# Modelling Urban Water Use in Developing Countries: A Preliminary Application to Lagos Metropolitan Area of Nigeria

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***Abstract***

*Water is a basic human need which its availability in potable form is gradually becoming grossly inadequate for domestic use in many countries, especially in the developing countries including Nigeria. Treatment and supply of potable water to rapidly growing urban and rural populations in developing countries is an enormous challenge for water supply agencies. Rapid increase in population coupled with improved standard of living in Nigeria has overstretched the existing water supply facilities and resulted in inadequate potable water supply. To resolve this problem, there is the need to shift from the conventional supply driven approach to one that integrates an understanding of water demand and its management. Therefore, it is imperative for water policy makers to understand current water use practices and coping mechanisms employed by households to meet their daily water needs. Understanding of this phenomenon will allow decision makers to evaluate water supply effects as well as economic of proposed and existing water supply facilities. This work explores how high-income, medium-income and low-income households in Lagos metropolitan area of Nigeria combine water from multiple sources to meet their daily water demand. The data that drives model results include estimates of water price and household willingness to pay for water from different sources. A simulation model is built to enable water planners estimate the quantity of water use by different household types from different sources.*

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*Keywords: water supply, simulation model, urban, economic, Lagos Nigeria*

## 1. Introduction

Water is an essential requirement for life on earth. The success of any economy is dependent on the citizens and inhabitants of the country. People must be healthy to be productive. Access to affordable, safe and reliable water supply is essential for public health as it reflected by one of the United Nations Millennium Development Goals (Target 10 of Goal 7) to reduce by half, the number of people without access to safe drinking water by 2015 (United Nations, 2000). It is projected that by the middle of this century, 2 to 7 billion people will be water-scarce (United Nations, 2003). Insufficient supply of safe water and inadequate sanitation are the major cause of illness in the world (United Nations, 2005) as well as the greatest threat to natural ecosystems and food security (Seckler, 2000). The developing world is the main prey for waterborne diseases because of the poor state of water supply and sanitation. Having a world devoid of water borne diseases requires provision of water of suitable quality and quantity by source development process, it becomes necessary to convey the supply to consumers via a distribution system comprising water mains, pumping stations and service reservoirs (Awopetu *et al.* 2013)

Consequently, the need to make urgent decisions in the water resources management sector is obvious, given the escalating demand for water resulting from population growth, increase in per-capita water use and the concentration of population in urban centres (Vairavamoorthy *et al*, 2008). Other factors such as the changing physical environment caused by climate change, affect the natural water balance. Contamination of streams and ground water from wastewater additionally affect water supply and often brings about the need to convey water from distant locations to the city. Also, archaic and dilapidated facilities used by utility companies and the distinct discrepancies in the allotment of opportunity based on social differences between residents of different part of the city core or suburbs all pose an incredible threat to urban water supply management (Vlachos and Brage, 2001).

Meanwhile, water supply in cities are generally supply driven and the usual solution to shortages is capital investment in new abstraction methods, treatment facilities and distribution networks (Vairavamoorthy *et al*, 2008). This approach is no longer sufficient to meet the reality of increasing urban population in cities of developing countries. The scarcity of resources for new capital investment as well as the need for sustainable solutions buttresses the need to adopt new better methods to manage water supply. Estimating daily water use or demand in developing countries is a challenge because different consumers have access to different sources of water unlike in developed countries where most people have access to the same source of water. This study developed a simulation model to show daily water used by households based on demand, availability and price of all the combine sources such that the cost of water to the household is minimised.

## 2. The study area

Lagos city, located in South Western Nigeria, West Africa, lies between latitude $6^0$ 22'N and $6^0$ 41'N, and longitude $2^0$ 42'E and $4^0$ 21'E (Fasona *et al*, 2005). It is one of the fastest growing mega cities in the world. Lagos is also a state in Nigeria. The Nigerian 2006 population census put the population of Lagos state at 9,113,605 people (National Population Commission, 2006) living in 20 local government areas, 4 in the sub-urban and 16 in the core city (though the Lagos state government say the population is 17million as there were several controversies over the census figure). The land area of Lagos state is 356,861 hectares (Lagos state government, 2010) with the landscape comprising of lagoons, low-lying wetlands, high dry lands, and coastal beaches. The major river receiving runoff from the city is River Ogun, which is also the major source of water for the Lagos State Water Corporation, LSWC. Lagos, like other parts of Nigeria, experiences two season which are the dry (November to March) and wet (April to October) seasons. It has average annual rainfall of 1250-1550mm/year (BBC, 2010).

## 3.Methodology

This study exploits information from the database of the National Population Commission of Nigeria, (NPC). Water production and cost data were from Lagos State Water Corporation (LSWC) and personal experience of living in Nigeria for over 20 years and being conversant with the water supply situation. Lack of sufficient data has always been a major challenge for demand estimation in developing countries (Nauges and Berg, 2009). A Microsoft Excel simulation model is utilized to explore residential water use for three different classes of households for a period of one-year. The study area was partitioned, using population density and income levels, into three distinct areas (designated as Low-income, Medium-income and High-income); with low income levels of mean monthly income of $100 and high income level having mean monthly income of $500. The following criteria were then used to define the specific study sites within each income group: (a) assess to potable water had been identified as a problem; (b) populated by people from different ethnic backgrounds who share different beliefs on many issues; and (c) contains politicians, public servants that are one way or the other involved in police making**.** Analyses of water use was carried out using IF statements and the demand is estimated using a demand function obtained using linear regression and applied to the model using Visual Basic Applications (VBA) functions

## 4. Results and discussions

4.1 The high-income household

The high-income earners live in houses on separate stand-alone yards or compound where they do not share common facilities with other households. The separate houses are sometimes part of an estate (a group of stand-alone houses or block of flats with a common feature such as architectural design, lawn size, and garden size among others). Most households in this group own the house they live in and others may be rented from large property management companies by reputable institutions or organisations for some of their members of staff. Private boreholes and the utility supply are their major source of water supply. This is because they can afford a connection to the public supply and they live in areas where there is adequate coverage from the utility company. In addition, they can afford the cost of construction and maintenance of the boreholes. They usually have standby power generating plants to provide energy for pumping water. These sources provide them with water indoors at the point of use. They sometimes depend on tanker supply to back up their private boreholes depending on the event they face.

