surveyed in Accra.

Figure 2: Fieldwork site locations in eastern Nairobi (Source: OpenStreetMap, 2014)

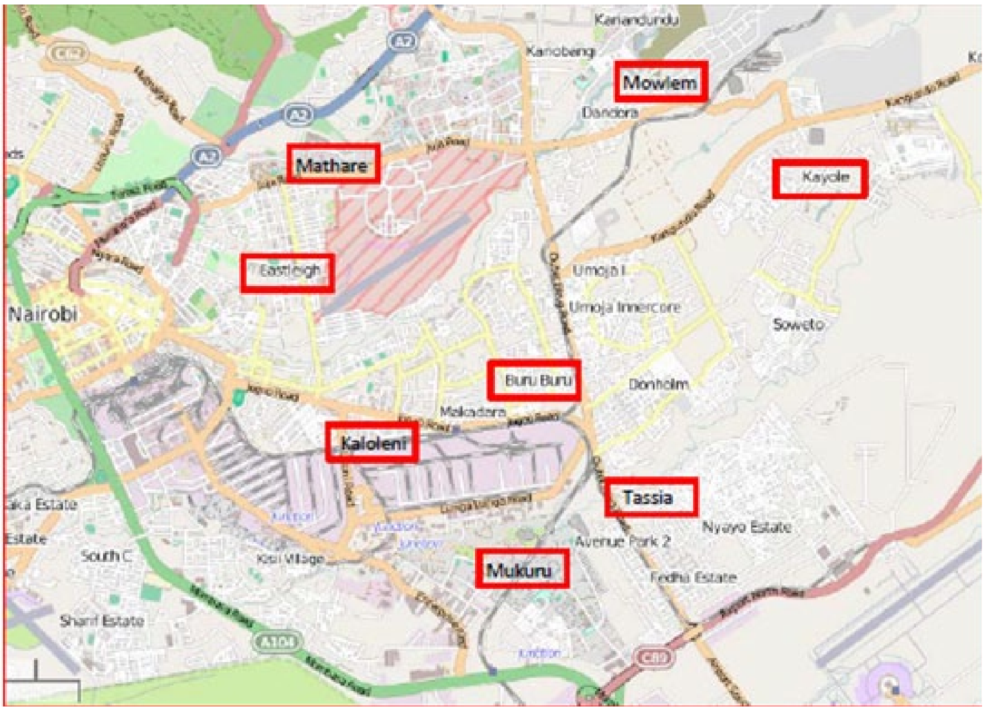
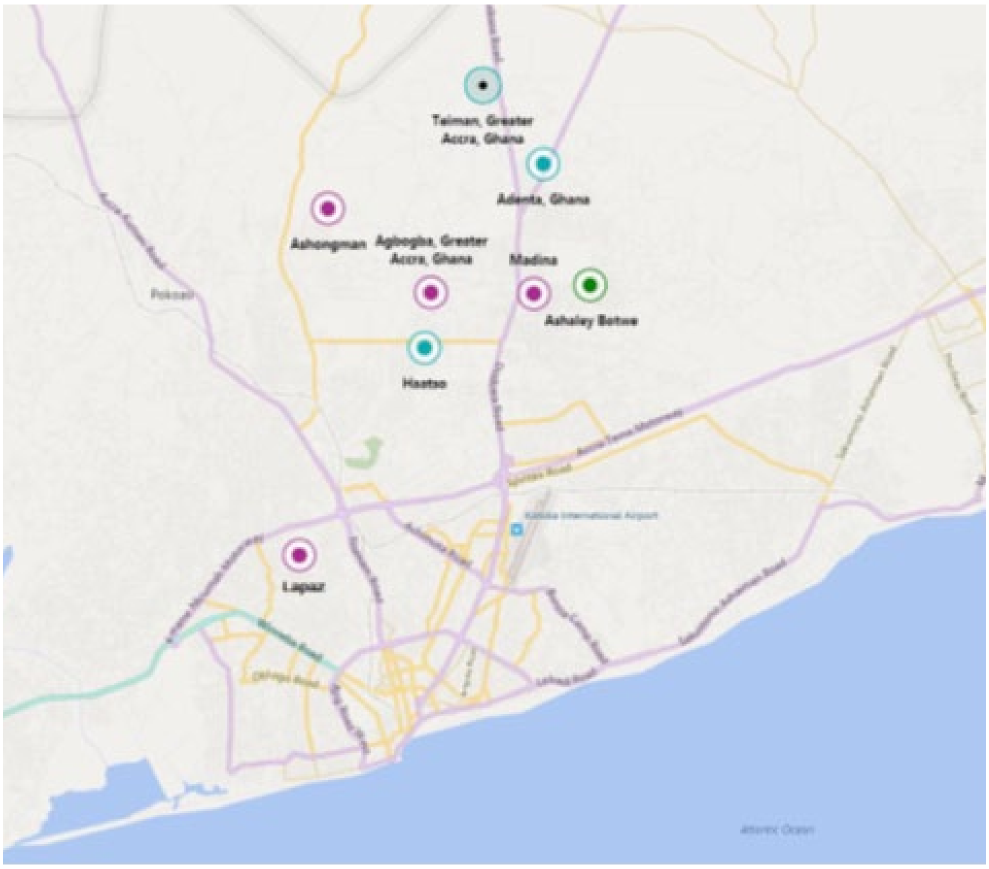


Figure 3: Fieldwork site locations in Accra (Source: Bing Maps)



A total of 191 household questionnaires were carried out in Nairobi and 97 in Accra in order to gather information on water accessibility, reliability and consumption patterns. Questionnaires were written in English, but administered by persons fluent in the local language and English.

Key variables gathered include:

- Demographics;
- Household characteristics;
- Primary, secondary and tertiary sources of water for drinking and household uses;
- Average daily consumption of water;
- Time taken and distance travelled to collect water;
- Cost of water;
- Water storage available within the household.

Household wealth was approximated by completing a separate questionnaire based on the approach used in the most recent DHS surveys of Kenya and Ghana, which gathered information on household income indicators. The advantages and disadvantages of this method are discussed further in Section 3.2.2.

As asking respondents about their water use in litres per day would likely not lead to accurate data, consumption for users collecting water was estimated by the interviewers by establishing the size of containers and the number of times they are filled per day. This was cross-checked and triangulated with the expenditure on water and daily or weekly water usage by activity. For those with household connections and yard taps, the consumption was calculated by estimating the size of storage containers and the number of times they are filled per day or week. However, it was observed that many respondents with piped connections seemed unsure of their water consumption and found it difficult to make an estimation of average consumption off-hand. Therefore, consumption values for these groups were back-calculated using their average monthly water bills and the NCWSC tariff, and checked against stated consumption values, as well as water usage by activity.

3.2.2 Household wealth assessment

Household wealth – as assessed using proxy variables of asset ownership – has been proven to be a more robust indicator of the financial stability of a household than income (Rutstein and Johnson, 2004), and was therefore the method chosen to estimate the finances of households for this study. The method involves asking households to identify from a list which assets they own, recording the number of people per sleeping room, and observing housing materials. The list of assets used as income indicators is termed the 'wealth index', and ranges from basics such as a bed, tables, and chairs to more expensive items such as washing machines and refrigerators. A wealth score for each household is derived from the wealth index by assigning weightings to each item through Principal Component Analysis (PCA), which is a statistical technique designed to identify underlying patterns in a large number of variables. These weightings are then multiplied with the value of the variable (which could be a binary value of '1' for 'owned' and '0' for 'not owned', or a numerical value such as '3 people per sleeping room') and the results are summed to produce the wealth score for each household.

It is important to acknowledge that the way in which an asset represents wealth can be very country-specific; for example, a bicycle may not have the same value in a mountainous country as in a flatter country (Rutstein and Johnson, 2004). For this study, the asset list for the income indicators questionnaire was taken from the most recent DHS survey in Ghana and Kenya, to ensure that the list was appropriate for the country.

Household wealth assessment indicators

The wealth index method avoids a number of disadvantages to measuring a household's financial stability by asking the respondent to state their average income. Firstly, income might fluctuate significantly if the main earner is unemployed or employed in the informal sector. Households might also feel an incentive to overestimate or underestimate their average earnings, or simply not know them. In some cases, members of the household may have incentive to not divulge extra earnings to each other and thus the total household income may not be revealed by the respondent. However, while having a number of advantages, the wealth index method was difficult to implement in the field for a number of reasons. Firstly, it was strongly felt by the translators in Nairobi that asking people in informal settlements whether they owned certain items (such as a washing machine) was insensitive. They also commented that it was disheartening for a household to have to admit to not owning a large number of items on the list. Eventually, the translators in Nairobi only asked households whether they owned items that were considered likely to be present within that neighbourhood (so nobody in the informal settlements was asked whether they owned a refrigerator, freezer or washing machine) so as not to cause embarrassment or discomfort. While considered unlikely, this may have had the effect of distorting the scores as households owning unusual assets within a neighbourhood would not have been identified. Secondly, some households in Nairobi were reluctant to complete the wealth index questionnaire as they felt that the information was unnecessary and unrelated to the purpose of the interview. They may also have felt that revealing this information could make their property vulnerable to theft. This problem could have been avoided by the fieldworkers providing a more detailed explanation of why the questions were necessary.

Analysis and interpretation of the income indicators was performed using a similar method to that used by the DHS (Rutstein and Johnson, 2004). Income Indicator data was entered into a Microsoft Excel spreadsheet using binary form for all dichotomous variables. Those variables for which all households had a positive/negative score were excluded, as these would not contribute any information on the relative differences between households in the sample. Factor analysis was then run on all variables using the principal components method available in the statistical software package SPSS, version 22. Only one factor was extracted. The resulting wealth scores were then divided into wealth categories using the k-means clustering tool available in SPSS. Wealth categorisation by clustering is viewed as superior to the traditional method of categorisation by quintiles (as used by the DHS), because it allows the formation of natural groups rather than artificially separating households who might otherwise be very similar (Hoque, 2014). A total of five wealth categories were created, and both the raw wealth scores and wealth categories were examined as household-specific variables when analysing water consumption patterns.

3.2.3 Water point observations in Nairobi

15 water point observations were carried out in the informal settlements of Mukuru, Mathare and Tassia, between the hours of 9.00am and 4.00pm. Data gathered in the water point observations was used to triangulate answers from household questionnaires concerning the amount of time devoted to collecting water (which was generally underestimated). The water vendors for each water point were also interviewed using the same household questionnaire as administered to the rest of the sample. The following was observed for a period of 15-20 minutes:

- The number of people coming to collect water;
- The average number and size of containers carried by each person;
- The average length of time taken to fill containers (hence estimating the flow rate);
- The gender and age of people collecting the water.

3.2.4 Focus groups

In Nairobi, focus groups were carried out in Mukuru and Mathare, each with six participants from community-based organisations (CBOs) who are involved in water, sanitation and hygiene service delivery, while one focus group was held in Accra. Information gathered in the Nairobi focus group was subsequently used to refine the household questionnaires by adding a specific question about water consumption resulting from laundry, which was highlighted as one of the main water uses in the household. This had the effect of highlighting large amounts of additional water that were being used on a weekly basis, and hence increasing average consumption values recorded per capita.

During the focus groups, participants were asked to discuss the following:

- Main uses of water in their households;
- Average amount of water used per day;
- Effects of young children on water consumption;
- Who in the household is responsible for collecting water;
- Differences in cost and accessibility of water in the dry and wet seasons;
- How water shortages are dealt with;
- The impact of hypothetical increases/decreases in cost, accessibility and reliability.

3.2.5 Expert interviews

Expert interviews were conducted in order to ascertain information about the water networks and planned improvements to them. The following people were interviewed.

Nairobi

- Ms Eden Mati and Mr Gerald Maina (WSUP Kenya);
- Mr John Chege (NCWSC, Informal Settlements Department);
- Mr Kagiri Gicheha (NCWSC, Distribution Department);
- Mr Mburu Kiemo (NCWSC, Non-Revenue Water Department);
- Mr Martin Kareithi (NCWSC, Geographic Information Systems (GIS) Department);
- Mr Boniface Kagwe (Nairobi Water Action Group, Chair).

Accra

- Regional Production Manager, Ghana Water Company Ltd.;
- Regional Distribution Manager, Ghana Water Company Ltd.;
- District Manager (Accra East District Office, Legon), Ghana Water Company Ltd.;
- Five private water vendors.

