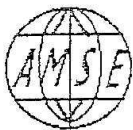


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Domestic Water Consumption Model for Abuja, Nigeria

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Abstract

This paper examined the residential water consumption pattern in the Federal Capital Territory (FCT) Abuja, Nigeria. The parameters considered were volume of water use, population, numbers of toilets and number of rooms in the houses at household level of residential areas. Analysis was carried out on hourly, daily and weekly bases to obtain the trend of water usage. Daily water use has been modelled in order to establish the structural relationship between the variables and household water demand and to reveal the determinants of the variation of water use. The results showed that the average water consumption rate is 251.47 litre/capita/day, which is much more than the minimum value of 120 litre/capita/day recommended by WHO. The test on model results indicated that number of toilets; number of rooms and household population are significant and are positively related to the average daily water demand.

Key Words:

Domestic, Water Consumption, Model, Demand

1. Introduction

Water is the source of man's existence in life. Water usage is the driving force behind the hydraulic dynamics occurring in water distribution systems. Anywhere that water can leave the system represents a point of consumption, including a costumer's faucet or tap, a leaky main, or an open fire hydrant (Walski et.al, 2003). Water demand apart from domestic use, also include commercial, industrial, agricultural and public uses. Water demand is the amount of water required to satisfy all human activities such as domestic, agricultural, industrial as well as fire fighting. As such, the accurate estimation of water demand is paramount for proper planning and designing of new and improvement scheme of water supply systems.

Stikker (1998) provides a general overview of the fresh water scarcity that parts of the world are facing today and will increasingly face in coming decade. He particularly demonstrated why and how many countries, developing and newly industrialized regions in the Middle East, Africa, Asia and South America will be vulnerable to lack of water. A common characteristic of water demand in urban areas worldwide is its inexorable rise over many years, and projections of continuing growth over coming decades. The main influencing factors are population growth, migration, standard of living, demographic, and effects of climate change (Largo et.al, 1998).

Estimating and forecasting of water demand became necessary as the urban population dependent on public water supplies increased rapidly and new demand for water could not easily be met. It is common to use models as an aid to conceptualizing the components of demand and their relationship with various factors. In modeling, the objective is to find simple relationship which account for as much of the variability of demand as possible. Cochran and Cotton (1995) used multiple regression models in a municipal water demand study for Oklahoma City and Tulsa. The results indicate that price per capita income were predictive variables for Oklahoma City's water demand while only per capital income was found to be 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 later was inversely (i.e. as household size increases, per capita water use decreases).

This paper assess and examine the water consumption pattern in Federal Capital Territory (FCT), Abuja, Nigeria based on the available data at FCT Water Board. The data include quantity of water used, population, numbers of toilets and rooms in the houses. Arbues, et.al (2003) identified water price, income or household composition as crucial determinant of residential water consumption. Generally, the rate of water consumption depends on the socio-economic, education, development, the nature of prevailing climate and hygienic characteristics of people (Gilg and Bars, 2006; Arbues, et.al, 2003; Schleich and Hillenbrand, 2009; Mohammed, 2008).

Lack of data has been identified as the principal factor that is hampering proper and adequate water demand estimation in Nigeria. The availability of reliable data has been identified as necessary tools in proper planning and water demand analysis (Alsharif, et.al 2008; Zhou, et.al, 2002; Schleich and Hillenbrand, 2008; Ruijs, et.al, 2008). Demand models provide simplification or abstraction of complex physical reality and the processes involved in it, and serve as tools in the solution of demand forecasting problems. The choice of an appropriate water demand modelling plays a vital role in planning and management decisions on water supply.

2. Materials and Methods

The study was carried out based on the consumption records obtained from FCT Water Board, Abuja, Nigeria. Domestic, institutional and commercial water uses are the main categories covered and discussed. The analysis that was carried out include:

1. Assessment of hourly domestic water use variation.
2. Assessment and determination of domestic daily water use.
3. Development of a mathematical model for daily per capita domestic water use.
4. Assessment of typical domestic week day and week end as well as average weekly water use variation on hourly basis.

Microsoft Excel and Stata8 Software are used in the analysis. The multiple regressions were used to obtain the model of Average Daily Household Water Use for the study area (eqt. 1).

$$Y = A_0 + A_1 X_1 + A_2 X_2 + A_3 X_3 + \dots + A_n X_n + E \quad (1)$$

Where Y is a dependent variable; A_1, A_2, A_3 , to A_n are coefficient of regression while X_1, X_2, X_3 to X_n are auxiliary variables. E is Standard error.