4.1.1 Combining sources: The indoor piped water supply is peculiar to the high-income households because they live in developed neighbourhoods where the government have constant interest in welfare and security. Private boreholes are common to this group not only because of the high cost of constructing and maintaining boreholes, but because of the operational cost of providing power for daily pumping of water. This is how it works; the utility supply is connected to a header tank, which then feeds the building through pipes. The borehole supply is connected to the same tank and feeds the building through the same pipe network as the utility supply. A control valve is used to switch between sources. When the utility supply is out, the water stored up in the header tank is used. If this runs out before the utility supply is restored, the valve if switched to the borehole supply and water is pumped into the header tank. Using the header tank (often placed on a steel tank stand, constructed with enough height to provide the required hydraulic head for steady flow and fixed in a position near the building) helps prevent the installation of two pipelines to feed the building from both sources. To maintain water quality, they carry out periodic cleaning of tanks and flushing of pipes.

4.2 The medium-income households

This group of people live in detached flats, or flats that are part of a block of flats. Households in this group can further be divided into two; the upper and lower middle class depending on the area of town where they live and house ownership (that is if they live in their own houses or rent the apartment).They constitute the largest group of households in Lagos as represented in Figure 3. Several sources of water are accessible to this group. Some of them have connections to the utility supply for indoor supply but mostly outdoor supply from a common yard tap. Some live in flats where boreholes or wells are provided and the cost of the water is included in their rent. Others get water from commercial boreholes, pushcarts or tankers depending on the season (dry or wet), the quality of water required and the price.

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4.2.1 Combining sources: For a typical medium income household, they depend on wells, piped supply outdoors, commercial boreholes (where they have to walk to the borehole, buy and haul the water to their homes) for their water supply. They commonly buy water from pushcarts (who buy from commercial boreholes using jerry cans, haul the water in carts to the household and sell at double the cost price). Two or more households often combine to buy water from a tanker and share among themselves or buy from water retailers if the need is urgent.

4.3 The low-income households: This group largely consist of the urban poor living in traditional huts and improvised informal dwellings, mostly in slum areas of Lagos. They have no access to piped water indoors or outdoors but have access to commercial boreholes and water retailers (who buy water from tankers, store them in water butts and sell in jerry cans and buckets to consumers). Their main source of water is the well (the type without the hand pump where people collect water manually using a bucket tied to a rope) and rainwater in the wet season. They also explore sources like streams, rivers and ponds.

4.3.1 Combining sources: This group get their drinking water from the commercial boreholes and retailers. There are few commercial boreholes and water retailers in the slums resulting in long queues for water, especially early in the morning. Water from the well and other sources is used for other domestic activities. They cannot afford the tanker supply and even if they could, they live in unplanned crowded settlements with very poor roads that tankers may not be able to drive through to the get their homes.

Figure 4 shows interactions between the different types of households discussed and the sources of water they explore.

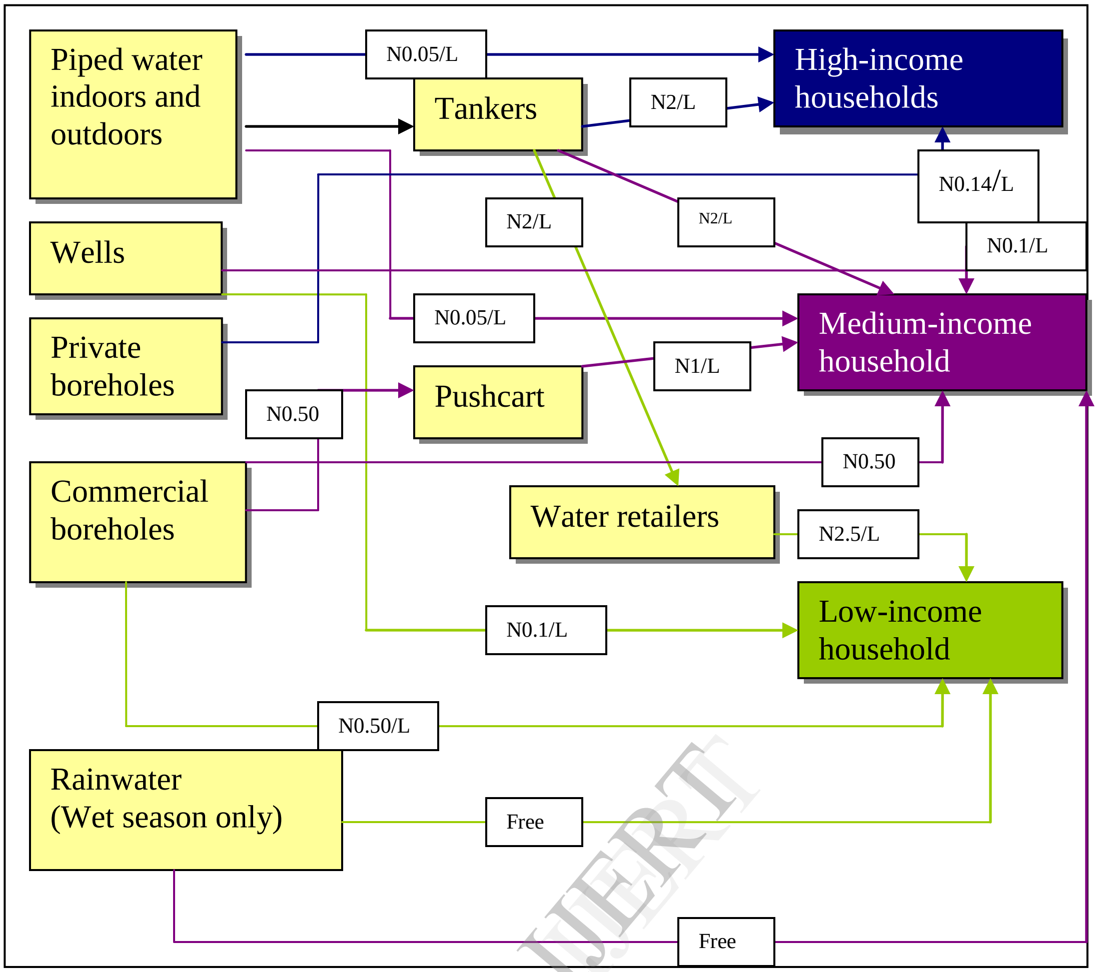


**Figure 1: Type of household, water sources and unit prices in Naira per litre.**

***Demand***: This study considers demand limited only by availability. It is estimated for each type of household using a demand function obtained from linear regression based on the price of sources explored by the households. A VBA function created with the regression results is used to enter demand values into the model. Therefore, demand is estimated as a function of a fixed price. Mathematically,

Demand, $D = f(P)w$

here, $P$ = unit price of water

Table 1 shows the estimated demand curve for each type of household considered in the study.

