

دراسة تحليلية لطلب الماء المنزلي في مدينة الحلة

رسالة

مقدمة الى كلية الهندسة في جامعة بابل
كجزء من متطلبات نيل درجة الماجستير في علوم
الهندسة المدنية

من قبل

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تشرين الاول ، 2004

AN ANALYSIS OF RESIDENTIAL WATER DEMAND IN HILLA CITY

A Thesis
Submitted to the College of Engineering of
the University of Babylon in Partial
Fulfillment of the Requirements
for the Degree of Master
of Science in Civil
Engineering

By

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October , 2004

لَا إِلَهَ إِلَّا اللَّهُ

﴿قَالُوا سُبْحَانَكَ لَا عِلْمَ لَنَا إِلَّا مَا عَلَّمْتَنَا إِنَّكَ أَنْتَ الْعَلِيمُ الْحَكِيمُ﴾

صدق الله العظيم
سورة البقرة
الآية (32).

قال رسول الله (ص) :

﴿مَنْ سَلَكَ طَرِيقاً يَلْتَمِسُ فِيهِ عِلْماً سَهَّلَ اللَّهُ لَهُ طَرِيقاً إِلَى الْجَنَّةِ﴾

صدق رسول الله (ص)

إلى

أئمة الهدى وأعلام التقى

آل بيته النبوي (ص)

إلى

من غرس في نفسي الطموم

والدتي والكتور داخل ناصر

إلى

من كانوا بمثابة الاخوة

منبع العلم والمعرفة أساتذتي الأفاضل

إلى

كل من يحبون لي الخير

إليهم جميعاً، اهدي ثمرة ما وفقني الله إليه

إسراء

الخلاصة

تتحرى هذه الدراسة تحليل طلب الماء المنزلي لمدينة الحلة مع إيجاد العوامل المؤثرة على هذا الطلب للفترة من الأول من شهر كانون الثاني الى نهاية شهر آب -2004 .

تم جمع البيانات المستخدمة في هذه الدراسة من خلال نموذج من الدور التي اختيرت عشوائياً من مختلف الأحياء السكنية للمدينة وتم الحصول عليها بشكل جيد من خلال تجهيز الأسر بمقاييس الاستهلاك المائي الجديدة والموحدة المنشأ والتي تم الحصول عليها من خلال جهد الباحثة وبمساعدة مديرية ماء بابل , وإعادتها بعد إنجاز البحث ، كما شملت هذه الأسر بالدراسة الاستفتائية للحصول على المعلومات التالية (الخصائص الأسرية) لكل دار والتي تعتبر من العوامل التي لها تأثيرات يعتمد عليها في طلب الماء المنزلي : حجم الأسرة ، مساحة البناء الكلي للدار ، مساحة الحديقة ، عدد كل من غرف النوم ، المرافق الصحية، الدوشات في الحمام ، المغاسل ، الحنفيات في الحديقة ، مبردات الهواء ، مكيفات الهواء ، مكائن الغسيل ، والسيارات .

تم استعراض نموذج الطلب بأربعة أشكال مختلفة من النماذج وهي : نموذج طلب الماء الكلي (يشمل استهلاك الماء داخل وخارج المنزل خلال فترة الدراسة) ، نموذج طلب الماء الشتائي (يشمل الماء المستهلك للأغراض داخل المنزل فقط على فرض إن استهلاك الماء خارج المنزل مقارب الى الصفر للفترة من الأول من شهر كانون الثاني الى نهاية شهر شباط) ، نموذج الطلب الصيفي (يشمل استهلاك الماء للأغراض داخل وخارج المنزل للفترة من الأول من شهر تموز إلى نهاية شهر آب) ، و نموذج طلب الرش والذي يشمل استهلاك الماء خارج المنزل أي انه الفرق بين الطلب الصيفي والطلب الشتائي للماء .

تم استخدام تحليل الانحدار المتعدد التدريجي للخصائص الأسرية التي تم ذكرها سابقاً لإيجاد العلاقة التركيبية بين المتغيرات لكل نوع من أنواع نماذج طلب الماء المنزلي، وتم تثبيت جميع نماذج الطلب بالصيغة (لوغاريتمي - خطي) .

في هذه الدراسة تم تخمين معدلات طلب الماء المنزلي لمدينة الحلة وكانت 1721 لتر/ دار في اليوم (273.2 لتر/ شخص في اليوم) لنموذج الطلب الكلي ، 586.13 لتر / دار في اليوم (93 لتر / شخص في اليوم) لنموذج الطلب الشتائي ، 2453 لتر / دار في اليوم (389.4 لتر/ شخص في اليوم) لنموذج الطلب الصيفي ، و 490 لتر / دار في اليوم (77.8 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 الأسرة وهو متغير مهم في كل نماذج الطلب بينما يكون عدد المغاسل هو المتغير المهم في نماذج الطلب الكلي والشتائي والصيفي .

إن مساحة البناء الكلي للدار وعدد الدوشات هي المتغيرات المهمة في نمودجي طلب الماء الكلي والصيفي .

A ABSTRACT

This study investigates the analysis of residential water demand for the city of Hilla along with determining the factors that affect such demand for the period from the 1st of January to the end of August – 2004.

In this study, the data used was collected by a survey made on a sample of dwellings that were randomly chosen from different districts of the city. These data were best obtained by metering of individual households when the researcher worked hard to get a new and identical charging meters from Babylon Water Directorate, and then lifted after the study has been done. The households were supplemented by questionnaire survey to get the information (household characteristics) for each house which are considered an important factors because of their reliable impacts on domestic water demand. These factors are: household size, the total built-up area of the house, garden area, number of each bedrooms, toilets, showers, washbasins, taps in garden, air-coolers, air-conditioners, washing machines, and cars.

The demand model was presented into four formulas: total, winter, summer, and sprinkling residential water demand.

Total demand was estimated to be equal to the total average daily water used for all purposes for the study period, while winter demand represented the water used for the in-house purposes for the period from the 1st of January to

the end of February , while the out-house use of water was hypothesized to be equal to zero .

Summer demand was considered to be equal to the use of water for the in-house and the out-house purposes for the period from the 1st of July to the end of August .

Sprinkling water demand was estimated by subtracting winter water consumption from summer water consumption , which it is equal to the water used for the out-house purposes .

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

All demand models were fitted in log- linear form .

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

The most significant factors affecting the demand appear in the fitted equations . Of these factors , household size was found to be the significant variable in all demand models , while number of washbasins variable was found to be the significant variable in the total , winter , and summer demand model .

The total built-up area of the house and number of showers were found to be the significant variable in the total and summer demand models .

A CKNOWLEDGEMENTS

I would like to express my sincere appreciation to Dr. Riyad H. Al-Anbari and Dr. Jabbar H. Al-Baidhani, my supervisors, for their able guidance and continuous encouragement and support during the various stages of this project.

Thanks are due to the University of Babylon, College of Engineering and Department of Civil Engineering for providing the necessary facilities during this study.

Great thanks are due to Dr. Dakhil Nassir Taha for his assistance to me in different ways.

Special thanks are due to Mr. Salman H. Kadhum, Head of Babylon Water Directorate and to Mr. Hussein Ali, employee in Hilla Meteorological Station.

Acknowledgement also goes to Mr. Hattem A.L.M. Salih for his assistance in statistical subject and to Mr. Ra'ad K. Al-Khalidi and Bashar K. Al-Janabi for typing this thesis.

**Isra'a Sadi Samaka
2004**

CERTIFICATION

We certify that the preparation of this thesis, entitled "**An Analysis of Residential Water Demand in Hilla City**" was prepared by "**Isra'a Sadi Abdul-Amir**" under our supervision at Babylon University, College of Engineering in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering.

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E XAMINATION COMMITTEE CERTIFICATION

We certify that we have read this thesis, entitled "**An Analysis of Residential Water Demand in Hilla City**", and as examining committee, examined the student "**Isra'a Sadi Abdul-Amir**" in its contents and in what is connected with it, and that in our opinion it meets the standard of a thesis for the degree of Master of Science in Civil Engineering.

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CHAPTER

INTRODUCTION

1.1 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 predictives of the quantity of water to be supplied in order to avoid the impoverishment 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, clothes washing, house cleaning, flushing toilets, and out-house purposes like: garden watering, air-cooling, car washing” (Danielson, 1979 ; Qasim et al. ,2000 ; Isehak ,2001) .

It is difficult to estimate the amount of water needed to maintain acceptable or minimum living standards. Moreover, different sources use different figures for total water consumption.

By World Bank and the World Health Organization, the “Basic Water Requirement (BWR)” ranges from 20 to 40 L/c/d of freshwater which is generally considered to be a necessary minimum to meet needs for drinking and sanitation alone.

The BWR was estimated at 50 L/c/d for meeting four domestic basic needs: drinking, sanitation, bathing and cooling, independent of climate, technology and culture (Gleick, 1996).

The figure of 100 L/c/d for personal use was used as a rough estimate of the amount needed for a minimally acceptable standard of living in developing countries (Falkenmark and Widstrand, 1992).

Water demand was classified into the following categories which refer to the components of municipal water demand as shown in Figure (1-1) below (Qasim et al., 2000):

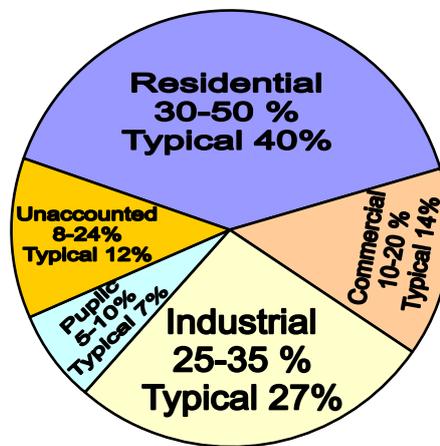


Fig.(1-1): Components of Municipal Water Demand (Qasim et al., 2000).