During the interviews in Kenya, the following documents and files were also made available to the project team (N.B. unless stated otherwise, these files are not generally publicly available):

- Reports discussing the implementation of a pre-paid meter pilot project carried out in Nairobi by WSUP Kenya;
- GIS layers for the Nairobi water and sewerage network and administrative boundaries;
- Maps of the Nairobi water and sewerage network and administrative boundaries;
- A spreadsheet showing the Nairobi water balance, including a breakdown of NRW;
- The rationing schedule for the Nairobi water network (publicly available);
- The current tariffs charged by NCWSC (publicly available).

3.3 Data analysis

Once data has been collected, the ranges and averages of variables (categorical and continuous) were checked and outliers flagged and/or removed. Consumption data was aggregated for each household and converted to units of litres per capita per day (lpcd). Data analysis involved the following:

- Data cleaning and characterisation;
- Identifying correlations within consumption-related variables;
- Checking for statistical differences in consumption between access categories;
- Constructing regression models with consumption as the dependent variable;
- Calculating average consumption values for each level of access;
- Carrying out factor analysis on consumption-related variables to identify patterns;
- Triangulating findings with previous work.

3.4 Scenario testing

A spatial picture of domestic water consumption in Accra and Nairobi can be constructed at a sub-city level using data on the percentages of the cities' population falling into different access categories, and the average consumption values of people within these access categories. Water supply improvement scenarios were then simulated by moving groups of the population from one access category to another. Scenario testing was carried out using a purpose-built modelling tool created by the project team in Microsoft Excel 2013, containing macros written in Visual Basic for Applications (VBA). Screenshots of the modelling tool are shown in Figures 4, 5 and 6.

Figure 4: Modelling tool, results tab

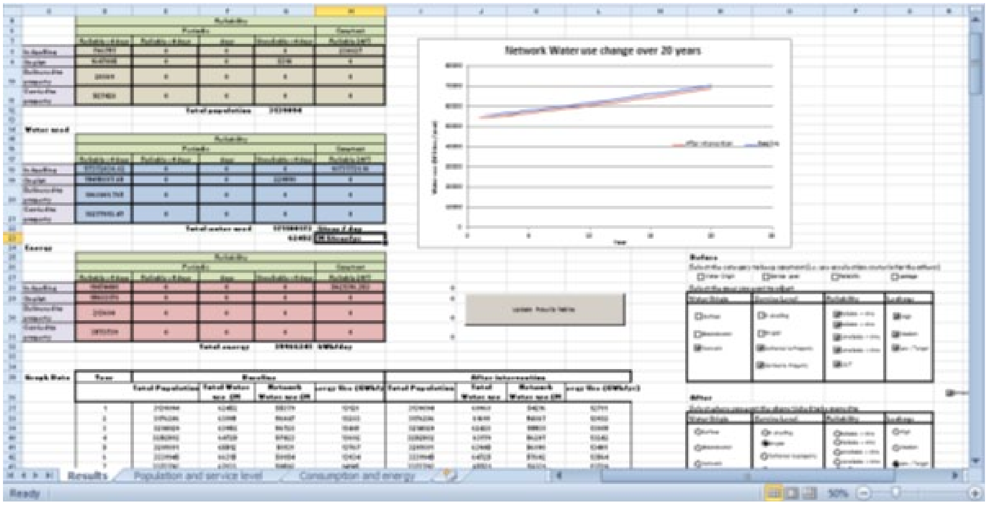


Figure 5: Modelling tool, population and service levels tab

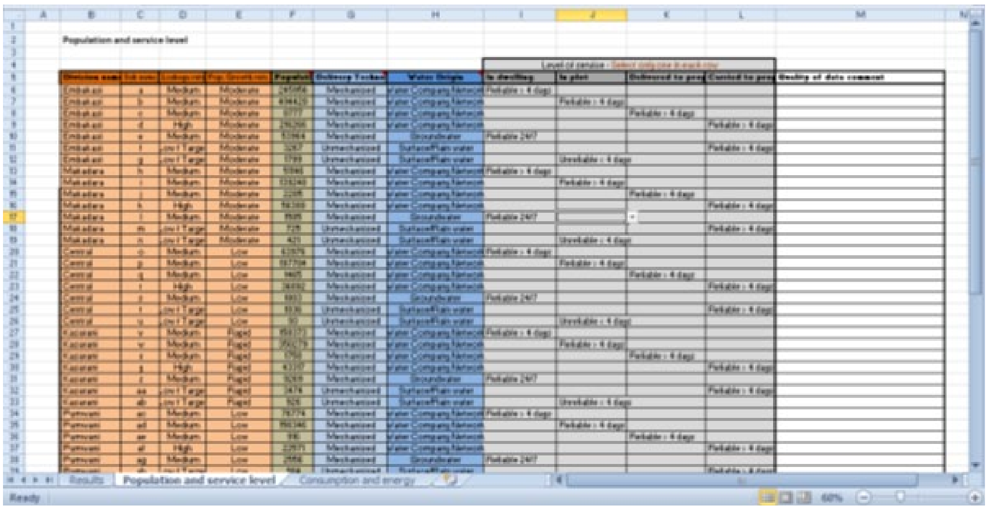
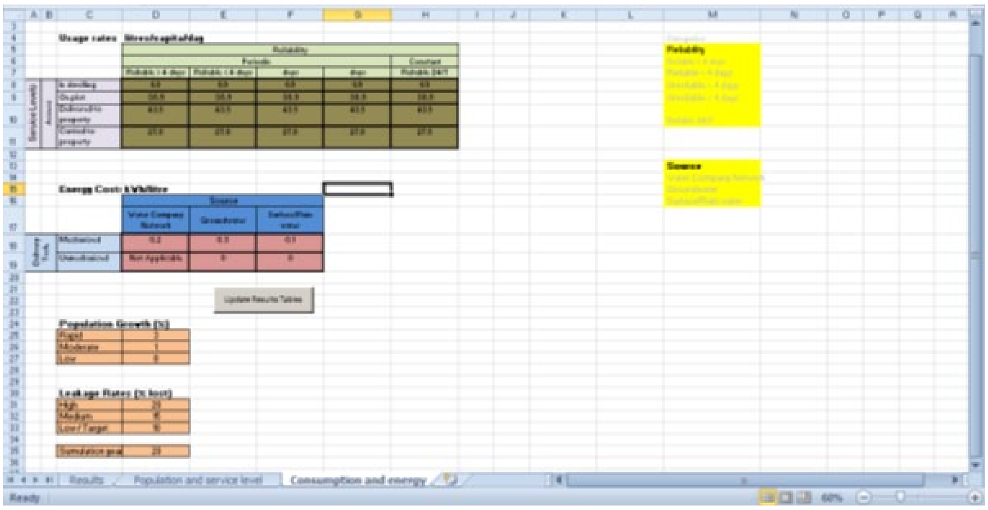


Figure 6: Modelling tool, consumption and energy tab



The tool contains three tabs, listed here in the order in which the user inputs information: 1) Results; 2) Population and service level information; and 3) Consumption and energy information.

The third tab (Figure 6) contains set-up information concerning characteristic values of consumption, energy usage, population growth and leakage. All of these parameters can be modified, allowing the tool to be tailored to the characteristics of a particular area. Firstly, details of the average water consumption in lpcd for different levels of service and reliability are entered into a table. Information concerning the average energy cost in kilowatt hours per litre (kWh/l) for mechanised and unmechanised methods of delivering water from three types of origin (water company network water, ground water and surface/rain water) is entered into a second table. Finally, values for three categorised rates of population growth and leakage (high, medium and low) can be defined.

The second tab (Figure 5) sets up a model of the population of the city with population groups assigned to different service levels, population growths, water leakage rates and water source origins. There is no limit to how much detail it is possible to include in this tab; the only constraint is the availability of data for accurate input. The model can be constructed at city-level or district-level, or at smaller units of location. For each unit, a row is created to describe each unique mode of access within that location. If the population of a location displays homogenous characteristics of water access (for example, everyone accesses water from the utility network at the same level of reliability and leakage, and the area has a relatively uniform population growth) then only one row is needed. However, if the population utilises a multitude of water access methods, with different levels of reliability, leakage and population growth, several rows are needed to describe all groups.

The first tab (Figure 4) displays the results of the simulation. Firstly, an overall view of which proportion of the city's population lies in each access category is shown. The model then takes each row of the second tab and multiplies the population present in that row by the characteristic water consumption and energy use for that row, as defined by the values in the third tab. The results are then aggregated to show the total water consumption for each category of accessibility and reliability. The same is done for energy consumption. City-wide water consumption (both from network water alone, and from network + groundwater + surface/rain water) is shown in tabular and graphical form, and projected to a user-defined number of years into the future.

The first tab also contains macro functions which allow the user to move different groups of the population (as defined by water source origin, level of service, level of reliability and/or level of leakage) to different water origins, levels of service, levels of reliability and/or levels of leakage. Consumptions for the baseline scenario and any changed scenario are shown in tabular and graphical form from the present up to a user-defined number of years into the future.

A full list of scenarios tested using the modelling tool and the effects their effects on city-wide water demand is provided in Section 5.

3.5 Methodological limitations

The methodology used in this study has been subject to a number of limitations. Firstly, time and resource constraints meant that it was only possible to survey 191 households in eight Nairobi neighbourhoods and 97 households in 10 Accra neighbourhoods. The samples should therefore not be considered statistically representative of the city as a whole. As a result, the project is heavily dependent on the availability of secondary data. Secondly, it was only possible to carry out fieldwork during the dry season, and thus the effects of the monsoon (termed locally as the 'rainy season') on water consumption could not be determined. However, seasonal variation in daily consumption can be significant (Andey and Kelkar, 2009), and should be considered in any continuation of this work. Finally, the modelling tool makes the significant assumption that when people are moved to a different level of access they behave in the same way as the people who are already in that category, which has been shown not always to be the case by Briand et al. (2009). While the simulations give a general indication of which changes are most likely to be seen in water consumption at the city level, it is important to remember that a highly simplified model of water behavioural change is being used. The inclusion of more rigorous statistical methods to control for selection bias would make the results more compelling.

4 Fieldwork results

4.1 Data cleaning and characterisation

After data cleaning, a total of 124 interviews were used in the final Nairobi analysis and 77 interviews were used in the final Accra analysis. Outliers were removed by visually inspecting box plots and histograms of consumption data.

Out of the 124 Kenyan interviews considered for further analysis, 101 were conducted with female respondents and 23 with male respondents. Of the 77 interviews held in Accra, 56 were with women and 21 with men. The ages of respondents ranged between 18 and 60 in Nairobi and between 18 and 70 in Accra, with 44% of respondents in Kenya falling into the first age bracket of 18-30 and 35% of respondents in Accra falling into the same category. Out of the respondents in Nairobi, 90% rented their properties, and 10% were owners. In Accra, 17% rented their properties and 9% rented a sole room; 74% were owners.

Out of the households surveyed in Nairobi, 98% used the same water source to obtain both drinking water and water for household uses. Furthermore, 92% of households specified primary water sources only, and no households specified tertiary water sources. It was therefore decided that for analytical purposes it would be sufficient to treat each household as obtaining all their water from a single source. In the service level table given in Table 1, a distinction is made between water availability being predictable or not. In our surveyed sample, 86% of respondents stated that their water supply is predictable. For the remaining 14%, the fieldwork team also had some doubts on whether or not the question was understood as intended. It was therefore decided to collapse the categories of predictability, due to these reasons and also to avoid splitting the already small sample size into more categories.

In Accra, a more detailed investigation of the primary and secondary sources shows that almost all households who carry water to their property as their primary source get this water either from kiosks or from neighbours getting water from the piped network or from tankers. The volume of water from the primary source on average accounts for 91% of the overall volume consumed. This water from the primary source is supplemented by small amounts of water from the secondary source, which is water bought in sachets and carried home for more than 70% of respondents. Therefore most of the sampled households get the majority of their water for domestic activities from taps in the yard, standposts or water kiosks while purchasing small volumes of drinking water in sachets. This is a common phenomenon in West Africa, described for example by Stoler et al. (2013).

