# A REVIEW OF APPROACHES TO WATER DEMAND ESTIMATES AND IMPLICATION FOR DEVELOPING COUNTRIES OF AFRICA

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## 1.0 INTRODUCTION

Increased infrastructural development and potable water consumption have highlighted the importance of accurate water demand estimates for effective municipal water services infrastructure planning and design (van Zyl, et al., 2008). Estimating and forecasting water demand have become necessary as the urban population dependent on public water supplies increases rapidly and new demands for water are not easily met. The literature on residential water demand has expanded significantly in recent years in terms of scope and sophistication, as quantitative, regression based studies have illuminated many relationships while simultaneously identifying several new research issues (Kenney et al., 2008). Considerable efforts have been put into the development of urban water supply projections in the last four decades which has resulted in a wealth of understanding and production of sophisticated forecasting techniques. There is no absolute level of accuracy that is appropriate in all demand forecasting situations. However, it is important to understand the key determinants of water usage. According to Nieswiadomy (1992) a consensus on the proper estimation methodology has not been reached. This is due to the fact that every region of the world has its own characteristics in respect of water usage and socio-economic influences.

Most studies have found climate, price, and seasonal changes to affect water demand. In their review studies, Worthington and Hoffman (2006) found that most employed least squares regression techniques in some way, with the remainder using other techniques, including logit, generalized methods of moments, instrumental variables and cointegration. Arbues et al., (2003) give a state-of-the-art review on estimation of residential water demand with distinct attention on variables, specification model, data set, and most common econometric problems. Wurbs (1994) made a general characterization of water use forecasting by (1) the level of complexity of the mathematical relationships between water use and explanatory variables and (2) the level of sectoral, spatial, seasonal, and other disaggregation of water users. The complexity of the relationships however depends primarily on how many and which explanatory variables are included in the equations. Other methods improve on this by considering many factors such as price, income, housing type, household size, climate, etc that are known to affect water use.

Recently, the use of multivariate model reduces the degree of subjectivity in the analysis and makes better use of available data. This method makes use of variables observed to be significantly correlated with water usage and not necessarily those suggested by a priori economic reasoning. The disadvantages are that data requirements may be considerable and may be difficult to collect. These models discussed above reflect more of correlation rather than causation and consequently may omit potentially important relationship. The econometric demand model however differs in that it is based on economic reasoning and include only variables which are either expected to be causally related to or found to be significantly correlated with water usage. A large number of studies of the demand for urban water have appeared in the literature since the classic Howe and Linaweaver study of 1967 (Martin and Thomas, 1986). This review work discusses the methodological framework of main water demand model estimation and forecasting with particular reference to the need of developing countries of Africa. It then highlighted the practical and conceptual approach to realistic estimate of water demand which was substantiated with application of a novel developed demand model on a modern city in Nigeria.

## 2.0 MODEL SPECIFICATIONS

### 2.1 Form

Most water demand models are usually of the form: Q = F (p, z) where Q is the quantity of residential water demanded (more likely consumed), p is some measure of water price, and z represents other independent variables thought to impact upon residential water demand which usually include income, household structure and size, property characteristics, and nonprice water restrictions (Arbues et al. 2003). It can be linear or logarithmic without categorical knowledge of functional form that gives better results. The formal is often criticized because it implies that the change in quantity demanded in response to a price change is the same at every price level (Arbues et al. 2003).

### 2.2 Estimation

The existing literature on the models used for estimation of the water demand involves numerous econometric techniques (Worthington and Hoffman, 2006): such as for cross-sectional data, the empirical techniques employed include ordinary least squares (OLS), generalised least squares (GLS), two and three-stage least squares (2SLS and 3SLS), logit and instrumental variables (IV) and for time series data there are vector autoregressive (VAR) models and cointegration techniques. Many techniques normally reserved for cross-section are equally applicable to pooled time-series, cross-sectional (or panel) data, including OLS, GLS, maximum-likelihood (ML) and 2SLS. (See for examples: Mitchel, 1999; Schleich and Hillenbrand, 2008; Mazzanti and Montimi, 2006; Hussain, et al., (2002) and Olmstead et al., 2007, Zhou, et. Al., 2002, Martínez-Espiñeira, 2007). The choice of any of these methods is a function of available data set.