1. Domestic Water Use. The residential water use is the portion of the municipal water supply that is used in different activities like: cooking, drinking, washing, bathing, using of toilet, watering lawn, etc. This study focuses on this component only.
2. Commercial Water Use. Commercial establishments include motels, hotels, office buildings, shopping centers, service stations, airports, and the like.
3. Industrial Water Use. Industrial water demands include industries, factories, and the like.

4. **Public Water Use.** Water used in public buildings (city halls, jails, schools, etc.) as well as water used for public services (including fire protection, street washing, and park irrigation).
5. **Unaccounted System Losses and Leakage.** In a water supply system there is a certain amount of water that is lost or unaccounted for because of meter and pump slippage, leaks in mains faulty meters, and unauthorized water connections.

It is very important to know that there are many factors affecting water consumption, thus the quantity of water demand cannot be assessed by the public science (Garg, 1988).

Factors affecting residential water consumption include (Grima, 1972):

- Utility management policy variables: water rates.
- Household economic variables: consumer income or wealth.
- Household physical features and technological variables: infrastructure of water-using and water-saving devices / lot size/ metered and unmetered.
- Environmental factors: temperature and precipitation.
- Demographic variables: number of household residents/ attitudinal and cultural variables.

Each study derives the specific variables from the above exhaustive summary which it believes to be significant according to its respective level of analysis or the problems addressed (Beijing Municipal Water Company, 2002).

Numerous studies of residential water consumption have been made in an attempt to build mathematical or statistical models capable of assessing reliable per capita requirements of drinking water resident.

The total domestic water consumption amount to 54% of the total produced (Willsie and Harry, 1974), 55%-60% of the total consumption (Garg, 1988), 30%-50% (Qasim et al., 2000), over half of the total municipal water use (Beijing Municipal Water Company, 2002).

It should be noted that no work was reported on the daily demand of residential water for Hilla City.

For the purpose of this work, a sample of dwelling units was randomly chosen in different areas of Hilla City and supplied with new and identical charging meters when the researcher worked hard to get them from the Babylon Water Directorate. A questionnaire survey was made to collect all necessary information seemed useful in estimating the daily consumption of domestic water for the period from the 1st of January to the end of August, 2004.

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

Stepwise method reduces the number of variables initially present to those that are actually significant.

Water consumption does not remain constant over all the year and it depends on the nature of the season, in hot months more water is consumed in drinking, bathing, and watering lawns and gardens (Al-layla et al., 1977), therefore, the study of domestic water demand has been divided into four studies : study no.1 (total residential water demand), study no.2 (winter residential water demand), study no.3 (summer residential water demand), and study no.4 (sprinkling residential water demand).

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 (from the 1st of January to the end of February, 2004). Summer demand includes water consumed for in-house plus out-house purposes in the summer season (from the 1st of July to the end of August, 2004).

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

1.2 Research Objectives

The objectives of the present work are to:

1. Evaluate household water use per day or per capita water use per day in liter (L/h/d or L/c/d respectively).
2. Identify domestic water use pattern in Hilla City under considerations: total, winter, summer, and sprinkling and general trend for total water use.
3. Explain the major factors that affect such demand and define their effects.
4. Developing model of residential water demand in the city under the above – mentioned considerations.

1.3 Thesis Presentation

The research procedure which undertakes its presentation in this thesis is as follows:

- Chapter Two presents a review of both early and recent studies on residential water demand along with factors affecting the demand.
- Chapter Three, theory of water use modeling is introduced. This chapter contains the required equations, tables, and figures for demand prediction.
- Chapter Four presents the data and the variables used in the analysis along with the survey, which was made.
- Chapter Five, the results of analysis and discussion for each of demand model under considerations: total, winter, summer, and sprinkling, are reported.
- Chapter six contains the conclusions obtained from this study and the recommendations for future works.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Residential water use is generally the most important component of municipal water use, not only because it may constitute well over half of the total municipal water use in many countries, but also because it usually requires higher quality and reliability which leads to high costs (Grima, 1972).

Historically, residential water use is directly linked with the health of general public, and it is always being given the top priority in municipal water supply and subject to other factors such as efficient demand management ; then the water literature is replete with studies on municipal water demand and factors affecting such demand.

When residential water demand justifies its importance in municipal water supply system by accounting for a large portion of total system demand, thus, the household becomes the basic unit of analysis and can be studied relatively directly (Jones and John, 1984). Household water demand results from resident's need to meet certain standards of living, enjoyment, comfort, hygiene, convenience, and aesthetic quality in domestic activities (Boland et al., 1984). Therefore, most parts of municipal water demand projections are in fact attempts to predict residential water use.

No projection can survive without sufficient and reliable data. Usually, the quantity and type of data available determine which forecasting method can be considered for application.

The most widely used technique to forecast residential water demand is multiple regression (Beijing Municipal Water Company, 2002).

Generally, there are two approaches for analyzing municipal water demand data: multiple regression and time series analysis.

Data on water use are the most important element of empirical studies of water demand. There are many types and configurations of data sets that can be used in modeling water use (Dziegielewski et al., 2002).

Generally, there are two types of data in residential water demand projection in addition to the type which combines these two types. This classification is based on the methods of observation like:

- 1- Time series data which are arranged in a chronological order and analyzed using multiple regression and time series methods.
- 2- Cross-sectional data which are arranged cross-sectionally and analyzed using multiple regression method.
- 3- Pooled data of both time-series and cross-section.

In the first type, data consist of repeated observations of water use and explanatory variables over a number of time periods at the same location (Jones and John, 1984; Gracia et al., 2001; Dziegielewski et al., 2002).

It is important to note that few studies estimate residential demand using a pure time series approach (Schneider and Whitlatch, 1991; Billings and Agthe, 1998).

Time series data, if collected for a sufficient time period, can be very useful for developing forecasting models because the trend in water use over time may be identified and hypotheses developed and tested regarding continuation of the trend into the future (Jones and John, 1984).

In the second type of data, there are simultaneous observations of many activities of the same sort at a number of locations during a single time period (Jones and John, 1984; Gracia et al., 2001; Dziegielewski et al., 2002).

The majority of urban residential water demand studies were based on cross-sectional data (Jones and John, 1984; Gracia et al., 2001).

Using the cross-sectional data, the necessary assumption would be that functional relationships that exist among the variables at a particular time will continue into the future. This makes cross-sectional data inferior to time-series data in projecting water use trends (Jones and John, 1984).

The additional type of data represents repeated surveys of the same cross-sectional sample at different periods of time. That means it combines cross-section with time series data in a panel approach.

The use of pooled data increases the number of observations (Balestra, 1996).

In spite of the availability of many studies of data of both the time series and cross-sectional type, most of these works estimate a demand model based on pure cross-sectional data analysis.

2.1.1 Analysis of Water Demand Data Arranged Chronologically

Maidment and Parzen (1984) examined a time series of monthly water use data in six Texas cities from 1961-1978.

The study demonstrated that more than 80% of the variation over time of monthly water use in these cities was attributed to four factors: (1) trend; (2) seasonality; (3) autocorrelation; and (4) climatic correlation.

The pattern of variation of time series of monthly water use was divided into long memory components and short memory components. The first accounted for 70% of the variation and they were trend and seasonality; trend reflected the effect from year to year of slowly-changing variables such as population, water price and family income, and seasonality

reflected the cyclic pattern of variation in water use over the year. The long memory components were described by functions which, once their parameters have been estimated, were considered to operate independently of the values of water use observed in any particular year.

The short memory components accounted for 15% (the value of standardized coefficient β in statistical analysis) of the variation and they were not fully predictable, since they depended upon the current and previous observations of water use.

In each city, trend was analyzed by stepwise regression of mean annual water use as dependent variable with the explanatory variables as independent variables such as population, number of water connections, household income and water price, of which population was the most significant variable for trends in water use from year to year.

The climatic correlation was strong in high plains of Texas where if one inch more than mean monthly rainfall or pan evaporation occurs, it results on average in a 10 gpcd (38 Lcd) change in mean monthly water use (decrease for rainfall, increase for evaporation).

Abdul-Majeed (1985) wrote a set of equations to represent a developed statistical model of monthly municipal water consumption and explained the effects of four factors on this consumption: trend, seasonality, autocorrelation and climatic (rainfall, evaporation, and temperature) correlation for the city of Kuwait.

The case study was classified according to the type of water into two cases: case study-1, represented monthly data of municipal water consumption for fresh water in Kuwait for the years 1972-1982, and case study-2, represented the monthly data of municipal water consumption for brackish water in Kuwait also for the years 1974-1982.

The model which represented the case study -1 explained 99% of the total variations, divided among the four factors as follows: trend (88.2%), seasonality (8.4%), autocorrelation (2.9%), and climatic correlation (0.0%).

While the model which referred to the case study – 2 explained 96% of the total variations, divided among the four factors as follows: trend (18.7%), seasonality (72.2%), autocorrelation (3.6%), and climatic correlation (1.2%).

Maidment and Miaou (1986) studied the daily water use in nine cities, three in each state of Texas, Florida and Pennsylvania (USA) for the year 1978.

They used the dynamic short –term response model of daily water use related to rainfall and air temperature changes.

Water use was classified into two components; base use (weather – insensitive) and seasonal use (weather – sensitive).

They remarked that the seasonal water use during rainless periods was closely related to air temperature once the maximum air temperature rise above (21C°) in all cities studied. A greater than this temperature, seasonal use raised slowly at first, then more rapidly as air temperature rose beyond 29-32centrigrade when the rate of rise was 3-5 times faster than when temperature was less than this level.

They also explained the impact of rainfall on seasonal water use. When rainfall of more than 0.05 inch (0.13 cm) occurs today, the seasonal water use will decrease tomorrow.

The dynamic response of water use to rainfall and air temperature changes was similar for all cities in each state.

