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ESTIMATING WATER DEMAND DETERMINANTS AND FORECASTING WATER DEMAND FOR NZIOA CLUSTER SERVICES AREA

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ABSTRACT

The accuracy of water demand projections depends on the availability of reliable population and water use data as well as an understanding of the distribution of different types of users within the community. The underlying problem for this study is that water demand in Kenya is based on the fact that operational demand of drinking water is based on experience and appropriated practices, rather than local empirical evidence. There is limited number of analytical studies on water demand and supply reliability. In the face of limited knowledge, per capita use statistics adapted from developed countries are applied to estimate water consumption in Kenya, and most probably will fail to depict the water use patterns. At the same time, there is the unknown component of suppressed consumption induced scarcity and water quality problems. Almost certainly, will release these constraints, will modify and disrupt the water demand and design baseline. Finally it is crucial to establish time varying water consumption patterns and the critical demand values. Correct prediction of these factors determines the extent to which a network can satisfy critical demand and maintain economic efficiency. The objective of this study was to model water demand mathematically to determine the significance of water determinants for systems design and operations management. To achieve this objective, a survey of water usage in towns in Bungoma and Trans Nzoia counties was done. The survey was done in Bungoma town and its environs, Webuye town and its environs, kitale town and its environs of Nzoia Water Services clustered company (NZOWASCO). Out of the sample size of 23,000 population a sample size of 517 consumers was chosen across the five categories of consumers namely; domestic, low income, commercial, industrial and institutional. The presentation has focused on development of water determinant for domestic and low income *consumers. Out of 517 population, the Primary data was collected in the field by use of structured questionnaire, whereas secondary data was collected from secondary sources of NZOWASCO. The primary data was used to develop the regression model. The secondary data was used for sensitivity tests and validation of the regression model. The results of the model were presented in various forms and compared with actual data for a period of 2005 and 2014. The model was able to determine historical water demand and water forecasts for domestic and low income consumers. The model generated values did not vary significantly with actual data for historical water demand and forecasting.*

Key words: regression model, water demand-determinants, forecasting, model, primary data and secondary data.

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1. INTRODUCTION

1.1. BACKGROUND INFORMATION

Forecasting the amount of water to be supplied is a very important factor for design and operational demand. To guarantee high reliability for water supplies, an intensive investment to augment flow and operational programme is required. The larger the flow to be transmitted, the more expensive the investment becomes. Operational demand of drinking water is presently based more on experience than empirical evidence and furthermore, water consumption is rarely monitored. When monitoring does happen, the data is scarcely used to improve day-to-day operations of the water utilities. Reitveld observes that water supply operations will ordinarily not include time varying aspects, but is rather fixed. Yet water demand in Kenya's urban areas is rapidly changing; the volumes and consumers are rapidly growing, although in a differentiated manner, and similarly the per capita consumption induced by improving income and lifestyle. Consequently the water demand is linked to complex interactions that influence it.

Water demand indicates both current and/or expected water consumption in any given area over specific time period. While several studies have been conducted in the developed countries to better understand the characteristics of municipal water uses, this may not be the case in the developing countries (Hidefumi *et al*, 2006). This knowledge is even less understood in Africa. Generally, water demands vary and consideration of the probabilistic nature of the variations lead to more instructive assessments of the performance and reliability of water distribution systems (Tanyimbo *et al*, 2005).

Little is known about water use statistics in Kenya. Firstly, because Kenya is developing economy, secondly because of the limited number of analytical studies on water demand and supply reliability, and finally because of the unknown scarcity induced consumption patterns and impacts of water quality on consumption. Convectional analysis may not be applied directly in Kenya and may even fail to explain the water use patterns. Moreover, previous design and reliability analysis methods for water distribution systems were based on a fixed value of demand. There is little information in the literature on this fixed demand value and how it can be calculated. In order to understand water supply demand in Kenya, it is necessary to identify and model the determinants of water use demand and investigate the disaggregated pattern of use. Plainly a water supply quantity at any given instance is a chance event limited by social and environmental conditions. Therefore studying the probabilistic nature of demand should lead to more realistic assessments of the demand and performance of water distribution systems.

1.2. NEED FOR DEMAND FORECASTING

Water demand forecasting has become an essential ingredient in effective water resources planning and management. Water forecasts, together with an evaluation of existing supplies, provide valuable triggers in determining when, or if new sources of water must be developed. In the NZOWASCO cluster region, this emphasis on accurate water forecasts is particularly important. There is an increased need for water demand forecasts as water rights conflicts continue, the area's population grows, the need for in stream flows is more accurately quantified, and additional uses and needs of water are identified. Demand for water comprises not only that required for customers but also leakage from the distribution network, since it is the combined amount which is put into supply. (Therefore is normally estimated by means of district metering. Forecasting provides a simulated, though rarely perfect, view of the future. Forecasting water demand is inherently challenging, as the factors that most directly affect water demand are difficult to predict. However, effective water resource planning can account for economic, social, environmental, and political impacts on water demand. Though water demand models assume various forms, model developed in this research is for forecasting water demand for a period of at least five years.)

