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RESIDENTIAL WATER DEMAND ANALYSIS IN HILLA CITY

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ABSTRACT:

This paper investigates the analysis of residential water demand for the city of Hilla which is the main town in Babylon government in Iraq(Population of about 258568 person , living in an area of 55 Km^2 according to Central Committee of Statistics – Babylon Census Directorate -1997) along with determining the factors that affect such demand for the period from the 1^{st} of January to the end of August -2004.

The cross-section data which was weekly observed was collected by a survey made on a sample of randomly chosen dwellings from different districts of the city.

A questionnaire survey was also made to collect all necessary information seemed useful in estimating the daily consumption of domestic water.

Demand relations are estimated for total residential, winter, summer, and Sprinkling demands.

Stepwise multiple regression analysis was employed to find the structural relationship between water demand per household per day and household characteristics (factors) for each type of demand.

All demand models were fitted in log-linear form.

In this survey, the average daily water demand for the city of Hilla was estimated to be 1721 L/h/d (273.2L/c/d) for total model, 586.13 L/h/d (93L/c/d) for winter model , 2453 L/h/d(389.4L/c/d) for summer model and 490 L/h/d(77.8L/c/d) for sprinkling model.

The most significant factors affecting the demand appear in the fitted equation. Of these factors, household size was found to be significant variable in all demand models, while number of washbasins variable was found to be the significant variable in the total, winter, and summer model. The total built –up area of the house and number of showers was found to be the significant variables in the total and summer models.

((دراسة تحليلية لطلب الماء المنزلي في مدينة الحلة))

الخلاصـــــة

يتحرى هذا البحث تحليل طلب الماء المنزلي لمدينة الحلة مع ايجاد العوامل المؤثرة على هذا الطلب للفترة من الاول من شهر كانون الثاني ال نهاية شهر آب – ٢٠٠٤ .

تم جمع البيانات المرصودة اسبوعياً من خلال نموذج من الدور التي اختيرت عشوائياً من مختلف الاحياء السكنية للمدينة والتي تم تجهيزها بمقاييس جديدة وموحدة المنشأ ، والتي تم الحصول عليها بمساعدة مديرية ماء بابل .

تم عمل دراسة استفتائية للحصول على المعلومات الضرورية في تخمين طلب الماء المنزلي.
تم تخمين علاقات الطلب باربع نماذج مختلفة :- الكلي ، الشتائي ، الصيفي ، والرش .
تم استخدام تحليل الانحدار المتعدد التدريجي لا يجاد العلاقة التركيبية بين المتغيرات (الخصائص الاسرية) ولكل نوع من انواع نماذج طلب الماء المنزلي ، وتم تثبيت جميع النماذج بالصيغة (لوغارتمي – خطي) .

في هذه الدراسة تم تخمين معدلات طلب الماء المنزلي لمدينة الحلة وكانت ١٧٢١ لتر/ دار في اليوم (٢٧٣,٢ لتر/ شخص في اليوم) لنموذج الطلب الكلي ، ٥٨٦,١٣ لتر/دار في اليوم (٩٣ لتر/ شخص في اليوم) لنموذج الطلب الشتائي ، ٢٤٥٣ لتر/ دار في اليوم (٣٨٩,٤ لتر/ شخص في اليوم) لنموذج الطلب الصيفي ، ٤٩٠ لتر/ دار في اليوم (٧٧,٨ لتر/شخص في اليوم) لنموذج طلب الرش .

إن العوامل الأكثر أهمية في التأثير على طلب الماء المنزلي تظهر في المعادلات المثبتة ولكل نموذج ، من هذه العوامل : حجم الاسرة وهو متغير مهم في كل نماذج الطلب بينما يكون عدد المغاسل هو المتغير المغاسل في نماذج الطلب الكلي والشتائي والصيفي .

إن مساحة البناء الكلي للدار وعدد مرشات الغسل هي المتغيرات المهمة في نموذجي طلب الماء الكلي والصيفي.

Introduction

For many years, water availability in the future is one of the main problems of the people in any country, as well as, municipal water planners and engineers have relied on very simplistic assumptions about what determines per capita water use and equity to plan municipal water use.

It thus becomes extremely important to define an amount of per capita consumption (demand) at the municipal level that will be adequate for the actual needs and accurate predictive of the quantity of water to be supplied in order to avoid the shortage of water resources.