The mean of annual water use for the nine cities ranged between 375.5 Lcd (in college station) to 977 Lcd (in Allentown).

The coefficient of determination (R^2) values were 0.96 in Texas, 0.73 in Florida, and 0.61 in Pennsylvania.

Metzner (1989) studied water use by customer class in San Francisco, Calif. He analyzed past water use by using multiple regression techniques and made forecast for water demand during five-years intervals

to the year of 2005. The historical water use in San Francisco was identified for the 1974-1986 period (in 1977 and 1978, water use was reduced by rationing because of drought).

The multiple regression model was written as:

$$Q = b_0 + b_1 x_1 + b_2 x_2 + \dots + b_n x_n + e \quad \dots (2.1)$$

Where Q = the quantity of water that was used or demanded over a given period of time (e.g., a year); b_0 =constant, b_1 , b_2 and b_n = regression coefficients; x_1 , x_2 and x_n = values of explanatory variables, and e = error term. The explanatory variables were included (population, number of people per household, precipitation deficit, marginal price, ..., etc).

The people per household (or household size) parameter was calculated by dividing the total population in households by the number of occupied housing units. The regression model was classified into four functions conducted with four customer classes in San Francisco; (1) one to four-family residences, (2) commercial and multifamily residences, (3) industrial, and (4) governmental.

The correlation coefficient ranged from 0.99 for commercial and multifamily class to 0.84 for governmental class. He concluded that the household size was the most effective on water demand (1% change in the explanatory variable cause 0.75% increase in water demand), while 1% increase in explanatory variable (precipitation deficit), causes 0.03% decrease in water demand.

The author made forecast for water demand to the year 2005 and the forecasted quantity was 48×10^8 cuft ($=1.36 \times 10^8 \text{ m}^3$) in that year.

Khalil (1994) used the average monthly water consumption as a data in his analysis of the two cities of Amman (from January 1985 to December 1990), and Kuwait (from January 1983 to December 1987) to derive three statistical models (multiple regression model with two other models) and he tried to select the most suitable model.

He mentioned that the statistical models helped to forecast or simulate water use for a period of weeks or months into the future.

The author saw that all the three models proved to be effective in forecasting future monthly demand, thus he used other water consumption data for one-year-ahead in each city (for 1991 in Amman and 1988 for Kuwait).

The value of coefficient of determination in multiple regression model was ($R^2=92.45\%$) for the city of Amman and ($R^2=99.21\%$) for the city of Kuwait.

The results showed that there is no general forecast model which can be utilized for different cities to give the same results, but the data determines the type of model used and not the opposite.

Marti'nez-Espñeira (2002) estimated domestic water demand functions in the Northwest of Spain by using a panel of monthly aggregate data under linear and non-linear tariffs.

Different communities offered data of years (between 1993 and 1999) and the number of towns effectively included in the calculations was 132 and the average length of the time series finally used was 25.64 months.

Price, billing, climatic, and sociodemographic variables were used as explanatory variables.

Marginal price elasticity estimates lied between (-0.12 and -0.16).

It was seemed that the marginal price elasticity was much higher in summer than its general value during the whole year. The climatic variables exerted a significant effect on monthly water use.

2.1.2 Analysis of Water Demand Data Arranged Cross-Sectionally

Gibbs (1978) gathered data from 355 households in a large metropolitan area, Miami, Florida, to study residential water demand over a period of one year, 1973.

His study used the quarterly household consumption for water as a dependent variable, while the explanatory variables were: annual household income, household size, percent of houses which used water heaters, dummy variable and water price variable.

The author showed two models of demand first; he used the average price, and the marginal price was used in the other model. Then he made a comparison between two models to study the effects of each price on the water demand.

Predictions of consumption varied from 22% to 107% between two models. In both models the dependent variable was transformed using logarithmic scale.

Finally, he concluded that the average price model significantly out estimated the response of consumption to price and income changes.

Seidel (1978) summarized and analyzed a raw data which was collected and published by AWWA in February 1974 (from water utilities through USA). This report classified utilities into two types: publicly owned and investor-owned throughout the country. The operating data were for the two years 1965 and 1970 and their analysis depended on information of water production and distribution, billing and rates, water revenue, operating costs, and other financial information.

The 1965 and 1970 surveys were conducted using combined AWWA and EPA mailing lists. In 1965, a response of samples of 861 utilities was recorded from a mailing of approximately 1800.

In 1970, 768 responses were received from mailing of 1900.

Seidel found that the trend in water production has historically been upward.

For publicly owned utilities, water rates charged increased 35-40 percent in the 1960-1970 decade. Revenue per capita and per residential service increased 50 percent and more during the decade, where revenue expressed as income per unit of production increased less than 25 percent.

Boland et al. (1980) performed a study which included using regressions for the two largest customer classes: monthly-billed apartments and quarterly-billed single family residential units including both water and sewer service. These two classes together accounted for approximately 70% of total WSSC (the Washington Suburban Sanitary Commission) water use.

In each regression, the dependent variable was taken as average water used per connection per period over the years 1974-1976. Approximately 1.4 million individual pairs of meter readings were performed to calculate these values. Separate regressions were used for seasonal and non-seasonal uses, where seasonal use was calculated as the difference between water consumption in summer (May-October) and winter (November- April) periods, and non-seasonal use was equated to the winter water use. Explanatory variables included household income, occupants per dwelling unit, gross area per dwelling unit (as a proxy for irrigated area), and summer precipitation from potential evapotranspiration.

They found that, for class-1 (residential water use, water and sewer), the household income variable was significant in both non-seasonal and seasonal water use, while in seasonal use both of average gross area per dwelling unit and average moisture deficit with household income variables were found to be significant as shown in the following equations:

For non-seasonal water use:

$$Q = 154.4 + 0.00354 x_1 \quad \dots (2.2)$$

With $R^2 = 0.107$, S.E.= 43.76, N=304

For seasonal water use:

$$Q = -9.85 + 0.0015 x_1 + 11038.9 x_2 x_3 \quad \dots (2.3)$$

With $R^2 = 0.156$, S.E.= 61.51, N=554

Where x_1 = average income per household, x_2 = average gross area per dwelling unit, and x_3 = average moisture deficit for the billing period. The low value of R^2 for two models can be attributed to a poor fit and the explanatory variables explained 0.107 and 0.156 of water demand only. Therefore, there was no strong relationship between independent variables and dependent variable, Q.

For class-2 (apartment water use, monthly billing cycle), they found that both household income and average number of occupants per dwelling unit-variables were significant in non-seasonal use only, while both average gross area per dwelling unit and moisture deficit-variables were significant in seasonal use only.

Williams and Byung (1986) investigated the factors that determine the water demand for different classes of users and the sensitivity of demand to price changes. The data of water quantity by different customer class, and the number of water customers for each category were obtained from : Survey of Operating Data for Water Utilities in 1976 by the American Water Works Association.

Residential water use model was:

$$Q_R = -9.0820 - 0.4835 P_1 + 0.6378 I + 1.0403 N_r + 0.0157 T - 0.0895 R$$

$$R^2=0.9580, n=86 \quad \dots(2.4)$$

$$Q_R = -10.5975 - 0.2543 P_2 + 0.7724 I + 1.0578 N_r + 0.0210 T - 0.1712 R \quad \dots (2.5)$$

$$R^2=0.9509, n=82$$

$$Q_R = -9.2359 - 0.2486 P_3 + 0.6681 I + 1.0609 N_r + 0.0159 T - 0.1921 R \quad \dots (2.6)$$

$$R^2=0.9488, n=86$$

$$Q_R = -8.6858 - 0.3150 P_4 + 0.5794 I + 1.0646 N_r + 0.0165 T - 0.1873 R \quad \dots (2.7)$$

$$R^2=0.9491, n=86$$

$$Q_R = -10.0245 - 0.1795 P_5 + 0.7127 I + 1.0679 N_r + 0.0191 T - 0.1880 R \quad \dots (2.8)$$

$$R^2=0.9469, n=86$$

Where:

Q_R = annual quantity of residential water used;

N_r = size of sample;

I = per capita income;

R = total rainfall during the summer months (in inches);

T = average temperature during the summer months;

P_1 = average revenue price ;

P_2 = marginal price for consumption between 750 and 3750 gallons (1 gallon = 3.785 liter);

P_3 = marginal price for consumption between 3750 and 7500 gallons;

P_4 = marginal price for consumption between 7500 and 75000 gallons;

P_5 = marginal price for consumption greater than 75000 gallons.

The authors concluded that the demand for water is relatively price inelastic for residential category. Average price elasticity are generally higher than the marginal price elasticity.

The estimated long run average price elasticity for residential was -0.485, whereas the estimated long run marginal price elasticity was -0.294.

They also concluded that in the residential sector, per capita income, temperature, rainfall, and the number of customers are also significant in determining water demand.

Martin and John (1986) made a comparison between price and quantity data of urban residential water demand for five cities: Coober Pedy, South Australia (1980-1984), Kuwait (mean, 1973-1981), Perth, Western Australia (1981/1982), Tucson, Arizona (1978/1979), and

Phoenix, Arizona (1979). This cross-sectional comparison attempted to demonstrate that precision of estimates of demand elasticities for a given area may not be necessary for policy purposes. Data in this study were obtained from other studies. Mean daily per capita water use in liters and gallons, associated marginal prices in dollars (in Australian dollars and U.S. dollars) per kiloliter, mean annual rainfall in millimeters and inches, and per capita income in dollars were presented for the five cities being compared. The five data points for price and quantity were modeled using an ordinary least squares method to fit demand curve:

$$Q = 5.10P^{-0.49} \quad \dots (2.9)$$

Where Q was the mean daily per capita water use in liters; P was the marginal prices in dollars; Adjusted $R^2=0.98$; S.E = 0.03, and the elasticity was -0.49. For policy purposes, the relevant hypotheses tested in this study were whether or not the elasticity of urban demand for water is greater or less than -1.0 and whether that elasticity is constant or changing.