### 2.3 Data Sets

There are different data sets that have been used in demand modeling studies ranging from individual household data to aggregate data. These include households' data from conducted survey, government survey, cross-sectional data and time-series data. Different kinds of data sets have been used ranging from household data to aggregate data. The quantity and type of data available determines which forecasting method should be considered for application. Mylopoulos et al., (2004) applied a cubic functional form of an econometric model to study a residential water demand which allows the use of different price elasticities for different levels of water demand. The data used for the econometric analysis were obtained through a survey of consumers in the city of Thessaloniki, Greece. Panel estimation methods were then employed to estimate model parameters. The results showed that a cubic form of the demand equation can provide appropriate estimates of price elasticities for different "consumption groups" of residential customers.

### 2.4 Variables

Water price, income and household characteristics have featured as important significant factors in most water demand studies (ie, Scheleich and Hillenbrand, 2008). In almost all industrialized countries, the residential water demand function is specified as a single equation linking (tap) water use (the dependent variable) to water price and a vector of demand shifters (household socioeconomic characteristics, housing features, climatologic variables, etc.) to control for heterogeneity of preferences and other variables affecting water demand (Nauges and Whittington, 2009). Kenney et al., (2008) posited that consideration for full spectrum of influences on water demand is necessary for understanding and projecting demand and for assessing opportunities for demand management and thereafter distinguished factors that are under control of water utilities (ie pricing and rate structures, nonprice strategies) and those that are not (ie weather, demographic considerations).

## 3.0 PAST WORKS

Cochran and Cotton (1985) used multiple regression models in a municipal water demand study for Oklahoma City and Tulsa, Oklahoma. The results indicate that price and per capita income were predictive variables for Oklahoma City's water demand while only per capita income was found to be a predictor for consumption in Tulsa. Mimi and Smith (2000) and Khadam (1984) employed this approach in water demand studies for Rammallah and Khartoum respectively. Both studies also found price and size of household significant, but the later was inversely (ie as household size increases, per capita water use decreases). However, regression models have several serious problems in domestic demand forecasting. First, many independent variables are needed to fully predict household demand, increasing the risk of multi-colinearity. Secondly, they are partial models. That is, they are based on a large set of variables, but for a small area, or a small set of variables for a large area, both cases leading to a poor spatial (and hence total) estimation of demand (Mitchell, 1999). An important problem regarding comparing the results of most studies is that the ways in which the price and quantity variable are defined differ between studies, and the definitions typically disappear from tables of comparison (Martin and Thomas, 1986).

Jansen and Schulz, (2006) attempt to provide a greater understanding of the factors that influence water consumption and an estimate of the price elasticity of water demand, using data obtained from households living on the Cape Flats in the Western Cape Province, South Africa. A panel data analysis (correcting for heteroscedasticity and serial correlation) demonstrates how different factors influence water consumption, among them the price of water and it was found that consumption is insensitive to price changes among the poor while the richest group of households react to price changes much more. It was also found that using actual prices in the estimation does not address the simultaneity in the data and a 2SLS analysis was therefore applied in the model. The model results reflected a negative price elasticity of demand for water in the short run and a major finding results from splitting the data into different income groups. Subsequently a price elasticity for water demand of only –0.23 for the lowest-income group while the high-income group has a price elasticity of -0.99 was found. The results may add to the knowledge needed to improve an Increasing Block Tariff (IBT) structure to achieve greater equity.

Martínez-Espiñeira, (2007) estimated and compares short-run and long-run price elasticities of residential water demand using data from Seville, Spain along with additional objective to assess the usefulness of the techniques of co-integration and error correction in the analysis of these price-elasticities of water demand. The approach avoids problems of spurious relationships that bias the results and provides a convenient and rigorous way to discern between short-run and long-run effects of pricing policies. Using monthly time-series observations from Seville, Spain, we find that the price-elasticity of demand is estimated as around -0.1 in the short run and -0.5 in the long run. These results are robust to the use of different specifications. The elasticities estimated suggest, in line with previous studies, that household water demand is inelastic with respect to its own price, but not perfectly so. The results show remarkable consistency between the different techniques used to analyze the dynamics of the relationships.

