CROSS SECTIONAL ANALYSIS OF RESIDENTIAL WATER CONSUMPTION IN THE CITY OF RIYADH

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Abstract: A cross sectional analysis for residential water demand was conducted to help understand and explain the spatial and temporal variations in per capita water use in the rapidly growing city of Riyadh, Saudi Arabia. The analysis was based on data previously collected from May 1983 to June 1984. 195 randomly selected households were distributed to three groups according to house condition, household income level, and social and cultural factors. The generated models using stepwise multiple regression indicated that plot size and number of males, females and children are the most significant independent variables. Although, coefficients of determination achieved for most of the developed models were low (0.2-0.5), the independent variables could still explain a part of the variations for such a complex social and cultural structure.

Keywords: Residential water demand, Regression, cross sectional analysis, Saudi Arabia

1. INTRODUCTION

Supplying water to urban areas requires major capital investment in resource development, treatment, storage and distribution. The demand for water worldwide is enormous and will continue to grow rapidly especially in developing countries due to the increasing population and their standard of living, industrialization, urbanization and agricultural development (Kindler and Rusell, 1984). The continuing need for upgrading and expanding the water supply systems to meet these flourishing demands dictated the necessity for accurately predicting future requirements so that maximum efficiency in funds allocation can be optimally achieved.

Forecasts of future urban water demand have traditionally been obtained by the projection of historic trends in per capita consumption and population. Such methods could be expected to give reasonably accurate predictions only while there is a steady uniform change in per capita consumption (Power, et al., 1981). One possible way to improve prediction is to use the component model, in which water consumption is divided into its major components. Future changes in each component are predicted and then the overall results are aggregated (Parker and Penning-Rowsell, 1980). This method, in contrast of the projection technique, is data demanding and more challenging since it attempts to explain the reason behind any changes in water consumption pattern. Therefore, factors, which are likely to influence the various components of water consumption, are identified, measured and their likely effects on future consumption are assessed.

Among the elements that contribute to the total urban water consumption - residential, industrial, commercial, public institution, and system losses - residential water use is generally the largest in terms of its quantity and size of investment. It may constitute well over half of the total municipal use in many communities (Kindler and Rusell, 1984). In addition, it commonly requires extensive and expensive distribution network and treatment facilities that meet high quality standards. Therefore, it is essential to estimate and examine in details the factors that influence its spatial and temporal variation for a given urban area. An example of the wide variation of this estimate is given for three selected countries, Netherlands, Sweden and USA as 104, 215 and 295 liter per capita per day (lpcd) respectively, which show the need for determining those variables responsible for these differences (Kindler and Rusell, 1984).

Many studies have been conducted to determine the factors that influence the level of residential water demand such as Schneider and Whitlatch (1991); Wilson and Luke (1990); Khadam(1985); Grima (1985); Weber (1989); Abu Rizaiza (1991) and Ayoade (1987). Most of these studies have agreed on the fact that family size and density of occupancy in a residence are the most important ones. Khadam (1985), for instance, realized that the per capita consumption decreases with increase in the family size and thereby implying an economy of scale. He also reported that White et al., in East Africa found that the larger per capita uses were found in households with working adults. A very small consumption was observed where there was only one elderly adult and the greater the number of children the smaller is the per capita water withdrawal. In a study of residential water demand and economic development in India, it was stated that the size of a household is negatively related to the level of water consumption. Consequently, water consumption tends to decrease with the density of occupancy.

Many investigators have studied the relationship between water pricing, level of income and the amount of water consumed. It has been found that, above a minimum essential level, water is needed as an economic commodity. The effect of pricing upon water use is of basic importance to residential water management. Price setting is one of the few instrumental variables at the disposal of the management. Prices may be used to allocate resources efficiently in publicly controlled monopolies such as municipal water works. On the other hand, income level of a household is an economic factor widely accepted as a determinant of residential water use (Grima, 1972).

The consideration of metering as a significant factor influencing the quantity of water use is widely accepted and justified (Khadam, 1985). Metering is an effective practice to discourage the excessive misuse of water because the consumer will tend to minimize his bill. Leaks from service pipes, running taps to waste, insufficient sprinkling and all other wasteful patterns of water use will be corrected promptly. Grima, (1972) found in his study on Toronto, Canada that the rate of water use for lawn sprinkling in non-metered areas is almost three times the rate of water use in metered areas on maximum day. Berry, as reported by Khadam (1985) observed that the introduction of metering in Honiara, British Solomon Islands reduced the water consumption by 50%.