3. Results and Discussion

3.1 Domestic Water Use

The analysis on hourly, daily and monthly basis are used to examine water consumption pattern in FCT, Abuja.

3.1.1 Hourly Water Use Pattern

The first set of data analyzed is that of Gudu area based on records of meter readings for some households taken between 9.00 a.m. and 6.00 p.m. The available data was for Monday (week day) and Saturday (weekend). The average water use in litre per capita per hour has been determined. The minimum and maximum value was 5.05 litre/capita/hour and 30.02 litre/capita/hour respectively (Table 1). The minimum usage occurs between the hour of 10.00 a.m. and 11.00 a.m. and rises to a peak at evening time between 3.00 and 5.00 p.m. as shown in Figure 1. This period of peak water use may be as a result of domestic water use when many people are expected to be at home preparing dinner and doing other household chores.

Table 1: Summary of Hourly Water Use (Gudu Area)

Variables	Per Capita Hourly Household Water Use (litre/capita/hour)			
	Mean	Standard Deviation	Minimum	Maximum
Week Day (Monday)	16.02	7.93	8.55	30.02
Weekend (Saturday)	11.87	7.43	5.05	28.97
Week Average	13.76	7.13	6.67	28.62

3.1.2 Typical Weekly Water Consumption Pattern on Hourly Basis

a) Typical Day

Table 2 shows the average summary for 24 hours water usage. Figure 2 depicts the hourly variation of water use for days and week average. Three main peak periods have been identified in the trend of hourly water use in this area and these occurred between the hours of 3 a.m. – 5 a.m., 9 a.m. – 11 a.m. and 22 – 23. But for Saturday only one peak is identified and that is between hours of 3 and 4. This unusual peak period on a Saturday means that residents tend to do a lot of cleaning, washing and cooking in the early hours of the weekend to allow them to have time for other activities during the day. There is low water use during weekday and weekend between 17 – 21 hours (Figure 2). This is because most residents are yet to return home as they may be busy shopping and also held up in traffic in the city.

Table 2: Summary of Hourly Water Use (Jabi Area)

Variables	Per Capita Hourly Household Water Use (litre/capita/hour)			
	Mean	Standard Deviation	Minimum	Maximum
Week Day (Wednesday)	24.27	12.71	1.32	49.58
Weekend (Saturday)	27.76	18.82	3.57	80.22
Week Average	24.43	11.59	4.11	47.53

b) Typical Week

Another set of data examined is the one presented on hourly basis for the whole week the summary of which is presented in Table 3. Week day and week end average domestic water use were at 22.53 litre/capita/hour and 16.73 litre/capita/hour respectively while weekly average was 20.87 litre/capita/hour. The minimum and maximum values of weekly water use occurred at

weekends as shown in the Table. Figure 3 shows the hourly variation for average week day, week end and overall weekly domestic water consumption. Two peak periods characterised these charts which occurred between the hours of 6 – 9 and 16 – 17 respectively while the average minimum is experienced between the hours of 11 and 12.

Table 3: Statistical Summary of Weekly Household Water Use on Hourly Basis

Variables	Average Household Water Use (litre/capita/hour)			
	Mean	Standard Deviation	Minimum	Maximum
Weekdays (Monday to Friday)	22.53	9.27	7.88	39.93
Weekend (Saturday & Sunday)	16.73	15.76	0.56	63.42
Weekly (Sunday to Saturday)	20.87	7.97	8.67	40.90