This research considers, modeling a regression model for domestic water demand forecasting based on population Size, Price (tariff) and Income. Population size for domestic consumers comprised of number of persons per connection whereas the price of water was considered per M^3 bearing in mind how the water pricing has changed over time and income per household variable which was considered during the survey period. The three variables were considered instrumental in providing utilities with the ability to micromanage water use, identify specific problem areas, and negotiate urban development based on resource supply. The modeling focused on domestic and low income consumption characteristics.

2. THEREOTICAL BASIS FOR MODELING OF WATER DEMAND FORECASTING

Modeling of water demand in Nzoia water services cluster company was based on the existing theoretical regulatory frame work. Water demand forecasting is a function of an underlying decision making process that takes water usage preferences and constraints on acquiring water into account (Larson *et al*. 2006). Essentially, this implies that the analysis of water demand is critical for designing an effective water demand policy for efficient use of water resources. Water is a social good that has attracted a strict administrative framework for both operations and marketing. These has affected the e fundamental decisions, like the determination of investments and prices. In such a framework where the regulator has to consult the market or customers before adjusting the tariff structure or price for water acquires a special significance, since the decision-makers require sufficient knowledge and information costs (Bithas kostasa and stoforos chrysostomosb,2006) . Furthermore, if the objective of water policy is t o ensure socially efficient use, demand analysis is a precondition of designing such a policy, since it defines the optimum socioeconomic water use and the respective water price (Martiner-Espineira *et al.* 2004, Espey *et al.* 1997, Arbues *et al.* 2003, Bithas and chrysostomosb,2006) [1–3].

$$Y_D = \beta i \, \Sigma Cij \ln Pj + \Sigma \gamma ik \ln Zk \qquad (1)$$

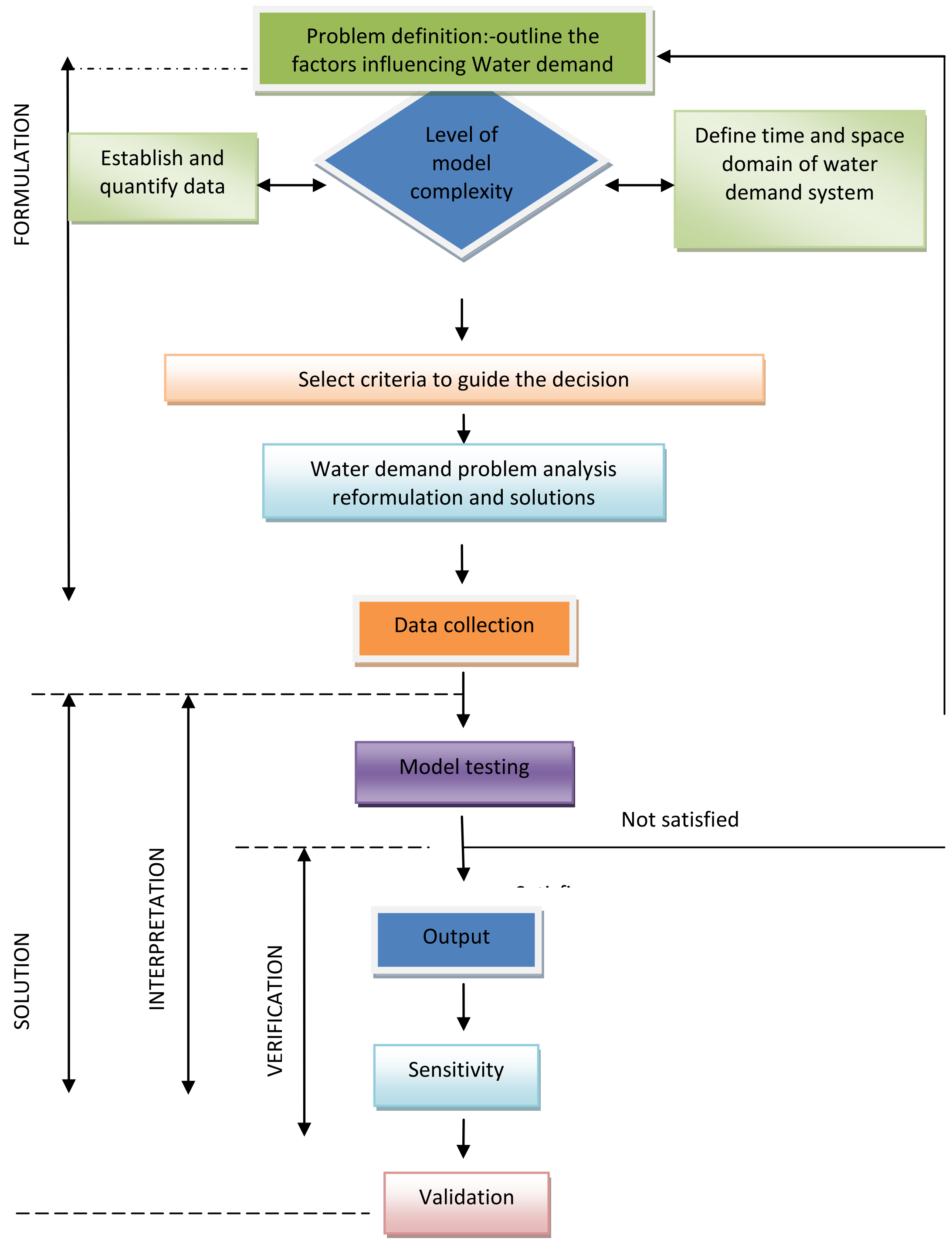

Figure 1 Conceptual Model framework for water demand model: Source (Munialo P. W. 2008)