The type of disposal system used for sanitary waste has also a considerable impact on the water use. In sewered areas or where dwellers are using septic tanks, it is likely that consumption will be higher than those using soakage pits, pit latrines, surface drains or similar methods.

Reduction in water use can be attained by appropriate modification of the conventional water-use appliances such as toilet flushing systems, showering and bathing facilities, hand washing sinks, dishwashers, washing machines etc... . The design and operation of these appliances could be reformed to provide acceptable services with minimum quantity of water without imparting adverse hygienic effect (Khadam, 1985).

As shown above several factors influence the quantity and pattern of residential water demand It is the purpose of this paper to conduct a cross sectional analysis, in which a slice through customer profile at specific time frame (1983-1984) is taken, to identify user attributes that might explain the variation in consumption among users in the city of Riyadh. Several predictive models using step-wise multiple regression are formulated for three common classes of users, while taking into consideration the seasonal variations of demand. The analysis is based on field survey and measurements previously collected for 195 households from May 1983 to June 1984 by Al-Kadi (1986). Study results are expected to explain the variation in per capita water consumption and subsequently, could be of value to consultants and planners in predicting future water demands in Riyadh.

2. RIYADH WATER DEMAND

Since the early seventies, the city of Riyadh, the capital of the kingdom of Saudi Arabia, has

Table 1. Various estimates of water demand per capita by various consultants (in liters/capita/day)

Consultant Name (year)	1965	1970	1975	1980	1985	1990	1995	2000
VBB (1964)*	160	-	-	-	240	-	280	-
Sogreah (1967)*	-	240	280	300	300	300	300	300
VBB (1976)*	-	180	200	220	240	260	280	300
VBB (1978)*	-	-	200	220	240	290	340	390
MAW, M.A. Butain (1977)*	-	-	-	280	300	320	330	335
Kalthem (1978)*	-	-	-	300	-	340	-	380
SWCC (VBB, 1978)*	-	-	240	320	350	375	385	395
Sir MacDonald & Partners (1978)*	-	-	-	-	-	-	-	400
Sogreah-Seureca (1979)*	-	-	-	280	310	375	415	450
Ratio between highest and lowest estimates	-	1.33	1.40	1.36	1.46	1.44	1.48	1.50

* As reported by Sogreah-Seureca (1979) & Abu-Rizaiza (1982)

been subjected to phenomenal growth of population and urbanization. The populated area of the city for example, has grown from less than one Km^2 in 1918 to about 1600 Km^2 in 1997. This fast growth required planning in all infrastructure systems especially water resources and water supply distribution network. Due to the lack of reliable data with respect to per capita water use in the city, water development consultants and planners, have been forced to use their experience or educated guesses in forecasting the water consumption in Riyadh. Table 1 shows an example illustrating the variation in these estimates, varying up to 50%. In addition, these values can be future compared to the United Nations' estimate of average water consumption around the world for the years 1966 and 2000, which are 156 and 235 lpcd respectively, (IWRA, 1982). It shows a dramatic variation form world average consumption.

As an attempt to come up with more accurate estimates, an extensive study was conducted by Al-Kadi (1986). He completed a field investigation for determining the daily per capita average, maximum and minimum residential water consumption for the city of Riyadh. In addition, an attempt was also made to study the individual influence of several factors on the actual consumption from May 1983 to June 1984. 195 individual houses were randomly selected representing random samples distributed to three groups- large villa occupants, small villa occupants and apartment occupants. Variables that were considered in the study were: week days, week ends, seasons, number of males, number of females, number of children, number of residents, connection to sewers, nationality, religion, income level, house plot area, type of house, and the presence of sabeel tap (a cold water tap fixed on the boundary wall of the house to be used for drinking of pedestrians)

Although Al-Kadi's study has revealed many important conclusions, it did not, however, show any attempt to simultaneously relate residential water consumption to its explanatory variables in order to determine those key variables that could explain its variation. This fact, which was also recognized by Al-Kadi, has encouraged Quraishi et al. (1990) to develop non-linear regression models to forecast water demand for both natives and expatriates living in villas and apartments. The low values of goodness of fit (0.22) for most of these generated models and the negligence of considering the seasonal effect on consumption were the initiative for this research.

3. DATA CHARACTERISTICS

Data involved in this study consisted of observations of relevant variables for 195 individual households as indicated previously. The variables were selected in order to reflect the social, economical, environmental and cultural characteristics that may influence water use. The selected variables can be classified into two categories: non-quantitative and quantitative variables.