c) Daily Variations

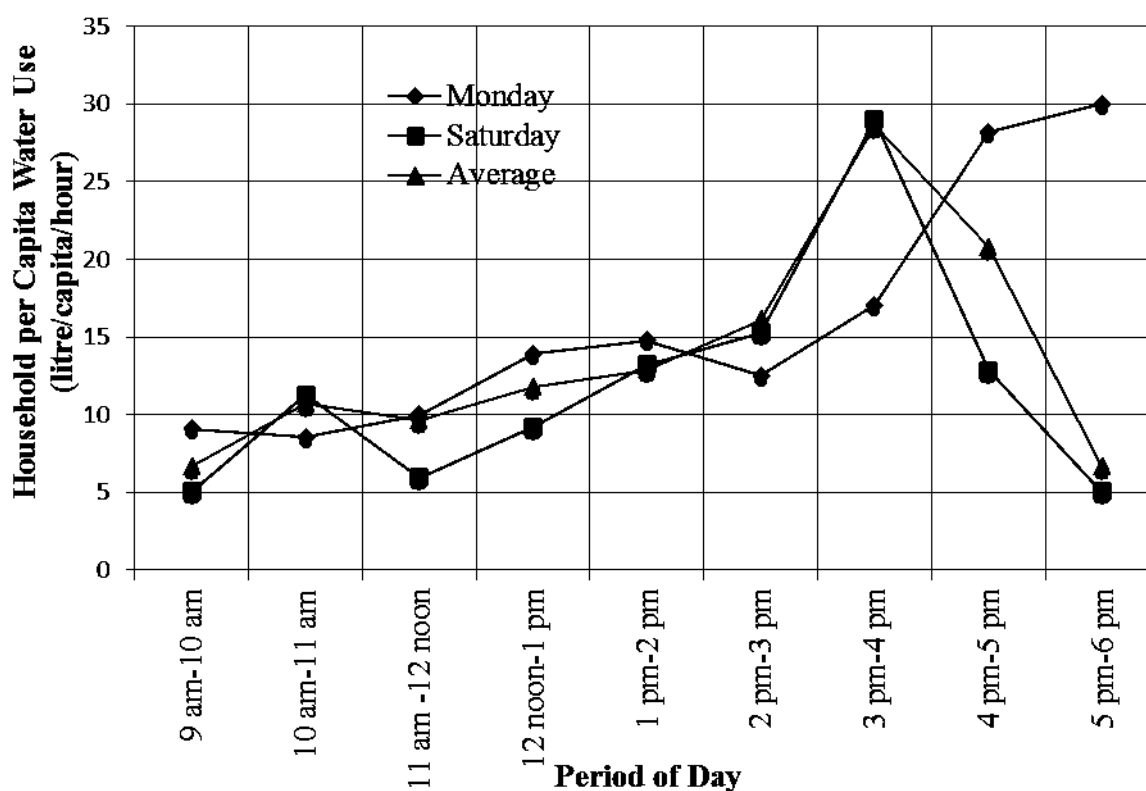
Average daily variations for different days of the week were also examined. The results are shown in Figure 4 and Table 4. The average daily per capita consumption has been estimated to be 20.87 litre/capita/hour while the minimum and maximum values stand at 16.16 and 24.96 litre/capita/hour respectively. The peak value occurs on Monday, Wednesday and Thursday. Low values on weekends indicate that many people travel out of the city during this period. High values on Monday show that there is increase in number of people who return to the city for the work during the week and hence there is increase in water use.

3.1.3 Daily Water Use Pattern

The monthly data presented on daily basis was used for the analysis. Average daily water used is classified in eight categories and the results are presented in Table 5. The analysis shows that over a quarter of the households have each member using between 200 and 399 litres of water per day. This is followed closely by 20 to 49 litres per capita per day with 400 litres per capita per day having the least frequency. Average daily water consumption has been estimated to be 251.47 litre/capita/day and that for planning purpose; the records used show that a value of 250 litre/capita/day can be adopted for FCT, Abuja.

Table 4: Average Daily Household Water Use on Hourly Basis

Parameters	Day of Week	Average Household Water Use (litre/capita/hour)
Days	Sunday	17.299
	Monday	24.298
	Tuesday	19.199
	Wednesday	24.616
	Thursday	24.964
	Friday	19.566
	Saturday	16.163
Summary	Mean Value	20.87
	Standard Deviation	3.70
	Minimum Value	16.16
	Maximum Value	24.96