Efficient use is defined as a pattern of use that maximizes the benefits arising from the exploitation of water resources (Tietenberg 1996, Pearce 1999) [7, 8]. Secondly, whereas in a competitive conditions, the price of water would be determined by the interaction of market demand and supply forces to reflect the actual costs of water usage (Bithas and stoforos 2006). The supply of water is a monopoly whose characteristics closely resemble those of a “natural” monopoly. Specifically, the extremely high infrastructure costs for transporting, treating and delivering water make difficult the operation of multiple water suppliers [5, 6].

Modeling of water demand forecasting for Nzoia Water Services Cluster Company was anchored on economic characteristics of water demand such as, customer behaviors, income levels, level of industrialization, etc. The mathematical equation applied in this model is

3. MATERIALS AND METHODS

The ultimate objective of this research was to come up with a mathematical model for water-demand forecasting. Figure 1 illustrates the conceptual frame work for water demand adapted in this research.

3.1. Study Design

Domestic water consumption is based on multifold factors including human behavior, culture, economic status, etc. These obvious seasonal variations too. Availability is yet another important factor in water consumption. (NGO Forum for Urban Water and Sanitation report, 2003) [9]. This study design incorporated the major factors influencing water consumption in Nzoia Water Company cluster region. A survey to determine spatially explicit characteristics of water demand, its determinants and forecast was carried out. The survey design incorporated complexities of the NZOWASCO clustered region morphology, covering three urban centers (Kitale, Webuye and Bungoma), selected survey instruments and identified procedures to follow.

The study made use of both primary and secondary sources of data. The primary data was collected from the users by using both structured (close ended) and unstructured (open ended) questionnaires. Questionnaires were designed targeting objectives of the study. Several questions were included to supplement the study and enhance the results. Besides the direct questions on water and its consumption, several indirect questions were asked to identify their economic status and sources of water. Observations were made by the enumerators to supplement grouping of economic class of the respondents. The survey was Random Sampling (RS) and Probability Proportional to Size (PPS) methods for selecting customers for domestic and low income consumers from the three NZOWASCO regions. Survey methodology was designed strategically in order to include all categories of users from all the three regions of NZOWASCO as much as possible. The secondary sources involved review of a variety of documents in order to gain more insight into the subject at hand. This included review of Company records on production, volume billed, revenue, customer care over the year, size of population within serving clients, reports and other published materials. Such documents were used to gain a deeper understanding of user characteristics.

In this research cluster sampling procedure with probability proportion to size of each sample was used. The categories of users identified in this study are Domestic and low income consumers. At the initiation of the study, NZOWASCO provided the researcher with a list and location of consumers. The consumers were based on volume of use and region. A sample of population 223 respondents consisting of low and domestic consumers was picked across the three regions (Kitale, Webuye and Bungoma towns). At first a minimum of 10 consumers were picked per category of consumers in each region for pretesting purpose. After this the questionnaire was corrected, areas that need clarification was done, ambiguity in questions was minimized. The sample frame was done based on Yamane (1967) formula. A sample is a smaller group or sub group obtained from accessible population (Mugenda and Mugenda, 2009) [4]. According to Yamane (1967), [10] sample size (n); is obtained as under:-

$$n = \frac{N}{1 + N(e)^2}$$

Where;

n = the sample size

N = the population size.

e = the error margin.

The sample picked per category was proportionately shared based on the number of customers per region. Random probability sampling was then used to study water use characteristics spatially explicit to category of users and to establish and estimate time varying trends linked to income, lifestyle, climate, price and other factors. A total of 323 consumers based on Yamane (1967) formula for both domestic and low income consumers was picked. Apart from the 323 respondents, additional 30 booster samples were collected from NZOWASCO supply area. The purpose of the 30 booster sampling was to compare water consumption in unconstrained situation.

3.2. Framework of Mathematical Modeling for Water Demand Forecasting

Analyzing and forecasting changes in demand across the users especially residential users over the long term is of interest to a wide variety of planning studies. This theses adopted a model is based on the static theory of optimizing consumer behavior assuming similarity of preferences, homogeneity of goods and perfect information.

According to microeconomic theory, the individual choice is conceived as an interrelationship among the quantity of goods that the consumer wishes and is able to buy in terms of price, income, y, his preferences as well as social and demographic characteristics. In other words, the consumer divides his income between quantities of goods and services, so that an increase in the utility level, u, derived by the individual consumption, is ascribed as: max $u = u(\text{q})$, $pq = \text{y}$ $pq = \Sigma piqi$ Using the appropriate substitutions, the demand functions are obtained by simple differentiation as follows:

$$Y_D = \beta i \, \Sigma Cij \ln Pj + \Sigma \gamma ik \ln Zk \quad (2)$$

Where; lnD is the logarithm of the corresponding demand, ln*P* is the logarithm of the price of water depending on customer category and lnZ other shift variables income, trend, etc.).

