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# Measuring residential water affordability and basic water needs in South Africa

Akhona Mgwele\*, Hiywot Menker Girma\*<sup>1</sup> and Johane Dikgang<sup>2</sup>

## Abstract

Designing a desirable block tariff structure for residential water use has been a challenging task for regulated utilities. In this study, we investigated whether the existing increasing block tariff design addresses the issue of affordability, especially for lower-income groups. Using the South African NIDS household-level panel data and municipal tariff data, we estimated household demand for water using a Stone-Geary specification. The Stone-Geary functional form allows price elasticity of demand to vary with quantity consumed and allows for the estimation of a basic threshold level of consumption below which demand is price inelastic. Truncated and quantile regressions were run to observe the impact of the different socio-economic variables on different categories of water-consumption and income levels. The results show that in general, the first block (i.e., 6 000 litres) of consumption set by water utilities does not represent a basic water need. The 'lifeline' or subsistence portion of water is found to be 11.51 kl of water per household per month. Moreover, when considering the poorest or low-income households, water charges raise affordability concerns in a number of important water-utility areas. Basic water is not affordable as the proportion of household income that must be spent to acquire it is high. Any household with an income of \$398 or less must spend a significant proportion of its income (above 5.88%) to receive the subsistence amount of water. Furthermore, a number of socio economic and environmental factors are found to affect the demand for water, and these will help in employing tailored economic and technological interventions for efficient utilization of water.

**Keywords:** demand, equity, lifeline, increasing block tariff, water affordability.

**JEL Codes:** H41, I30, L32, Q25.

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## **1. Introduction**

In developing countries, a significant proportion of households experience limited access to safe and clean drinking water, due mainly to infrastructural inaccessibility. There is a wide notion among policy makers that this is exacerbated by under-pricing of water services resulting in inefficient delivery of the services. One of the main reasons given for the under-recovery of water services is that water tariffs are not cost reflective. Affordability is often cited as the main reason tariffs are usually set below the cost of provision of the service. Rising costs of water provision, increasing water demand, climate change and water-quality concerns have brought renewed and increasing attention on the affordability of water services.

According to Vanhille et al. (2018), water policymakers and regulators face the exercise of designing water tariff structures that reconcile conservation and cost-recovery objectives with equity principles. Considering the rising costs of water provision, there is pressure on government to ensure that the poor can afford water services. To achieve this, government must calculate affordability correctly. According to Teodorom (2018), meaningful and accurate assessment of affordability is vital, as water utility decision-makers seek to serve low-income customers while also raising the revenue required to maintain and advance public health and conservation.

Due to complexities involved in water price setting and tariff-structure determination, water charges are not always equitably distributed among all income groups. As a result, access to basic services such as safe drinking water may be very unequal among water users within the same country (Ruijs et al., 2008; Ruijs, 2009; García-Valiñas et al., 2010). Inequality among customers of the same water utility is also observed. Affordability of water become a problem in Sub-Saharan Africa, like other developing regions, when water tariffs are increased significantly in pursuit of cost-recovery objectives (Komives et al., 2005; Foster and Yepes, 2006). In order to understand the extent of the problem, several affordability measures have been developed, most of which entail dividing water expenses by an index of purchasing power (OECD, 2003; Reynaud, 2008). However, these measures have several shortcomings. Designing a desirable tariff structure for residential users has been a challenging task for regulated utilities. Studies that assist in understanding the pros and cons of the different designs are scarce, especially in developing regions. This is particularly important in highly unequal societies, such as South Africa, where significant focus is placed on improvement of access to basic services like water in order to support economic and social development. In South Africa, affordability of basic services such as water

remain high on the agenda as the increasing financial cost of basic service provision can impede the realisation of equal access to safe and clean potable water. Utilities cannot pursue economic efficiency only when setting tariffs but must also take into consideration social goals such as equity (access and affordability), sustainability, and the political economy. Hence to ensure the provision of basic water services, especially to low-income poor households, accurate assessment of affordability is critical.

This study investigated whether the implemented increasing block tariff (IBT) design on residential water in South Africa addresses the issue of affordability, especially for lower income groups. An average 'lifeline'/basic free water amount was estimated for all households in the 83 municipalities and affordability indexes were calculated using average income of households. The analysis was done using truncated regression to estimate all our parameters. The current tariff structure does not address equity in relation to water demand, as water is not affordable for a significant proportion of the population i.e., low-income households. Water in South Africa is currently affordable only for the high-income households, but less so for the poor households. Basic water is not affordable as the proportion of household income that must be spent to acquire that amount is high. Any household with an income of \$398 or less must spend a significant proportion of its income (above 5.88%) to receive the subsistence amount of water, which is estimated to be 11 kilolitres, for an average household size of 6. An affordability index of 5.86% is just above the 3% to 5% range recommended by international institutions.