Table 3: Access method for primary source of water in Nairobi and Accra

Access method	**Frequency**		**Percent**	
	Nairobi	*Accra*	*Nairobi*	*Accra*
Carried to property	55	50	44.4	64.9
Delivered to property	11	5	8.9	6.5
In yard	31	19	25	24.7
In dwelling	27	3	21.8	3.9
Total	124	77	100	100

4.1.1 Water consumption

Nairobi

Average consumption data for all Nairobi households has a mean value of 40.9 lpcd and a median value of 31.4 lpcd and ranges from 4.8 lpcd to 208.0 lpcd. This is comparable to the average water consumption for urban Kenyan households stated in another study examining domestic water use in East Africa – Drawers of Water II – which found a mean value of 45.2 lpcd (Thompson et al, 2001). A histogram of average consumption in Nairobi (Figure 7) shows that the distribution is strongly skewed to the left, with a skewness value of 2.467 and a kurtosis value of 8.268. A log-10 transformation of average consumption gives a normal distribution, as shown in Figure 8. Figure 9 shows water consumption histograms disaggregated by water source category.

Figure 7: Histogram of average water consumption in Nairobi

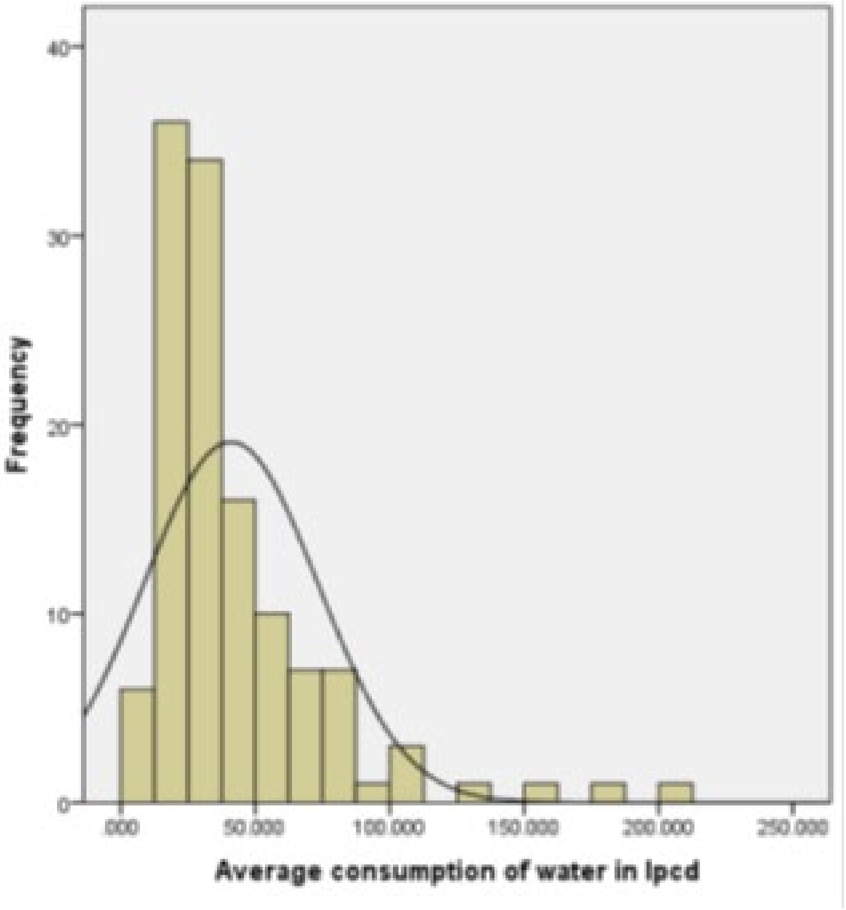


Figure 8: Histogram of log-transformed average water consumption in litres per capita per day in Nairobi

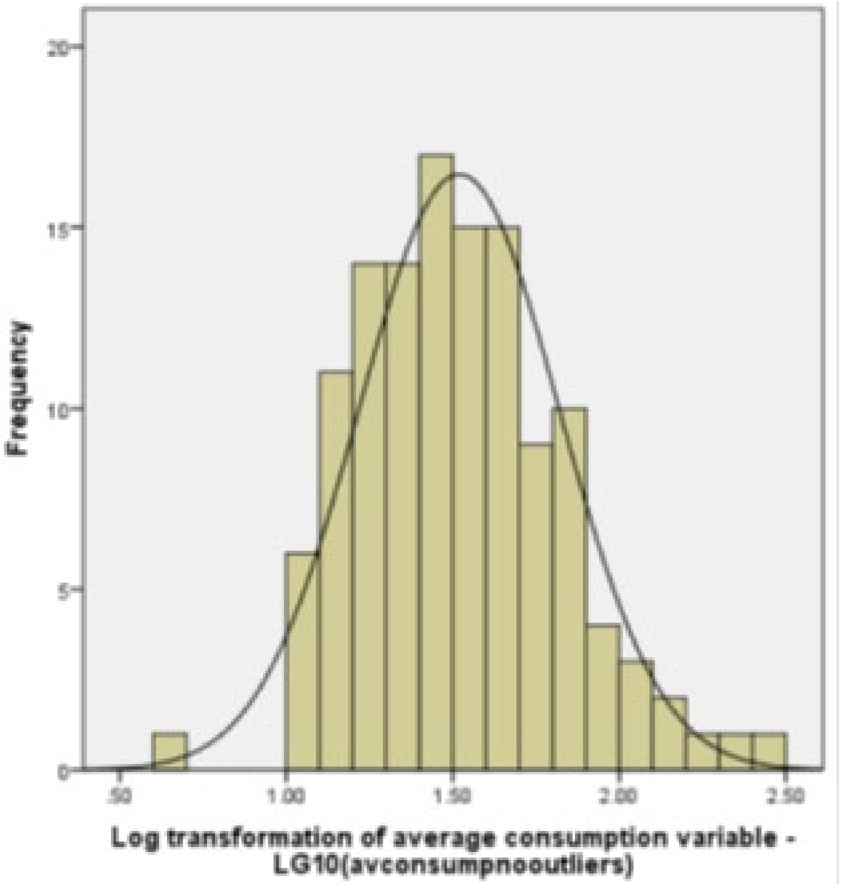
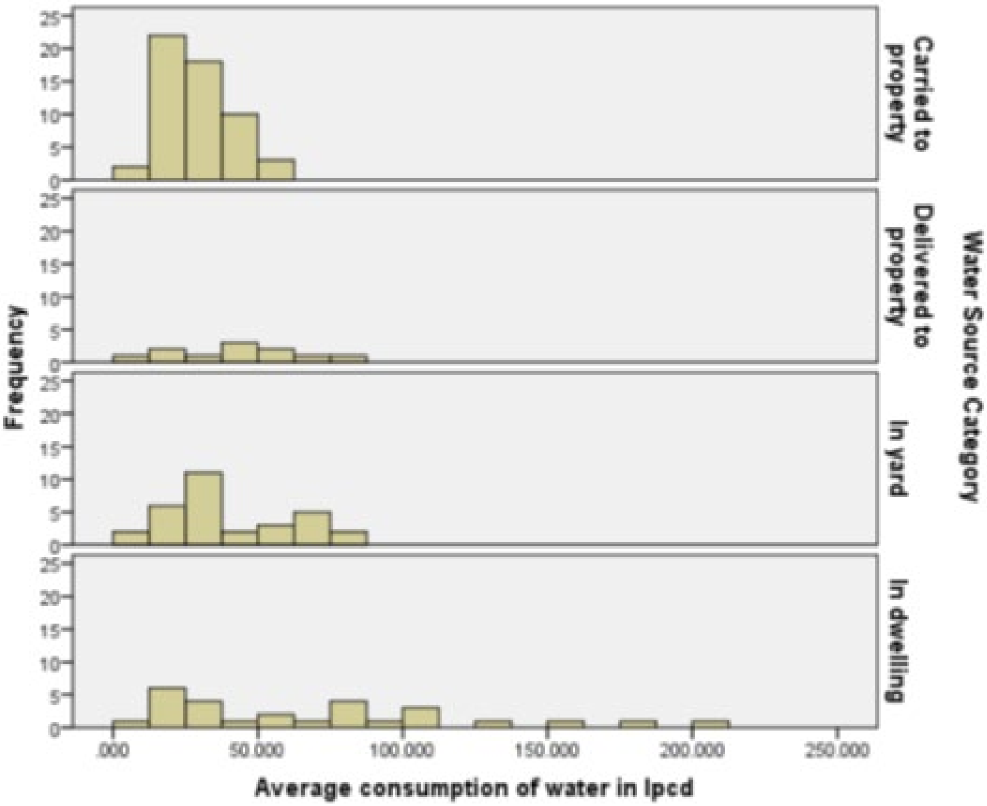


Figure 9: Histograms of average water consumption in Nairobi disaggregated by access method



Accra

The calculated average consumption for all Accra households has a mean value of 46.8 lpcd and a median value of 41.7 lpcd, ranging from 5 to 128 lpcd. A histogram of average consumption is provided in Figure 10 and shows that the distribution is slightly skewed to the left, with a skewness value of 1.167 and a kurtosis value of 1.789. Water consumption for the whole sample can be seen to follow a reasonably smooth distribution. Histograms disaggregated by the primary water source are given in Figure 11. No histograms were produced for the groups of users getting water delivered to property or who had a tap in their dwelling as they contained only five and three responses respectively. The two remaining distributions are relatively similar, although the distribution for users with a water source in the yard is slightly more skewed to the right.

Figure 10: Histogram of average water consumption in Accra

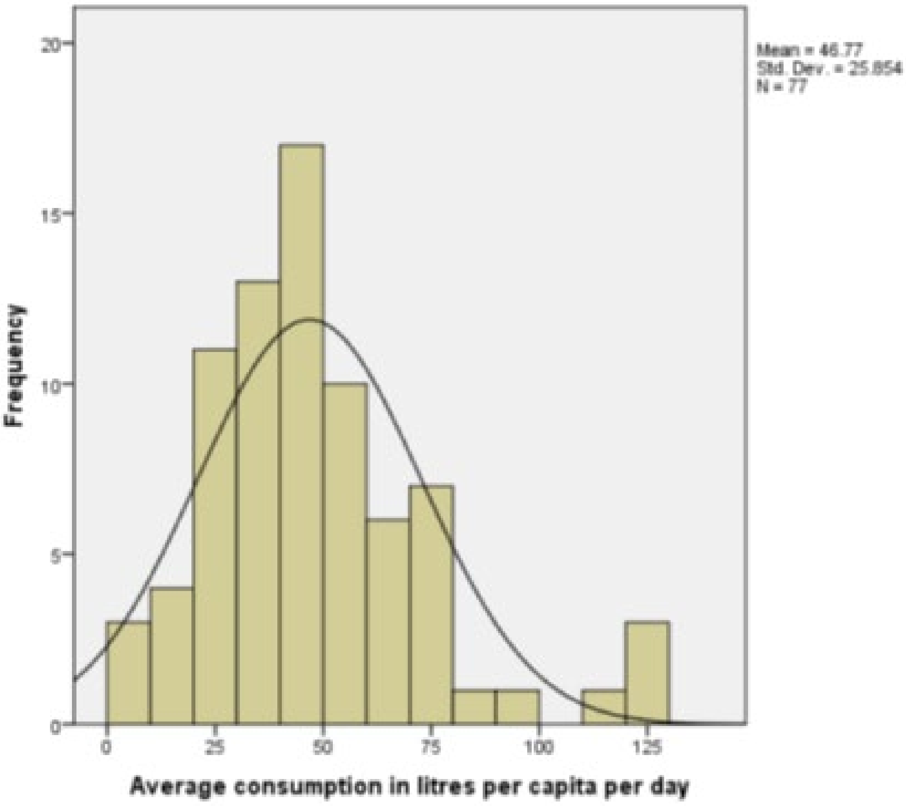
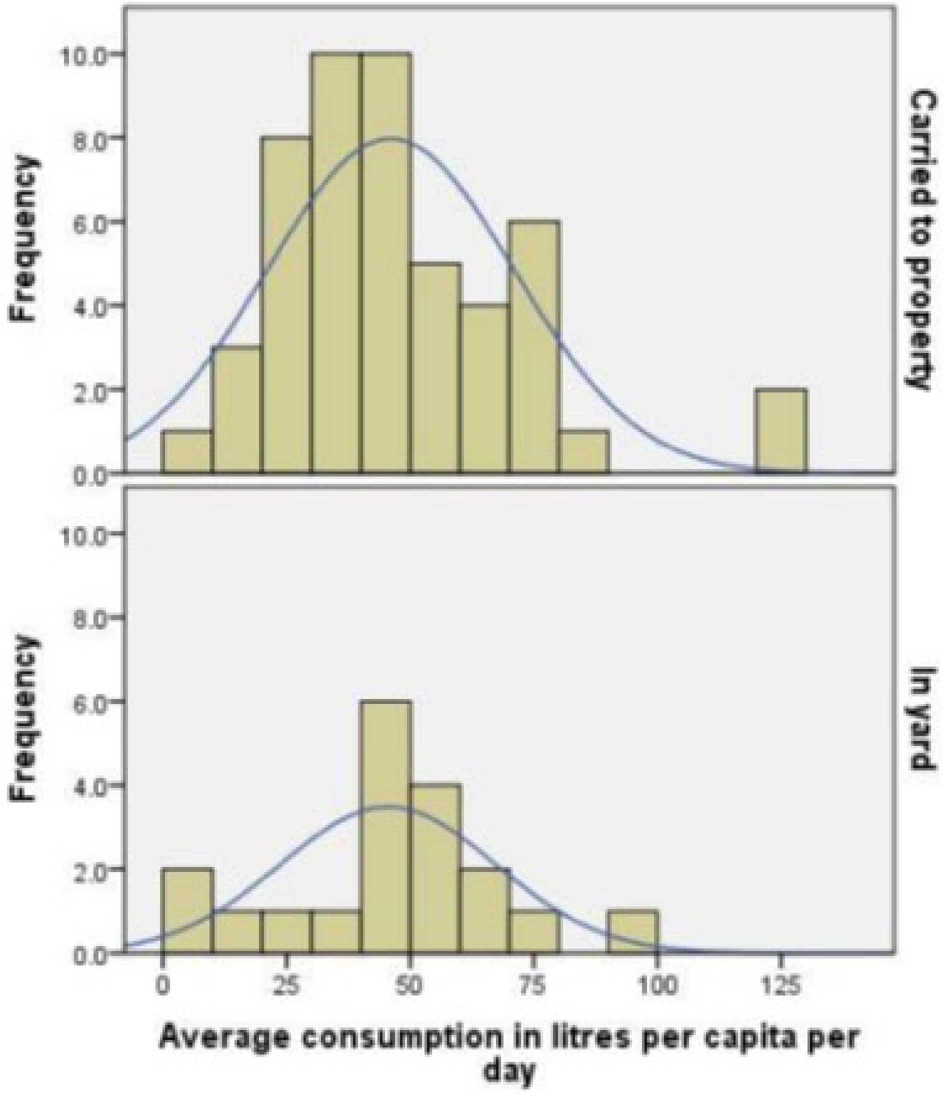