**Table 1:Estimated demand and unit prices used for linear regression**

| Household type | Sources of water | Demand (litres) | Unit price (N/litre) |
|---|---|---|---|
| High-income | Piped water indoors | 2150 | 0.05 |
| | Tanker | 534 | 2.00 |
| Medium-income | Well | 1250 | 0.10 |
| | Pushcart | 380 | 2.00 |
| Low-income | well | 800 | 0.10 |
| | Water retailers | 200 | 2.50 |

A simulation model was made to relate water demand, water availability and water use for the different types of households considered in the study. Data on water availabilities were estimated based on observation and experience of living in Nigeria for over 20years. Results (Table 2) from the model show that each household type obtains over 90% of its water from non-piped sources.

Table 2: Summary of Model Output

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|---|---|---|---|---|---|
| Household type | Total annual water use (litres) | Total annual Water use from non piped sources (litres) | Water use from non-piped sources (%) | Annual cumulative water cost (N) | Average Unit Cost of Water Used (N/litre) |
| High Income | 663,751 | 638,720 | 96 | 116,538 | 0.18 |
| Medium Income | 218,844 | 202,582 | 93 | 110,647 | 0.51 |
| Low Income | 101,679 | 101,679 | 100 | 39,877 | 0.39 |

Of these sources, the private borehole was the most used. This is because it is accessible to the high-income group who can afford to construct and maintain boreholes and they have a higher water demand. The quantity of water they consume is mainly affected by fuel scarcity or a breakdown of the water pump. The high-income household has a total water use that is about three times that of the medium income household and over six times more than the low-income household. The average annual cost of water to the medium-income and low-income households are more than twice that of the high-income household. This obviously shows that the poorer people pay more for water than the rich do even when they consume less and have more hardship in accessing the water.

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Whenever there is breakdown in the communal water supply, high-income households are less affected because of the high efficiency of their private borehole supply (see Figure 8 to 11). Conversely, when the borehole water pump breaks down, they are greatly affected since it is their major source of water supply. They resort to using the expensive tanker supply and daily supply is not guaranteed. Furthermore, when there is fuel scarcity (which is a reoccurring problem in Nigeria); households have less access to petrol or diesel to run their electricity generators that provides energy for water pump. At such times, fuel is mostly bought from the 'black marketers' (fuel retailers) at very exorbitant rates which results in high cost of water.

For the medium-income and low-income households as shown in Figure 12 to 15 and 16 respectively, the case is similar. When cheaper sources are out, they consume less from sources that are more expensive.