This study concluded that while E_d (price elasticity of water demand) could hover near -1.0 at intermediate levels of prices and quantities, it will also be inelastic at high price and low use.

The author found that with increasing water scarcity, future price changes are likely to be outside the range of previously observed variation for any given area, and a cross-sectional comparison with similar areas may be the most reliable analysis for policy use.

Hassan (1987) randomly chose 50 households in Basrah city, Iraq. In the first stage, he applied a multiple regression technique to estimate residential water demand as a function of the number of fixtures, the household size, the price, and the tap water pressure inside each house over the period from January 1977 to February 1978.

The demand model was put in four formulas: total, summer, winter, and seasonal residential water demand.

Seasonal demand model was the quantity of water used by customer per day for a year was estimated by subtracting winter (mid-October to mid-March) consumption from summer (mid-March to mid-October) use. He proved that the number of fixtures was the most significant variable in all demand models.

In the second stage, the regression analysis was depended on estimating the separate contribution of the different types of fixtures (toilets, washbasins, showers, air-coolers, and washing machines) to the above- mentioned water demand models.

Hassan reported that on the average each air-cooler caused an increase of 46.89% in the seasonal demand which was equivalent to 284 liter per household per summer day back in 1977.

Khadam (1988) studied the outline of basic factors influencing per capita consumption for the city of Khartoum/Sudan as a case study of urban areas.

He classified the consumers according to their accessibility to water supplies in two groups; (1) consumers with piped supply (about 75%) and (2) consumers obtaining water from water vendors or from stand pipes (squatter settlements) (about 25%).

The analyzed data were selected randomly for the two groups with 186 dwellers represented the sample for the first group and 124 dwellers for the second.

The factors which were taken into account to have an impact on domestic water consumption for two groups metered households and used to generate equations relating these different variables were such as: number of occupants, number of children, income level, price of water, lot size, sprinkling area, number of facilities consuming water including (washing cars, cleaning floors, air coolers, washing machines), number of rooms, number of taps in the courtyard for the first group and number of

animals watered in the house, distance of the house from the water source for the second group.

The stepwise regression procedure was used and the equations of the best fitting obtained are as given bellow:

For first group consumers:

$$Q = 305.60 - 407.30 P - 19.84 N - 2.57 S + 0.15 A \quad \dots\dots (2.10)$$

where Q = average annual quantity consumed in Lcd,

P = price of water,

N = number of members in the household,

S=sprinkling area in square meter, and

A=lot size in square meter.

The most significant factors affecting the consumption appear in each fitted equation for the two groups.

For class (2) consumers:

$$Q = 95.57 - 4.36 N - 3.91 P - 0.02 A \quad \dots (2.11)$$

with adjusted $R^2=0.80$

The author found that the price had a significant impact on demand and it was used as a tool to ration or discourage water consumption in the piped connection household and to increase the rate of consumption in the standpipes households.

He found that the houses with piped connections consumed water with a comparatively high level, ranging between (18-734) Lcd.

This range reflected the differences in living and economic conditions of the people, but the houses of the second group consumed water at a level ranging between (11-74) Lcd.

Water consumption in these areas was compatible with low income level.

Hall et al. (1988) made a survey by South West Water of England over a 13-month-period, from March 1977 to April 1978 to estimate the domestic water consumption.

This study was based on a sample of 1000 households which were selected using a two-stage procedure to choose the sample of households.

All high consumption households with eight or more residents were chosen as a final selection.

The information depended on are: house type, number and type of water-using appliances, number of cars, number of occupants, and their approximate ages.

The author found that the average domestic consumption recorded for the Authority's area over the period was 113.4 L/h/d. This figure would increase to 131.6 L/h/d in 1985.

Al-Samawi and Hassan (1988) used data depending on cross-sectional metered water collected by Humphries and Brown (H&B, 1979) from the survey of household conducted between January, 1977 and February, 1978 in the city of Basrah, Iraq.

200 dwellings were randomly chosen and filtered to 50 houses.

The other houses were eliminated from the original sample because of some reasons (such as: the complete set of data was not available, the tap water pressure was less than 4.2 m, and the winter water consumption was higher than the summer consumption).

The water consumption demand was classified into four types: total, summer, winter, and sprinkling (seasonal) demand.

The authors assumed that water demand was a function of : number of fitments per dwelling unit, number of occupants living in each house, area of the house, lot price of each house, and tap water pressure in the house-variables.

The number of fitments (number of toilets, washbasins, showers, air-coolers, and washing machines-variables) were the significant variables in the total and summer demand model, but the winter demand model had all these fitments except a number of air-coolers.

The authors mentioned that the number of fitments per dwelling variable explained the largest proportion of the variation in the demand models.

They found that both number of occupants per dwelling and area of house variables were to be statistically insignificant in all water demand models.

Al-Samawi and Hassan (1989) used the case study of the city of Basrah, Iraq, using the same filtered data used in their previous study in (1988), but in this study they tried to find the contributions of the different types of fitments of household to residential water consumption.

They used the stepwise regression procedure to estimate residential water demand as a function of number of toilets, washbasins, showers, air-coolers, and washing machines per dwelling, and they performed demand model in four types, namely: total, summer, winter, and sprinkling with most significant variables in each type.

The explanatory variables of winter and summer model were suggested to include all fitments that had been mentioned, but the number of air-coolers variable was eliminated from the winter model and replaced with the price variable. For the sprinkling demand model, the authors included the number of air-coolers, and the tap water pressure-variables only.

Finally, they showed that the number of air-coolers per dwelling was the most significant variable, and it used the larger quantity of water from each model (total, summer, and sprinkling) and it was equal to 38%, 40%, and 47% of water consumption respectively.

For the winter demand model, they found that the number of washing machines in each house was the most significant variable and each washing machine was found to use 45.8% of the winter water consumption.

The number of showers per dwelling variable was found to be statistically insignificant in all water demand models.

Murdock et al. (1991) investigated the relationships between demographic, social, cultural factors and residential water use, and the implications of these relationships for residential Water demand projections.

Data on the dependent variable, residential water use for 667 Texas cities from 1974 to 1983, was obtained from the Texas Water Development Board. Three-month averages of uses were calculated for one summer period (June, July, and August) and one winter period (December, January, February). There were 57 variables in total-demographic, economic, and housing, considered in this study.

Individual household level water use was also analyzed by using primary data collected from telephone surveys of 814 respondents of eight Texas communities. Information on the respondent's water use and conservation, water costs, type and size of housing units, use of water for bathing, washing clothes, washing dishes, toilets, etc. were collected.

For the secondary analysis, 28 out of 57 independent variables were selected for estimation by conducting multicollinearity analysis and computing the variance inflation factors.

Ordinary least-square and stepwise regression were applied for the estimation.

For the primary data analysis, 24 independent variables plus seven city dummy variables were selected for estimation of water use at household level.

The authors demonstrated that sociodemographic and socioeconomic variables did influence average daily per capita water use. The key variables identified by the authors were: the percentage of the population that is of Spanish-origin, the percentage of family households, and the total number of housing units.

CIDA Funded Project Team (1999) made a study to summarize the characteristics of urban water use of 32 sample households, which were visited from May 18 to June 28, 1999 in municipalities of Beijing and Tianjin, China .11 samples were in Tianjin and 21 samples were in Beijing.

Per capital municipal water consumption increased from 247 liters in 1990 to 315 liters and 360 liters by the year 2000 and 2010,with residential water use was around 110 L/c/d. Residential water consumption only was usually one third to one half of the municipal number.

The randomly chosen households were represented by four types of residential building typologies in Chinese cities (Beijing and Tianjin).

The four types were: high – rise buildings accounted for 43.8 percent, multi-story buildings which were lower than seven-story accounted for 40.6 percent, old courtyard or one to three stories traditional buildings accounted for 6.3 percent and infill building 9.3 percent respectively.

The specific objective of this survey was to evaluate household water use with regard to the increasing living standard and the scarcity of water resources.

A questionnaire survey was made first, in order to find the factors affecting water use and then to carry out efficient water planning, balance supply and demand to facilitate a sustainable water use. By empirical investigation and analytical study, this research would provide a policy relevant information and substantial data for municipal water planning in a timely fashion, especially for understanding the urban household water use.

Factors which were studied in this survey were: Housing environment, socioeconomic, water amenities, water behavior and perception as well as dweller's environmental attitudes.

For finding the structural relationship between these variables and household water demand, a multiple regression analysis of household characteristics was employed. Four models were developed for each housing category which explained over half of the variance (except for multi-story category) in water consumption in each respective category.

The average water use in typical urban housing per resident, however, was some 3 cubic meters each month.

Finally, this study indicated that the urban residents in both Beijing and Tianjin were still conservative in water use. There was a difference between the young and old generations.

Isehak (2001) estimated residential water consumption for the city of Baghdad and determined the variables that affected such demand over the period from 1995-1998. The author used stepwise multiple regression procedure to estimate residential water demand as a function of (household size, number of bedrooms, number of toilets, number of showers, number of washbasins, number of taps in the garden, total built-up area, number of air-coolers, number of air conditioners, area of the garden). When 200 dwellings were randomly chosen from different areas in Baghdad, only 50 dwellings were found to be supplied with metered water. Only these dwellings were included in this study.

This study had a questionnaires survey to get some information for each house; this information was mentioned above.

Demand relations were estimated for total, summer, winter, and seasonal (or sprinkling) residential water demand.

Total residential demand was assumed to be equal to the annual average daily consumption for all purposes, while summer demand represented the water use for the in-house and the out-house purposes for

the period from the middle of March to the middle of October. Winter demand was considered to be equal to the use of water for the in-house purposes for the period from mid-October to mid-March, while the out-house use of winter was assumed to be equal to zero.