Figure 11: Histograms of average water consumption in Accra by primary water source



The reliability of water sources was found to be very high in the sampled population in Accra. More than 90% of respondents reported that their primary water source is reliable for seven days a week, while this proportion is even higher for the secondary water source, at 97%. The primary water source was reported to be available for either 12 or 14 hours a day by more than 85% of respondents, while all respondents said their secondary source was available for more than 12 hours a day. This high reliability can be explained by the fact that most of the sampled population use kiosks or other public sources as their primary water source. These kiosks usually store water and therefore water is available even though (as mentioned in Section 2.1.2) there is water rationing in Accra and most users of the piped network do not receive water for seven days a week. Furthermore it is likely that users know when water will be available at their kiosk, which increases the perceived reliability.

Water consumption for the whole sample can be seen to follow a reasonably smooth distribution without clumping around particular values. However, histograms of consumption disaggregated by water source show that lower levels of access (i.e. water is carried to the property, delivered to the property, or in the yard) tend to be concentrated around a certain range, while piped water at home displays the largest range of all access modes.

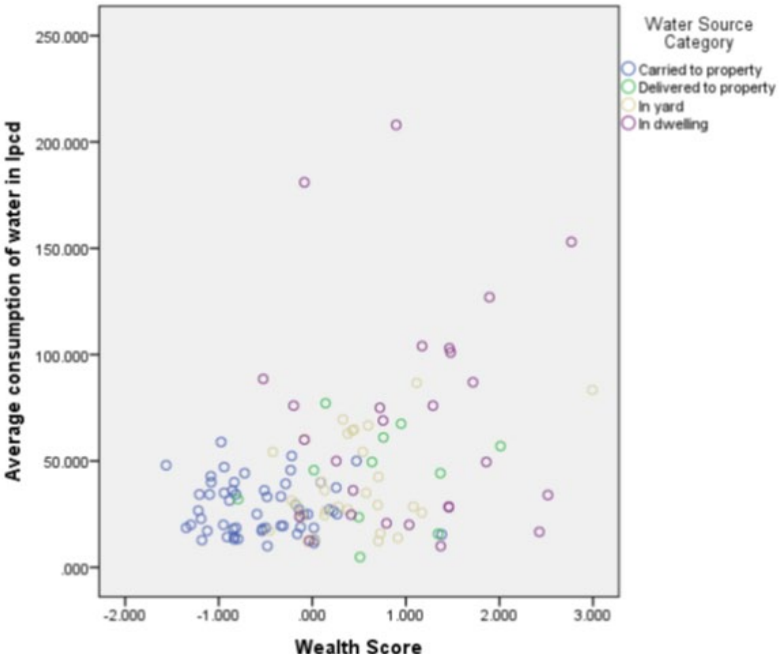
4.1.2 Water consumption and wealth

Nairobi

The relationship between average consumption and household wealth score in Nairobi is shown in Figure 12. Markers are coloured by household water source. Four key observations can be made:

1. There is some indication of a linear relationship between average consumption and wealth. A regression analysis suggests a positive relationship (as is intuitively stable), with r=.362 and p=.000. This relationship is therefore significant (i.e. highly unlikely to have occurred by chance); however, only 12.4% of variation in the consumption data can be explained by wealth (i.e. the adjusted R square value is .124). This suggests that other variables are also important in determining the level of water consumption.
2. Water-carrying is the predominant mode of access for those with lower wealth scores, while household taps are the predominant mode of access for those with higher wealth scores. Yard taps and delivered water appear as a mode of access towards the middle of the wealth scores.
3. Consumption values for those who carry water tend to be strongly clustered, with a mean value of 27.8 lpcd and a standard deviation of 12.2. The standard deviation for those who carry water is considerably lower than the corresponding figure for those with a water source in the dwelling (52.2) and also lower than the corresponding figures for those with a water source in the yard and those who have water delivered (21.6 and 22.4 respectively). It seems intuitive that greater variation in consumption should be seen with increased ease of access (and also with increased wealth), as those with more resources might be freer to choose from a greater variety of lifestyles. It also seems intuitive that the time limitations and the physical strain involved in carrying water to a dwelling would place an upper bound on the level of water consumption to be achieved.
4. Average consumption values tend to rise with increased ease of access. It is the upper bound of consumption that rises and not the lower. It might therefore be suggested that ownership of a tap is necessary, but not sufficient, to indicate increased water consumption.

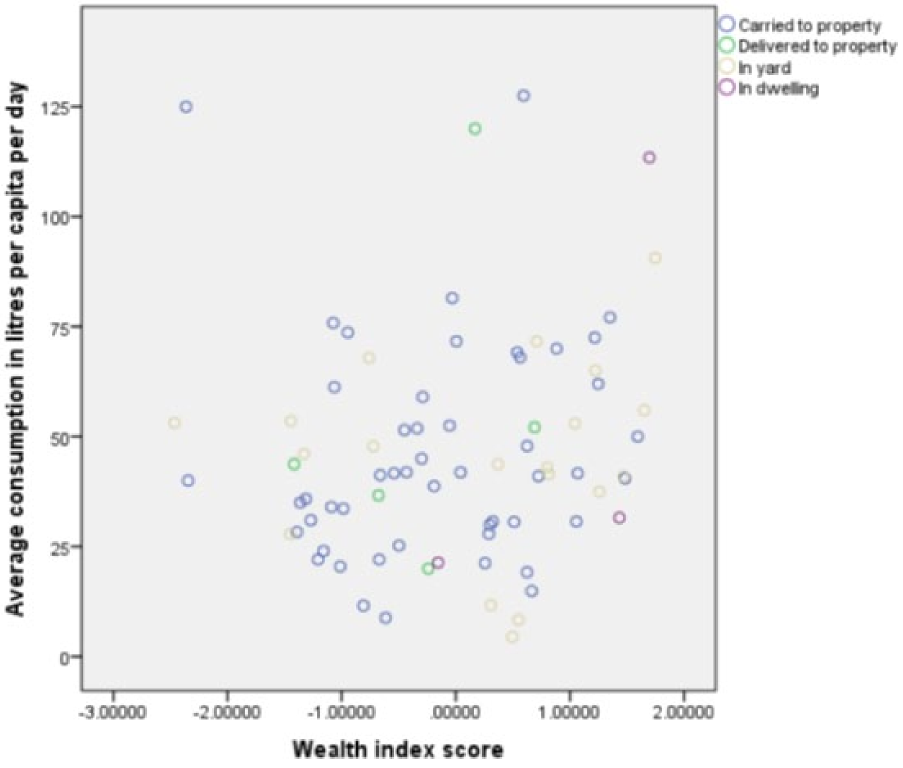
Figure 12: Scatterplot of average water consumption and household wealth score in Nairobi



Accra

The relationship between average consumption and household wealth score in Accra is shown in Figure 13. Markers are coloured by the primary household water source. There appears to be no obvious relationship between average consumption and wealth score, or of method of access and wealth score. However, the wealth score is constructed so as to measure relative variation in wealth within the sample and if there is a small amount of variation then the score does not contain a lot of information. As the sampled households showed relatively low variability regarding their socio-economic status, the wealth score constructed from the sample used in this study is not considered particularly meaningful. Therefore no association between wealth score and average consumption or accessibility is expected. Sampling a wider range of socio-economic and geographical groups would enable a better analysis of the impact wealth has on accessibility and average water consumption. Due to these limitations, the wealth score constructed from the sample was not used in any further analysis of water consumption.

Figure 13: Scatterplot of wealth score and average water consumption in Accra



4.2 Patterns within the data

4.2.1 Nairobi

A correlation matrix was produced to show the relationships between all variables that were considered important, shown in Table 4. Variable relationships which are significant at the $p<0.01$ level are coloured in pink, while variable relationships which are significant at the $p<0.05$ level are coloured in yellow.

It can be seen that there are a number of strong correlations within the data, but none with a Pearson Correlation value (r) of greater than .8, suggesting that multi-collinearity is not likely to be a problem with the dataset (Pallant, 2005).

The strongest correlations observed – which all had an r value =>.550 – were found to be positive relationships between: wealth score and neighbourhood category (r=.673); wealth score and water source category (r=.655); and water source category and neighbourhood category (r=.583). The strongest significant relationship for the average consumption variable was found to be with water source category (r=.443). Significant (but not so strong) relationships were also found to exist with wealth score (r=.362) and neighbourhood category (r=.366). It is notable that variables for number of children, number of infants, education category, ownership of property and length of time resident in property did not appear to have any significant effect on water source or consumption.

A partial correlation was carried out to assess the strength of the relationship between water consumption and wealth score while controlling for water source category. Before controlling for water source category, the correlation between water consumption and wealth score is positive, moderately strong and significant (r=.362, p=.000); however, after controlling for water source, this correlation becomes insignificant and weak (r=.107, p=.239). On the other hand, a partial correlation to assess the strength and direction of the relationship between water consumption and water source category was relatively unchanged by controlling for wealth score (relationship prior to controlling: r=.443, p=.000; relationship after controlling: r=.292, p=.001). This suggests that higher wealth leads to better accessibility which is turn leads to higher consumption, but higher wealth itself is not associated with higher water consumption if the water source is unchanged. Water sources with higher accessibility, however, seem to lead to a higher average consumption, even if wealth is unchanged.