The current model is based on a model where the pattern of water consumption is the endogenous variable and price, income, population and water production are the main determinants of the system. The functional form of the equations and the parameters needed for forecasting purposes are derived from Equation 2.

3.3. Scope of the Model under Study

The objective of the study was to develop the mathematical model to predict the water demand. The scope consist of mathematical equations for water forecasting based on water determinants in Nzoia Water Company Cluster. The primary data from the field was used for model formulation wheas the secondary data was used for testing and validation of the model.

3.4. Background to the model

Nzoia Water Services Company has in operation since 2005. The clustered company covers a companied coverage area of over 300 Km^2. Nzoia water Services Company covers the area of 110 km^2 in Trans-Nzoia county specifically Kitale town with its environs , Webuye and Bungoma towns and their environs covering an area of 50 Km^2 and 65 Km^2 respectively. Both towns are in Bungoma County. Kimilili covers 110 Km^2, whereas Malaba, Kocholia, Malakisi and Amukura covers companied area of 80 Km^2. The study focused on the three towns, Kitale, Webuye and Bungoma. The three towns have a companied population served of 360,000. The water coverage in these towns is over 80%. The companied customer base is about 21,000. Nzowasco cluster area has a typical tropical climate with a mean temperature at. NZOWASCO cluster region has a typical mean temperature of 27.3 °C with the highest temperature on the highlands being at Kitale at 25 °C and highest temperatures in low areas like Bungoma being at 29.3 °C . The minimum temperature during the day is in the range of 18 °C. The mean total precipitation of the area is 1400 mm/year, Relative Humidity is between 65% and 63% in July and the average maximum temperature is 31 °C in January. Nzoia cluster is located in a hot and wet climate region. Nowadays, water is almost exclusively provided by the Nzoia water Services Company, which until 2004 was under Local authorities and ministry of water development and national water and conservation management. The state is still the main decision-maker for water policy. The state mandated the regulator i.e. Water Services Regulatory Board (WASREB) through Lake Victoria North Water Services Board to regulate the provision of water services for water services providers of which Nzoia water Services Company was licensed to operate in tran-nzoia and Bungoma counties.

This research examines water use across the domestic users in Nzoia cluster with a purpose of developing a mathematical model to predict water demand forecasting. Domestic use in Nzoia cluster accounts for over 80% whereas other categories of users account for less than 20%. Furthermore, the case of demand for water in the region presents some interesting history in water pricing for the last eleven years where by the water tariff has changed three times that is phase one pricing was between 2005 to 2008, phase two was between 2008 to 2011 and phase three was between 2011 to 2014.

Between 2008 and 2014 major investments were undertaken in the cluster and water prices were increased and as the public realized, through strict administrative measures and extensive water coverage, the water coverage increased and customer base also increased from a mere 6000 connections to 21000 connections level in 2014. In this context, water demand management is of paramount importance for the sustainability of the Nzowasco cluster water system.

3.5. Sources of Data for demand forecasting model.

In order to estimate water demand determinants, annual time series across the category of users for the NZOWASCO cluster area. The data was captured by a questionnaire tool on water pricing consumption or demand, size of household or number of persons per connection, the income per household, hours of supply across category of consumers. The data collected during the survey was used for modeling. Secondary data from NZOWASCO covering the period of 2005 and 2014 that is time varying trends like pricing (pricing, consumption trends, population growth trends, population were used for validation of the model).

3.6. Model Formulation

3.6.1. Normality Test

The normality test among the categories i.e. Domestic, Low income, industrial, institutional and commercial was done to investigate the skewness of demand. The consumption of water in all categories of consumption in study area is normal based on the probabilistic normal graph drawn over the demand pattern for water within a year hence no positive or negative skewness for the demand. The mean and standard deviation of the data was considering the sample of 517.