Sprinkling demand was calculated by subtracting winter consumption from summer consumption, which was equaled to the water use for the out-house purposes only. The author estimated the average daily water consumption which was 249 Lcd for total demand, 285 Lcd for summer demand, 195 Lcd for winter demand, and 89 Lcd for sprinkling demand.

Many models were investigated, and stepwise linear regression models (linear form) carried out through the origin were found to be the most appropriate for different demands.

The author found that the total built-up area and number of showers variables were the most significant variables in the total, summer, and winter demand models, while the number of air-coolers variable was found to be significant in total, summer, and sprinkling demand models. The household size variable was significant in all demand models. Isehak used raw water as a dummy variable and concluded that if a household was supplied with raw water then, it would decrease the water consumption by the ratio of 25% of the summer water demand.

Porras et al. (2001) made a large-scale, repeated, cross-sectional study of domestic water use in East Africa, based on the landmark book *Drawers of Water* by Gilbert F. White et al. (1972), which was the large-scale assessment of domestic water use and the environmental health in Africa.

It concentrated on changes in domestic water use with the changes in cost of water use for two types of households, the first is with piped connections and the other is without, in rural and urban areas in Kenya, Tanzania and Uganda over 30 years (1967-1997).

They collected data from two types of areas, with two types of households and they used a statistical analysis to get the results.

The study focused on the long-term trends which reflected changing in water price and population. The results showed that, the average water cost has decreased for piped households and increased for those without piped water connections.

Water was significantly more expensive for unpiped households, and the cost doubled since 1967. Water was most expensive for unpiped households in urban areas, where dependency on vendors and other private suppliers was larger.

The gap between rural-urban unpiped had doubled since 1967, from 30 to 60 US cents per cubic meter (pcm).

Heaney et al. (2002) studied domestic water use by choosing 12 cities to represent a diverse collection of single-family water use patterns across North America, a sample of 1000 houses was selected from each city. Then detailed monitoring was done on each of these houses during two 14-day periods, one warmer and one cooler.

The average household size in the study was 2.8 persons and questionnaire survey was made to collect information about household income level, level of education and the age of house.

Annual water use and estimated indoor and outdoor water use for each city is shown in Table (2-1).

Table (2-1): Annual Indoor and Outdoor Water Use for 1,000 Houses in Each of 12 Cities (Heaney et al., 2002).

Study site	1,000 gallons per house per year			%	
	Total	Indoor	Outdoor	Indoor	Outdoor
Boulder, CO	134.1	57.4	76.7	42.8	57.2
Denver, CO	159.9	64.4	95.9	40.3	59.7
Eugene, OR	107.9	63.9	44	59.2	40.8
Las Virgenes, CA	301.1	71.6	229.5	23.8	76.2
Lompoc, CA	103	62.9	40.1	61.1	38.9
Phoenix, AZ	172.4	71.2	101.2	41.3	58.7
San Diego, CA	150.1	55.8	94.3	37.2	62.8
Scottsdale/ Tempe, AZ	184.9	61.9	123	33.5	66.5
Seattle, WA	80.1	49.5	30.6	61.8	38.2
Tampa, FL	98.9	53.9	45	54.5	45.5
Walnut, CA	208.8	75.3	133.5	36.1	63.9
Waterloo, ON	69.9	54.3	15.6	77.7	22.3
Average	147.6	61.8	85.8	41.9	58.1
Standard deviation	64.80	8.00	58.98		
Coefficient of variation	0.44	0.13	0.69		

Estimates were based on one year of monthly meter readings. Indoors water use is estimated by averaging water use during the non-irrigation season.

The majority of residential water use in Boulder (57%) and Denver (60%) was for outdoor purposes, primarily lawn watering. While the variability in indoor water use for cities across north America was low, it was much higher for outdoor water use.

Indoor water use patterns for Boulder and Denver were compared to indoor use in the other 10 cities in Table (2-2).

Table (2-2): Summary of Indoor Water Use for 12 Cities in North America (Heaney et al., 2002).

	All values in gallons per capita per day				% of
	Boulder	Denver	Other	Average	
User Category	Colorado	Colorado	10 cities	12 cities	Indoor
Baths	1.4	1.6	1.1	1.2	1.7
Clothes Washers	14.0	15.6	15.0	15.0	21.6
Dish Washers	1.4	1.2	0.9	1.0	1.4
Faucets	11.6	10.5	10.9	10.9	15.7
Leaks*	3.4	5.8	10.5	9.5	13.7
Showers	13.1	12.9	11.3	11.6	16.7
Toilets	19.8	21.1	18.1	18.5	26.7
Other Domestic	0.2	0.5	1.9	1.6	2.3
Total indoor	64.9	69.2	69.7	69.3	100.0

* Leaks were assumed to be indoor . They were actually a combination of indoor and outdoor leakage .

Toilets were the major use of water indoors comprising 26.7 of the total, and other components were put in the previous table. The average water use rates per capita for Boulder and Denver were 64.9 and 69.2 gallons per capita per day(245.6 L/c/d and 261.9 L/c/d), with average indoor water use in 12 cities was 69.3 gpcd (262.3 L/c/d)

These results were higher than the previous studies that estimated it at about 60 gpcd (227.1 L/c/d) (Maddaus, 1987).

The major source of the difference was probably in how leaks were evaluated. Indoor residential water use per capita was quite stable in the United States reflecting the fact that it was for relatively essential purposes.

Outdoor water use exceeded indoor water use in more arid parts of the country. Also, it constituted the majority of the peak summer demand that taxed the capacity of urban water systems.

Loh and Coghlan (2003) studied domestic water use in Perth (the capital of the state of Western Australia) with a population of about 1.4 million persons over the period from November 1998 to November 2001.

Perth's total demand for scheme water 241 GL (GL=10⁹L), distributed as shown in Figure (2-1) below:

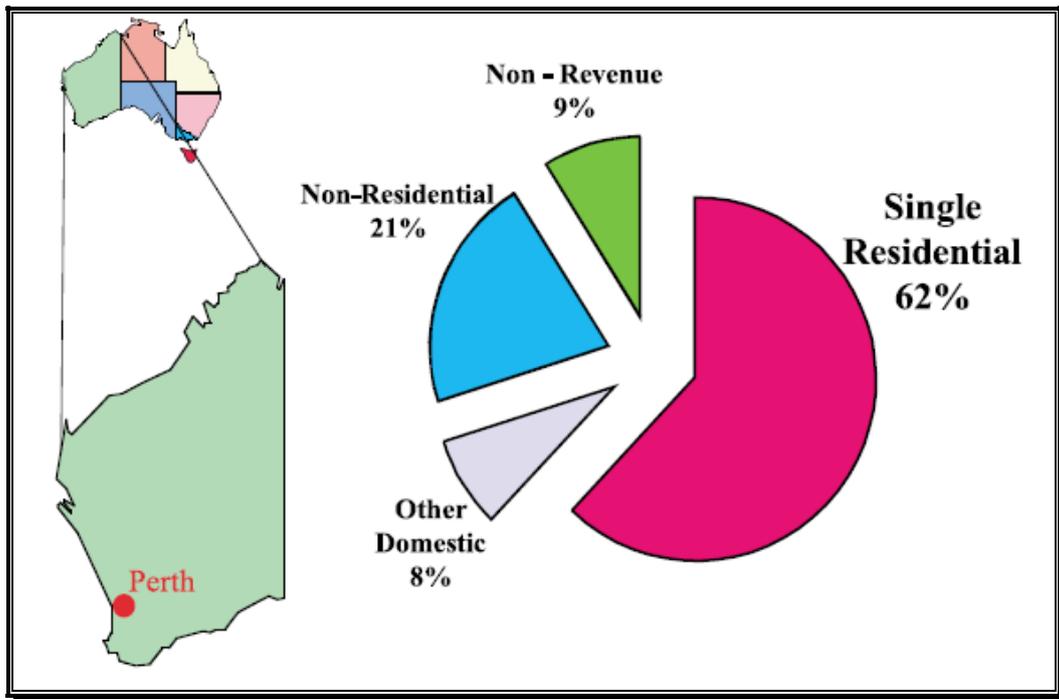


Fig.(2-1): Perth Metropolitan Water Use 1999 / 2000(Loh and Coghlan,2003).

A detailed study of domestic water use in Perth was last undertaken in 1981/82, almost 20 years ago (Metropolitan Water Authority, 1985).

In 1995, the Water Corporation of Western Australia completed the Perth Water Future Study (PWF) (Stokes et al, 1995) which committed the corporation to a new Domestic Water Use Study (DWUS) that would provide a more current understanding of domestic water use patterns and trends.

Statistical analysis of data collected from 1000 volunteer households, 720 of them represented single residential households and the other represented multi-residential household helped in determining the major variables affecting domestic water usage. The authors classified households type one into three levels: low, medium, and high income level.

For the single residential households, the study included questionnaire surveys which helped to collect data and they consisted of three separate questionnaires, the first used to cover ownership of water-using appliances and demographics. Two additional questionnaire surveys, one at the end of each of the two summer periods in the study time frame, covered attitudes to water use.