Residential water demand can be defined as "the total quantity of water used for domestic purposes which include in-house purposes like: drinking, cooking, bathing, house cleaning ...etc., and out –house purposes like: garden watering, air-cooling, ..., etc." (Qasim et al., 2000; Isehak, 2001).

The present was based on the statistical approach using stepwise multiple regression analysis method to establish a relationship between demands per household per day that include weather related variables.

The water consumption relates on the nature of the season, so that, the study of domestic water demand has been divided into four formulas: study no. 1,2,3, and 4 to analyze the total, winter, summer, and sprinkling residential water demand respectively.

Total demand includes water used for in-house and out-house purposes throughout the whole period. Winter demand was assumed to be equal to in-house purposes only through the winter season. Summer demand includes water consumed for in-house plus out-house purposes in the summer season.

The difference between winter demand and summer demand was related to sprinkling (seasonal) demand which equals to out-house water consumption only.

There are many types and configurations of data sets that be used in modeling water use which are mainly based on the methods of observation (Jones and John, 1984; Gracia et al., 2001) like:

(1) Time series data which are arranged in a chronological order and analyzed using multiple regression analysis and time series methods;
(2) Cross-sectional data which are arranged cross-sectionally and analyzed using multiple regression method. The present study data falls in this type;
(3) Pooled data of both time -series and cross-section .

In Iraq, Isehak, R.J. (2001) investigates the analysis of residential water demand for Baghdad city, while Al-Samawi, A.A., and Hassan, J.S.(1988) investigate the analysis of residential demand for water in the city of Basrah .

Hall, M.J., Hooper, B.D., and Postle, S.M. (1988), study the domestic per capita water consumption in South West England, but Loh, M., and Coghlan, P. (2003), investigate the domestic water use in Perth, Western Australia for the period of 1998-2001 .

The Study Objectives

The objectives of this work are: (1) To evaluate household water use per day or per capita per day in Liter (L/h/d) or L/c/d respectively); (2) to identify domestic water demand pattern in Hilla city under considerations: Total, Winter, and Summer and general trend for total water use; (3) to explain the major factors that affect such demand and define their effects; (4) to develop
a model of residential water demand in city under the considerations : total , winter , summer , and sprinkling.

Field work

For the purpose of this work a sample of dwelling units was randomly chosen in different areas of the city which is the main town in Babylon governorate in Iraq with population of about 258568 person and area of about 55Km^2 and supplied with new and identical charging meters. A daily water demand readings for four types of study were depended beside the questionnaire survey to supplement the data of the individual household and the completion of diaries for each major element of water use for the period from the 1st of January to the end of August, 2004.

The Regression Analysis Technique

Residential water demand from earlier efforts to the recent works indicates that the statistical approach appears to be the most promising for the residential category (Jones and John ,1984) . There are two approaches which are the most common (Kindler and Russell,1984) : Statistical and engineering.

So that, the stepwise multiple regression analysis was used to view water consumption as a result of a number of explanatory factors.

SPSS program for windows version 11.0 is used to carry out the linear multiple regression analysis between the dependent variable (Y) and the independent variables (X_1.X_2, X_3 …)

The general form of multiple linear regression equation is (Dancey and Reidy ,2002;Abdi,2003):

$\hat{Y}$ =b_0+b_1X_1+b_2X_2+ b_3X_3+……..b_kX_k …………….(1)

Where $\hat{Y}$ is the predicted value of the dependent variable (water demand).

X_1, X_2, X_3,…X_K are the independent variables (predictors).

b_0 is the intercept coefficient (Constant)

b_1, b2, b3,…..b_k are the partial regression coefficients of the independent variables.

K is the number of independent variables included in regression equation.
If model carried out through the origin , then b_0=0(Snedecor and Cochran ,1980; Legendre and Desdevises,2002)

The regression technique bases on the principle of the least squares, which it is a method that gives what is commonly referred to as the "best -fitting" line. It determines a regression equation by minimizing the sum of squares of the predicted distances between the actual Y values (measured) and the predicted values $\hat{Y}$ (i.e. ***e***) (Mason et al., 2000):

Four forms of transformation were used for each type of demand to investigate which form gives the best fitting of data.

Transforms are used to force all variables to normal distribution and to correct a positive skew distribution (www.chass.ncsu.edu/garson/pa765/regress.htm).