In addition, incorrectly designed IBTs cannot be effective in incentivising households to reduce water wastage. Understanding the factors that affect water demand of households help in employing tailored economic and technological interventions for efficient utilization of water. Owning a washing machine, having bigger household size and number of dwelling rooms, ownership of a swimming pool, facing higher amount of-annual rainfall and price, and income affect water use significantly. Owning household appliances (such as a washing machine) or a swimming pool and having more dwelling rooms in a house affect water consumption differently for different water-consumption groups. Water consumption does not seem to be affected by household size and amount of rainfall in higher water-consumption groups.

This study adds to the empirical literature on water tariff design. Although there is an increasing number of studies in this area, most if not all are in developed countries. We are not aware of any studies in Sub-Saharan Africa that estimates water 'lifeline' and affordability due primarily to lack

of data or poor quality data. We had to visit all water utilities in South Africa to collect their water tariffs going back to 2008, and merge it with income dynamics panel dataset, which resulted in a unique dataset that has never been used before in South Africa. What we end up is access to water use and income information for approximately 30 000 individuals with five waves. We are not aware in this literature any study undertaken with such a comprehensive dataset.

## **2. Literature review**

Access to safe drinking water and affordability are the two most important concepts in the water-service environment, at least as far as equity is concerned. These issues are closely related, as well as being strongly linked to the setting of water prices (García-Valiñas et al., 2010). Inadequate access to safe drinking water contributes to “ongoing poverty both through the economic costs of poor health and in the high proportion of household expenditure on water supplies in many poor communities, due to the need to purchase water and/or time and energy expended in water collection” (Howard and Bartram, 2003). A review of the literature shows increasing attention paid and effort put into attempts to measure water-affordability levels.

According to OECD (2010), affordability can be determined by comparing the water price (in this case, the amount spent on the water bill) with the ability of users to pay. In this case, approximation of the effort made by users to access water services is possible. Espiñeira and Nauges (2004) calculated a residential water demand function based on a Stone-Geary utility function using time-series monthly data from Seville (Spain) from 1991 to 1999. They found that the minimum ‘lifeline’ threshold was 6.4 m<sup>3</sup>/month, and the price elasticity of water demand was -0.1, which is consistent with other elasticity studies.

In South Africa, aside from a single study on price elasticity by Bailey and Buckley (2005), there is not much evidence pertaining to known effects of water prices on household consumption behaviour and the affordability of water for households. Bailey and Buckley estimated water demand in Durban between 1996 and 2003, using monthly average household water consumption data for low-, middle- and high-income group samples. Using both linear and log linear regression models, the study revealed the price elasticity of water demand to be -0.55 (log-linear) and -0.52 (linear) for the low-income group, -0.14 (both linear and log-linear) for the middle-income group, and -0.10 (both linear and log-linear) for the high-income group. Although water demand in Durban is inelastic, as revealed by the study (because the absolute elasticity value is less than 1),

it can be noted that a comparison of the elasticity figures show that water demand is more elastic among low-income earners than among middle- and high-income earners.

Arbues, Valiñas and Espiñeira (2010) estimated a minimum water threshold of 128.16m<sup>3</sup> per household per year (which translates to 10.68m<sup>3</sup> per month), which is equivalent to around 112 litres per person per day. They used information regarding a basic or 'lifeline' level of domestic water use obtained from a water demand function based on a Stone-Geary utility function for a representative household with an average size of 3.14 members, in a sample of municipalities in Andalusia/Southern Spain. The study calculated the price elasticity of water demand to be -0.06. Residential water use is usually assumed to be a normal good, and the bulk of water demand studies worldwide find estimates of price elasticity well below a value of one (Arbués et al., 2003; Worthington and Hoffman, 2008). Therefore, demand is inelastic, but not completely rigid. A study by Dharmaratna & Harris (2012) in Sri Lanka also estimated the minimum water threshold from a water demand function based on a Stone-Geary utility function. They found it to be between 2.7 and 4.5m<sup>3</sup> per household per month, for an average household size of 4.2 members. The threshold per capita per month is between 0.64 and 1.06 m<sup>3</sup>, which is lower than other empirical studies that suggest a range between 2.52 and 13.58m<sup>3</sup> per capita per month. The study also calculated the price elasticity of water demand that ranged from -0.11 to -0.14. This showed that while price of water is inelastic in nature, price increases in water may lead to some changes in water consumption patterns.