The non-quantitative variables include location, type of construction, presence of swimming pools, connection to public sewerage, nationality, religion and availability of sabeel tab. The quantitative variables, on the other hand, include plot area, number of males, number of females, number of children, ground water tank volume, upper water tank volume, and monthly income level. Table 2 shows both the independent and dependants variables.

The 195 samples were divided into three groups - A, B, and C based mainly on location, which might reflect their cultural behavior. Group A represents relatively high income tenants

Table 2. Variables included in the analysis

Variable Number	Variable Name	Variable Description
1	LOC	Location
2	DEW	Type of dwelling
3	POOL	Presence of swimming pool
4	SEW	Connection to public sewage
5	NAT	Nationality
6	REL	Religion
7	SAB	Sabeel water
8	PA	Plot area
9	NOM	Number of males in a household
10	NOF	Number of females in a household.
11	NOC	Number of children in a household.
12	FS	Number of household members
13	TV	Total volume of ground water tank and upper water tank in m^3
14	MIL	Monthly income level: 1) less than SR 5000; 2) between SR 5000 and SR 10000 and 3) more than SR 10000.
15	Q_s	Average quantity consumed in summer season in m^3
16	Q_w	Average quantity consumed in winter season in m^3
17	Q_a	Average annual quantity consumed in m^3

living in big villas with large landscape that mostly include swimming pools. Group B houses consisted of medium size villas with small garden areas accommodating medium income people. Finally, group C is mostly low-income residence living in apartment buildings with neither gardens nor swimming pools (Al-Kadi, 1986).

4. THE HYPOTHESIZED MODEL

Since the pattern of water use is related to the living environment of the residents and changes in climate, the demand can then be estimated for each of the three groups of consumers by formulating predictive models that reflect annual and seasonal variations. A summer season which is assumed to extend for duration of 8 months (Mid March thru Mid November) and characterized by an average temperature higher than 20°C. The winter season is assumed to include the remaining four months of the year where the average temperature is lower than 20°C.

Accordingly, eighteen different predictive models were formulated estimating residential water use in liters per capita per day averaged over the (1) summer period (2) winter period and (3) whole year. These variables are used as dependent variables and they are used in turn for six groups and subgroups of water users in Riyadh. These groups are (a) group A consumers (b) group B consumers (c) group C consumers (d) consumers in all groups combined (e) consumers living in villas in all groups and (f) consumers living in buildings in all groups.

The hypothesized linear model proposed can be represented in the following form:

Q_i = F(LOC, DEW, POOL, SEW, NAT, REL, SAB, PA, NOM, NOF, NOC, FS, TV, MIL)

Where:

Qi = average quantity consumed in m^3 /household for a specified period (i.e. season, or year, Q_s, Q_w or Q_a)

Other terms are as defined in Table 2

4.1 Cross sectional Regression Analysis

First order correlation matrix for all dependent variables for each user group was calculated. This correlation matrix is used to provide a basis for judging the effects of interdependency among the independent variables themselves and the dependent variables as well. A minimal interdependency among the explanatory variables was found with few exceptions. Stepwise regression was then applied to determine the best-fit models as shown in Table 3. As an attempt to improve the models prediction as indicated by the low values of R^2, regression was carried out on the logarithmically transformed data resulting in the nonlinear relationships shown in Table 4.

Table 3. Best-fit linear models

Type of Users	Regression Model	R^2
Group A Users	Q_s = 104. 343 + 77. 816 NOM + 0. 976 PA	0.234
	Q_w = - 6.977 + 41.243 NOM + 0.292 PA	0.162
	Q_a = - 111.320 + 119.059 NOM + 1.269 PA	0.213
Group B Users	Q_s = - 58.557 + 45.891 NOF + 0.506 PA	0.293
	Q_w = -7.347 + 20.908 NOF + 0.136 PA	0.200
	Q_a = 63.347 + 66.488 NOF + 0.639 PA	0.278
Group C Users	Q_s = 446.335+35.897 FS - 144.728 NOC + 93.573 NOF	0.484
	Q_w = 100.268+21.131FS- 97.220 NOC + 59.009 NOF	0.499
	Q_a= 546.603+57.023 FS - 241.948 NOC+152.582 NOF	0.470
All Groups	Q_s = -103.479-11.193 NOC + 62.638 NOF + 0.954 PA	0.334
	Q_w = -331.378+17.968 NOM+25.772 NOF+0.207 PA+125.392 MIL	0.300
	Q_a = -926.652+61.313 FS-70.331 NOC+1.018 PA+334.606 MIL	0.335
All Users Living In Villas	Q_s = -1021.47 + 108.93 NOM + 50.45 NOF + 0.65 PA+ 253.12 MIL	0.297
	Q_w = -453.25 + 53.94 NOM + 21.07 NOF + 0.148 PA+ 130.41 MIL	0.211 0.273
	Q_a = -1475.76 + 162.89 NOM + 71.48 NOF + 0.8 PA + 383.98 MIL	
All Users Living In Apartments	Q_s = 24.920-83.000 NOC + 102.861 NOF + 0.971 PA	0.434
	Q_w= -105.070-63.587 NOC + 69.091 NOF + 0.489 PA	0.456 0.447
	Q_a = -80.150-146.587 NOC + 171.951 NOF + 1.460PA	