The following models were proposed and investigated:

1. Linear – linear model

$$Q = b_o + b_1 x_1 + b_2 x_2 + ... + b_{12} x_{12} \qquad \text{……………….(2)}$$

2. Log-log model (double log model)

$$\ln Q = b_o + b_1 \ln x_1 + b_2 \ln x_2 + ... + b_{12} \ln x_{12} \qquad \text{……………...(3)}$$

3. Linear-log model (semi-log model)

$$Q = b_o + b_1 \ln x_1 + b_2 \ln x_2 + ... + b_{12} \ln x_{12} \qquad \text{………………(4)}$$

4. Log-linear model (inverse semi-log model)

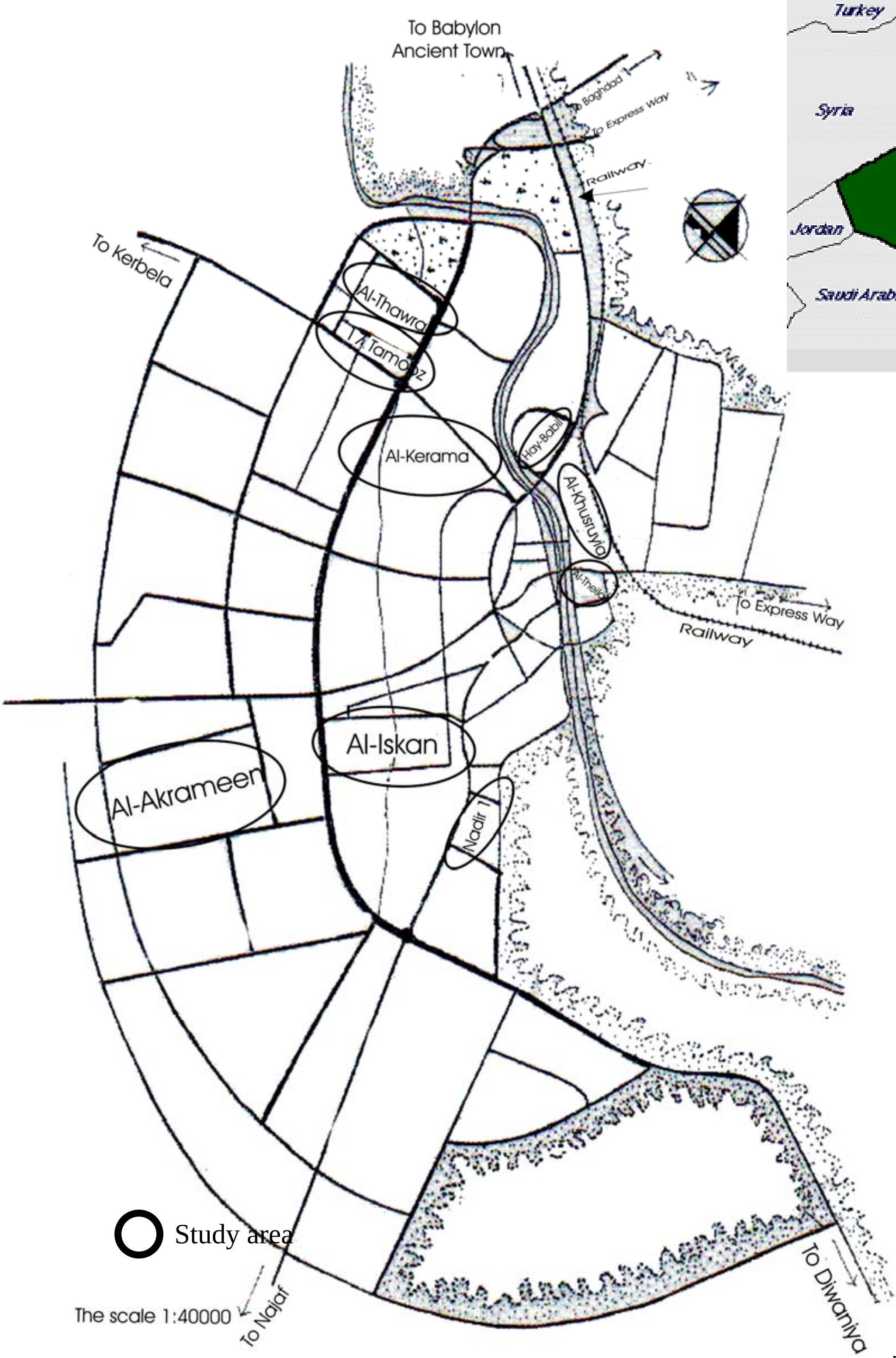
$$\ln Q = b_o + b_1 x_1 + b_2 x_2 + ... + b_{12} x_{12} \qquad \text{.................... (5)}$$

Where Q = average daily water demand in L/h/d (liter per house per day);
X_1,X_2,X_3,……X_{12}= The independent variables.