Using household-level panel data from Tucson, Arizona, Clarke, Colby and Thompson (2017) estimated residential demand for water via a Stone-Geary specification. The study found that the minimum threshold of water demanded in Tucson changes seasonally from around 11ccf (31.2m<sup>3</sup>) per month in the summers, to lows below 10 ccf (28.3m<sup>3</sup>) in the winter, reflecting the seasonal nature of household water demand. The price elasticity values indicate that water demand is inelastic, yet less inelastic in winter months than in the summer, while the most 'elastic' demand at the end of the sample period (a mean of -0.20, in January 2011) is on par with the most inelastic demand in the early sample period (a mean of -0.19, in July 2002). This study shows that in developed areas, expectedly, the minimum lifeline is high, because of high-income households that use water not just for basic services, but also for household appliances such as dishwashers and washing machines, and for swimming pools. The more sophisticated the households in a

country, the more water is used. In South Africa, as a developing nation with high inequality, the lifeline will be much lower, but affluent households are likely to have higher expenditure on water.

### 3. Approaches

#### 3.1 Theoretical model

The Stone-Geary functional form has an advantage over other forms, such as Cobb-Douglas, in the estimation of demand for goods whose demand differs with levels of consumption – water being one such good. The minimum volume of water required for necessities of life such as drinking, and cooking is extremely inelastic. In addition, water demand has different elasticities at different levels of use and in different price ranges, as seen when using IBTs as a price mechanism for water. Therefore, the Stone-Geary functional form has two main advantages: it allows for non-constant price elasticities, and it considers two components of water consumption. The two components include the fixed quantity that cannot be adjusted immediately after a price change, and a residual that can adapt instantaneously to change (Dharmaratna and Harris, 2012).

A double objective is pursued by calculating a portion of the inelastic level of water use and the derivation of the equity index of water bills, through the estimation of a water demand function derived from this Stone-Geary utility function (Garcia-Valinas, Martinez-Espineira and Gonzalez-Gomez, 2010).

The Stone-Geary model underlying our assumptions is that households have a given level of income and face a set of prices for water supply and other goods. Households must satisfy their basic needs first, so they purchase a subsistence level of goods and services then allocate the remainder of their income in fixed proportions to each of the other goods and services according to their preference parameters.  $Q_w$  and  $Q_z$  are the demands for water, and for all other goods and services respectively, while  $P_w$  and  $P_z$  are unit prices.  $Y_w$  and  $Y_z$  are minimum threshold levels, and  $I$  is income. The Stone-Geary demand function is estimated from a utility function of the following form:

$$U = \beta_w \ln (Q_w - Y_w) + \beta_z \ln (Q_z - Y_z) \quad (1)$$

where  $\beta_w > 0$ ,  $\beta_z > 0$ ,  $\beta_w + \beta_z = 1$ ,  $(Q_w - Y_w) > 0$  and  $(Q_z - Y_z) > 0$ .  $\beta_w$  and  $\beta_z$  represent the fixed parts of the supernumerary income (i.e., the income remaining after the purchase of basic water services and all other goods,  $Y_w$  and  $Y_z$  respectively) that the household will allocate to water ( $\beta_w$ ) and the numeracy good ( $\beta_z$ ). It follows that a household maximises its utility, subject

to the relevant budget constraints and after considering several simplifying assumptions (see e.g., Gaudin et al., 2001; Martínez-Espineira and Nauges, 2004). Considering that we are primarily interested only in water consumption, we look at a utility function where the consumer derives utility from water and some aggregation of all other goods used as the numeraire. Such a utility function generates the following demand function (see Gaudin, Griffin and Sickles, 2001):

$$Q_w = (1-\beta_w) Y w + \beta_w (I/P_w) + Z + \mu \quad (2)$$

One of the advantages of the Stone-Geary function is that it is theoretically consistent and uses only two parameters for each type of good or service, while considering non-constant elasticities that may increase with price. Moreover, both parameters have an intuitive economic meaning:  $Y$  can be deemed a threshold below which consumption is not affected by changes in either price or income, while  $\beta$  represents the marginal budget share allocated to the good or service considered.  $Z$  is a set of variables that describe the water utility, and  $\mu$  is the usual idiosyncratic error term. In accordance with the specification in the literature (which points out to variables that are hypothesised to affect water consumption), economic intuition and given our dataset, the following demand model was specified:

$$Q_w = a + \beta_0(I/P_w) + \beta_1Age + \beta_2Washmownsh + \beta_3Hhsizer + \beta_4Anrf + \beta_5Dwlrms + \beta_6Nfswimspn + \beta_7Toi \quad (3)$$

where  $a = (1-\beta_w) Y w$ ;  $Q_w$  is monthly water consumption;  $I$  is household income;  $P_w$  is marginal price for the last unit purchased;  $Age$  is dummy variable;  $Washmownsh$  is ownership of washing machines;  $Hhsizer$  is number of household members;  $Anrf$  is a vector of weather variable (annual rainfall);  $Dwlrms$  is a vector of number of rooms in the dwellings;  $Nfswimspn$  is vector of swimming pool maintenance; and  $Toi$  is presence of flushing toilet. The empirical functional form considers water consumption to be made up of two parts- fixed and a residual component. These two components enable estimation of a basic threshold where water consumption does not respond to price changes.