## 4.0 MODEL METHODOLOGY OPTIONS

### 4.1 Residential and Nonresidential Water Demand Models

Selection of a water demand forecast methodology is a function of three primary criteria: planning objective, available data and available resources. The planning objective for development of a water demand forecast defines the level of detail needed by the water resource decision-makers who will utilize the water demand forecast information. Broadly defined the methodological options are: (1) Trend extrapolation (2) Per capita method (3) Number of unit times a per unit use approach, where the per unit use is fixed and; (4) Number of unit times a per unit use approach, where the per unit use is variable and related to influencing factors. The first two methods do not incorporate information regarding factors that influence water demand. The forecasting methodologies discussed below follow the general format of number of unit times a per unit use while each methodology examines a different approach to determining the per unit use element. Each of these methodologies follows the approach (Davis, 2006):

$$\boldsymbol{Q_{c,m,y} = q_{c,m,y} \times N_y} \qquad \textbf{(1)}$$

Where:
Q = monthly water use; q = per unit use; N = number of units; c = customer class;
m = month; y = year

The per unit value of (q) is estimated in one of the following methods (Davis, 2006):

### 4.2 Average Rate of Use

This approach assumes an average per unit use value of (q) for a defined geography and time period, and is held constant throughout the forecast period:

$$q_{c,m,l} = \frac{Q_{c,m}}{N_c} \qquad (2)$$

where:
q = average use per account; c = customer class; m = month; l = location (i.e., county); u = utility Q = water consumption; and N = number of accounts

### 4.3 Disaggregate Factor Forecast

The disaggregate factor forecast allows an adjustment to the per unit use factor and follows the general form:

$$Q = N \times q$$

where:

$$q_{c,m,y} = (Q_b/N_b)_{c,m}(X_{1f}/X_{1b})^{\beta 1_{c,m}}(X_{2f}/X_{2b})^{\beta 2_{c,m}} \cdots (X_{nf}/X_{nb})^{\beta n_{c,m}} \qquad (3)$$

and:
q = adjusted per unit use; c = customer class; m = month; y = year (b = base period; f = future year);$Q_b$ = base year per unit use; $N_b$ = counting unit (e.g., account, housing unit, population, etc.); $X_b$ = base year factor variable; $X_f$ = projected factor variable; β = elasticity

### 4.4 Functional Per Unit

The functional per unit use model estimates values of per unit use and follows the general form:

$$Q = N \times q \qquad (4)$$

where:

$$q_{u,c,m,y} = \propto \left(X_1{}^{\beta_1} X_2{}^{\beta_2} \cdots X_n{}^{\beta_n}\right)_{u,c,m,y}$$

and
q = per unit use; u = utility; c = customer class; m = month; y = year; α = intercept; X = explanatory variable; and β = elasticity

### 4.5 Functional Population

The functional population model follows the general form:

$$Q = POP \times gpcd \tag{5}$$

Where:

$$gpcd_{c,m,y} = \propto \left(\left(X_1{}^{\beta_1} X_2{}^{\beta_2} \cdots X_n{}^{\beta_n}\right)\right)_{c,m,y}$$

and:
gpcd = gallons per capita day; u = utility; m = month; y = year; α = intercept;
X = explanatory variable; and β = elasticity

### 4.6 Industrial Water Use

The traditional method of forecasting industrial water use is the water requirement approach (Hanemann, 1998). This approach postulates that water use in an industrial establishment varies proportionately with the scale of production in that establishment. Scale is measured in terms of physical units of output, monetary value of output or the size of labour force employed. There are two approaches. The first approach is a constant factor of proportionality which leads to the following forecasting equations:

$$X_i = \alpha_i y_i \tag{6}$$

Alternatively,

$$X_i = \beta_i E_i \tag{7}$$

Where
- $X_i$ ≡ water intake in an establishment in the ith type of industry
- $y_i$ ≡ production by the establishment
- $\alpha_i$ ≡ water intake per unit of output in the ith type of industry
- $E_i$ ≡ number of employees in the establishment
- $\beta_i$ ≡ water intake per employee in the ith type of industry

In this approach, $\alpha_i$ and $\beta_i$ are treated as constants. They vary by industry, i, but are fixed over all the establishments in an industry.