The stepwise multiple linear regression for log-linear model carried out through the origin was found to be the most appropriate model for four types of water demand.

The Study Area

Figure (1) shows the different locations of the study areas in Hilla city.



AL-Thawra	١
17 Tamooz	٢
AL-Karama	٣
Hay-Babil	٤
AL-Khusruyia	٥
AL-Theila	٦
AL-Iskan	٧
AL-Akrameen	٨
Nadir 1	٩

Fig.(1): The Main Design Chart of Hilla City Including the

Locations of the Study Areas .

Source: The Office of Constructional Planning – Babylon , 1993 .

Results and Discussion

Table(1) shows the ,most important statistical features of each type of water demands in Hilla City **Table(1):** Descriptive Statistics for Dependent variable(Observed Water Demand) for Each Type of Demand)

Water Consumption		N	Range	Minimum	Maximum	Mean	Std.
		Statistic	Statistic	Statistic	Statistic	Statistic	Statistic
Total	L/h/d	50	1798.29	368.31	2166.60	1229.051	491.9117
	L/c/d	50	371.93	61.39	433.32	211.6502	104.9623
Winter	L/h/d	50	1520	230	1750	745.54	375.196
	L/c/d	50	389.63	47.87	437.50	136.89	87.3648
Summer	L/h/d	50	2772.049	409.84	3182.33	1753.3388	713.70072
	L/c/d	50	555.32	68.30	623.62	306.9748	159.97220
Sprinkling	L/h/d	50	2570.03	122.64	2692.67	1061.7392	636.71191
	L/c/d	50	449.41	20.44	469.85	191.9628	136.39751

For total water demand, the observed value of 212 L/c/d was found to be higher than that reported by Al-Samawi and Hassan (1988) for the city of Basrah back in (1977- 1978). They reported a value of 137 L/c/d as an average daily taken over one year period.

Al- Samawi and Hassan (1988) reported a lower value for average daily consumption during winter time Basrah City than the value for Hilla city when they reported the value as 88 L/c/d

For summer demand, the average daily water demand was about 307L/c/d which was much higher than that reported by Al- Samawi and Hassan (1988) for Basrah city. This indicates that s significant increase in trend of water demand occurred in Iraq during the last two decades.

For sprinkling water demand, the average daily value was very close to 192 L/c/d and it is higher than the value reported by Al- Samawi and Hassan (1988) for Basrah city when they recorded the value of 92 L/c/d, but for city of Baghdad (2001), Isehak reported a lower value of 458.66 L/h/d and 89.31 L/c/d.

In Hilla city, the winter water consumption is about 60.7 % of the average daily total demand. Hammer reported the value of 80 % in 1975. The summer consumption is 42.66% higher than the total demand. In 1975, hammer reported a value of 30 %. Then in this work, the peack factor value is found to be (1.43). AL-Adwi(1983) concluded a value ranged between 1.2-1.6 for maximum seasonal domestic water demand.

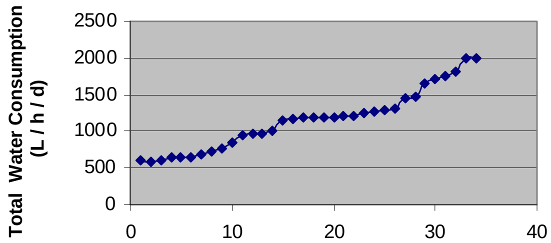
The sprinkling demand is about 86.40 % of the total average daily.

During the observation of water consumption in the city , it can be seen that 90 % of houses consume(2077, 1250, 3130, and 1609 L/h or less) of water per day for total , winter , summer , and sprinkling water demand respectively . While Isehak

(2001) found that (2000 L/h or less) of water per day was consumed by 87.8 % , 93.5% , and 81.3% of houses in Baghdad City for total , winter , summer demand , respectively, but only 50 % of houses consume 500 L/d or less.