The Stone-Geary utility function imposes some important theoretical restrictions. The assumption pertains to the strong separability between goods, that the marginal propensity to consume is positive for all relevant goods and services, and that for a positive  $Y$  the demand for the good in question is inelastic (Garcia-Valinas, Martinez-Espineira and Gonzalez-Gomez, 2010). These underlying assumptions are not too compromising, considering that in past studies, water demand has usually been found to exhibit such properties. Water use in urban areas is routinely found to



be a normal good, and the bulk of water demand investigations estimate a value for price elasticity of demand of less than one (see Arbués et al., 2003; Worthington and Hoffman, 2008). In the second assumption, all goods are assumed to be gross complements to water consumption (Gaudin et al., 2001).

The Stone-Geary functional form is inflexible due to its assumption of a completely inelastic level of consumption – despite the demand function becoming more elastic immediately above that level. But this is a realistic assumption in the case of household water demand, because of the existence of basic essential needs and strong habits. Despite the above, a household water demand function based on this approach is particularly useful in this context, because it makes it possible to determine a more accurate measure of the minimum threshold of consumption within which water users have no ability to adjust their consumption in the short run (Martínez-Espiñeira and Nauges, 2004; Worthington and Hoffman, 2008).

### **3.2 Empirical approach**

Firstly, an average ‘lifeline’/basic free water amount was estimated for all households in the 83 municipalities. Secondly, affordability indexes were calculated using average income of households.

A truncated regression was used to model the demand for water due to the presence of households that consume water but do not have to pay (some municipalities offer a certain amount of free water), and our interest in estimating the average water need of households regardless of their bills. Truncated regression addresses the bias that could be introduced by using OLS regression with truncated data. In this case, the variance of the dependent variable (quantity of water) will be reduced. In addition, the quantile regression approach is implemented to observe the distribution of the water affordability index by income groups, while controlling for the impact of the different socio-economic variables on different categories of water demand consumption levels.

As is the case in a study by García-Valiñas, Martínez-Espiñeira, and González-Gómez, (2010), we follow up estimation of the basic threshold with a development of a water affordability index that allows for quantifying of the levels of relative water affordability. In contrast to García-Valiñas et al., (2010), we do not use these affordability index to compare relative water affordability among different water utilities. Instead, we calculated the average water affordability for a typical South Africa household. The method used in this study was to investigate the cost of ‘lifeline’ of four

different quantiles in relation to their income. In order to develop the index, the proportion of the average income in the country taken by the whole water bill that an average individual household would be expected to pay for the 'lifeline' is calculated. This can be interpreted as the inverse of an affordability index based only on the inelastic consumption threshold calculated in the previous section (see García-Valiñas et al., 2010).

Income is highly skewed in South Africa and we are interested in what predicts water consumption levels for the different quantiles, especially the lowest (i.e., 25<sup>th</sup> percentile). The amount of money spent on water expenditure is skewed, and quantile regression is useful as the objective is to make inference about different quantile levels. The quantile regression is most suited, compared to other models such as OLS or Latent Class Models. The quantile regression is specified as follows:

$$Q_w = a + \beta_0(I/P^w) + \beta_1Age + \beta_2Washmownsh + \beta_3Hhsizer + \beta_4Anrf + \beta_5Dwlrms + \beta_6Nfswimspn + \beta_7Toi \text{ If piped\_} == 1; \text{ quantile}(.25 .5 .75 .95) \text{ reps}(100) \quad (4)$$

The biggest advantage for using simultaneous quantile regression is that it narrates a detailed picture of the conditional distribution rather than in one mean regression.

## 5. Data

South African households face non-linear pricing, and the same water tariff structure is administered across all water utilities. The tariff system consists of two types of charges: fixed and volumetric. The volumetric charge varies and is subject to increasing block pricing with a varying number of blocks. A look at the water tariff schedule reveals that the number of blocks ranges from 2 to 10. The size of blocks varies among the water utilities. Under the IBT system, consumers' monthly water bills under different blocks can be mathematically expressed as follows:

$$\begin{aligned} B_1 &= [MP_1 * Q] + F \text{ IF } 0 < Q \leq q_1 \\ B_2 &= [MP_2 * (Q - q_1) + MP_1 * q_1] + F \text{ if } q_1 < Q \leq q_2 \\ B_8 &= [MP_8 * (Q - q_7) + MP_6 * (q_7 - q_6) + MP_6 * (q_6 - q_5) + MP_5 * (q_5 - q_4) \\ &+ MP_4 * (q_4 - q_3) + MP_3 * (q_3 - q_2) + MP_2 * (q_2 - q_1) + MP_1 * q_1] + F \text{ if } q_7 \leq Q \end{aligned} \quad (5)$$

where  $B_i$  is the monthly water bill of a customer using  $Q$  units of water;  $MP_i$  is the marginal price ( $MP_8 > \dots > MP_4 > \dots > MP_1$ );  $q_i$  is the break point of the price schedule ( $i=1-8$ ); and  $F$  is the monthly fixed charge.