The second approach is more sophisticated. It relaxes the assumption of strict proportionality and postulates as follow:

$$X_i = \alpha_i y_i^{\gamma} \tag{8}$$

Alternatively,

$$X_i = \beta_i E_i^{\gamma} \tag{9}$$

where $\boldsymbol{\gamma}$ may or may not vary with industry i. Water use increases less than proportionately with scale of production if $\gamma < 1$, and more than proportionately if $\gamma > 1$. Dziegielewski (1988) found that a value of $\gamma = 0.7$ fit the data well for US manufacturing industry. Several studies have reportedly found the number of employees to be highly correlated with water demand and therefore, in a unit use approach, may be used to estimate a water coefficient for a group of establishment (Cook et al, 2001). Gross Domestic Product (GDP) is also commonly used in industrial water demand models. Past studies in a number of countries have shown a reasonable correlation between GDP and industrial water use. However, no account is taken of the changing nature of industrial production and the effect on water demand. Improvement in technology of industrial production can lead to significant water saving.

In a study carried out by International Water Management Institute in 1998, a relationship was produced between per capita water withdrawals and GDP in the year 2025 for countries with a per capita industrial water demand of 1000 cubic meter or above in 1990. The relationship was based on GDP estimates for various countries provided by the International Food Policy Unit and forecast industrial water withdrawals in 2025. However, it should be noted that the correlation coefficient of 0.56 is relatively low indicating that there was a relatively high degree of scatter in the data (HR Wallingford ltd, 2003). Details computational estimates for various industries are found in HR Wallingford ltd (2003).

## 5.0 IMPLICATIONS OF USING SOPHISTICATED STATISTICAL AND ECONOMETRIC MODELS FOR AFRICAN COUNTRIES

According to Nauges and Whittington (2009), studies of residential water demand in industrialized countries have mainly concerned measurements of price and income elasticities. In these countries almost all households have connection to piped borne water of good quality which is the primary source for all water uses. These characteristics permit a relatively straightforward estimation of the household water demand function. The only methodological issue is the nonlinearity of the pricing scheme, which may cause endogeneity bias at the estimation stage. Most of the sophisticated statistical and econometric models are not entirely applicable in developing countries of Africa. Oyegoke and Oyesina (1984) contend that in estimating design parameters for water demand in developing countries, the philosophy should be to provide first for the basic needs and then incorporate various factors that may affect demand in the particular situation.

However, for many households in the developing countries (LDCs) water is a heterogeneous good, which is not usually the case in industrialized countries. Households often rely on a variety of water sources, including piped and non piped sources with different characteristics and levels of services (price, distance to the source, quality, reliability, etc.). Analyses of household water demand in LDCs first appeared in the work of White and others (1972), Katzman (1977) and Hubbell (1977) but remain limited even today due to difficulty in analyses of household water demand in these regions (Nauges and Whittington 2009). This is mainly because conditions surrounding water access often vary across households. With this variability it is almost impossible to base a comprehensive analysis of household water demand on secondary data from the water utility. Obtaining water from non-piped sources outside the house involves collection costs that need to be taken into account to assess household behavior accurately.

Nauges and Whittington (2009) categorize households in LDCs in to three large groups each with its own distinct set of water and sanitation challenges. The third large group of households lives in the rural areas of sub-Saharan Africa and South Asia on less than US$1 per person per day. In-house piped water services are prohibitively expensive for this group and may remain out of reach for the foreseeable future. The design of rural water supply projects and programs to reach this third group of households has a long history of failure (Therkildsen, 1988; Nauges and Whittington, 2003). The authors discussed the technique that uses data from utilities and household surveys to estimate household water demand functions and not papers that investigate water demand behavior based on stated preference techniques, revealed preference techniques, or experimental methods. Their findings on the main determinants of water demand in LDCs suggest that despite heterogeneity in places and time periods studied, most estimates of own price elasticity of water from private connections are in the range of –0.3 to –0.6, close to what is usually reported in industrialized countries. However, the empirical findings on household water source decisions are much less robust and should be a high priority for future research. Detail of the study and findings along with implications for water utility manager in LDCs are available in Nauges and Whittington (2009)