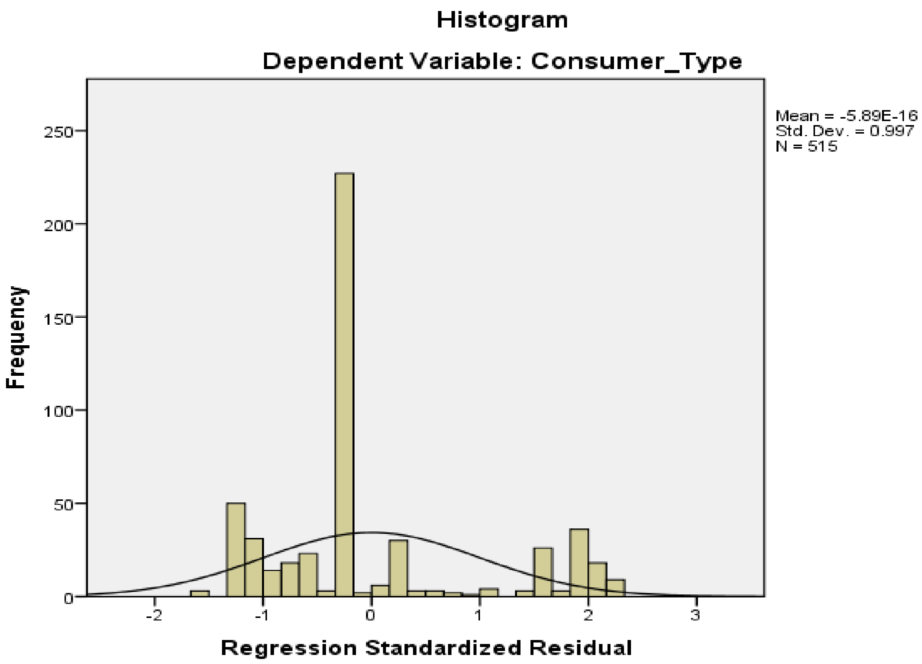

Figure 2 Water demand normality test

3.6.2. Modelling

According to the methodology described in chapter three, the following equation was used to validate mathematical model for demand forecasting.

$$Y_D = \alpha + \beta i \ln Pw + \gamma i \ln + \delta i \ln X + \varepsilon i \tag{3}$$

Where Y_D stands for the quantity of residential water demanded, Pw for the water price, in real disposable income, X for the vector of other variables (in this particular case a trend variable as a proxy to weather variations) and ε the error term. Moreover price and income are expressed in real terms using CPI as the deflator.

It is important to stress that income captured under domestic and low income and the size of household population was used for deriving domestic and low income consumer's category. Equation 3 was transformed depending on the variables used to estimate water demand for Nzoia cluster region. The results of multiple regression analysis model was generated and recorded in the Tables below. (Tables 1 and 2).

Table 1 Regression Analysis for the determinant of water for the Domestic and Low income

Independent Variables	Coefficients			T	Sig.
	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta		
(Constant)	6210.923	3845.739		1.615	.000
Household Size	29.452	119.482	.099	.247	.000
Income	26.029	678.245	.072	.038	.000
Tariff	-12.066	37.707	-.018	-.320	.000

a. Dependent Variable: Quantity Supplied Month

Table 2 Model Summary for domestic and low income consumers

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.024[a]	.0567	.099	20319.339

a. Predictors: (Constant), Tariff, Household Size, Income

4. DISCUSSION OF RESULTS

4.1. Domestic and Low income water determinant Regression Model

The result showed a positive correlation of r=0.024 with a high coefficient determination of r^2=0.0567 and its adjusted value of 0.0829 at 95% significance level.

$$Y_D = f(\alpha, HHz, In, Tariff, £) \quad (4)$$

Where Y_D - the water consumption demand

A - Constant

HHz - Household Size

In - income per month

Tariff = price of water per month

£ - Error term

$$Y_D=\alpha+\beta_{HHz}+\mu_{In}-x_{Tariff}+£$$

$$Y_{D=}6210.92+0.099_{HHz}+0.072_{In}-0.018_{Tariff}+£$$

The result above shows that Income, Population size and Tariff were statistically significant determinant of water demand in the study area. The tariff applied on water use has a strong negative effect on residential water consumption. As such, water consumption decreases when tariff growth is recorded. Thus, according to the literature, tariffs are frequently used as a tool for improving water savings. The implementation of efficient water-pricing practices that promote equity, efficiency and sustainability in the water sector is probably the simplest conceptual instrument. Using tariffs as a manner in which to regulate water consumption could potentially have a greater effect on lower income households, since water has no substitutes for basic uses and there is an amount of water that is highly insensitive to price changes.

While income per capita and household size has a positive effect of 0.099 and 0.072 on water consumption for domestic and low income hence for any change by a unit in income and population size leads to a corresponding significant increase in water demand. Figure 3 illustrate the model generated based on determinant of water demand. Figure 3 below shows the estimation of water demand under domestic and low income categories using different population size, income and tariffs.