We exploit a unique data set to estimate basic water levels and affordability indexes, controlling for the standard demand factors (i.e., household size, income, age). The data used in this study

cover the period from 2008 to 2014, and is extracted from the National Income Dynamics Study (NIDS) databases. NIDS is the first national household panel study in South Africa. The dataset comprises 83 water utilities. The water utilities serve as retail providers and handle the billing in their respective areas thus pricing and non-pricing conservation strategies are different across the various utilities. The data shows water expenditure levels for the period 2008 to 2014. Since our model requires that we have information on water consumption quantities, and this information is not available from the NIDS data, we had to supplement the NIDS data from other sources. Household water expenditure data is not publicly available from the different surveys done by the official national statistical agency, Statistics South Africa (StatsSA). The surveys (Census 2001 and 2011; annual General Household Survey, Community Survey 2006 and 2011) cater more for supply-side and the quality of water than quantity of water consumed by households. Because water tariffs for the water utilities are not readily available, we assembled a research team to visit water utilities and collected their water pricing schedules. Schedules for 83 water utilities were collected. This data was merged with the NIDS dataset, and this enabled the conversion of information in the database from water expenditure to quantities of water consumed by households.

Using household co-ordinates information in the secure data, these observations were aggregated up to the water utility level; we thus derived the average annual water consumption per household per water utility in each wave tract area. Since our model requires that we have some socio-demographic information to inform water consumption decisions, and this information is available from the NIDS dataset, we also aggregated this information to water utility level. The data was also checked for internal consistency by comparing water expenditure with household income levels. In sum, our analysis is concerned with panel of 115 observations corresponding to 83 water utilities across South Africa, for the period of the four waves.

## **6. Empirical Results**

### **6.1 Descriptive Results**

The sample, detailed in Table 1 below, consisted of household members between the age of 0 and 113 years, with an average age of 26.7 years. Age dummy is a variable considered in the study, where it takes the value of one if the household average age is above 60. The most notable statistic is that the average household size (HHsize) in the sample was six. This is less than the average

household size (eight) that was used to calculate the 6 000kl-per-month minimum ‘lifeline’ currently applied in South Africa. Average household income was calculated to be \$391<sup>3</sup> per month, while average amount spent on water (water expn) was \$8 per month. Average amount of water used per month was 20.87 kl, and average price paid for water across municipalities was R29.66 per kilolitre.

The average annual rainfall for the study years 2008, 2010, 2012 and 2014 was 549.42mm, which is slightly higher than the average rainfall of 450 mm per annum usually experienced in South Africa. Average number of dwelling rooms was 4, even though there was a maximum outlier of 44 rooms. Swimming pool maintenance cost was taken as a proxy for a functioning pool, and the monthly expenditure value varied from 0 to \$107. Households use different types of toilet facilities, as shown in Table 1 below; and as the interest of the study is water use, the two types of toilets used most were identified. These are flush toilets with offsite disposal, and others, such as chemical toilets. Ownership of a washing machine is a dummy variable that takes a value of one if a household owns such a machine, and zero otherwise

**Table 1:** Descriptive Statistics

Variable	Variable definition	Mean	Std. Dev.	Minimum	Maximum
Dwelling rooms	Number of rooms	4.43	2.46	1	44
Household size	Number of household members	5.998	3.56	1	41
Household income	Aggregated income of household in \$	391.12	10835.47	0	68 181.20
Rainfall	Annual rainfall in millimetres	549.42	268.40	1.8	1591
Water expenditure	Amount spent on water in \$	8	18	0	6 712
Water consumption	Quantity of water consumed (kl)	20.87	29.31	0	716.60
Price	Water tariff rate per kl in \$	2	2	0	9
Age	Age of household head	26.74	20.26	0	113
Swimming pool	Amount spent on maintenance of swimming pool in \$	0.33	3	0	107
Flushing Toilet	Binary variable=1 if a household uses flushing toilets; 0 otherwise			0	1
Washing Machine	Binary variable=1 if a household uses washing machine;0 otherwise			0	1

<sup>3</sup> US\$1 = South African Rand R14.90 at the time the analysis was done.

## 6.2. Econometric Results

### 6.2.1 Basic/subsistence/lifeline water

As mentioned above, estimating a water demand function based on the Stone-Geary utility function makes it possible to distinguish explicitly between the fixed portion of water and an additional quantity that can adapt almost instantaneously to price and/or income changes. The fixed portion cannot be easily adjusted after a price and/or income change in the short run (i.e., it is highly price-inelastic and income-inelastic). The fixed component constitutes a proxy for the 'lifeline' or basic free water, which is difficult to alter in the face of changing prices.