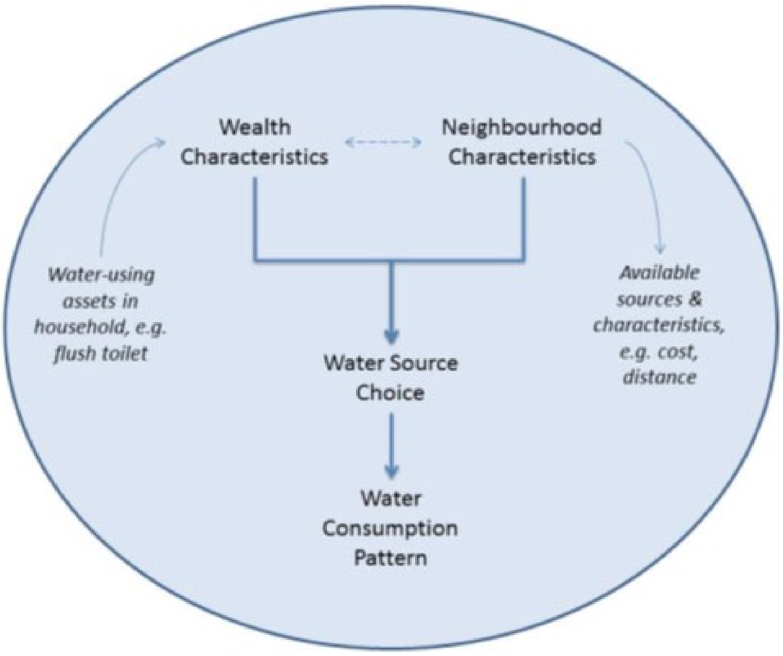
To conclude, it could be theorised that the strongest factors in determining a household's water source are their residential neighbourhood and wealth, and once a source has been established this then becomes the most important variable in determining the amount of water that the household consumes. The relationship between consumption and wealth or consumption and neighbourhood could then be interpreted as secondary, being linked mainly by the choice of water source. This theory is shown visually in Figure 14.

Table 4: Correlation matrix, Nairobi.

		Wealth score	Water Source Category	Property has a flush toilet	Distance to source (metres)	Water is included in rent	Cost of 20 litres of water (Ksh)	Average consump-tion of water (lpcd)	Neigh-bourhood Category	Reliability in days per week	Age Category	Number of people in the house-hold	Length of time resident in property	Household owns property	Time to collect (minutes)	Available volume of storage on property (litres)	Number of children in household	Education category	Number of infants in the household
Wealth Score	Pearson correlation	1	.655	.412	-.381	.325	-.213	.362	.673	-.137	.007	.309**	.210*	.086	-.206*	.289**	.139	.195*	.032
	Sig. (2-tailed)		.000	.000	.000	.000	.018	.000	.000	.132	.935	.000	.021	.341	.028	.001	.123	.030	.724
Water Source Category	Pearson correlation	.655	1	.371	-.361	.417	-.456	.443	.583	-.295	-.075	.159	-.105	-.110	-.105	.199*	.115	.085	.097
	Sig. (2-tailed)	.000		.000	.000	.000	.000	.000	.000	.001	.410	.077	.253	.222	.263	.027	.202	.347	.282
Household has a flush toilet	Pearson correlation	.412	.371	1	-.245	.199	-.132	.252	.333	-.047	-.067	.128	-.083	-.084	-.047	.200*	-.010	.076	.062
	Sig. (2-tailed)	.000	.000		.016	.030	.152	.006	.000	.615	.466	.164	.375	.363	.627	.029	.915	.413	.504
Distance to source (metres)	Pearson correlation	-.381	-.361	-.245	1	-.232	.256	-.181	-.115	.006	.113	-.053	-.031	.018	.400**	-.151	-.083	-.097	.007
	Sig. (2-tailed)	.000	.000	.016		.020	.010	.070	.257	.949	.259	.595	.763	.862	.000	.132	.410	.337	.948
Water is included in rent	Pearson correlation	.325	.417	.199	-.232	1	-.527	-.116	.172	-.507	-.149	-.061	-.107	-.156	.079	.001	-.036	.004	.169
	Sig. (2-tailed)	.000	.000	.030	.020		.000	.201	.058	.000	.098	.502	.247	.083	.399	.994	.689	.969	.060
Cost of 20 litres of water (Ksh)	Pearson correlation	-.213	-.456	-.132	.256	-.527	1	-.121	-.152	.262	.014	-.035	-.042	.078	.119	-.016	-.046	.164	-.081
	Sig. (2-tailed)	.018	.000	.152	.010	.000		.180	.094	.003	.881	.702	.650	.390	.206	.863	.608	.069	.369
Average consumption of water (lpcd)	Pearson correlation	.362	.443	.252	-.181	-.116	0.121	1	.366	.108	-.029	.020	-.005	.036	-.033	.125	.042	.094	-.089
	Sig. (2-tailed)	.000	.000	.006	.070	.201	.180		.000	.237	.745	.826	.956	.688	.723	.166	.647	.300	.325
Neighbourhood Category	Pearson correlation	.673	.583	.333	-.115	.172	-.152	.366	1	-.157	-.010	.085	.114	.013	-.165	.075	.003	.171	-.026
	Sig. (2-tailed)	.000	.000	.000	.257	.058	.094	.000		.085	.912	.352	.218	.891	.079	.411	.971	.058	.778
Reliability in days per week	Pearson correlation	-.137	-.295	-.047	.006	-.507	.262	.108	-.157	1	.086	.015	.126	.050	-.243**	.065	-.065	-.174	-.168
	Sig. (2-tailed)	.132	.001	.615	.949	.000	.003	.237	.085		.346	.867	.173	.584	.009	.478	.475	.054	.063
Age Category	Pearson correlation	.007	-.075	-.067	.113	-.149	.014	-.029	-.010	.085	1	.208*	.433**	.278**	.138	.043	.219*	-.272**	-.147
	Sig. (2-tailed)	.935	.410	.466	.259	.098	.881	.745	.912	.346		.020	.000	.002	.141	.636	.015	.002	.102
Number of people in household	Pearson correlation	.309	.159	.128	-.053	-.061	-.035	.020	.085	.015	.208*	1	.155	.097	.040	.220*	.628**	-.168	.214*
	Sig. (2-tailed)	.000	.077	.164	.595	.502	.702	.826	.352	.867	.020		.091	.285	.671	.014	.000	.062	.017
Length of time resident in property	Pearson correlation	.210*	-.105	-.083	-.031	-.107	-.042	-.005	.114	.126	.433**	.155	1	.345**	-.086	.180*	.105	-.032	-.160
	Sig. (2-tailed)	.021	.253	.375	.763	.247	.650	.956	.218	.173	.000	.091		.000	.371	.050	.255	.730	.082
Household owns property	Pearson correlation	.086	-.110	-.084	.018	-.156	.078	.036	.013	.050	.278**	.097	.345**	1	-.084	.122	.128	-.001	-.190*
	Sig. (2-tailed)	.341	.222	.363	.862	.083	.390	.688	.891	.584	.002	.285	.000		.372	.177	.156	.987	.035
Time to collect (mins)	Pearson correlation	-.206*	-.105	-.047	.400**	.079	.119	-.033	-.165	-.243**	.138	.040	-.085	-.084	1	-.085	.079	-.078	.064
	Sig. (2-tailed)	.028	.263	.627	.000	.399	.205	.723	.079	.009	.141	.671	.371	.372		.367	.404	.406	.495
Available volume of storage on property (litres)	Pearson correlation	.289**	.199*	.200*	-.151	.001	-.016	.125	.075	.065	.043	.220*	.180*	.122	-.085	1	-.111	.015	.213*
	Sig. (2-tailed)	.001	.027	.029	.132	.994	.863	.166	.411	.478	.636	.014	.050	.177	.367		.219	.867	.018
Number of children in household	Pearson correlation	.139	.115	-.010	-.083	-.036	-.046	.042	.003	-.065	.219*	.628**	.105	.128	.079	-.111	1	-.182*	-.042
	Sig. (2-tailed)	.123	.202	.915	.410	.689	.608	.647	.971	.475	.015	.000	.255	.156	.404	.219		.043	.644
Education Category	Pearson correlation	.195*	.085	.076	-.097	.004	.164	.094	.171	-.174	-.272**	-.168	-.032	-.001	-.078	.015	-.182*	1	-.046
	Sig. (2-tailed)	.030	.347	.413	.337	.969	.069	.300	.058	.054	.002	.062	.730	.987	.406	.867	.043		.612
Number of infants in household	Pearson correlation	.032	.097	.062	.007	.169	-.081	-.089	-.026	-.168	-.147	.214*	-.160	-.190*	.064	.213*	-.042	-.046	1
	Sig. (2-tailed)	.724	.282	.504	.948	.060	.369	.325	.778	.063	.102	.017	.082	.035	.495	.018	.644	.612	

* Correlation is significant at the 0.01 level (2-tailed). ** Correlation is significant at the 0.05 level (2-tailed). Variable relationships which are significant at the p<0.01 level are coloured pink, while variable relationships significant at the p<0.05 level are coloured yellow.

Figure 14: Theoretical relationships determining water consumption in Nairobi



4.2.2 Accra

A correlation matrix for the data gathered was produced and is given in Table 5. No relationships within the Accra correlation matrix had a correlation coefficient of greater than 0.8, suggesting that multi-collinearity is not likely to be a problem within the dataset. Significant (i.e. $p<0.05$) negative correlations exist between average water consumption and: number of household members and distance from the source. No correlation was noted between average consumption and water source; however, given the small variety in water sources examined and the limited sample size for two of the categories (delivered to property and private tap), it is perhaps not surprising that no significant association would be detected.

Wealth score was noted to be significantly positively correlated with education category, primary water source ease-of-access category and presence of a toilet. Wealth score is significantly negatively correlated with insecurity of tenure status (as rated on a scale increasing with increased tenure insecurity). This is intuitively correct and shows that although the wealth index of the sample does not explain water consumption patterns, it does capture the socio-economics of the sample to a certain extent.

Partial correlations were carried out between average consumption and distance from the source, while controlling for the water source category. The relationship was still found to be statistically significant.