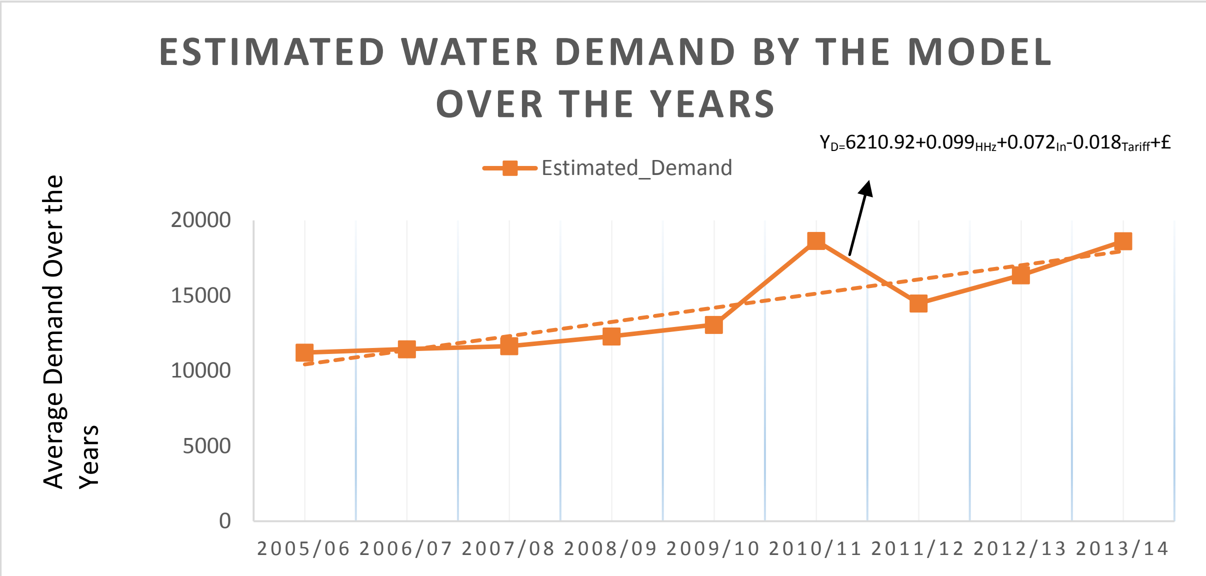

Figure 3 Model generated based on determinant of water demand for domestic and low income consumers

4.2. Sensitivity of the Model in the Area

Sensitivity of the model in estimating water demand was investigated through estimating water supplied against water demand over the years. The model was used to forecast the demand over the years and comparing the water supplied that time. The line of best fit was drawn over the estimated water estimate line over the years.

In order to assess the sensitivity of the model and its credibility of results, the model was run over the sample period (2005–2014). In Figures 3 and 4, comparisons between actual and fitted values are presented. It is clear that the actual demand and estimated demand are reasonably close**.** Additionally, two statistics for examining the forecasting accuracy, namely the correlation between determinants of water demand (R^2) and the standards deviation error of the estimates are reported as indicated in Table 1 demand for domestic and low income and Table 2 for other consumer categories. The statistics suggest that the model tracks historical water demand patterns fairly well. Overall, the results for both stages can be considered promising, a fact that permits us to continue with the post sample prediction through policy scenarios.

4.3. Further Sensitivity and Forecasting Demand

In order to be able to recognize the possible policy and theoretical implications of the results, it was considered important to conduct a further sensitivity analysis. Five scenarios were examined. The first scenario considered the Forecasting demand for a constant tariff, 10 ten percent increase in connections and five percent increase in income. In the second scenario the model was used for projection of Demand forecasting for a reducing tariff of (10%), increment in connections (10%) and income (5%) across the five year period. In both scenarios, real historical figures to carry out projections prices are assumed to be fixed for the period 2015–2020 and the income, house hold size growth of customer base is determined from historical figures. In third scenario demand forecasting for increment in tariff by 4% annually, connections (10%) and income (5%). The fourth scenario was demand forecasting for increment in tariff (20%), is applied during the base year and is to run for five years, connections (10%) and income (5%). The fifth scenario was forecasting demand for %increment tariff by 20% and connection (10%). Finally the sixth scenario forecasting demand for %increment in tariff by 4% and connection (10%). The explanations of the findings are illustrated in the following figures.