Demand for water is estimated as a function of socio-economic and weather variables. Water consumption is not only affected by price and income but by other factors including weather variables and relevant demographic characteristics. The size and composition of the household, household age distribution, the type of residence, ownership of a washing machine, ownership of swimming pool, possession of garden or electrical appliances that use water for cleaning purposes like washing machines, dishwashers, and whether or not the household has a flushing toilet affects water demand.

Table 2 below shows the estimated water consumption of households resulting from using the Stone-Geary demand function formulation.

**Table 2:** Determinants of water consumption

Variables	Coefficient	Standard Error	P> z
Income/price	0.001	0.0002	0.000
Ages of household members	0.754	0.98	0.44
Washing machine	4.78	0.75	0.000
Average household size	0.33	0.08	0.000
Annual Rainfall	-0.01	0.002	0.000
Number of dwelling rooms	0.67	0.16	0.000
Households with a flushing toilet	-0.87	0.23	0.000
Households with swimming pool	0.02	0.007	0.000
Constant	11.5	1.21	0.000

As shown in Table 2 above, most of the estimated coefficients are significant, except for the age variable. Most importantly, and as expected, both the constant and income-price terms are positive

and significant. Owning a washing machine increases the demand for water significantly (by 4.8kl). Age does not seem to affect the use of water. Household age distribution has varying expected impacts on residential water use. Household water consumption is likely to increase for a greater number of adults compared to children, while larger numbers of senior residents also increase water usage, as they spend more time at home during retirement. The effect of household size on water demand is positive and significant, as shown by the estimated coefficient (0.3268). This means that each additional family member in the household increases water use by 0.33kl. This is in line with empirical studies that have shown water consumption to be positively related to number of household members; though due to economies of scale, such an increase in water use is less than proportional to the increase in household size. The number of dwelling rooms also has a positive effect on water consumption where having an extra room in a home increases water usage by 0.67kl. The amount of money spent on a swimming pool maintenance is used as a proxy for a functioning pool. The bigger amount spent on maintenance the more frequent use of swimming pool, and a unit increase in spending increases household water usage by 0.02kl. As some studies show, much of residential water consumption occurs outdoors; to capture this variable, presence or size of pool are included in models of water demand (Clarke et al., 2017; Wentz and Gober, 2007; Balling, Gober and Jones, 2008; Harlan et al., 2009; Halper et al., 2015). A variable with an unexpected negative sign was household's ownership of a flush toilet. The negative coefficient shows that having a flush toilet does not increase demand for water. In the analysis, the water use of a flush toilet is compared with that of a chemical toilet, a pit latrine and a bucket toilet, it is not indicated in the data whether the pit latrines are dry toilets or pour-flush pit latrines. Lastly, households located in areas that receive more rainfall than others have reduced demand for water as is expected. Other studies also confirm this finding (see Dharmaratna and Harris, 2012).

Using the parameter estimates of the Stone-Geary demand function, the 'lifeline' or subsistence portion of water that is not responsive to price in the short run was calculated to be **11.51kl** or **11 506** litres of water per household per month, which translates to 63.9 litres per person per day for a family of six. This results in a monthly bill of \$23, which represents an average of 5.86% of monthly household budget, on an average income of \$391.

### 6.2.2 Affordability

The process of utilities setting water-tariff rates is a very complex undertaking. Utilities cannot pursue economic efficiency only when setting tariffs but must also take into consideration social goals such as equity (access and affordability), sustainability, and the political economy. In South Africa, the IBT pricing structure are believed to help municipalities achieve some of the multiple goals of water-service provision, such as cost recovery, revenue efficiency, equity and affordability, as described in previous chapters. In practice, however, there has been little empirical evidence quantifying the efficiency of IBTs in simultaneously achieving even some of these goals. In this regard, this chapter empirically assesses the equity and affordability of IBT pricing, as applied across the various South African municipalities.

#### 6.2.2.1 Country-wide average affordability of water

Table 3 below shows the calculated average affordability for South Africa as a whole. Affordability of 5.86% is just above the 3% to 5% range recommended by some international institutions – such as the World Bank, the Asian Development Bank and the United Nations Development Programme (UNDP). The Organisation for Economic Co-operation and Development (OECD) and the European Commission have suggested that water bills should not exceed 4% of a household’s income in order for water to be affordable. Accordingly, water is currently not affordable in South Africa at the mean level of income.

**Table 3:** Average affordability Index of water

	Lifeline	Price paid for water – average	Cost of lifeline	Household income –mean	Affordability (%)
All households	11.5057	\$2	\$23	\$391	5.856

Further analysis was conducted using quantile regression to analyse the impact of the different socio-economic and environmental variables on different categories of water consumption levels; and hence the ‘lifeline’ amount of water; which in turn – and together with household incomes – determines the affordability of water. The data is broken down into four quantiles of water demand, from the lowest users of water to the highest.