Table 4. Best-fit logarithmic models

Type of Users	Regression Model	R^2
Group A Users	$log\ Q_s = 2.4378 + 0.0275$ NOM + 0.000323 PA	0.385
	$log\ Q_w = 1.9414 + 0.0357$ NOM + 0.000327 PA	0.299
	$log\ Q_a = 2.5697+0.0299$ NOM + 0.0175 NOF+0.00019 PA	0.340
Group B Users	$log\ Q_s = 2.1105 + 0.0483$ NOF + 0.000403 PA	0.278
	$log\ Q_w = 1.7820 + 0.0435$ NOF + 0.000266 PA	0.187
	$log\ Q_a = 2.2547 + 0.0475$ NOF + 0.000390 PA	0.282
Group C Users	$log\ Q_s = 2.4670 + 0.000300$ PA + 0.0109 TV	0.474
	$log\ Q_w = 1.9654 + 0.999261$ PA + 0.0153 TV	0.485
	$log\ Q_a = 2.5405 + 0.0218$ TV	0.351
All Groups	$log\ Q_s = 2.4125- 0.0027$ NOC + 0.0083 NOM+ 0.0169 NOF + 0.000316 PA	0.449 0.395
	$log\ Q_w = 1.9555+0.0158$ NOM + 0.0144 NOF + 0.000288 PA	0.396
	$log\ Q_a = 2.3858+0.0155$ NOM + 0.0143 NOF + 0.000197PA	
All Users Living In Villas	$log\ Q_s = 2.2701 + 0.0399$ NOM + 0.0192 NOF + 0.000267PA	0.398
	$log\ Q_w = 1.8504 + 0.0539$ NOM + 0.000275 PA	0.296
	$log\ Q_a = 2.2513 + 0.0473$ NOM + 0.0199 NOF + 0.000153 PA + 0.0805 MIL	0.371
All Users Living In Apartments	$log\ Q_s = 2.0370 + 0.000447$ PA + 0.3295 MIL	0.498
	$log\ Q_w = 1.6045 + 0.0124$ FS - 0.0189 NOC + 0.000244PA + 0.2930MIL	0.551 0.378
	$log\ Q_a = 2.3202 + 0.0087$ FS + 0.2869 MIL	

Table 5. Predicting water use from best fit linear models using mean values of independent variables

	Type of cross section					
	Group (A)	Group (B)	Group (C)	Overall	Villas	Buildings
PA (m^3)	582	641	989	826	777	979
NOM (#)	5.8	5.0	14.0	7.6	5.0	15.8
MOF (#)	5.6	4.8	15.5	7.9	5.2	16.2
NOC (#)	4.1	1.7	11.0	5.2	3.4	42.3
FS (#)	15.5	11.4	40.1	20.6	13.6	42.3
TTV (m^3)	31.3	32.7	32.7	32.0	30.8	35.6
MIL (level)	2.66	2.10	2.00	2.33	2.47	1.89
Q_s						
m^3/season	1178.5	486.1	1744.2	1121.3	916.6	1745.5
lpcd	316.8	177.7	181.2	227.0	280.8	171.9
Q_w						
m^3/season	481.0	180.2	792.8	471.9	363.1	1279.6
lpcd	258.6	131.7	164.8	190.0	222.5	261.4
Q_a						
m^3/season	1660.4	665.4	2537.0	1591.2	1279.6	2551.
lpcd	297.6	162.1	175.7	214.6	261.4	167.7

Table 6. Predicting water use from best fit logarithmic models using mean values of independent variables