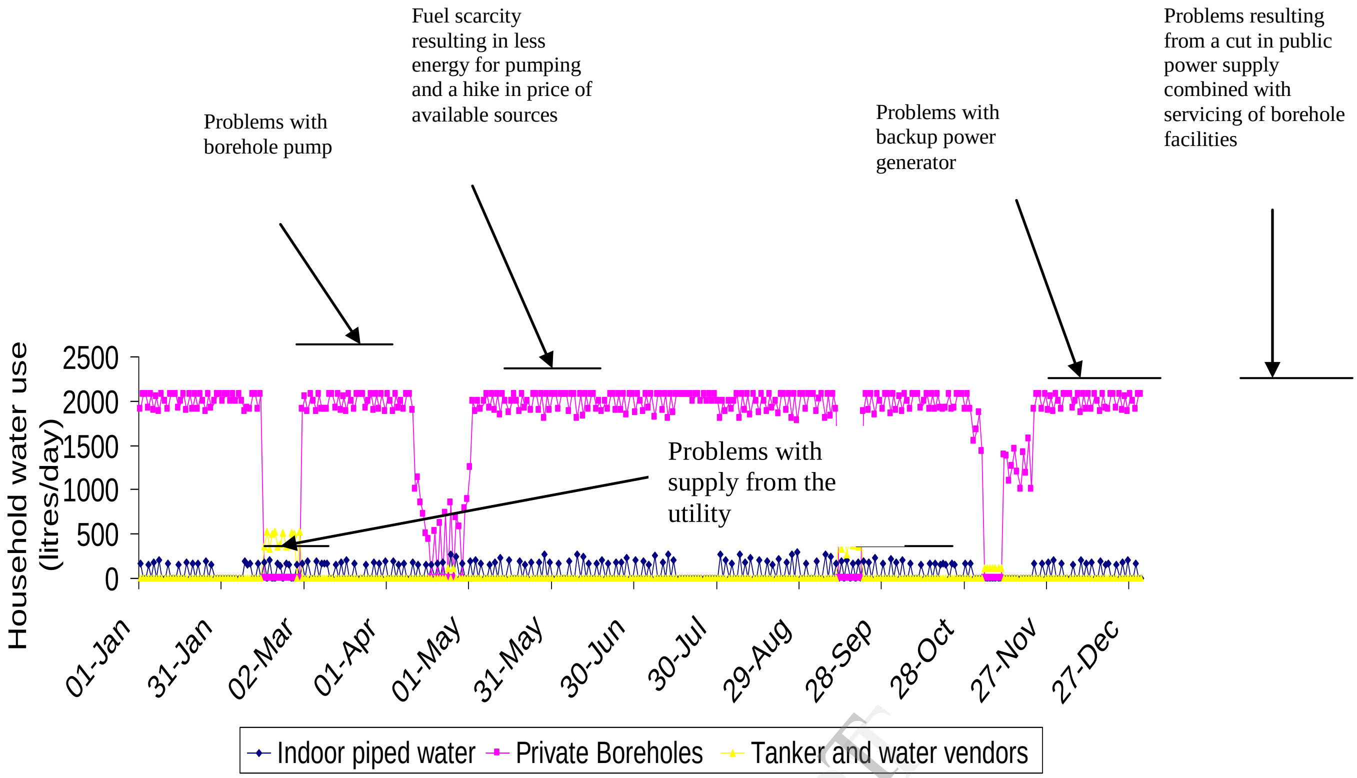


**Figure 2: Scenarios and their effect on water use for high-income households**

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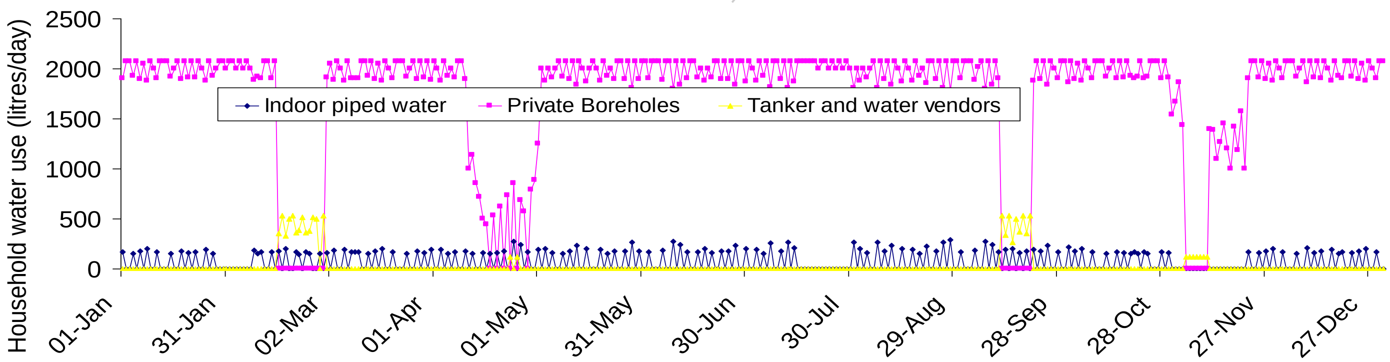