Table 5: Correlation matrix, Accra

		Wealth index score	Age category of respondent	Number of people	Number of infants	Number of children	Education category	Tenure status	Length of residence (years)	Dry season primary source, cost (US $ per 20 litres)	Dry season, primary source, hours per week reliability	Dry season, primary source, hours per day reliability	Dry season, primary source, hours per day collecting	Average consumption in litres per capita per day	Volume of storage available (litres	Toilet?	Distance from source (metres)	Dry primary drinking source - recode	Dry secondary drinking source - recode
Wealth index score	Pearson Correlation	1	-.169	-.100	-.198	.032	.547**	-.292**	.065	-.009	-.038	.096	.327	.138	.211	.471**	.271	.230*	.082
	Sig. (2-tailed)		.141	.386	.084	.781	.000	.010	.572	.940	.750	.431	.253	.231	.057	.000	.277	.044	.479
Age category of respondent	Pearson Correlation	-.169	1	.057	-.242*	.218	-.125	.224	.173	-.006	.078	-.084	.110	-.017	-.053	-.146	-.013	.182	.038
	Sig. (2-tailed)	.141		.623	.034	.057	.278	.050	.131	.962	.510	.491	.709	.884	.652	.208	.959	.113	.743
Number of people	Pearson Correlation	-.100	.057	1	.151	.580**	-.039	-.168	.456**	-.034	-.113	-.178	.157	-.355**	.107	-.166	.281	.003	-.030
	Sig. (2-tailed)	.386	.623		.191	.000	.734	.144	.000	.775	.338	.144	.591	.002	.358	.151	.259	.980	.799
Number of infants	Pearson Correlation	-.198	-.242*	.151	1	-.176	.020	.037	-.186	.166	-.073	-.031	-.143	-.124	-.006	.077	-.107	-.123	-.017
	Sig. (2-tailed)	.084	.034	.191		.125	.860	.747	.105	.160	.537	.802	.626	.284	.962	.506	.672	.288	.882
Number of children	Pearson Correlation	.032	.218	.580**	-.176	1	-.100	.077	.336**	.008	-.173	-.227	.248	-.187	.076	-.271*	.550*	.107	-.060
	Sig. (2-tailed)	.781	.057	.000	.125		.388	.508	.003	.947	.140	.060	.392	.104	.513	.018	.018	.354	.606
Education category	Pearson Correlation	.547**	-.125	-.039	.020	-.100	1	-.211	-.190	-.031	.063	.041	-.149	.208	.294*	.345**	.386	.133	.129
	Sig. (2-tailed)	.000	.278	.734	.860	.388		.066	.097	.797	.594	.736	.611	.070	.010	.002	.114	.250	.262
Tenure status	Pearson Correlation	-.292**	.224	-.168	.037	.077	-.211	1	-.134	.080	.121	.012	-.148	.004	-.142	-.229*	-.073	.037	-.124
	Sig. (2-tailed)	.010	.050	.144	.747	.508	.066		.245	.503	.304	.919	.613	.973	.222	.047	.774	.750	.284
Length of residence (years)	Pearson Correlation	.065	.173	.456**	-.186	.336**	-.190	-.134	1	-.015	.075	-.182	-.070	-.111	-.048	-.127	-.331	-.193	.032
	Sig. (2-tailed)	.572	.131	.000	.105	.003	.097	.245		.899	.524	.134	.813	.339	.683	.273	.180	.092	.784
Dry season, primary source, cost (US $ per 20 litres)	Pearson Correlation	-.009	-.006	-.034	.166	.008	-.031	.080	-.015	1	.033	-.309*	-.141	-.040	-.080	-.013	-.125	-.321**	-.145
	Sig. (2-tailed)	.940	.962	.775	.160	.947	.797	.503	.899		.782	.010	.631	.734	.506	.915	.633	.006	.221
Dry season, primary source, days per week reliability	Pearson Correlation	-.038	.078	-.113	-.073	-.173	.063	.121	.075	.033	1	.198	-.999**	.086	-.512**	-.172	-.044	.009	-.216
	Sig. (2-tailed)	.750	.510	.338	.537	.140	.594	.304	.524	.782		.103	.000	.464	.000	.146	.868	.937	.064
Dry season, primary source, hours per day reliability	Pearson Correlation	.096	-.084	-.178	-.031	-.227	.041	.012	-.182	-.309*	.198	1	.103	-.040	-.020	.061	.384	.521**	.025
	Sig. (2-tailed)	.431	.491	.144	.802	.060	.736	.919	.134	.010	.103		.726	.744	.871	.619	.175	.000	.838
Dry season, primary source, hours per day collecting	Pearson Correlation	.327	.110	.157	-.143	.248	-.149	-.148	-.070	-.141	-.999**	.103	1	-.166	.606*	.229	-.338	-.122	-.113
	Sig. (2-tailed)	.253	.709	.591	.626	.392	.611	.613	.813	.631	.000	.726		.571	.022	.451	.662	.678	.701
Average consumption in lpcd	Pearson Correlation	.138	-.017	-.355**	-.124	-.187	.208	.004	-.111	-.040	.086	-.040	-.166	1	.043	.060	-.532*	.035	.038
	Sig. (2-tailed)	.231	.884	.002	.284	.104	.070	.973	.339	.734	.464	.744	.571		.714	.606	.023	.763	.741
Volume of storage available	Pearson Correlation	.211	-.053	.107	-.006	.076	.294**	-.142	-.048	-.080	-.512**	-.020	.606*	.043	1	.258*	.438	-.074	.190
	Sig. (2-tailed)	.067	.652	.358	.962	.513	.010	.222	.683	.506	.000	.871	.022	.714		.026	.069	.524	.100
Toilet?	Pearson Correlation	.471**	-.146	-.166	.077	-.271*	.345**	-.229*	-.127	-.013	-.172	.061	.229	.060	.258*	1	.091	.013	.045
	Sig. (2-tailed)	.000	.208	.151	.506	.018	.002	.047	.273	.915	.146	.619	.451	.606	.026		.718	.910	.703
Distance from source (metres)	Pearson Correlation	.271	-.013	.281	-.107	.550*	.386	-.073	-.331	-.125	-.044	.384	-.338	-.532*	.438	.091	1	.325	-.115
	Sig. (2-tailed)	.277	.959	.259	.672	.018	.114	.774	.180	.633	.868	.175	.662	.023	.069	.718		.188	.649
Dry primary drinking source - recode	Pearson Correlation	.230*	.182	.003	-.123	.107	.133	.037	-.193	-.321**	.009	.521**	-.122	.035	-.074	.013	.325	1	-.078
	Sig. (2-tailed)	.044	.113	.980	.288	.354	.250	.750	.092	.006	.937	.000	.678	.763	.524	.910	.188		.500
Dry secondary drinking source - recode	Pearson Correlation	.082	.038	-.030	-.017	-.060	.129	-.124	.032	-.145	-.216	.025	-.113	.038	.190	.045	-.115	-.078	1
	Sig. (2-tailed)	.479	.743	.799	.882	.606	.262	.284	.784	.221	.064	.838	.701	.741	.100	.703	.649	.500	

4.3 Statistical difference between groups

To see whether differences in the means of water consumption between water source category groups are greater than those occurring within groups and whether they are likely to have occurred by change, a one-way analysis of variance (ANOVA) test was conducted. In Accra, the differences in means between the groups were not found to be statistically significant. However, given the small number of interviews conducted for all categories except 'water carried to property' and 'yard tap' it is not necessarily to be expected that a significant difference would be detected.

In Nairobi, the differences were found to be statistically significant (p=0.000); however, post-hoc comparisons using the Tukey HSD test showed that significant differences at the p<0.05 level only exist between consumption from taps in dwelling and carried water, and consumption from taps in dwelling and taps in the yard (see Table 6). The difference between consumption from taps in dwelling and delivered water is close to being statistically significant (p=.066), which can be termed a suggestive difference. The Eta squared value for the difference between groups is 0.24, which is classed as a 'large effect' by Cohen's terms (Pallant, 2005).

A two-way between-groups ANOVA was also conducted to check the impact of wealth category and water source category on average water consumption in Nairobi. There was no significant interaction effect between wealth category and water source category (p=0.801), thus indicating that variation of consumption within water source categories is not significantly influenced by wealth category.

Table 6: Difference in means between water source categories in Nairobi (significant differences highlighted)

		In dwelling (x=69.0 lcpd)	In yard (x=38.9 lpcd)	Delivered to home (x=43.5 lpcd)	Carried to home (x=27.8 lpcd)
At home	Difference in mean		30.1 lpcd	25.5 lpcd	41.2 lpcd
	Significance level		0.001	0.066	0.000
In the yard	Difference in mean	30.1 lpcd		4.6 lpcd	11.08 lpcd
	Significance level	0.001		0.968	0.315
Delivered to home	Difference in mean	25.5 lpcd	4.6 lpcd		15.7 lpcd
	Significance level	0.066	0.968		0.350
Carried to home	Difference in mean	41.2 lpcd	11.08 lpcd	15.7 lpcd	
	Significance level	0.000	0.315	0.350	

To determine whether or not reliability (defined as days per week on which water is available) has a statistically significant impact on water consumption in Nairobi, the mean water consumption for two levels of reliability was compared using a t-test. The data set was split into two groups of users receiving water for more than four days a week and those who get water for four or less days a week. Although there is a difference in the means, it was found not to be statistically significant (p=0.248). This suggests that increased reliability does not necessarily lead to higher water consumptions in the overall sample. Analysing each water source individually shows that for three of the sources, the means for both groups of reliability do not show a statistically significant difference: carried water (p=0.161), delivered water (p=0.923) and household connections (p=0.092). For the yard tap group however, a statistically significant difference could be found (p=0.042). Users of yard taps that are reliable for more than four days per week consume significantly more water than users who receive water for four days or less. However, the sample size in this category is rather small (n=31); therefore, this result should be seen as indicative and would benefit from further investigation in a more rigorous manner using larger sample sizes.

4.4 Regression models

4.4.1 Nairobi

Multiple regression models were constructed to produce equations with average per capita water consumption as the dependent variable. The aim was to produce models capable of predicting average per capita water consumption from a set of easily observable household characteristics.

All regression models constructed were statistically significant (p<.001) and did not display any degree of collinearity; however, none were able to produce an adjusted R squared value of greater than 0.3, indicating that the models still struggled to explain the majority of variation in the data. The first model was initially produced using 13 variables, and then subsequently refined to remove variables without significance (i.e. p>.005). The models were then tested on the data with two outliers removed, to see if this greatly changed the percentage of variation explained.

The initial variables included were: wealth score, age category, time to collect water in minutes, cost of 20 litres of water, household owns property (dummy), volume of storage available on property, number of people in the household, reliability in days per week, distance to source in metres, neighbourhood category, inclusion of water in rent (dummy) and water source category. A model containing all these variables had an adjusted R squared value of .301; however, many of the variables contained within the model were insignificant. Refinement of the model to contain significant variables only produced a model with an adjusted R squared value of .289, which contained the variables: wealth score, water source category and inclusion of water in rent (dummy).

Upon removing outliers, the regression model (using the same variables) produced a lower adjusted R squared value of .254; however, the residuals plot produced for this model showed more homogenously distributed residuals, indicating a more valid model. This has been termed 'Model 1', and is described below in Table 7. A model using wealth score alone had an adjusted R squared value of .126; this has been termed 'Model 2' and is described below in Table 8.

Table 7: Model 1 characteristics

	Coefficient	Standard error	P
Constant	23.561	4.663	0.000
Wealth score	5.375	2.738	0.052
Water source category	8.328	2.143	0.000
Water included in rent	-17.389	4.630	0.000
Number of observations	121		
Adjusted R squared value	0.254		
Model significance	0.000		
Number of case-wise diagnostics	0		

Table 8: Model 2 characteristics

	Coefficient	Standard error	P
Constant	36.338	2.035	0.000
Wealth score	9.558	2.230	0.000
Number of observations	121		
Adjusted R squared value	0.126		
Model significance	0.000		
Number of case-wise diagnostics	1		

Regression models are data-driven, i.e. the model is derived purely from patterns in the data without any reference to the real world meaning of the values involved. For this reason, regression models must be constructed with care and the results interpreted with caution. It is also important to remember that the models cannot distinguish between correlation and cause. For instance, it might be surprising to note that having 'water included with rent' (as in Model 1) appears to have a negative effect on water consumption; however, in practice this may in fact be due to the strong and significant correlation between having yard taps as a water source and having water included in rent (r=.628, p=.000) and the relatively low average water consumption of yard tap users. Thus, within this particular data set the inclusion of water in rent is correlated with lower average consumption values but does not necessarily cause them. With these limitations, care must be taken not to extrapolate from the results without due thought.

It should also be noted that categorical and ordinal variables such as water source and neighbourhood have been allocated quasi-arbitrary values with which to indicate the degree of ease of accessibility or neighbourhood formality. However, this does not necessarily form a continuous or accurate scale. For example, water access modes are allocated values of 1 to 4, with 1 indicating the least ease of access (carrying water to the dwelling) and 4 indicating the greatest ease of access (having water available in the dwelling). Spacing between these four modes of access is not necessarily equidistant and the scale does not take into account the subtleties existing between access modes. For instance, having water delivered to the property is rated as a lower access mode than having a yard tap, but this is a question of personal judgement. These issues make these variables not entirely suitable for conducting any kind of correlation or regression analysis, despite them containing highly relevant information. The wealth score, on the other hand, has been produced so as to form a continuous variable. This characteristic makes it more useful in regression analysis than the subsequent categorisation into wealth clusters, or other categorised variables. Given the close correlation between wealth score and water source (r=.655, p=.000), wealth score is here considered suitable as a proxy for water source, hence making Model 2 the potentially more useful and robust model. However, for the reasons described, the regression models have not been considered further as they fail to explain the majority of variation in the data and are not considered suitable techniques for this purpose at present.

4.4.2 Accra

A regression model was constructed with average water consumption in litres per-capita per day as the dependent variable and the number of people in a household and the distance from the source as independent variables, these two having been identified to be significantly correlated to average water consumption. A summary of the model is presented in Table 9. The regression model constructed was statistically significant (p=0.05) and did not display any degree of collinearity. However, it was not able to produce an adjusted R-squared value of greater than 0.3, indicating that the model struggled to explain the majority of variation in the data. Therefore the number of people in the household and the distance to source cannot be used to predict average water consumption. As discussed above, the wealth score constructed from the sample was not considered meaningful and therefore, no regression using wealth score as an independent variable was conducted.