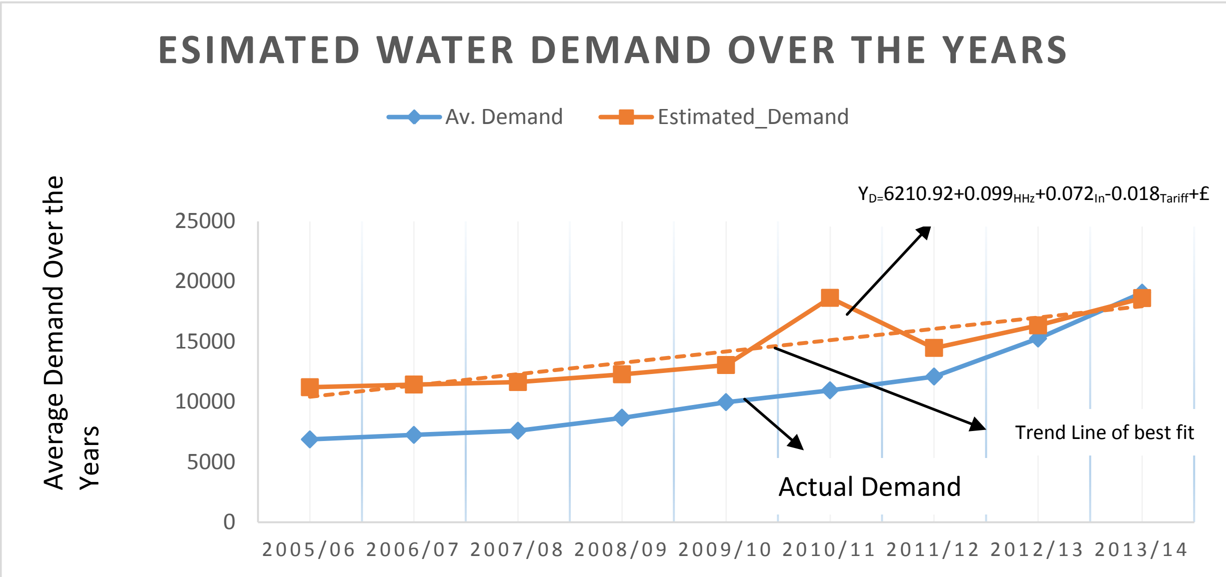

Figure 1 Estimating water demand using the regression model

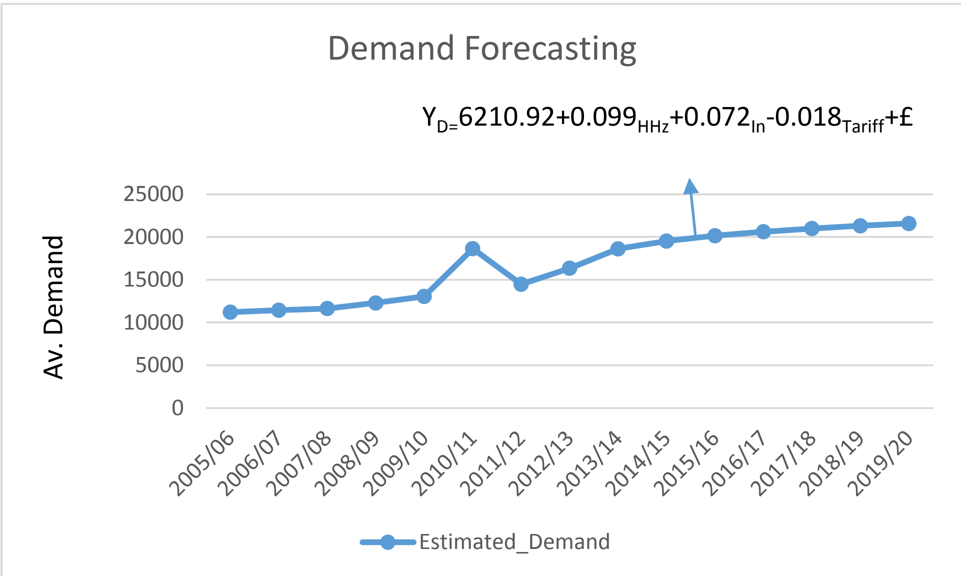

Figure 5 Forecasting demand for a constant tariff, %increment in connection (10%) and income (5%)

When a forecast was conducted to investigate the rate of consumption over the years until 2020, the results showed that for any increment of connections by 10% and income 5% p.a at a constant tariff there is increase in water demand by 3.2%. The graph above illustrate the estimated forecast values of water demand based on domestic consumption category.

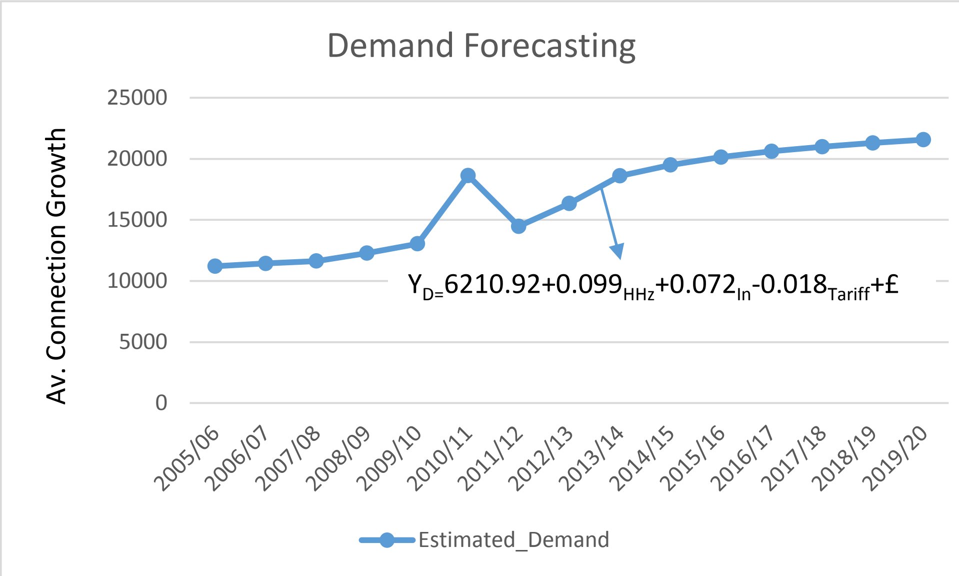

Figure 6 Demand forecasting for a reducing tariff (10%), increment in connections (10%) and income (5%)

Investigation on the variation of water demand when the tariff reduced by 10% and increment of connections at 10% and income increase at 5%. The result illustrated above shows that for any indicated change there is a change in water demand at a rate of 3.3%. The change shows that water price is significant in determining the consumption such that for any reduction made there will be an increase in water demand under domestic category.