**Figure 3: Daily water use from each source by high-income households**

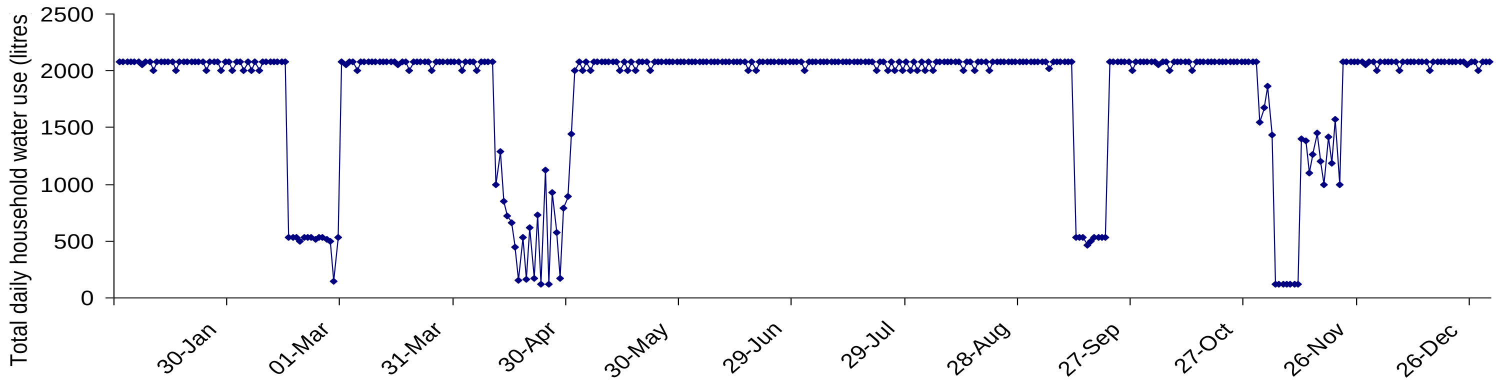


**Figure 4: Total daily water use by high-income households**

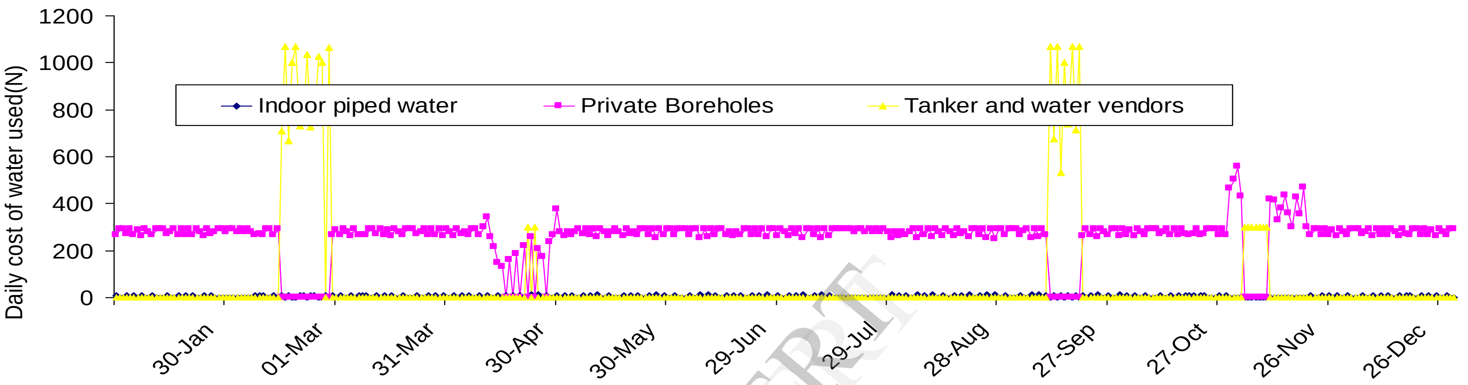


**Figure 5: Daily cost of water used by high-income households**

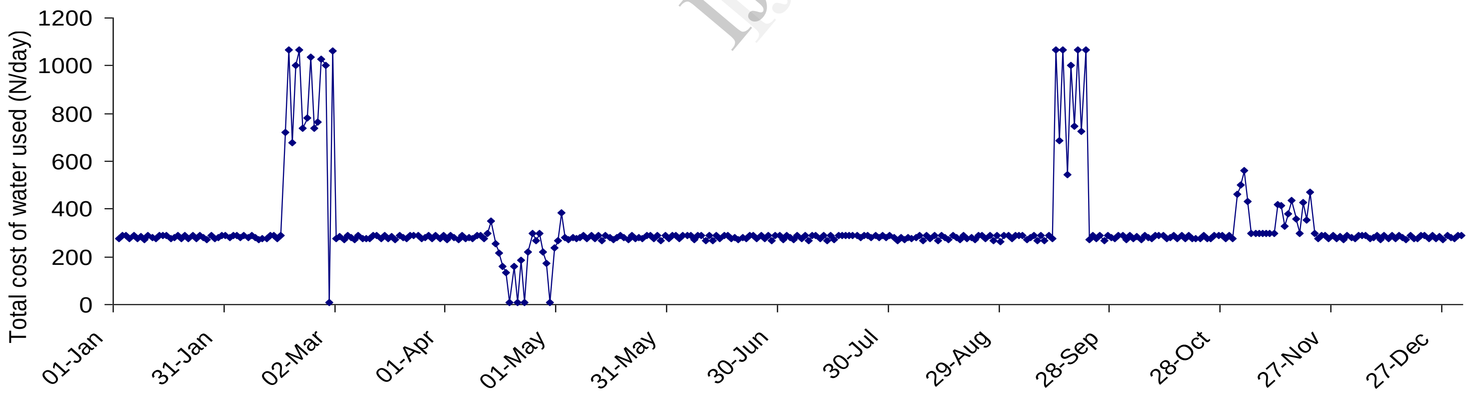