Pattern of Deferent Average Daily Water Demand in Hilla City

Figure (2), (3) and (4) display the pattern of average daily water consumption of households, weekly observed during the specific period for total winter, and summer water demand respectively.



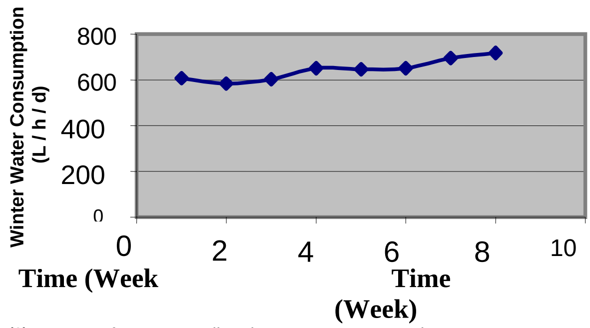


Fig.(2): Pattern of Average Daily Total Water Consumption Per House (by Week) for the Period (from the 1st of January to the End of August).

Fig. (3): Pattern of Average Daily Winter Water Consumption Per House by Week) House (by Week) for the Period (from the 1st of January to the End of February).

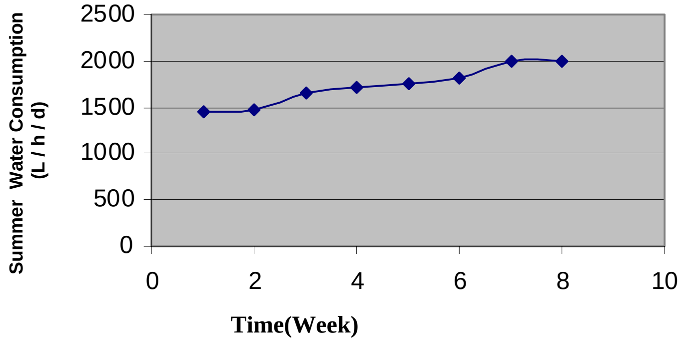


Fig.(4): Pattern of Average Daily Summer Water Consumption Per House (by Week) for the Period (from the 1st of July to the End of August).

Through Figure (5), it can be noticed that was a general upward trend with increasing variability.

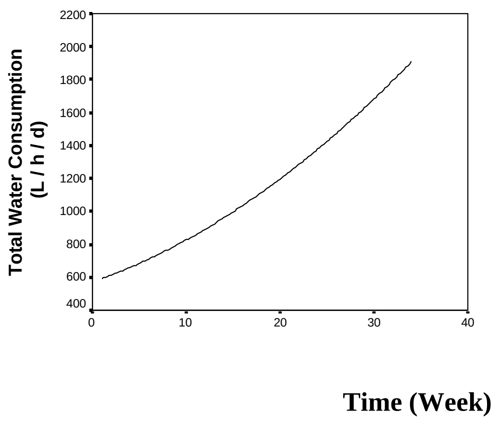


Fig.(5): Trend of Average Daily Total Water Consumption Per House (by Week) for the Period (from the 1st of January to End of August).

Model for Different Types of Demand

By (SPSS), the output tables are arranged in three tables (A, B, AND C): summary, ANOVA* , and coefficients table, each table gives some of results.

According to procedure of stepwise multiple linear regression analysis, there are greater than one model are listed in tables , but the technique is based on choosing the finding one which has the high value of R^2 (or adj R^2), lower value of both standard error of the estimate and mean square error , and the good value of t , and F test which they test the significance of both regression coefficients and the regression model respectively.

It should be noted that the factors included in this study are:
x_1= household size ; x_2= No. of bedrooms X_3= No. of toilets , X_4= No. of showers ;x_5 No. of washbasins; x_6=No. of taps in the garden ; x_7 = No. o air-coolers ; x_8 = No. of air-conditioners;x_9= total built up area of house ; x_{10} = area of garden ; x_{11}= No. of washing machines; x_{12} = No. of cars.

For each type of demand model, the researchers toke number of factors which are considered an important because of their reliable impacts on that demand.

Refereeing to table (2), the out coming of this work; (i.e.) the most suitable model for different water demands can be written as the following:

Study No. 1 (total water demand)

$$\text{Ln } Q_{total} = 2.042\, X_5 + 0.201\, X_1 + 0.00809 X_9 + 1.22 X_4 \quad \text{…….. (6)}$$

Where Q_{total} = average daily total water demand L/h/d.