## 6.0 MODIFIED PER CAPITAL METHOD AS AN ALTERNATIVE

The findings on the subject as discussed in the previous sections motivated the authors to conceptualize an appropriate model to estimate water demand in developing countries of Africa such as Nigeria. The approach most widely used for water forecasting is the per capita method, which assumes that the population is a single explanatory variable. It provides adequate explanation on water use and assumes other variables to be unimportant or perfectly correlated with population. The objective is to find simple relationship which accounts for as much of the variability of demand as possible. Hence in the formulation of the model, water demand is addressed as basically non-irrigation demand which include the following principal determinant components typical of urban water requirement**:** residential, industrial, commercial, institution and system losses. The forecasting relationship to estimate water demand is based on specific assumption reflecting the following local situations common in most developing countries**:**

- urban water uses are predominantly residential and commercial
- water use are not metered and
- fixed rates, independent on amount consumed, thus quantity has no correlation and causation with price,

The model is formulated to take into account the major uncertainty associated with water demand which is the population. Therefore, the per capita method is used and estimate of principal components incorporated. The justifications for this are: (1) paucity of long period socio-economic data; and (2) no large contingents of seasonal residents. The total urban water demand $U_{wd}$ forecast model is estimated as given in Equations 10**:**

$$U_{wd} = \gamma\left( x\left(P_t(1+r)^n\right) + \sum_{j=1}^{m} \sum_{i=1}^{k} q_{ji} b_i \right) \tag{10}$$

Where:

$U_{wd}$ = water demand in cu.m per day in year n

$P_t$ = population at present time t,

r = rate of growth of population

n = the length of time for which the projection is made

$x$ = per capita water requirement in cu.m for domestic/residential use

$\gamma$ = a factor greater than 1 to account for system losses and contingent usage
$q_{ji}$ = estimated water requirement of establishment i per employee, pupil, or bed space in category j
$b_i$ = number of employees, pupils, bed spaces, etc
m = no of principal determinant components (m = 1 for commercial, m = 2 for institution, m = 3 for industrial)
k = no of establishment in commercial/Industrial/Institution categories

## 6.1 Institutional and Commercial Water Demand

For urban institutional and commercial water demand estimate where there is no available metered record, one estimation method is to apply a demand allowance on a per capita basis for various institutions and commercial buildings. Typical allowances for commercial and institutional establishment are as shown in Table 1. These allowances assume piped water connections and waterborne sanitation, and should be adjusted down where the establishments have a lower level of service for instance, standpipes, hand pumps or VIP latrines in schools.

Table 1: Typical demand figure for commercial and institution establishments in urban areas

| Usage | Demand allowance |
|---|---|
| Small businesses, shops and Offices | Up to 35 litres / capita / day (applied as per capita allowance to the whole urban population) |
| Offices | 65 litres per day per employee* |
| Departmental stores | 100 -135 litres/day/employee* |
| Hospitals | 350-500 litres/day/bed |
| Hotels | 250 litres/day/bed |
| Schools | 25-75 litres/day/pupil* |

Note: These values should only be applied when the above are operating or open
Source: HR Wallingford Ltd (2003)

## 7.0 MODEL APPLICATION, RESULTS AND DISCUSSION

The water demand model was applied to a water supply scheme in Offa Township, the headquarters of Offa Local Government Area (LGA) in Kwara State. The Offa township is completely inside the catchment which lies entirely inside Kwara State of Federal Republic of Nigeria (Fig. 1) between latitudes $8^o$ 38' and $9^o$ 50' N and between longitudes $8^o$ 03' and $8^o$ 15' E. The catchment is oblong in shape and it is very long compared with it's breadth. The climate of the catchment is the type common with the tropical savannah grassland of Africa. There is not much climatic variation and hence the hydrologic variation in the catchments is also insignificant (Adebosin, 1986). Primary data on the customer categories connected to the public utility are collected from Kwara State Water Corporation (KWWC), the state owned corporation responsible for municipal water supply. The standard water usages (Table 1) were used in the estimation of the principal components of water demand in the model based on the primary data and on the available numbers of individual components.

The urban water demand was estimated as given in the model (Equation 1) and computed using C++ code.