**Figure 6: Total cost of water used by high-income households**

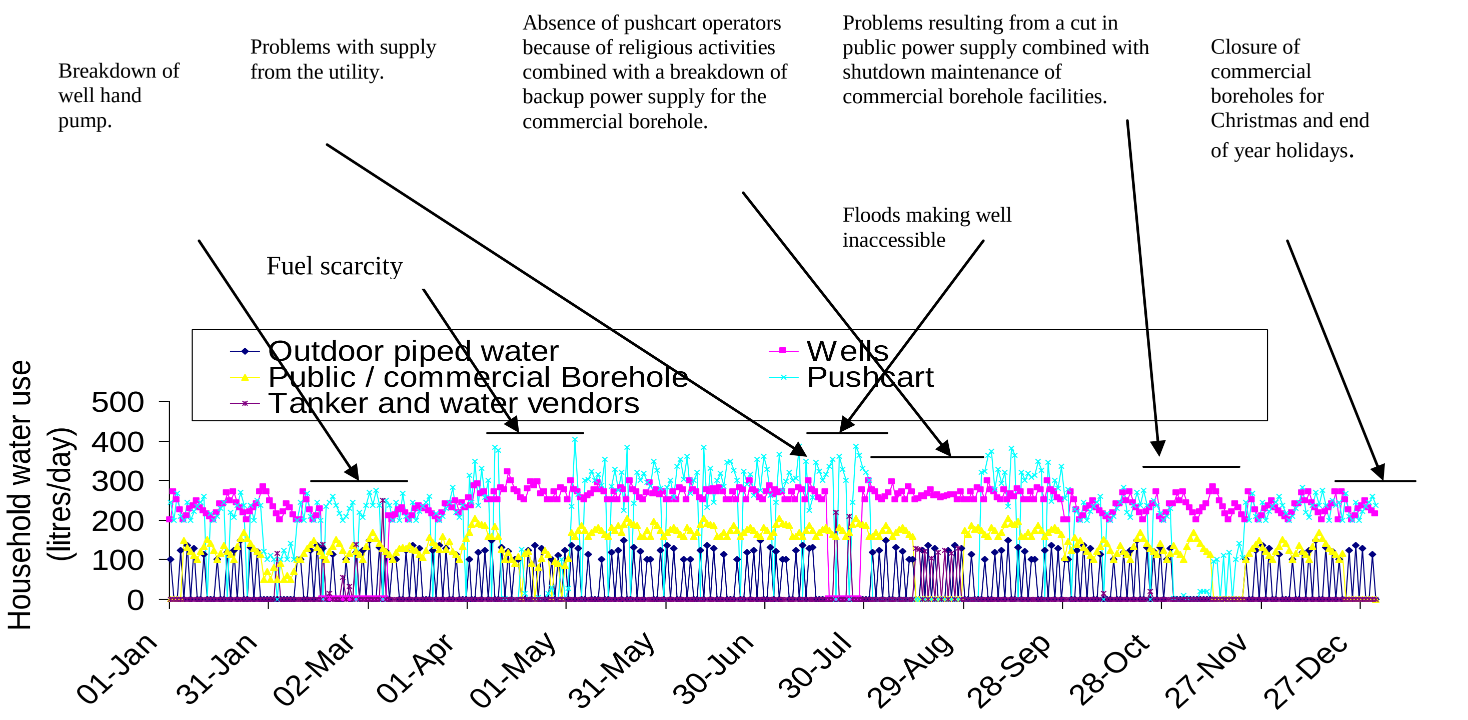


**Figure 7: Scenarios and their effect on water use for medium-income households**

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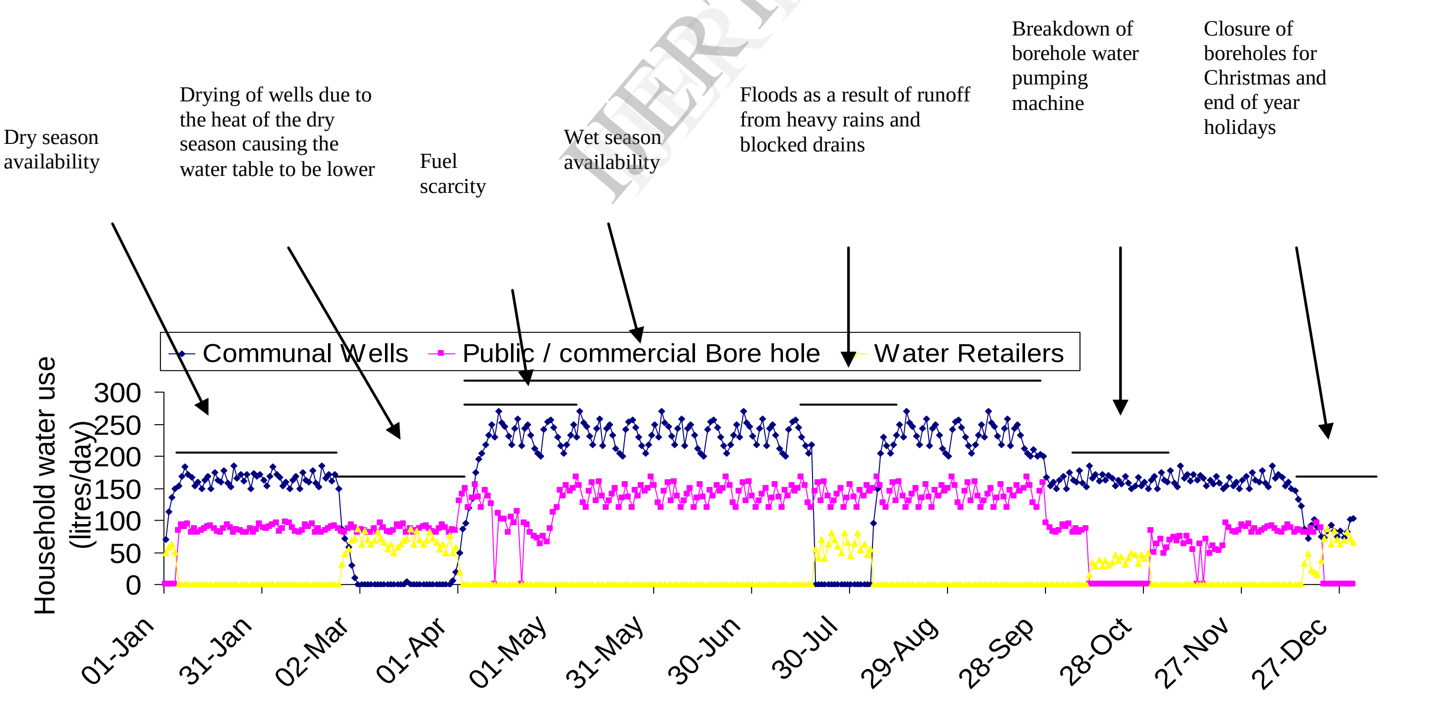