In this model, four out of all independent variables assumed to have a reliable impact on total demand : number of washbasins (X_5) , household size (X_1) , total built up area of house (X_9) , and number of showers (X_4) , are the most significant variables and there is a positive impact of the above-mentioned variables on total water demand .

The consideration of each one unit X_5, X_1, X_9, and X_4 is 2.042, 0.201, 0.00809, and 1.22 L/d respectively for natural logarithmic form of consumption.

On the other hand, this contribution takes the value of 471.58, 46.42, 1.87, and 281.75 L/d respectively for linear form of consumption.

Number of washbasins explains most of the percent production power in total demand model (36.2%). While other variables explain 17%, 28.2%, and 18.6% respectively as shown in Table (2-c) represented by the values of standardized coefficients (Beta).

By regression model, the estimated average consumption in Hilla city is about 1721 L/h/d or is not far from 273.2 L/h/d.

The value of 1721 L/h/d is higher than that estimated by hall (1988), who found that the residential demand in South West England was increased from 113.4 L/h/d in 1977 TO 131.6 L/h/d in 1985.

Heaney et al., 2002 estimated the annual water demand for cities of North America of 1530.7 L/h/d; this value is lower than that reported in this study.

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* Analysis of variance

Table (2): Linear Regression for Deferent Log-linear Water Demand Models (L/h/d).

Model Summary

Model	R	R Square a	Adjusted R square	Std. Error of the Estimate
6 Total	0.990	0.979	0.977	1.05684
4 Winter	0.992	0.984	0.982	0.86139
4 Summer	0.989	0.978	0.976	1.15141
3 Sprinkling	0.979	0.958	0.956	1.42877

a. For regression through the origin (the no-intercept model), R Square measures the proportion of the variability in the dependent variable about the origin explained by regression. This CANNOT be compared to R square for models which include an intercept.

The value of 273.2 L/c/d is higher than that forecasted by Haiste and Partners (1981) , who estimated average daily domestic consumption to be about 235 L/c/d for Baghdad City , 2000.

Khadam (1988) estimated the value of 50.32 L/c/d for the Khartoum metropolitan area.

Steel and McGee found a value of 300 L/c/d for the year 2000 in American cities.

Loh and Coghlan (2003) estimated annual demand in Parth/ Western Australia of 375.82 L/c/d , and such a value is considered to be higher than that estimated for Hilla.

Study No.2 (winter water demand)

$LnQ_{win.} = 0.884X_2+1.553X_5+0.162X_1+0.695X_3$……………..(7)

Where $Q_{win.}$ = average daily winter water demand L/h/d .

Number of bedrooms (X_2), number of washbasins (X_5), household size(X_1), and number of toilets (X_3) are the most significant independent variables and there is a positive correlation between dependent variable and the four independent variables.

The contribution of each one unit of X_2, X_5, X_1 and X_3 is 0.884, 1.553, 0.162, and 0.695 L/d respectively for natural logarithmic scale of demand.

Number of bedrooms explains most of the percentage contribution in prediction of water demand model 36.3% , but X_5, X_1 and X_3 explain 32.2% , 16.1 % and 15.4 % respectively.

By apply the model, the estimated winter water demand is nearly 586.13 L/h/d or about 93 L/c/d. Twort et al. (1985) suggested a value of 160 L/c/d .

In Canada (1996) , and U.S.(1998) , the average daily indoor water use (winter) was 326 and 262.3 L/c/d respectively which is higher than the value reported by this study (www.chs.ubc.ca/china/Pdf%20Files/Zhang/Ch%202%20Lit%Review.pdf.);
(www.environment.agency.gov.UK,1999).

Darmody et al. (1998) found the value for three cities: Sydney, Bangkok, and East Bay Municipal Utility District (EBMUD) which were 184, 190, 244 L/c/d respectively.

Loh and Caghlan (2003) estimated the value as 155 L/c/d for Perth /Western Australia.

Heaney et. al. (2002) reported the value of 262.32 L/c/d (640.9 L/h/d) for 12 cities of North America.

Study No.3 (summer water demand)

$Ln\ Q_{sum.} = 2.609X_5+0.211X_1+0.006135X_9+1.264X_4$………….. (8)

Where $Q_{sum.}$ = average daily summer water demand L/h/d.

In this model , number of washbasins(X_5) , household size (X_1) , total built-up area of house (X_2) , and number of showers (X_4) are the most significant variables and there is a positive impact of the four variables on water demand.