The rate of water usage during the winter period was essentially the same for all single residential households but higher income households use more water during summer. About the total water usage the authors found that the average total usage per household is shown in Table (2-3) below:

Table (2-3): The Average Total Usage per Household (Loh and Coghlan, 2003)

	L/house / day	% total use
Ex-house	707	56
In-house	523	42
Leaks	29	2
Total	1259	100

And the component usage per household was set out in Figure(2-2) below:

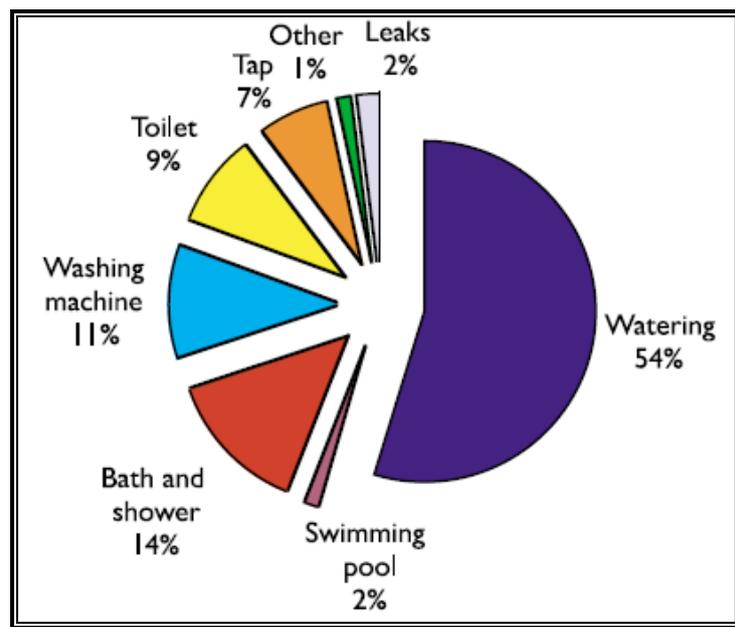


Fig.(2-2): Component Usage of Single Residential Household(Loh and Coghlan,2003).

For ex-house use, the average component usages per household are shown in Table (2-4) below:

Table (2-4): The average Component Usages per Household (Loh and Coghlan, 2003).

Component	L/house/day	%ex-house	% total use
Watering	687	97	54
Swimming pool	20	3	2
Total ex-house	707	100	56

Finally, they found that for ex-house usage and for single-residential households the ownership of reticulation systems off the mains has increased considerably from only 5% in 1981 to over 41% in 1998.

About 25% of households own a fully automatic system.

There was no strong relationship between irrigable area and total ex-house water usage, that means many households were watering inefficiently.

Highly income households used more water with almost all of this used ex-house, and because of using an automatic reticulation system they consumed water with an average more greater than the households without an automatic reticulation system.

Thus, the authors mentioned that a major influence on ex-house water usage is the ownership of an automatic reticulation system.

For in-house usage with single residential households, the per capita usage at about 155 L/person/day has remained the same since 1981.

They found that the toilet usage has decreased from 32% to 21% of in-house usage due to increased ownership of dual flush toilets (from 1% in 1981/82 to 65% in 1998/2000), but washing machine usage has increased from 18% to 27%. This is due to the increase in the ownership of automatic washing machines from 64% to 93% and in their capacity since 1981/82.

There have been small increases in the ownership levels of other in-house appliances including dishwashers, evaporative air conditioners and spas.

The average component usages for in-house use per household are shown in Table (2-5) below:

Table (2-5): The Average Component Usages for In-House Use Per Household(Loh and Coghlan,2003).

Component	L/house/day	%in-house	% total use	L/person/day
Bath and shower	171	33	14	51
Washing machine	139	27	11	42
Toilet	112	21	9	33
Tap	83	16	7	24
Other	18	3	1	5
Total in – house	523	100	42	155

2.1.3 Analysis of Water Demand Data Arranged Chronologically and Cross- Sectionally

Danielson (1979) estimated residential water demand based upon pooled data of monthly cross-section and time series meter readings from a random sample of 261 households in the city of Raleigh, North Carolina. The data for his analysis were observed cross-sectionally over 68 time periods of approximately 30 days each, from May 1969 to December 1974. The demand model was estimated as a function of temperature, rainfall, house value, water price, and household size. Households were deleted from the sample if the family occupying the home moved during the sampling period or if a complete set of data was not available for some other reason.

Demand relations were estimated for total, winter, and sprinkling residential water demands. Total residential water demand is that quantity of water consumed in a given period for all residential purposes including

in-house purposes (e.g., in kitchens, bathrooms, laundry rooms, and for outside purposes (e.g., for washing cars, and sprinkling lawns).

During the winter, total residential demand was assumed to equal in-house demand. During the summer season it was assumed to equal in-house demand plus outside (sprinkling) demand.

Sprinkling use per period per customer for each year was estimated by subtracting winter (November – April) from summer (May – October) use. The estimated sprinkling demand was found to be highly responsive to changes in water price and the level of the climatic variables (inversely correlated with rainfall per unit of time and was positively correlated with average temperature), while the total and winter demands were less responsive to price changes.

Lot size was found to be collinear with house value, thus, it was deleted, while household size explained the largest proportion of the variation in the data.

The model of this study was double-log in estimating regression equation for total, winter, and sprinkling residential demand, and reported that estimates of coefficient of correlation were not valid because of data transformations made to overcome the problem of serial correlation.

Howe (1982) developed a new set of demand functions based upon new ‘insights and their implications’ using the original Johns Hopkins Residential Water Use Project data from 1963-1965.

This data was originally used in one of the earliest studies to describe demand function for residential water use (Howe and Linaweaver, 1967).

The data was collected from 21 geographical locations: 11 in the Eastern United States, and 10 in the West.

- I- Winter demand function (combined between East and West i.e. based on 21 areas):

$$q_w = 234 - 7.20 D_w + 4.04V - 127.9 P_w \quad \dots(2.12)$$

II- Summer demand function:

East:

$$q_s = 385 - 12.11D_s + 8.01V - 795.60P_s + 157.77MD \quad \dots (2.13)$$

West:

$$q_s = 430 + 57.77D_s + 13.11V - 342.63P_s - 39.98MD \quad \dots (2.14)$$

where:

q_i = the number of gallons demanded per house per day ($i=w,s$; w =winter; s =summer); v = residential property value (thousand of dollars); D_w =intra marginal rate of structural quantity for winter; P_i = marginal price for water usage (dollars); $D_w=TR_{min.}-Q_wP_w$; $TR_{min.}$ =total revenue per billing period during winter month; Q_w =quantity demanded per household or billing period during winter months; $D_s=TR_{max.}-Q_sP_s$, $TR_{max.}$ =total revenue per billing period during summer time; Q_s =quantity demand per billing period during summer months.

The moisture deficit, MD is defined as: $MD = b(w_r-0.6r_s)$; where b =outdoor irrigable area in square feet; w_r =summer average potential evapotranspiration rate, and r_s =the average summer precipitation rate.

The author found that the marginal price elasticity for winter was -0.06, whereas the marginal price elasticities for summer were -0.568 for the East, and -0.427 for the West. Compared to the price elasticities estimated by Howe and Linaweaver (1967), the current re-estimated price elasticities were much smaller for winter as well as for summer periods. This study's re-estimated value for winter was -0.06 compared to -0.23 obtained by Howe and Linaweaver (1967).

The re-estimated price elasticities for summer in the East and West were -0.568 and -0.427, respectively, compared to -0.860 and -0.519 obtained by Howe and Linaweaver.

Billings and Mark Day (1989) run two models of urban residential water demand with time-series and cross-section data from three utilities

in the Tucson, Arizona, metropolitan area to estimate the response of water use to variations in price, household income, and a variety of socioeconomic and climatic variables. Demand models were estimated using average price in the first model and marginal price in the second cooperation with the other variables. The study covered the period between 1974-1980.

By multiple regression technique, the temperature was the most effective variable on water use that 1% increase in temperature cause 0.63,0.81 percent increase in water use in the average and marginal price model respectively.

The effect of price was negative with water use and ranged from -0.52,-0.7 in first and second model respectively.

Each regression had an adjusted R-squared of 0.84 (indicating that 84 percent of the observed variation in water use was explained by the regression equation), and other test statistics demonstrated that the models were highly significant.

Related to the type of price he found that demand responded to the average price more than that to the marginal price.

Griffin and Chang (1990) investigated the use of average price versus marginal price in the analysis of community water demand.

Monthly water quantity for thirty communities was obtained from the annual reports of the Texas Water Development Board. Water and sewer rates for the period from January 1981 to December 1986 were obtained from utilities using a mail survey. Information on personal income and ethnicity were taken from U.S. census, and data from nearby weather stations were used to calculate monthly climatic variables information.

By using ordinary least square method, the demand for residential water in thirty communities was estimated as the following model:

$$Q = 26.84 - 26.78 AP - 1.23 PO + 5.36 CH + 9.95 I + 0.185 SP + 0.0731 C \dots\dots$$

.....(2-15)

$$(2.21) \quad (-11.91) \quad (-0.35) \quad (-1.55) \quad (7.88) \quad (0.70) \quad (23.67)$$

(R²=0.47; n=1031) Note: figures in parentheses are the t-values.

Where:

Q = per capita residential and commercial water consumption (gallons per capita per day); AP = average price of water paid by an average 2.84 person household; MP = marginal price of water paid by an average 2.84 person household (average and marginal price included both water and sewer rates); PO = difference between marginal and average price (MP-AP); CH = rate change dummy variable (1 if a rate change occurred during the current or previous two months, zero otherwise); I = annual personal income per capita (thousands of dollars); SP = percent of the population of Spanish origin; and C is a climatic variable (number of days without rainfall 0.25 inches times average monthly temperature in Fahrenheit). The average price and PO were included in order to compare the sensitivity of average price and marginal price to the demand function.

The study concluded that the model was more sensitive to average price than to the marginal price. The unique climatic variable developed for this study was highly significant.

Nieswiadomy (1992) estimated water demand in the U.S. using AWWA (1984) data. Three different models (marginal price model, an average price model, and Shin's price perception model) were estimated for four regions of the country. The data were obtained from a survey of 430 water utilities in the United States with populations over 10000 conducted by the American Water Works Association (AWWA).

The monthly rainfall and temperature data were obtained from the National Oceanic and Atmospheric Administrations Climatological data and the demographic data was taken form the Department of Commerce.

The U.S. was divided into four regions: (1) North Central; (2) Northeast; (3) South; (4) West.