**Figure 8: Scenarios and their effect on water use for low-income households**

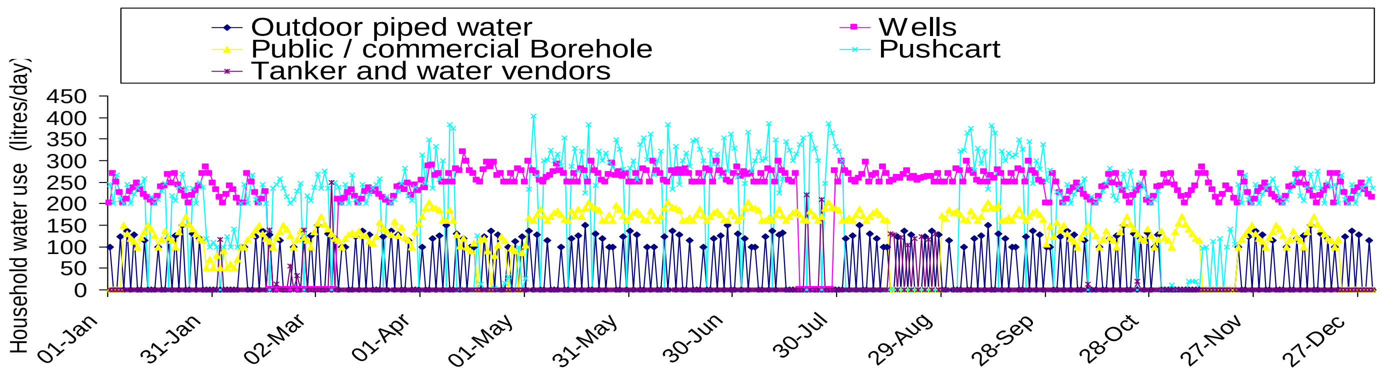


**Figure 9: Daily water use from each source by medium-income households**

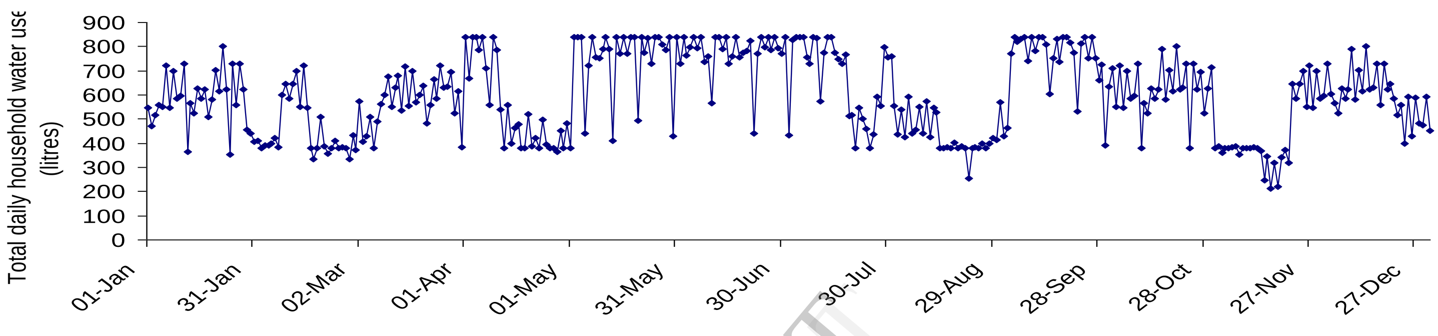


**Figure 10: Total daily water use by medium-income households**

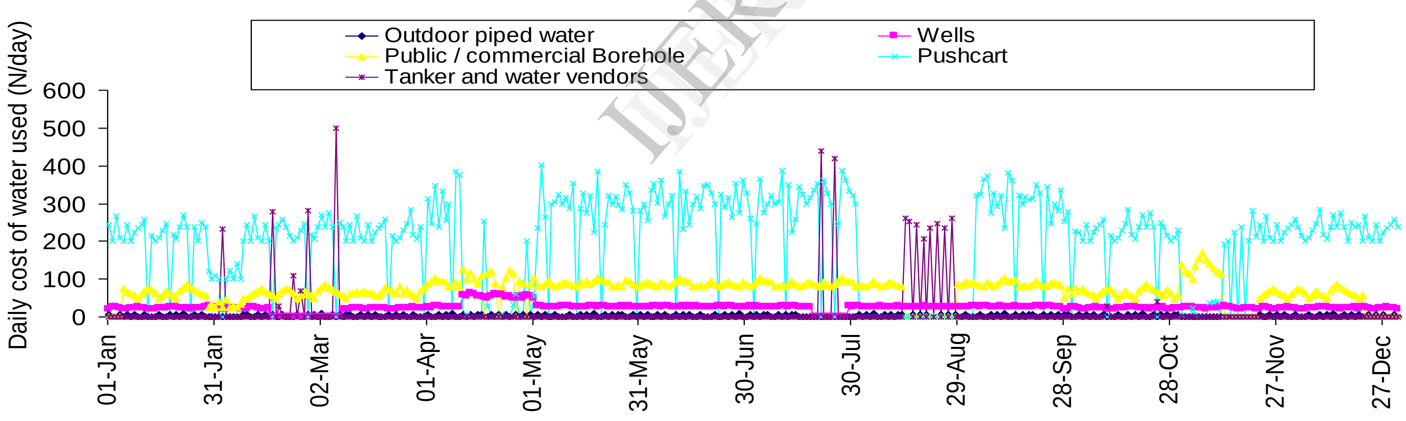


**Figure 11: Daily cost of water used by medium-income household**

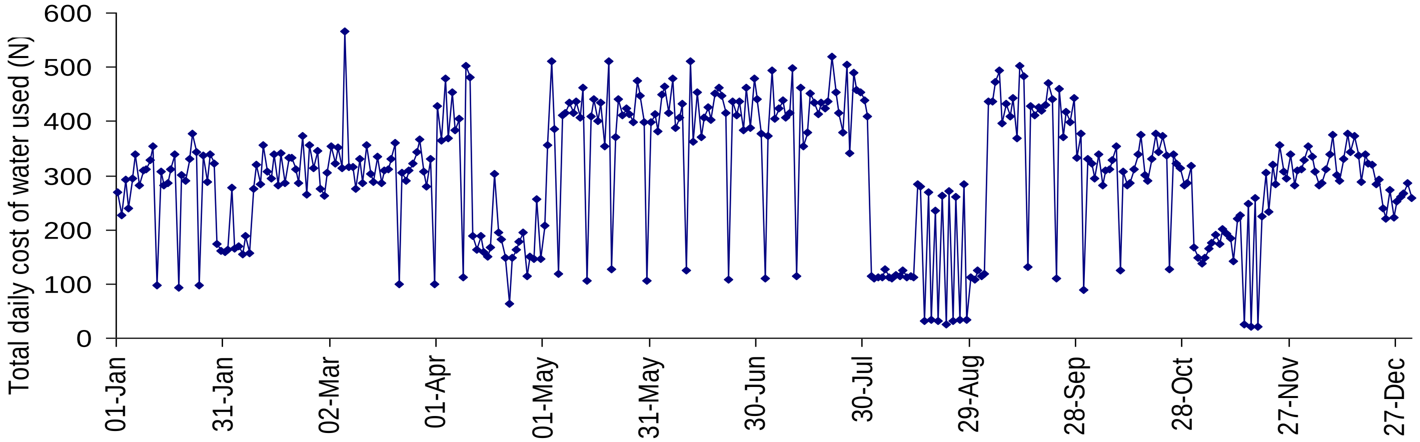


**Figure 12: Total cost of water used by medium-income household**

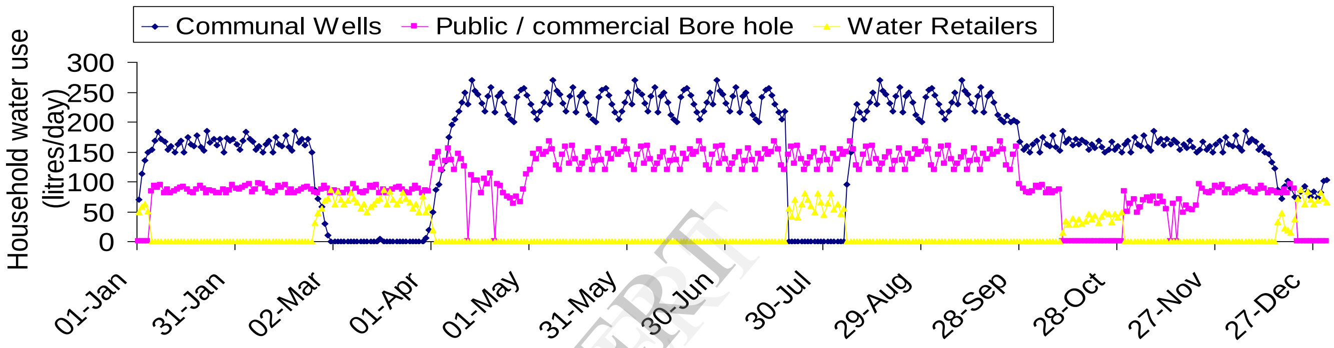


**Figure 13: Daily water use from each source by low-income households**

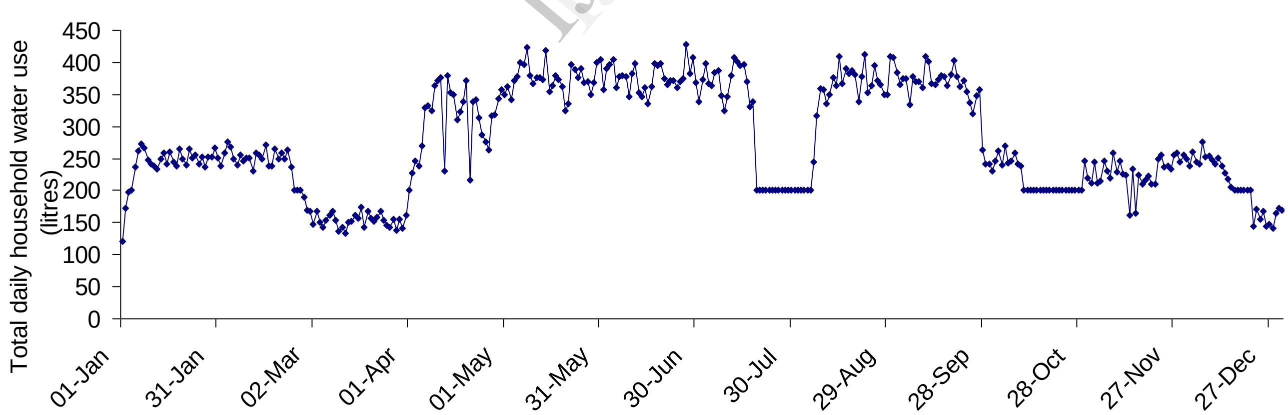


**Figure 14: Total daily water use by low-income households**

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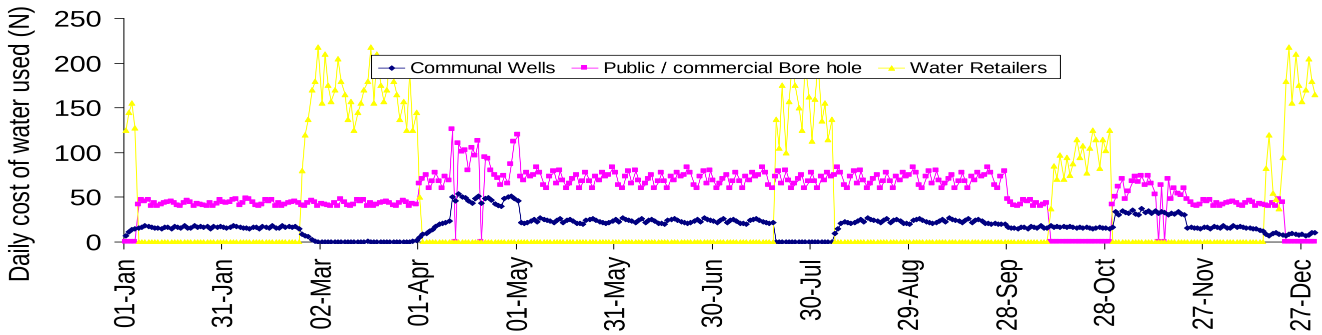


**Figure 15: Daily cost of water used by low-income household**

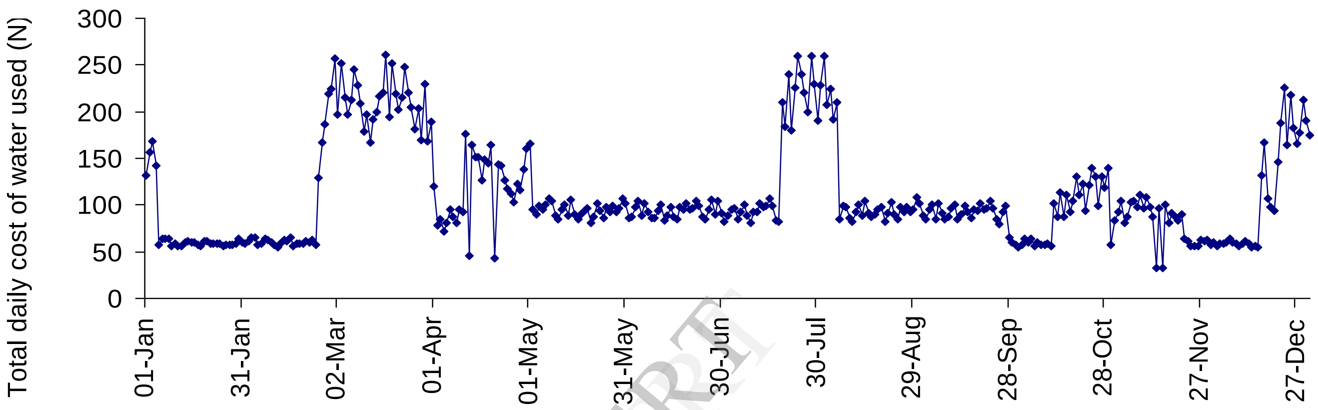


**Figure 16: Total cost of water used by low-income households**

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From the model, high-income households get 95% of their water from private borehole, medium-income get 38% from wells and 54% from public/commercial boreholes and pushcarts (both are water from the same source but access differently by the household). Low-income households get 59% of their water from wells and 36% from commercial boreholes. The utility supply only accounts for about 4% of the total water used by all three households in a year.

This shows that, despite huge investments in the water sector, Lagos residents still access the most of their water from other sources. The question then arises; is it worth continuing to invest in larger water supply projects in Lagos? These results reveal the need to shift from the current supply driven approach to a demand management approach for water supply. This will improve reliability, efficiency and protect the environment so water abstraction limits will not be exceeded. To do this, an application of the framework described above is required to give an estimate of the residential water demand for Lagos. The model also gives a profile of the effect of changes in availability, which can be used to monitor the effect of new interventions adopted to improve water supply.