The contribution of each one unit of X_5,X_1,X_9 , and , X_4 is 2.609 , 0.211 , 0.006135 , and 1.264 L/d respectively for natural logarithmic form of demand .

The model indicates that X_5 explains most of the variation in percent prediction (44.1%) in the summer model, while X_1, X_9, and X_4 explain 17.1 %, 20.4%, and 18.45 % respectively.

By this model, the estimated average summer consumption is about 2453 L/h/d or not far from 389.4 L/c/d .

Loh and Coghlan(2003) estimated the value of 1230L/h/d in Perth/ Western Australia, and this value is lower than the estimated value for Hilla City .

Study No.4 (sprinkling water demand)

$Ln\ Q_{spr.} = 0.496X_1+0.0133X_{10}+0.737X_7$ …………. (9)

Where $Q_{spr.}$ = average daily sprinkling water demand L/h/d.

The model shows that the explanatory variables; household size(X_1) , garden area (X_{10}) ,and number of air-cooler(X_7) were the significant variables , and there is a positive correlation between the water demand and the three independent variables .

The contribution of each one unit X_1, X_{10}, and X_7 is 0.496, 0.0133, and 0.737 L/d respectively for natural logarithmic scale of sprinkling demand.

Household size explains most of the percent prediction power (50.5%). On the other hand, X_{10}, and X_7 explain 31.9 % and 17.6 of the variation respectively.

The estimated average daily consumption is 490 L/h/d or about 77.8 L/c/d.

Loh and Coghlan (2003) estimated values of 707 L/h/d, and 211 L/c/d, and both values are higher than the estimated value for Hilla City.

In U.S. (1998) the average daily outdoor water use was 381.5 L/c/d (www. environment.agency.gov.UK, 1999.). This value is higher than the estimated value of the study.

Test for validity of each type of demand were made to check the accuracy of regression model, and then to show if it regarded as statistically.

Each demand model was adequately envelops observed water use and it was in agreement with all measurements of validation.

Conclusions

- From the results analysis of the present work which was based on using stepwise multiple linear regression analysis, one concluded that the most suitable predicting, model for the four types of residential water demand is a linear relation in (log-linear) form.
- The most appropriate model with the most significant independent variables is:

A: total water demand

$Ln\ Q_{total} = 2.042\ X_5+ 0.201\ X_1+0.00809X_9 +1.22X_4$

$adj.R^2 = 0.977$

B: winter water demand

$$LnQ_{win.} = 0.884X_2+1.553X_5+0.162X_1+0.695X_3$$

$adj.R^2 = 0.982$

C: summer water demand

$$Ln\,Q_{sum.} = 2.609X_5+0.211X_1+0.006135X_9+1.264X_4$$

$adj.R^2 = 0.976$

D: sprinkling water demand

$$Ln\,Q_{spr.} = 0.496X_1+0.0133X_{10}+0.737X_7$$

$adj.R^2 = 0.956$

All models have a pass significant (F=0.000) and all regression coefficients are significant at 0.05 confidence level.

- The regression model shows that there is a positive impact of the independent variables appeared in each model on its dependent variable (water demand). When the model is in log-linear form , the contribution of each one unit of each independent variable for natural logarithmic transformation of dependent variable is :

2.042 , 0.201 , 0.00809 , and 1.22 respectively for total demand; 0.884, 1.553 , 0.162 , and 0.695 respectively for winter demand; 2.609 , 0.211 , 0.006135 , and 1.264 , respectively for summer demand ; 0.496 , 0.0133 , and 0.737 respectively for sprinkling demand.

- The percentage contribution power of each independent variable in estimated demand is : 36.2% , 17% , 28.2 % , and 18.6 respectively for total demand ; 36.3% 32.2% , and 15.4 % respectively for winter demand ; 44.1 % , 17.05% , 20.4 %, and 18.45 respectively for summer demand ; 50.5 % , 31.9 % , and 17.6 % respectively for sprinkling demand .
- It was found that 90% of houses in Hilla City consume 2077, 1250, 3130, and 1609 L/h or less of water per day for total, winter , summer , and sprinkling demand respectively .
- The average daily winter water consumption in the city was found 60.7% of the average daily total consumption, but summer water consumption was 42.66% higher than the total consumption, while sprinkling water consumption was found to be 86.4 % of the total water consumption.

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