At the lowest-demand users of water (*Appendix 1, Table A1*)– the first quantile, q25 – need a ‘lifeline’ or basic water amount of 7.38 kilo litres per household per month for a family of six.

This translates to a monthly bill of \$15. Household size and swimming pool are significant at 10% for low-demand water consumers, though the impacts are minimal.

In the second quantile, q50 (*Appendix 1, Table A2*), the 'lifeline' is much higher than that for the first quantile: 16 490 litres of water per household per month for a family of six, which translates to a monthly bill of \$33. Household size, age, rainfall, and use of flush toilets do not affect water consumption for mid-range users of water. Household size, age, size of dwelling rooms and use of flush toilets are not significant. Washing machine ownership, rainfall, and ownership of a swimming pool are significant.

The third-quantile users of water (*Appendix 1, Table A3*) require a 'lifeline' or basic water amount of 14.32 kilolitres per household per month for a family of six, based on the demand estimation. This translates to a monthly bill of \$29. Owning a washing machine and having larger number of dwelling rooms increase water consumption by 14.06kl and 1.36kl respectively. All variables except age and household size are significant, though at different significance levels.

The biggest users of water (*Appendix 1, Table A4*) have a higher 'lifeline' or basic water amount, as expected. An amount of 21.93 kilolitres per household per month for a family of six was calculated, based on the demand estimation. This translates to a monthly bill of \$44. Owning a washing machine and number of dwelling rooms increase water consumption by 18.97 kl and 3.21kl respectively. Having a flush toilet and swimming pool affects water consumption significantly. Age, average household size and rainfall seem not to affect water consumption.

The last part of the analysis constituted calculating affordability indexes, using income quantiles of 10 (income categories subdivided into 10 groups), i.e., dividing the above expenditure lifeline by each income decile to analyse how affordable water is compared to household income. The results are shown in Table 4 below:



**Table 4:** Affordability index percentage (by income quantiles)

	Income Quantile	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
		\$56	\$107	\$149	\$194	\$245	\$308	\$398	\$534	\$789	\$1 978
Affordability Index (%)	Q25	26.22	16.38	11.91	9.22	7.33	5.88	4.61	3.43	2.32	0.74
	Q50	58.60	36.59	26.61	20.61	16.37	13.13	10.29	7.67	5.19	1.98
	Q75	50.98	31.83	23.15	17.93	14.24	11.43	8.96	6.67	4.51	1.72
	Q95	79.24	49.48	35.99	27.87	22.14	17.76	13.92	10.37	7.01	2.68

An analysis of the income deciles in relation to the expenditure lifeline calculated monthly in Table 4 above reveals that water is affordable for almost all households that earn \$534 per month or more (Q8 on the table). The lowest consumers (Q25) use about 3.4% of their income for water, while the biggest water users (Q95) spend 10.37% of their income on water. The table also shows that water is very affordable for the richest income quantile (Q10), who only spend 2.68% of their monthly income on water. However, for the poor households, with income of \$56 (Q1), the lowest water users (Q25) would have to spend 26.22% on water, while most households in the second quantile (Q50) would use an astonishing 58.6% of their income to pay for water. In fact, Table 4 shows that any household with income of \$398 or less must spend a significant proportion of its income (over 5.88%) to receive the subsistence amount of water. The above affordability indexes were calculated using the average price of water (\$2). Affordability of water becomes even worse when different average prices of water for each quantile group is considered to calculate the indexes (Appendix I, table A5).

## 7. Summary and Conclusion

The impact of an increasing block tariff structure on household water-use behaviour was analysed using the Stone-Geary demand function. Household- and municipal-level data were obtained from NIDS, municipal offices, and the South African Weather Services. Several socio-economic and environmental factors were found to have a significant effect on household water consumption. Owning a washing machine, household size, number of dwelling rooms, ownership of a swimming

pool, annual rainfall, price, and income are associated with water consumption and affect water use significantly.

The lifeline – i.e., the amount of water required by households to meet subsistence needs – is estimated to be 11kl for an average household size of 6. National average affordability index and income-disaggregated indices calculated show that any household with an income of \$398 or less must spend a significant proportion of its income (above 5.88%) to receive the subsistence amount of water.

Affordability has major implications, especially for low-income households, as they allocate a significant proportion of their income to be able to consume the basic amount of water. Water in South Africa is currently affordable for ‘rich’ (high-income) households, but less so for ‘poor’ households. Basic water is not affordable, given the proportion of household income that must be spent to acquire it. In addition, the incorrectly designed IBTs cannot be effective in incentivising households to reduce water wastage. Efficient use of water by households can provide the necessary extra water to distribute to that section of the population that is less able to afford it.