## 5. Conclusions

Provision of water supply is challenging for developing countries. Continuous population growth in Lagos has put pressure on the poorly existing water supply infrastructure. Indiscriminate construction of buildings and the development of slums and shantytowns have delayed the extension of water supply network. The Lagos state government is currently building mini-waterworks and carrying out other major water projects in partnership with the World Bank to improve household water supply, still, a large percentage of the residents of Lagos do not have access to piped water supply. People depend on multiple sources of water to meet their daily water demand. Households explore other available sources depending on price and other characteristics such as quality and proximity to their dwelling and so on.

To provide a sustainable solution to these problems, urban water managers and policy makers need a detailed and realistic knowledge of current household water demands and use patterns in the state to form baseline for future projections and planning. Water consumption from all other sources explored by households and consumption behaviour of different types of households is also required. There is also the need to shift from the supply driven approach to demand management. Knowledge of the current demand for water will enable water managers to compare the capacity of existing facilities to cope with the demand and adopt the most appropriate method (demand management method) for judicious use of the scare resource, rather than continue to extract from the environment. This is important because the population of Lagos is predicted to continue growing and the current approach will mean more water works and more abstraction from the environment. The construction of new water works without a shift to demand management will not provide a sustainable solution but would rather stretch water resources to their limits

This work provides framework to estimate urban water use given availability and price of respective sources. Demand function for each source is estimated using linear regression analysis and VBA in Microsoft Excel. Application of this framework provides total water use and cost for each source and for different types of households whether high, medium or low income. An application of the framework will help the Lagos state government to align its water supply approach to the peculiar water supply problems in the state to accomplish the desired sustainable result of adequate, reliable water supply.

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