**Figure 1: Domestic Water Use Variation in Gudu Area**

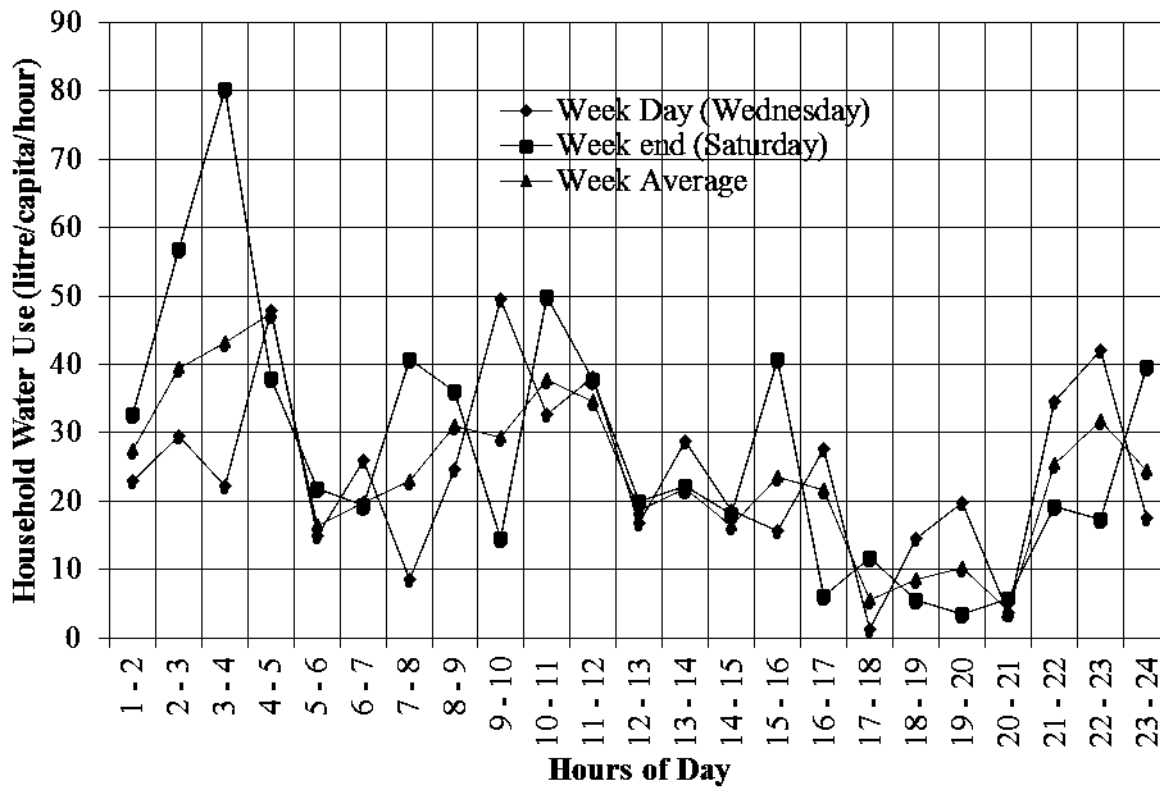


Figure 2: Daily Water Consumption Variation on Hourly Basis (Jabi Area)