Taking a closer look at the factors determining water demand is useful in employing appropriate economic interventions and new technologies to incentivise efficient utilisation of water. Owning household appliances (such as a washing machine) or a swimming pool and having more dwelling rooms in a house affect water consumption differently for different water-consumption groups. Household size and rainfall do not affect water consumption in the higher water-consumption groups.

On average eleven kilolitres is the minimum amount of water that is required by households to meet their household needs. This is more than the 6kl lifeline estimated previously and used by municipalities to offer free water to households in the country. Water allocation for an average household size of 6 is low compared to what households need, i.e., 11kl. In addition, the ‘lifeline’ or subsistence level of water that households need is not uniform across water-consumption groups, which also contributes to differences in affordability. For an average household water is not affordable in South Africa. However, disaggregating the figures by income groups shows that, using the current tariff structure, high-income groups can afford to buy water, but it is not affordable to lower-income groups. Households that earn \$336 or more per month can afford to buy the minimum amount of water, while those households earning below the \$336 threshold cannot.

Hence, the current South African tariff structure does not address equity in relation to water demand, as water is not affordable for a significant proportion of the population i.e. low-income households. According to the Poverty Trends Report for 2006 to 2015, more than half the people in South Africa – 30.4 million people, or 55.5% of the population –are living in poverty, where water is one dimension.

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## Appendix 1: Water demand by quantiles

Table A1: Water demand for the first-quantile water-consumption group

<b>Kilo litres of water per household per month</b>	<b>Coefficient</b>	<b>Standard Error</b>	<b>P&gt; z </b>
<b>q25</b>			
Income/price	0.001	0.000	0.066
Age dummy	-0.015	0.033	0.648
Washing machine	0.056	0.085	0.510
Average household size	-0.009	0.004	0.030
Annual rainfall	0.002	0.002	0.306
Number of dwelling rooms	0.007	0.004	0.127
Swimming pool maintenance	0.044	0.021	0.041
Households with flushing toilets	0.006	0.006	0.315
Constant	7.377	1.552	0.000

Table A2: Water demand for second-quantile water-consumption group

<b>Kilo litres of water per household per month</b>	<b>Coefficient</b>	<b>Standard Error</b>	<b>P&gt; z </b>
<b>q50</b>			
Income/price	0.0006	0.0009	0.485
Age dummy	-9.82e-17	0.0541	1.000
Washing machine	4.7583	1.4989	0.002
Average household size	-0.0003	0.0025	0.879
Annual rainfall	-0.1095	0.0020	0.000
Number of dwelling rooms	0.0020	0.0133	0.879
Swimming pool maintenance	0.0950	0.0347	0.006
Households with flushing toilets	0.0007	0.0029	0.808
Constant	16.4935	1.3923	0.000

Table A3: Water demand for third--quantile water-consumption group

<b>Kilo litres of water per household per month</b>	<b>Coefficient</b>	<b>Standard Error</b>	<b>P&gt; z </b>
<b>q75</b>			
Income/price	0.0022	0.0008	0.008
Age dummy	-2.78e-15	1.8763	1.000
Washing machine	14.0571	1.2589	0.000
Average household size	0.1236	0.1132	0.275
Annual rainfall	-0.1151	0.0020	0.000
Number of dwelling rooms	1.3623	0.3879	0.000
Swimming pool maintenance	0.1032	0.0498	0.038
Households with flushing toilets	-0.4058	0.1706	0.018
Constant	14.3259	1.7253	0.000

Table A4: Water demand for fourth-quantile water-consumption group

<b>Kilo litres of water per household per month</b>	<b>Coefficient</b>	<b>Standard Error</b>	<b>P&gt; z </b>
<b>q95</b>			
Income/price	0.0173	0.0070	0.014
Age dummy	-2.0116	3.9310	0.609
Washing machine	18.9660	4.4732	0.000
Average household size	-0.1951	0.2696	0.469
Annual Rainfall	-0.0038	0.0085	0.656
Number of dwelling rooms	3.21102	1.0763	0.003
Swimming pool maintenance	0.41009	0.1159	0.000
Households with flushing toilets	-2.8033	0.5335	0.000
Constant	21.9323	0.0070	0.014

Table A5: Affordability Index of Water by quantiles

<b>Quantiles</b>	<b>Lifeline</b>	<b>Average Price of Water</b>	<b>Cost of Lifeline</b>	<b>Household Income-Mean</b>	<b>Affordability %</b>
<b>Q25</b>	7.3858	\$1.65	\$12	\$93	13.1435
<b>Q50</b>	16.5036	\$1.88	\$31	\$207	14.9776
<b>Q75</b>	14.3571	\$2.23	\$32	\$381	8.4003
<b>Q95</b>	22.3185	\$2.72	\$61	\$1 222	4.9762