Table 9: Regression model for average water consumption

	Coefficient	Standard error	P
Constant	74.619	13.034	0.000
Number of people in household	-2.085	2.055	0.326
Distance from source in metres	-0.072	0.034	0.050
Number of observations	77		
Adjusted R squared value	0.240		
Model significance	0.050		

4.5 Principal component analysis

Factor analysis techniques such as PCA (described in Section 3.2.2) are commonly used within the social sciences to develop and evaluate scales of measurement for abstract qualities (Pallant, 2005). PCA was applied to 13 variables considered to be important to water consumption in order to identify important patterns within the Nairobi data set and draw out a small number of underlying factors. Prior to performing PCA, the factorability of the data was assessed through Bartlett's test of sphericity, the Kaiser-Meyer-Olkin (KMO) test, and visual inspection of the correlation matrix, all of which indicated that the data was suitable for this technique (Bartlett's test: p<0.005 and KMO >0.6) (Pallant, 2005, p.191). Inspection of the scree plot and the use of parallel analysis (using the free software Monte Carlo PCA for Parallel Analysis (Watkins, 2000)) supported the extraction of four independent factors for further investigation. Each factor can be interpreted as a 'super-variable' being composed of a number of related variables, with a defined character. The four factors explain 61.5% of the variance, with factors 1, 2, 3 and 4 explaining 25.7%, 15.0%, 11.4% and 9.5% of the variance respectively.

Varimax rotation was performed on the factors to assist with interpretation. This technique rotates the dataset so as to present the pattern of loadings in a way that brings out the underlying nature of the factors more clearly. The rotated solution is shown in Table 10, with only significant factor loadings (greater than .3) displayed for clarity.

Table 10: Rotated coefficients pattern

	Component			
	1	2	3	4
Neighbourhood category	0.810			
Wealth score	0.758			
Water source category	0.705	-0.448		
Household vends water (dummy)	-0.687		0.318	
Water is included in rent (dummy)		-0.821		
Cost of 20 litres of water (Ksh)		0.756		
Reliability (days per week water is available)		0.707		-0.303
Age category of respondent			0.730	
Household owns property (dummy)			0.696	
Available volume of storage on property (litres)			0.566	
Number of people in the household			0.417	
Time to collect water per day (minutes)				0.824
Distance to water source (metres)				0.737

The four factors can be loosely defined as the following:

1. Degree of asset possession (as determined by source category, wealth score and neighbourhood);
2. Financial elements (such as the cost and payment arrangements for water);
3. Demographics and household characteristics (such as number of people, ownership, size of storage, age);
4. Accessibility factors (such as time taken and distance travelled to collect water).

There are a few anomalies and unclear relationships within these factors. The presence of 'household vends water' and 'reliability' within factors 1 and 2 seem out of place, while 'household vends water' also seems to fit poorly within factor 3. For the most part, however, it would appear that four independent dimensions of water supply have emerged suggesting that further investigation may be worthwhile. The definition of four independent factors covering different aspects relating to water consumption could facilitate the construction of a scale measuring ease of access to water. Such a scale would include a balanced number of questions concerning each of the four identified dimensions – degree of asset possession, financial elements, demographics and household characteristics and accessibility – which would then be combined into a single continuous scale. A continuous variable of this type might make subsequent analysis of consumption and ease of accessibility more feasible with techniques such as multiple regression.

5 Scenario testing results

The impact of various scenarios in which users are moved to higher levels of service were assessed using spreadsheet version 9A (Mac) produced by Dr Andrew Sleigh, which is described in Section 3.4.

5.1 Nairobi

Five scenarios were examined in Nairobi and are described below. All scenarios were extrapolated to 20 years into the future using characteristic population growth rates for each sub-district. Changes to service levels are assumed to take place instantly, meaning that the time of implementation and the gradually increasing water demand is neglected. As the goal of this scenario testing is to assess the resulting changes in water demand and the final volume of water needed, neglecting the incremental increase in demand during implementation is considered acceptable.

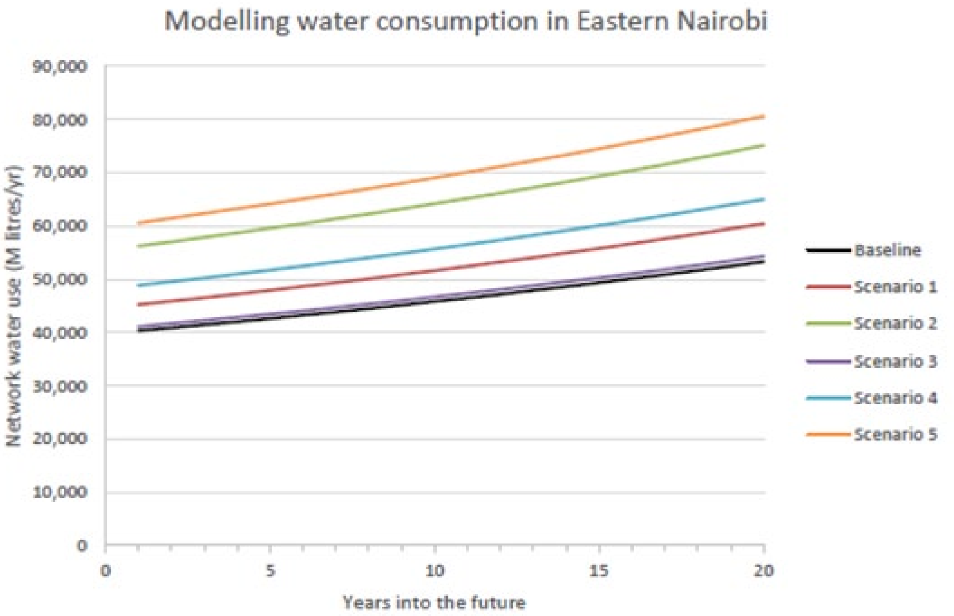
In the scenarios it is assumed that for everyone currently obtaining water from the NCWSC network:

1. Reliability of yard taps was increased to more than four days per week for all current yard tap users;
2. All households with yard tap connections were changed to have household connections;
3. All households with no connections (i.e. water is carried or delivered) were changed to have yard tap connections with a reliability of up to four days per week;
4. All households with no connections (i.e. water is carried or delivered) were changed to have yard tap connections with a reliability of more than four days per week and reliability for all current users with yard taps was increased to more than four days per week;
5. All households with no connections and yard tap connections were changed to have household connections.

In the first run, our model estimated a baseline domestic consumption including physical losses of around 57,500 Ml per year. This was compared with the total amount of water produced according to NCWSC. A water balance for the year 2013 was shared with the research team and showed a total system input volume of 199,432 Ml per year. Commercial and industrial users account for 32% of the overall water demand (IBNet, 2015), which leaves about 135,550 Ml per year for domestic consumption. Therefore, a large gap remained between the initial result and the actual water production. An investigation into average consumption patterns on the sub-city scale showed that consumers in western Nairobi tend to use significantly higher volumes of water than residents in the eastern part of the city. Ledant et al. (2011a) found consumption values of 129 to 288 lpcd in western Nairobi, while values in the east tend to be around 30 lpcd. The fieldwork locations used in this study were all located in the east of the city, because of the higher variability of water sources and socio-economics found there, and because this study is focused on improving service levels in poorer, more informal neighbourhoods. To retain the focus on these informal areas, the model was adapted to only include improvements in the eastern neighbourhoods, where consumption values from this study agree with the values found by Ledant et al. (2011a), while average water consumption by the population in the west that had been removed from the model was assumed to be 180 lpcd and added to the baseline water use.

This adapted model estimated a baseline water demand of around 120,000 Ml per year, a value within around 15% of the actual production, which can be considered acceptable accuracy. Figure 15 shows the results of the five scenarios described above for the eastern part of the city.

Figure 15: Scenario results, Nairobi



It can be seen that moving all users with yard taps to a higher level of service by improving their reliability leads to an 11% higher water consumption in eastern Nairobi, which is a 4% increase in city-wide water demand. This is a relatively minor impact on the total demand; however, results in significantly improved services for this group of users.

Providing people currently using yard taps with household taps has a relatively large impact on water consumption, causing water use in the eastern part of Nairobi to rise by 40%, which corresponds to a 12% increase in total water demand. This is caused by the large number of people currently using yard taps, but also means that all of them receive significantly better services after the intervention.

Conversely, the action of moving all users without a network connection onto the lowest form of connection (i.e. a yard tap with low reliability) causes only a very small increase in water consumption, just 2% more than the baseline scenario in the eastern part of town, which is an increase of less than 1% city-wide. If the new users are provided with yard taps with high reliability, the increase is 9% in the eastern part of the city and 3% overall. Thus, providing a yard tap to people who currently access water from the network in any form can be expected to have minimal effects on city-wide water demand, if any at all. It does however significantly increase the level of service to users by reducing the amount of time spent on collecting water every day.

Moving all users without a connection to yard taps with high reliability and improving the reliability for current users of yard taps was found to increase the water demand in eastern Nairobi by 21% and represents an increase of 6% in overall water use. This is a bigger impact, but also provides a higher level of service to users.

Increasing the level of service to a household tap for all people currently accessing water from the network has the highest impact, increasing water consumption in eastern Nairobi by 50%, which is a 15% increase in city-wide water demand. Although this is a relatively large increase, it also means providing household connections to about 1.5 million residents, which improves living conditions for a significant part of Nairobi's residents. It also means that by having a private connection, these 1.5 million residents become paying customers, thereby helping to increase cost recovery for the utility.

5.2 Accra

The total water production in Accra (gathered from key informant interviews with utility staff) is around 158,045 Ml per year. Van-Rooijen (2008) report that commercial, industrial and institutional users account for about 20% of total water consumption, which brings the remaining water for domestic consumption to about 126,000 Ml. The baseline domestic network water consumption obtained in our model is around 104,000 Ml to 108,000 Ml, including the commonly cited 27% to 30% physical losses (Adank et al., 2011, Abraham et al., 2007), which leaves around 20,000 Ml unaccounted for. There are several explanations for the difference between the estimated consumption and the actual production. Leakage rates are notably hard to assess precisely and are often misreported (Frauendorfer and Liemberger, 2010), so the actual physical losses could be higher. There could also be commercial or industrial users which are not accounted for, thereby reducing the total amount available for domestic consumption. Another explanation is the large number of transient workers. Every day, a large number of people come to Accra to work as day labourers, which is a population not captured in the census population. Water consumption of this transient population is difficult to assess, however it can be assumed that they consume at least 2.5 lpcd for drinking, 4 lpcd for sanitation and 4.5 lpcd for cooking (The Sphere Project, 2011). Assuming a number of one million day labourers, their water demand on that basis would be around 400 Ml per year, which does not explain the difference between the total water demand obtained from our model and the water production gathered from key informant interviews.

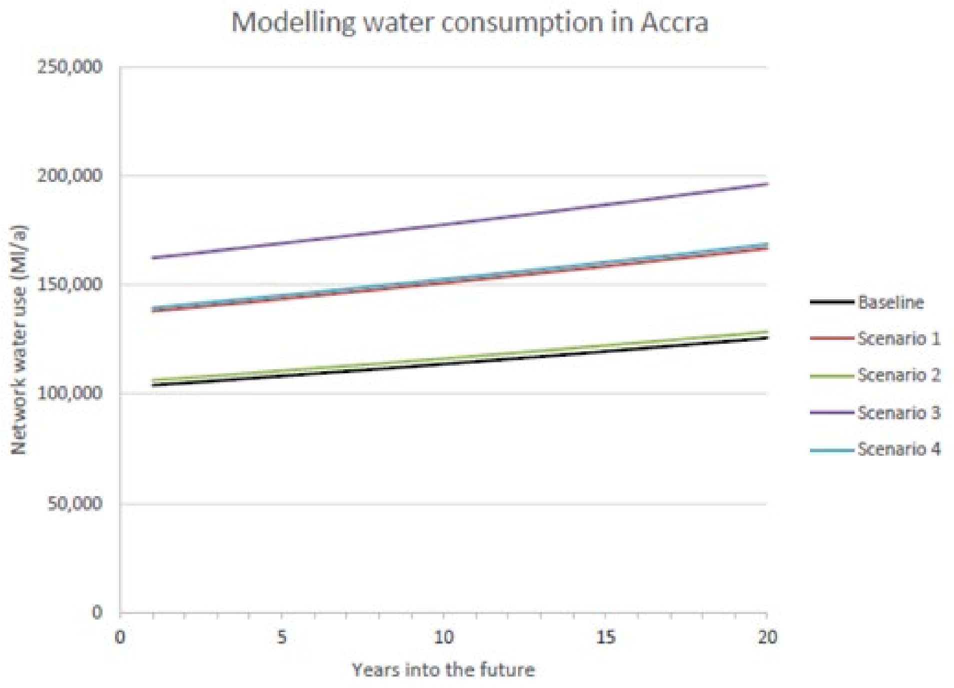
Therefore a gap remains between the amount of water produced as gathered by interviews with utility staff and the results of our model. As explained above, higher leakage or unauthorised or unaccounted for commercial use could be one explanation for the gap. Furthermore, in the model all users of one accessibility category are assumed to use the same amount of water every day. In reality some households, especially in high-income neighbourhoods, might be using significantly higher quantities, which would lead to an underestimation of total water demand.