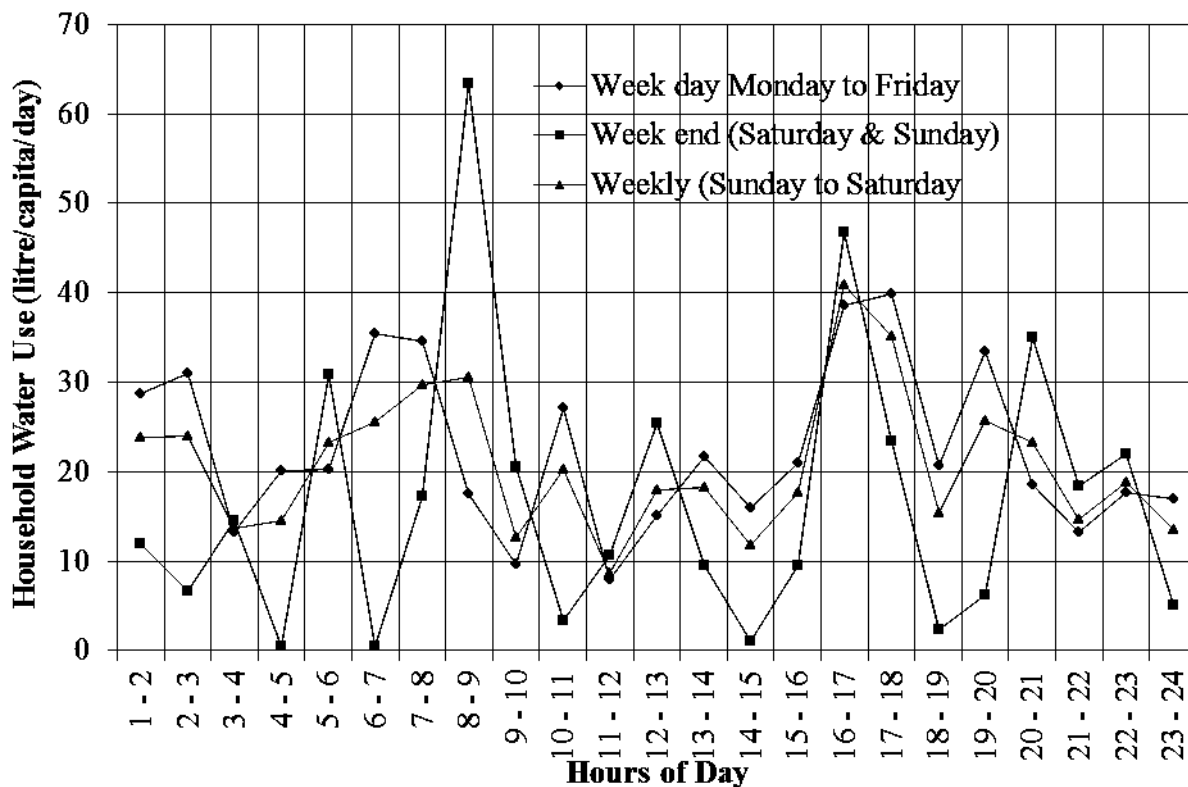


Figure 3: Typical Weekly Water Consumption Variations on Hourly Basis

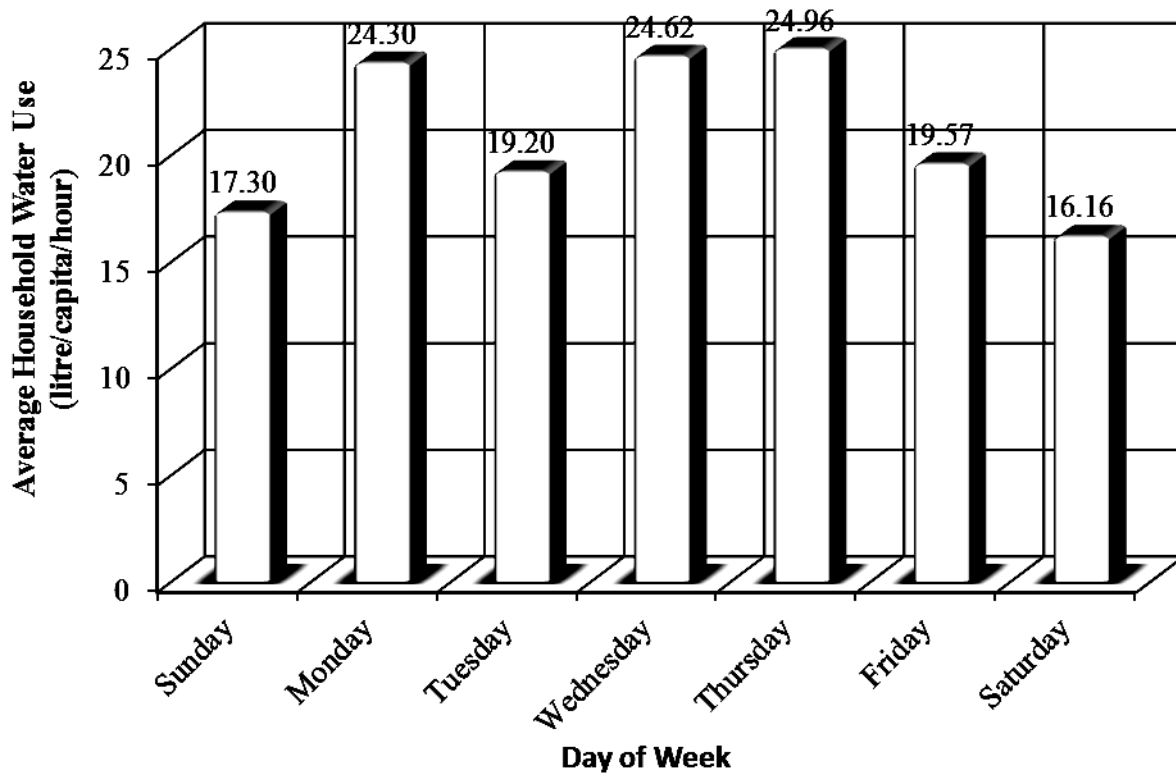


Figure 4: Average Daily Domestic Water Use

3.1.4 Modelling of Daily Domestic Water Use

Multivariate statistical analysis was performed to establish the structural relationship and the determinants of the variation of water use. The model of the following form has been used to establish the said relationship (Zhang and Brown, 2005)

$$Q = f(X_1, X_2, \dots, X_n) + E \quad (2)$$

Where Q is the dependent variable or household water consumed per day

$f(.)$ denotes the function of explanatory independent variables.