	Type of cross section					
	Group (A)	Group (B)	Group (C)	Overall	Villas	Buildings
PA (m^3)	852	641	989	826	777	979
NOM (#)	5.8	5.0	14.0	7.6	5.0	15.8
MOF (#)	5.6	4.8	15.5	7.9	5.2	16.2
NOC (#)	4.1	1.7	11.0	5.2	3.4	10.8
FS (#)	15.5	11.4	40.1	20.6	13.6	42.3
TTV (m^3)	31.1	32.7	32.7	32.0	30.8	35.6
MIL (level)	2.66	2.10	2.00	2.33	2.47	1.89
Q_s						
m^3/season	745.6	398.7	1318.7	717.9	598.3	1251.3
lpcd	200.4	145.7	137.0	145.2	183.3	123.3
Q_w						
m^3/season	267.3	145.0	541.7	267.4	215.6	521.9
lpcd	143.7	106.0	112.6	108.2	132.1	102.8
Q_a						
m^3/season	1008.9	540.4	1792.1	972.9	811.0	1700.0
lpcd	180.8	131.7	124.1	131.2	165.6	111.6

5. PROJECTING WATER USE

Table 5 represents the average seasonal and annual water use for the various groups and subgroups considered in this study. It is developed by substituting mean values of the independent variables into the corresponding best-fit equation developed and presented in previous sections. Table 6 is similar to Table 5 but it is based on using the transformed equations. In general, the average predicted per capita water uses for all groups considered using the transformed equations were found lower than average values obtained when the original best fit equations are used for prediction. Based on the results of Tables 5 and 6, the average per capital water uses for consumers in group A were the highest among all groups. Similarly, the average per capita water uses for consumers living in villas for the reasons considered were found higher than corresponding values for consumers living in buildings. This is expected since consumers in villas will use more water to irrigate their gardens, which are almost nonexistent for people living in building. As expected the average summer water use for each group considered was found higher than the winter water use.

6. RESULTS

The effect of each considered independent variable on the level of water use is presented below:

6.1 The Plot Area

The developed water use prediction models indicate that the plot area (PA) is a major factor in determining water use. This was the case for groups A and B. However, for group C the plot area (PA) did not appear to be a contributing factor. This is obviously because of the absence of gardens in buildings so water is mostly used indoor.

6.2 Number of Males

Number of males (NOM) is proven to be a significant variable in determining water use only for group A water users and also for water users living in villas.

6.3 Number of Females

The number of females (NOF) was a significant variable in predicting water use for group B water users and for consumers of all groups living in villas.

6.4 Number of Children

The effect of number of children (NOC) on water consumption was found significant in predicting water use for group C users and consumers of all groups living in buildings. This result is found consistent with results of Al-Kadi [1986] which show that the average per capita water consumption decreased as the number of children in the household increased.

6.5 Family Size

Because of the strong correlation between family size (FS) and both number of males and number of females one expects that this variable will indicate same contribution to water use level. Family size is found significant in predicting water use for group C consumers.

6.6 Monthly Income Level

The monthly income level (MIL) is shown significant in predicting water use for consumers of all groups living in villas. It has positive regression coefficient in all seasons considered, indicating the increase in water use level with the increase in the values of (MIL). This result seem more sensible when compared to corresponding results derived by Al-Kadi which shows a decrease in consumption when (MIL) increased from level one to level two.

6.7 Total Water Tank Volume

This independent variable is proved to be significant in the transformed equations of group C water uses. However when the original best-fit equations are considered this factor proves insignificant.

7. CONCLUSIONS

In this study the use of linear multiple regression analysis in predicting and explaining the variations in per capita water consumption in the city of Riyadh is investigated. Eighteen prediction models were developed to represent summer, winter and annual water use variations for four cross sectional groups stratified according to aggregated economic and social factors (Groups A, B, C and overall) and according to the type of residence consumers of all groups are living in (villas and buildings). The generated models indicate that the plot area (PA), the number of males (NOM), females (NOF) and children (NOC) are the most significant variables in predicting the variation in water use for the various groups.

However, the low values of the coefficient of multiple correlation (R^2) in all models developed (0.551 for best model) one should conclude that the independent variable considered could not fully explain the variations in the level of water use. This means that other important variables were left out in the analysis. Anyhow, Such an output is expected for a such complex social and cultural structure.

Also due to changes in standards of living and water pricing since data was collected, one might expect some deviation in the consumption pattern nowadays. Therefore, a similar study is undergoing on recent data. Based on which, a comparative outlook might be of a great interest to planners to be considered in studies of future water demand projection.

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