The general model used was linear in logarithmic form. The variables included in the model were: Monthly water use (Q) in 1000 gallons per household, which was assumed to be a function of per capita monthly income (I); marginal price, in dollars per 1000 gallons (MP); ratio of the average monthly price per household to the marginal price (AP/MP); average monthly rainfall for the months between the last spring freeze month and first fall freeze month (R); average temperature for the months between last spring freeze month and first fall freeze month (T); number of persons per household in 1980 (pers); percentage of homes built before 1939 (Home); percentage of homes that are owner occupied in 1980 (O_{cc}); conservation program (Cons) where the value was 1 or 0; and public education program (Pub Ed) where the value was 1 or 0.

The models were estimated using marginal and average price for each region.

The author concluded that Southern and Western areas had higher price elasticities than the other two regions. He suggested that consumers in these areas are more responsive to shortages of water.

Conservation did not decrease water use, but public education appeared to reduce water usage in the West. Nieswiadomy concluded that, based on Shin (1985) price perception tests, consumers react more to average price than marginal price in all regions.

It is worth noting that in a study based on AWWA (1970) data Williams (1985) observed that consumers reacted more to marginal prices.

Michelsen et al. (1998) developed three residential water demand models to investigate consumer response to the effects of price and nonprice conservation programs and other factors that influence demand on single-family residential consumption in different urban areas of the Western U.S.

Seven study areas were selected with the cooperation of water utilities in three southwestern states information on residential water consumption, rate structures, revenue and nonprice conservation programs covering the period from 1984 through mid-1995.

The study area cities were: Los Angeles and San Diego, California; Broom field and Denver, Colorado; and Albuquerque, Las Cruces and Santa Fe, New Mexico. The objectives of this study were summarized in collection, enter a database and document water demand information for selected regions in Southern California, Colorado and New Mexico, analyzing the data using statistical methods to identify trends in residential water use, impacts of water conservation efforts, socioeconomic, and climatic – related parameter changes.

All the above helped to develop three models of water demand that can be broadly applied in different urban and regional areas.

By this study, the authors needed to explore the interaction of weather, price and conservation programs.

A database of the residential water demand information was created and consisted a series of monthly observations for all the water demand variables for each study area, which was developed, refined and analyzed using maximum likelihood regression of the pooled ten-year time series, cross-section.

The first model (Regional) assumed that consumers in different cities respond similarly across the region and throughout the year to a rate

structures, price levels, nonprice conservation programs, climate, income and other factors.

The second model (Season Specific) was designed to investigate seasonal variations in consumer response across the region to changes in rate structure and other factors mentioned above.

The third model (City Specific) was designed to investigate individual city and seasonal variations in consumer response to all the factors above. After applying statistical analysis procedure, all three models predicted water demand with a high degree of accuracy and almost all of the coefficient estimates were statically significant and had the expected demand relationship, but Regional model compared water use patterns across cities while the Season Specific model was a variation of the Regional model that looked at water behavior during specific seasons of the year. The City Specific model evaluated water use patterns in individual cities.

Climate affected residential use in a predictable ways, i.e. when water use was strongly correlated with average monthly temperature and seasonal variation in temperature.

Precipitation was consistently insignificant in all models when all cities were semi-arid to arid in climate, and thus the ratio of evaporation to precipitation was much greater.

Random and infrequent rains did not change residential watering patterns to significant degrees.

Other variables, such as residential income and the size of the city, also vary but their influence was estimated to have a relatively minor impact on residential use.

Finally, their results indicated that nonprice conservation programs were effective.

CHAPTER Three

THEORETICAL BACKGROUND

3.1 Introduction

This chapter is arranged to give a theoretical background on the statistical model which is used in this study; and its application on the data of metered water consumption readings. As well as it will review the methods of finding the suitable model for types (total, winter, summer, and sprinkling) water demand, and goodness of fit tests required in the final model.

3-2 Graphical Representation (Analysis) of Data

It is the first step in data analysis, when data is organized into a frequency distribution, they can be presented in a graphical form. The purpose of graphs in statistics is to convey the data to the viewer in pictorial form. It is easier to comprehend the meaning of data presented graphically than data presented numerically in tables or frequency distributions. Statistical graphs can be used to describe the data set or analyze it. Graphs are also useful in getting the audiences attention in a publication or a speaking presentation. They can be used to discuss an issue, reinforce a critical point, or summarize a data set. They can also be used to discover a trend or pattern in a situation over a period of time (Bluman, 2001).

There are three types of graphs which are commonly used to present data such as: histogram or frequency histogram, frequency polygon, and the ogive (Spear, 1969; Spiegel, 1972; Hayslett, 1974; Mason, 2000; Bluman, 2001):

3.2.1 The Histogram

It is one of the most common types of graphs to display the classified data by using vertical adjacent bars of various heights to represent the frequencies. That means that the classes of selected intervals of the random variable are marked on the horizontal axis and the frequency of occurrence on the vertical axis.

3.2.2 A Frequency Polygon

It is a line graph of classes frequencies plotted against class marks. It can be obtained by connecting midpoints of the tops of the rectangles in the histogram.

3.2.3 Cumulative Frequency Distribution (Ogive)

The graph of the cumulative frequency distribution is called an ogive. Many ogives have an appearance which is distinctly S-shaped. It represents the cumulative frequencies for the classes in a frequency distribution.

The graph is polygon constructed of line segments connecting points plotted for the cumulative number (or percentage) of observations at each division point of the horizontal axis.

Dots are placed opposite to each value of observation, at whatever frequency (or number of observations) is appropriate, to indicate how many observations are less than the value.

The cumulative sum (cusum) chart is constructed by plotting the sum of the numbers L_i , that is plotting:

$$S_n = \sum_{i=1}^n L_i \quad \dots (3.1)$$

Where n is the size of the sample, ($n=1, 2, 3, \dots$), and L is the number (or percentage) of observations.

3.3 One Sample Test of Mean

Statistically, the study sample is classified as a large sample when the sample size is larger than or equal to 30, therefore, the formula of z-distribution (standardized normal) test would be used with the case of unknown variance of population to test a hypothesis about the mean of a population.

The z-expression is as follows (Hayslett, 1974; Mason, 2000; Bluman, 2001):

$$z = \frac{\bar{x} - \mu}{s/\sqrt{n}} \quad \dots (3.2)$$

where \bar{x} = sample mean.

n = sample size in which \bar{x} is respectively, the mean

S = standard deviation of sample

μ = population mean for water consumption

$$s = \sqrt{\sum (x_i - \bar{x})^2 / (n-1)}, i = 1, 2, 3, \dots \quad (3.3)$$

The hypothesis that is usually tested is ($H_0: \mu = \mu_0$) or $H_0: \mu - \mu_0 = 0$

- **Procedure for Testing $H_0: \mu = \mu_0$ Versus Alternative Hypothesis (Variance Unknown), $H_1: \mu > \mu_0$ (Hayslett, 1974; Mason, 2000):**

1. Formulate the null and alternative hypothesis :

$H_0: \mu - \mu_0 = 0$ as null hypothesis versus

$H_1: \mu > \mu_0$ as alternative hypothesis.

2. Decide upon the α -level of the test (always it is taken as $\alpha = 0.05$ in engineering applications) and then find the tabulated value of z .

3. Calculate \bar{x} of the sample.
4. Estimate the value of S from Equation (3.3) of sample when σ of population is unknown.
5. Calculate Z from Equation (3.2).
6. Make the decision to reject or accept the null hypothesis.

When $H_1 : \mu > \mu_o$. This is a one – tailed test . Refer to Z_α , the critical region consists of all values greater than or equal to Z_α as shown in Figure (3-1).

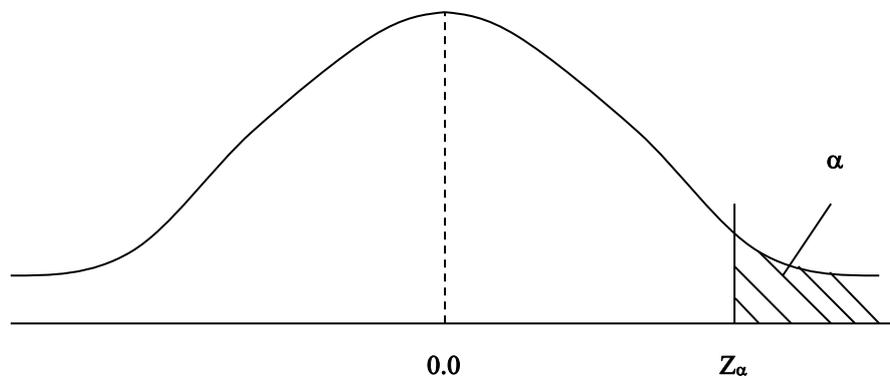


Fig.(3-1): Standard Normal Distribution Curve for Z-Test (One-tailed test)(Hayslett,1974).

Reject H_o if calculated Z is in the critical region. Accept H_o otherwise, this means that there is a significant difference between μ and μ_o (i.e. $\mu > \mu_o$).

3.4 Residential Water Demand Analysis

Residential demand analysis is an effort to understand the relationship between the different variables that influence demand. Two approaches are most common (Kindler and Russell, 1984):

- Statistical – it is a numerous attempts – trying to infer from observations pertaining to many users at a point in time, or the same user over a period of time, or from combination of both

types of observations, the structure of the water demand relations producing the observations.

- Engineering – attempt to construct the relation from fairly detailed engineering knowledge of the production or consumption unit processes, and the associated substitution possibilities, carried out by activity.

In addition, there is another approach – the requirements approach, it is noted with fixed water requirements or "need" inferred from total sales and production in utility service areas.

The engineering approach is seldom used outside industrial category, because of its special attention on unit processes and flow between units. As far as the requirements approach is concerned, it is normally oversimplified by relating the demand to only one variable such as population based on per capita projection technique and historical data. This limitation has been proved by many studies in residential water use. Thus, the statistical approach is usually taken into consideration of many water demand determinants and is widely used among municipal water planners.