Equation (3) has been fitted using multiple regression analysis while Tables 6, 7 and 8 show the regression statistics, analysis of variance (ANOVA) and values of test results of coefficient of regression respectively.

$$HTWU = 148.27 HP + 182.98 NR + 124.42 NT - 827.08 \quad (3)$$

Where: $HTWD$ = Household total water use in litre per day (l/d)

HP = Household population

NR = Number of rooms in the house

NT = Number of toilets in the house

Table 5: Average Daily Water Use distribution

Range of Average Daily Water Use (litre/capita/day)	Frequency	Percentage
< 20	8	6.90
20 - 49	28	24.14
50 - 99	13	11.21
100 - 149	14	12.07
150 - 199	13	11.21
200 - 399	30	25.86
400 and Above	10	8.62
Total	116	100.00

Table 6 presents the summary of regression statistic parameters obtained from Table 7. The probability value for the F-test statistic (0.000) is less than 0.05 (5% level of significance), which indicates that the model is adequate and is useful for predicting water use. Moreover, since the calculated F-value (163.52) is much greater than $F_{critical}$ (2.705), it further shows that the regression equation is adequate. The value of R as shown in Table 8 was obtained to be 0.92 and *R Square* (0.84), and it shows that about 84 % of the variation in *Average Daily Household Water Demand* is explained by the model. Table 8 shows the detail regression coefficient of the variables considered for this model. From the Table, for each of the variables, the value in the column marked $P>|t|$ shows their statistically significant contribution to the Average Daily Household Water Use. All the variables (i.e. number of toilets, number of rooms and household population) has their $P>|t|$ values less than 0.05, hence they all made significant contribution to the prediction of Average Daily household Water Use. In addition they are positively related to the Average Daily Household Water Use since they all have positive coefficient values (Table 8). The Table further shows the Standard errors at 95% confident limit interval.

Table 6: Regression Statistics

Parameters	Value	Parameters	Value
Number of observations	95	Multiple R	0.92
F {3, 91}	163.52	R-Square	0.84
Probability>F	0.00 ^s	Adjusted R-Square	0.84

^s Significant

Table 7: ANOVA Table

<i>Source</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Square</i>	<i>F-Value</i>	<i>Significance F</i>
Regression	3	2.39E+08	79609658	163.52	1.57E-36
Residual	91	4.43E+07	486849.3		
Total	94	2.83E+08			

Table 8: Regression Coefficients, standard error and t-value

Total Household Water Use Variables	Coefficient	Standard Error	t-value	P> t	[95% Conf. Interval]	
Population	148.27	24.99	5.93	0.00	98.63	197.90
No of Rooms	182.98	37.81	4.84	0.00	107.88	258.08
No of Toilets	124.42	44.45	2.80	0.01	36.13	212.71
Constant	-827.08	108.30	-7.64	0.00	-1042.20	-611.96

4. Conclusion

The results of this work have established the amount of water that is used on daily basis for different categories of users. In some sections of the study area, many people were found to consume less than the minimum basic water requirement value of 50 litre/capita/day as recommended in the literature. However an average value of 251.47 litre/capita/day obtained using monthly records was found to be more than the minimum value of 120 litre/capita/day as recommended by WHO. On hourly water variation, the analysis shows that two peak periods always exist (morning and evening) when people are most likely to be at home either preparing to go out for work or preparing for household dinner and some other domestic chores. On the model formulated, all the variables (i.e. number of toilets, number of rooms and household population) made significant contribution to the prediction of Average Daily household Water Use. These variables are also positively related to the Average Daily Household Water Use. This shows that the model is therefore very useful for the prediction of water use in the study area and other urban areas in Nigeria and elsewhere with similar socio-economic futures.

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