Despite this gap, it was decided to use the water use modelling tool with our estimated baseline consumption to assess the impacts of changing service levels for Accra's population. The scenarios examined are described below.

1. All households with yard tap connections were changed to have household connections;
2. All households with no connections (i.e. water is carried or delivered) were changed to have yard tap connections;
3. All households with no connections and yard tap connections were changed to have household connections;
4. All households with no connections and yard tap connections were changed to have household connections while physical losses were reduced to 15%.

The last scenario investigated is the strategy of increasing coverage while reducing leakage. Currently, physical losses amount to 27% (Adank et al., 2011), which is a value commonly found in water supply systems in developing countries. However, leakage can be reduced significantly by measures such as pressure management and leakage detection activities (Kingdom et al., 2006). Therefore, one of the scenarios includes these measures which lead to a reduction of physical losses to 15%. As this scenario also includes a wide expansion of the current network, a reduction of overall physical losses is quite realistic even without targeted leakage reduction activities, as the newly laid pipes are less likely to leak. Results from all four investigated scenarios are shown in Figure 16.

Figure 16: Scenario testing results, Accra



As shown in Figure 16, providing yard taps to all users who currently carry water home or get it delivered only increases total water demand by 2%, which is understandable as there is no statistically significant difference between the consumption values of these groups. This suggests that this measure could be a practical way to improve services for a large part of the population with only minor or negligible impact on the city-wide water resources.

Improving the service level for all consumers currently using yard taps by providing them with private connections would increase the overall water demand by 33%, shown as Scenario 1 above. Giving all consumers in the city access to a tap inside the dwelling has the largest effect on water consumption, causing a 56% increase of city-wide water demand. This however also corresponds to a significant increase in service for a large proportion of Accra's residents. If all users are provided with a private connection and physical losses are reduced to 15%, as simulated in Scenario 4, total water demand only increases by 34%. Therefore, the increase in total water demand can be effectively mitigated by efforts to reduce leakage. In this scenario more than 2.5 million residents gain access to a private household connection, which is not only a significant improvement in their standard of living, but also means that these people become paying customers to the utility. If steps would be taken to reduce commercial losses as well as physical losses, for example by improving bill collection efficiency, this scenario might be financially viable to the utility.

With all results above, it should be remembered that the model was populated with consumption values drawn from a small sample of households. Better estimates of water usage could be obtained through a larger-scale field study that is statistically representative of the entire city. The outcomes of this modelling exercise should therefore be seen as indicative results. They do however show that estimating impacts of changes to service levels on a city-wide scale can be relatively straightforward once the necessary primary data has been collected. This way, informed planning decisions can be made by analysing a number of scenarios for improving the city-wide water supply system and the impacts these improvements have on total water demand.

Additional measures to increase the accuracy of the model could be taken by:

- Correcting water access average values for self-selection using the two-step Heckman technique, as described by Briand et al. (2009);
- Using Monte-Carlo simulations within the spreadsheet to account for the distribution of water consumption values within the household tap category;
- Investigating the use of complexity techniques as a consumption predictor tool.

6 Discussion

6.1 Limitations

The limitations of these studies are the very small sample sizes, which means results should be seen as indicative. Consumption values for one of the groups in Accra and ratios of users accessing source types had to be triangulated using secondary literature. Using the modelling tool with consumption data obtained from a more rigorous study that is statistically representative of the entire city would lead to more accurate results and enable planners to make informed decisions for improvements to the water supply in Accra and Nairobi.

A number of further variables would retrospectively have been useful to obtain during fieldwork, and it is recommended that any continuation of this work should consider their inclusion in a questionnaire. These are as follows:

- Ownership of water-using assets (such as type of shower, washing machine etc.);
- The average household income per month;
- Whether the occupants are generally at home during the day or absent due to school/employment.

Before commencing fieldwork in Nairobi, it was anticipated that a structured random sampling method would be applied to select households within a neighbourhood. However, structured methods proved very difficult to employ in the field. Methods such as 'interviewing the third household on the left side of each defined street in a grid pattern' were found to be challenging because streets were poorly defined, twisting, and not shown on maps. Even just defining where one informal settlement village section ended and another began was not straightforward, and required consultation with local residents (who did not always reach a consensus). This made it hard to ensure even coverage across villages. In the end, to compromise between time constraints and the representativeness of the sample, the fieldwork team moved through the slum conducting arbitrary interviews, while trying to give a reasonably even geographical coverage of households across villages. The lack of a structured sampling method may have given a bias to the sample; however this is not believed to be significant enough to interfere with the conclusions.

Other induced biases include the fieldwork being carried out between the hours of 9am and 4pm. This means that, for the most part, households were only sampled when a member was at home during that time, which may potentially give a bias towards those who are unemployed or who have young children. Young children tend to consume more water (as a result of washing diapers and regular feeding) so this could have the effect of increasing average water consumption. However the presence of infants or young children in the household was recorded and it is therefore possible to disaggregate them from the sample to examine the significance of this effect. Some people were also interviewed in their place of work, which had the advantage of being able to definitively include some members of the working population.

It should be noted that water rationing in Nairobi takes place on a weekly basis, whereby water pressure is rotated to various neighbourhoods over the period of a week. Water point observations at each site were carried out within a single day, and hence flow rates might not be fully representative. If this work was to be extended, it is recommended that water point observations should be repeated for each site over the course of a week so as to gain a fully representative picture.

No payment was made to the focus groups; however we were subsequently advised that payment is the norm in Nairobi, as participants make significant sacrifices of their time to take part and thus expect compensation of around 100Ksh per person. It is recommended that this is considered for future fieldwork.

For the results of the water use model, it should be remembered that a great deal of variability was shown within the household tap consumption category. Indeed, 25.9% of the household tap user group consume no more than the average user in the water carried group, and 40.7% no more than the average user in the yard tap user group. Thus, it can be seen that a great many household tap users do not significantly increase their consumption as a result of having a household tap alone. Therefore having a household tap may be necessary but not sufficient to increase consumption. In order to account for this, it is recommended that a more accurate picture of water consumption change scenarios might be produced by:

- Correcting water access average values for self-selection using the two-step Heckman technique, as described by Briand et al. (2009);
- Using Monte-Carlo simulations within the spreadsheet to account for the distribution of water consumption values within the household tap category;
- Investigating the use of complexity techniques as a consumption predictor tool (discussed further in Section 5).

Overall, due to the methodological constraints in this study, especially the limited sample size, the outcomes of this modelling exercise should be seen as indicative results. They show, however, how relatively straightforward it is to simulate the impacts of changing service levels for large groups of users once the necessary primary consumption data has been collected. Running the simulation using data from more representative samples, obtained in a more rigorous study, would enable policy-makers to run a number of scenarios in a simple manner and make informed planning decisions for improvements to the city-wide water supply system.

6.2 Other options for improving service levels in Nairobi

Reported rates of leakage in Nairobi seem low; most sources suggest that physical losses from the network are not excessive but that commercial losses are high. This suggests that formalising current informal service provision and giving consumers both the rights and responsibilities that go with that could contribute to improved water management (see for example the work of Liemberger and partners on leakage in Nairobi).

WSUP-Kenya are in the process of engaging with NCWSC about installing pre-paid water meter kiosks in a few informal settlements in Nairobi. This approach would involve households topping up a card with credit and using it to purchase water at the tap stand, which would automatically dispense a fixed amount once the card is held up next to it. The largest effect of this on currently unconnected households could be to bring the cost of water down from a fluctuating 2-10 Ksh per jerrycan to a predictable set rate of 0.5 Ksh per jerrycan, which would help in reducing the currently very high prices paid for water by those without piped connections and would thereby be a step towards greater equity. Other impacts might include: more confidence in the water (as coming from an official source so may be less likely to be contaminated), shorter distance and time to collect (if NCWSC are able to extend the network to bring these systems into the slums which would bring the water closer to households; queueing time might also be reduced due to the automatic payment) and more reliable supply (water can no longer be cut off at the whims of middlemen to push the price up). Unfortunately it was hard to gauge any relationship between consumption and price from the data, so it is difficult to model the impacts of this intervention with confidence. More detailed data collection and modelling of on-plot and community level consumption in selected informal settlements might be timely and useful.

7 Conclusions

This report investigated water consumption in ten neighbourhoods in Accra, Ghana and eight neighbourhoods in Nairobi, Kenya. A total of 97 household surveys were conducted in the former city and 191 in the latter in order to calculate average water consumption for different levels of accessibility. After data cleaning, 77 of the Ghanaian and 124 of the Kenyan questionnaires were used in the final analyses.

In Accra, it was found that water from the primary source on average accounts for 91% of total volume of water consumed. Therefore, the respondents use a primary source, which can be a yard tap, water from kiosks or a private connection for domestic uses, and supplement this water with small quantities bought for drinking, mostly in sachets. Average water consumption was found to be significantly correlated to the number of people in a household and the distance to the water source. However, a regression model with these two variables was found not to explain most of the variability in the data collected in Accra. The average consumption values calculated from collected primary data range from 45.5 lpcd for users of yard taps to 55.5 lpcd for consumers with household connections. The differences in average consumption were found not to be statistically significant. Due to the very small number of respondents in the household connection category, the calculated consumption value for this group was not used for the modelling exercise but it was replaced by values from secondary literature.

Average per-capita water consumption in Nairobi did not correlate particularly strongly with any of the variables gathered. The strongest correlation was with water source category, which was numbered from 1 – 4 in order of ease of access. Within water source categories, variables such as education, wealth and cost of water appeared to have little impact on consumption. Conversely, water source category was correlated with a number of other variables with the strongest relationships being with wealth score and neighbourhood category (which are themselves closely related). It can thus be theorised that water source category choice is determined by factors such as household wealth and neighbourhood, which are themselves closely related and determine both the number of water-consuming assets owned by the household and the water sources available. Once a water source is determined, this then becomes the primary factor in determining average per-capita consumption. Figure 14 in Section 4.2.1 shows a visual representation of this theory.

While there is a different mean consumption value associated with each water access category, the differences between these mean values are not necessarily statistically significant. A one-way ANOVA test identified that statistically significant differences are only present between consumption from water sources outside of the dwelling and consumption from taps within the dwelling. Different levels of reliability were found to lead to statistically significant changes in mean consumption values only for yard taps, where having water for more than four days per week leads to higher average consumptions. It might be suggested that providing a yard tap to those currently without any form of water connection may not result in a high change in city-wide water consumption. The simulations performed by the modelling tool showed that the effects of moving unconnected households obtaining water from the network to a yard tap supplying water for up to four days per week only resulted in a city-wide network consumption increase of less than 1% in Nairobi and 3% in Accra. This is a small increase in water demand compared to the physical and mental health benefits that may be realised from having a water source significantly closer to home. Thus, from a water resources perspective, it may be possible to realise large health benefits with only minimal increases in city-wide water consumption. Upgrading all consumers to a household tap would increase water demand in both cities, but that demand would be lessened if leakage and non-revenue water could be reduced, making that scenario more financially viable for utilities.

Inequitable water distribution within a population is not desirable, and the ultimate goal of any water utility should be for the entire population within their service area to receive a sufficient amount of safe water that is adequate for their daily needs. In Nairobi, an average daily per-capita consumption of 40 litres does not necessarily meet that goal; indeed, this level of consumption does not even reach the allocated amount for low-income members of the city, which is stated as 80 lpcd (Purshouse, 2014). However, for the sake of making swift and practical improvements to water supply in low-income areas, connecting more households at least to yard taps leads to an improved level of service for residents, even if they do not consume the stated 80 lpcd. Based on the results of this study, water utility companies do not necessarily need to be fearful that improving services in this way would result in large increases in the total water demand that the city's water resources will not be able to meet.

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