The domestic, commercial, industrial and institutional water demands between the periods 1996 and 2008 are estimated. The standard estimated water usage values in Table 1 are used in the estimation of principal components of water demand based on the available confirmed numbers in individual component. The domestic estimates are based on 120 lcpd and 2.83% annual population growth rate. The population projection was based on 1991 estimate (Okeola, 2000). Figures 1 show the trend in the different categories of water demand for the period. Due to lack of reliable data on industry, commercial and institutions for making future projections, the long term water demand forecast for the year 2020 was limited to domestic demand (Fig. 2). It was based on 2006 population census figures (NPC, 2007). There is a steady growth in the population and water demand up till year 2020 as shown in figure 3.

## 8.0 CONCLUSIONS

The paper gives various methods of household water demand estimation and forecasting and contend not suitable for application in most developing countries of Africa for management and planning of metropolitan water supply. It stresses the need to appropriate water demand model in that respect. An alternative water demand model that takes cognizance of the peculiarity of most developing countries of Africa was developed and applied to Offa Township in Kwara state, Nigeria. The study can serve as an organized baseline for future work, particularly in obtaining improved estimate for industrial, commercial, institutional water use categories and planning conjunctive uses of water resources. The findings of the study can be a vital input into the demand management process for long term sustainable water supply of the town and by extension to urban township with similar characteristic in Nigeria and African countries.


**Figure 1. Map of Nigeria showing Kwara State**

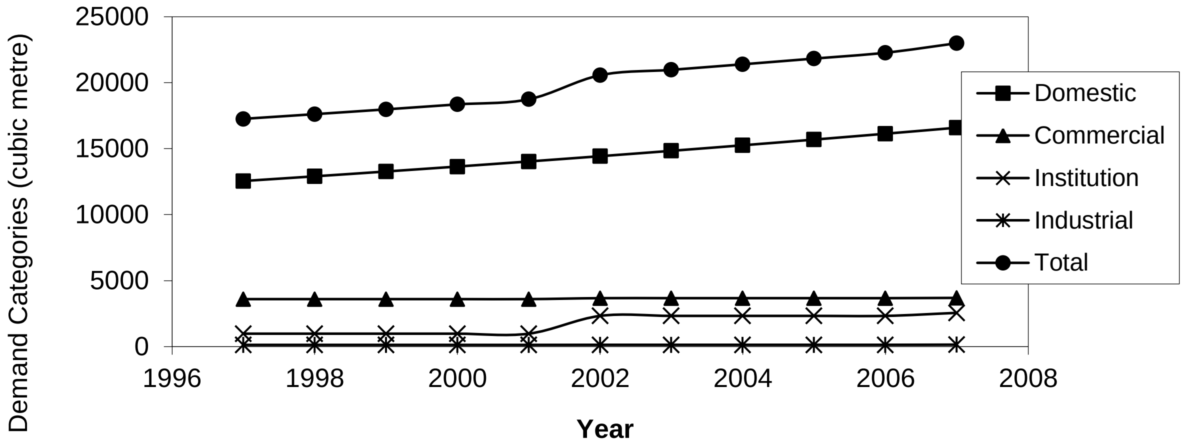


**Fig. 2 Offa Water Demand Trend between 1996 and 2008**

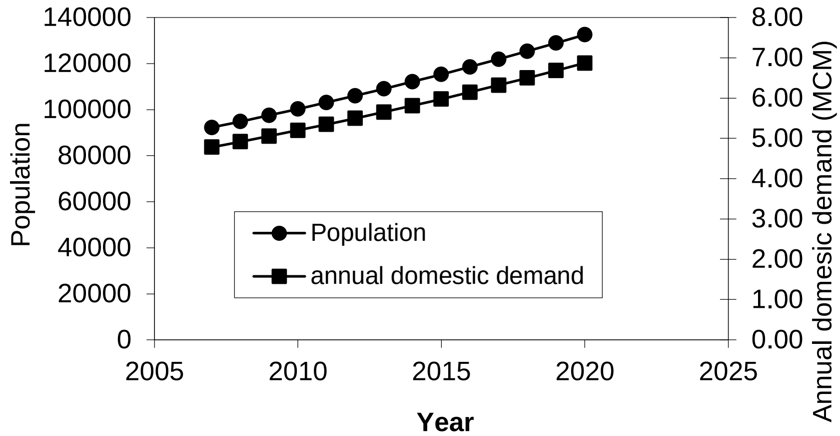


**Fig. 3 Projection of Offa Population and Annual Domestic Demand**

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