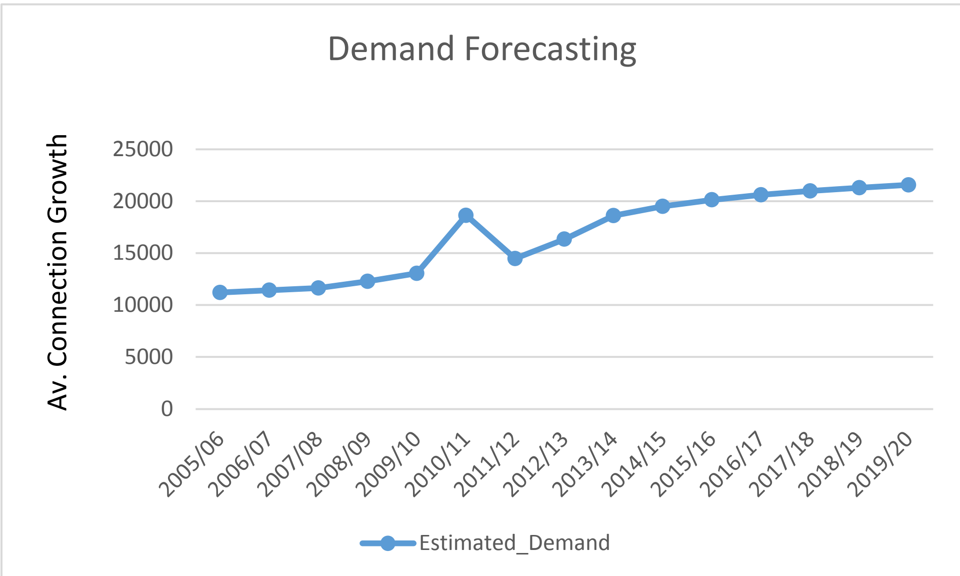

Figure 7 Demand forecasting for increment in tariff (20%), connections (10%) and income (5%)

Further investigation was tested based on increase of tariff by 20%, connections by 10% and income by 5%. The results showed that for any increment in water tariff there will be a significant reduction in water demand by 1.5% as compared to a case where the tariff was reduced by 10%. These results reveals that for any larger percent increment of tariff will lead to a significant reduction in water demand.

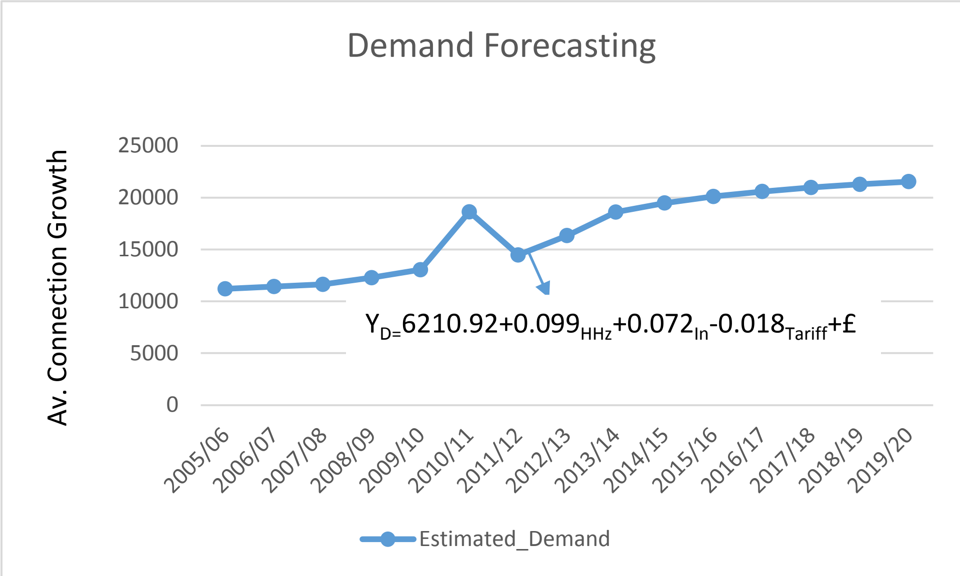

Figure 8 Demand forecasting for increment in tariff (4%), connections (10%) and income (5%)

A test was conducted to investigate what will happen to demand when a tariff changes with smaller percentage of 4% and increment in connections by 10% income 5%pa. The results reveals that for any above changes effected there will be water demand at a rate of 2.4%. As compared to above case where there was increase of tariff by 20% the demand rate for smaller percent change is higher than a larger percent. Therefore the model stands advise that if the company would like to increase water demand, the percentage increase in tariff should be reasonable.

1. This Research in water resource management has revealed the key parameters to forecast water demand for domestic and low income consumers are price for water, population size/ Household size or number of persons per connection and income for consumers
2. The model thus, ($Y_D = 6210.92+0.099_{HHz} + 0.072_{In} - 0.018_{Tariff} + £$)

   Where Y_D-the water consumption demand, α- Constant, HHz-Household Size In-income per month, Tariff = price of water per month, £-Error term

   $Y_D = \alpha + \beta_{HHz} + \mu_{In} - x_{Tariff} + £$, to predict water demand for domestic users has been developed.

These conclusions also represent hopeful applications of the research completed in this thesis. Water demand forecasting model has been estimated using the following equations/models;

$$Y_{Ddl} = f(\alpha, HHz, In, Tariff, £) \quad (5)$$

$$Y_{Dics} = \alpha + \beta_{HHz} + \mu_{In} - x_{Tariff} + £ \quad (6)$$

Combined Equation $Y_D = Y_{Ddl} + Y_{Dics}$

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