3.4.1 The Statistical Approach

Residential water analysis suggests to view water consumption as a result of a number of explanatory factors. This nature of residential water demand makes it the most suitable domain to be subjected to statistical analysis, especially multiple regression analysis. In fact, the progression of 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 et al., 1984).

3.4.1.1 The Regression Analysis Technique

Regression analysis is used for explaining or modeling the relationship between a single variable Y , called the response, predicted, estimated, or dependent variable, and one or more predictor, explanatory or independent variables, x_1, \dots, x_k . When $k=1$, it is called simple regression but when $k>1$ it is called multiple regression.

The most important use of the technique is to find the best predictive model with a minimum number of independent variables.

The coefficient of determination (R^2) reflects the overall accuracy of any predictive model (Draper, 1966; Amara and Taofeek, 1990; Wonnacott, T., and Wonnacott R., 1990; Keller and Warrack, 1994; Mason et al., 2000; Faraway, 2000; Bluman, 2001; Dancey and Reidy, 2002; Abdi, 2003).

The various elements of multiple linear regression equation can be illustrated from the general form of the following equation (Mason, 2000; Bluman, 2001, 2001; Abdi, 2003):

$$\hat{Y} = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + \dots + b_k x_k \quad \dots (3.4)$$

Where \hat{Y} is the predicted value of the dependent variable.

x_1, x_2, \dots, x_k are the independent variables (predictors).

b_0 is the intercept coefficient (constant), or the value of the dependent variable when the independent variables are zero.

b_1, b_2, \dots, b_k are the partial regression coefficients of the independent variables.

k is the number of independent variables included in regression equation.

3.4.1.1.1 The Principle of Least Squares

Bryant, 1966; Volk, 1969; Mason, 2000; Johnson, 2003, explained 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 vertical distances between the actual Y values (measured) and the predicted values \hat{Y} . To illustrate this concept, it is important to define the error, e , (or residual).

$$e_n = Y_n - \hat{Y}_n \quad \dots (3.5)$$

In which e is the difference between the predicted (\hat{Y}) and measured (Y) value of the dependent variable, n is the size of the sample.

The positive value of e indicates over-prediction, while a negative residual indicates under-prediction. The principle of least squares is to minimize the sum of the squares of the errors;

$$S_e = \min \sum_{i=1}^n e_i^2 \quad \dots (3.6)$$

$$S_e = \min \sum_{i=1}^n (\hat{Y}_i - Y_i)^2 \quad \dots (3.7)$$

For simple regression analysis \hat{Y} equal:

$$\hat{Y} = b_0 + b_1 x \quad \dots (3.8)$$

By substituting Equation (3.8) in Equation (3.7) gives;

$$S_e = \min \sum_{i=1}^n (b_0 + b_1 x_i - Y_i)^2 \quad \dots (3.9)$$

Here S_e is a function of b_0 , b_1 and for min (S_e):-

Put S_e derivatives with respect to b_0 and b_1 equal to zero:

$$\frac{\partial S_e}{\partial b_0} = \sum_{i=1}^n 2(b_0 + b_1 x_i - Y_i) = 0 \quad \dots(3.10a)$$

$$\frac{\partial S_e}{\partial b_1} = \sum_{i=1}^n 2(b_o + b_1 x_i - Y_i)(x_i) = 0 \quad \dots(3.10b)$$

Then the two equations are solved:

$$nb_o + \sum_{i=1}^n b_1 x_i = \sum_{i=1}^n Y_i \quad \dots(3.11a)$$

$$\sum_{i=1}^n b_o x_i + \sum_{i=1}^n b_1 x_i^2 = \sum_{i=1}^n x_i Y_i \quad \dots(3.11b)$$

In Matrix

$$\begin{vmatrix} n & \sum x_i \\ \sum x_i & \sum x_i^2 \end{vmatrix} \begin{vmatrix} b_o \\ b_1 \end{vmatrix} = \begin{vmatrix} \sum Y_i \\ \sum x_i Y_i \end{vmatrix}$$

Solution of equations (3.11a) and (3.11b) gives:-

$$b_1 = \frac{\sum xY - (\sum x \sum Y)/n}{\sum x^2 - (\sum x)^2/n} \quad \dots(3.12a)$$

$$b_o = \bar{Y} - b_1 \bar{x} = \frac{\sum Y}{n} - \frac{b_1 \sum x}{n} \quad \dots(3.12b)$$

For multiple regression analysis, refer to Equation (3.4), using the principle of least squares. From Equation (3.7), the objective function becomes:

$$S_e = \min \sum_{i=1}^n e_i^2 = \min \sum_{i=1}^n \left(b_o + \sum_{j=1}^k b_j x_{ij} - Y_i \right)^2 \quad . (3.13)$$

Where i indicating the observation and j is the specific dependent variable.

The method of solution is to take the $(k+1)$ derivatives of the objective function (3.13), with respect to the unknowns, b_o and b_j , ($j=1, 2, 3, \dots, k$); setting the derivatives equal to zero; and solving for the unknowns. The equations obtained will be as follows:-

$$\begin{aligned}
nb_0 + b_1 \sum x_1 + b_2 \sum x_2 + b_3 \sum x_3 + \dots + b_k \sum x_k &= \sum Y \\
b_0 \sum x_1 + b_1 \sum x_1^2 + b_2 \sum x_1 x_2 + b_3 \sum x_1 x_3 + \dots + b_k \sum x_1 x_k &= \sum x_1 Y \\
b_0 \sum x_2 + b_1 \sum x_2 x_1 + b_2 \sum x_2^2 + b_3 \sum x_2 x_3 + \dots + b_k \sum x_2 x_k &= \sum x_2 Y \\
b_0 \sum x_3 + b_1 \sum x_3 x_1 + b_2 \sum x_3 x_2 + b_3 \sum x_3^2 + \dots + b_k \sum x_3 x_k &= \sum x_3 Y \\
&\vdots \\
b_0 \sum x_k + b_1 \sum x_1 x_k + b_2 \sum x_2 x_k + \dots + b_k \sum x_k^2 &= \sum x_k Y
\end{aligned}$$

... (3.14)

Where n =number of observation set of data points.

Equations (3.14) can be solved by any method for the solution of simultaneous linear equations to evaluate the regression coefficients b_1, b_2, \dots, b_k , and the intercept b_0 . (Bryant, 1966; Volk, 1969; Spiegel, 1972; Mason, 2000; www.public.iastate.edu/~mervyn/stat401/Trans/tr11-4.pdf).

3.4.1.1.2 Multiple Regression Computations Using Matrix Notation.

Matrix notation is a method used to determine the regression coefficients.

Let Y ($n \times 1$ vector) refer to a column of y values (average consumption value for each house) and the symbol X refers to a "matrix" of the independent variables and each row represents one observation (house) with all its independent variables values which are known from the data. Figure (3-2) shows the structure of the X and Y matrices.

$$X = \begin{bmatrix} 1 & x_{11} & x_{12} & \cdot & \cdot & x_{1k} \\ 1 & x_{21} & x_{22} & \cdot & \cdot & x_{2k} \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ 1 & x_{n1} & x_{n2} & \cdot & \cdot & x_{nk} \end{bmatrix}, \quad Y = \begin{bmatrix} y_1 \\ y_2 \\ \cdot \\ \cdot \\ y_n \end{bmatrix}$$

Fig.(3-2): The Structure of the X and Y Matrices.

Where n = number of observations.

K = number of independent variables included in regression equation.

The constant 1 is for the intercept term, b_0 .

Similarly, the unknown term (regression coefficients) can be written in $n \times 1$ vector:

$$b = \begin{bmatrix} b_0 \\ b_1 \\ \cdot \\ \cdot \\ b_k \end{bmatrix}$$

For n observations, the linear regression model may be written in the form:

$$Y = X b \quad \dots \quad (3.15)$$

Finally, these equations are solved to determine b 's value by using matrix algebra (numerically stable methods).

$$X^T = \begin{bmatrix} 1 & 1 & 1 & \cdot & 1 \\ x_{11} & x_{21} & \cdot & \cdot & x_{n1} \\ x_{12} & x_{22} & \cdot & \cdot & x_{n2} \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ x_{1k} & x_{2k} & \cdot & \cdot & x_{nk} \end{bmatrix}$$

Where X^T =transpose of matrix X , which means that a matrix is "rotated" on its axis.

The solution may be written in the form

$$\hat{b} = (X^T X)^{-1} X^T Y \quad \dots(3.16)$$

Where \hat{b} = estimated value of regression coefficient.

(www.public.iastate.edu/~mervyn/stat401/Trans/tr11-4.pdf);

Lib.stat.cmu.edu/~kass/smn/notes/9/pdf; www.economics.utoronto.ca/benjamin/Lecture5pdf; Faraway, 2000; Johnson, 2003; Abdi, 2003).

3.5 Computer Program, SPSS

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, \dots). The method of stepwise multiple regression analysis is used to make regression analysis which is essentially a forward selection procedure. In this procedure, a variable that is entered in the earlier stages of selection may be eliminated at later stages. (McCune, 1985; Kinnear, 1995; Ganeem and Sabri, 2000; Dancey, 2002).

3.6 Assessing the Model

In almost all applications of regression analysis, it is important (for at least two reasons) to assess, or judge, the usefulness of the model. First, the researcher frequently has more than one model available that one could use, thus, a measure should be depended on comparing the appropriateness of competing models. Second, it is needed to know whether the model selected is likely to be useful in predicting and analyzing relationships.

It must be noticed that higher value of R^2 does not necessarily give a good fit, but there are other tests like F-test, t-test, and standard error of estimate (Keller, 1994; Bluman, 2001).

3.7 Output Tables of Data

The output data for each model should be arranged in three tables; model summary, ANOVA (analysis of variance), and coefficients table (Table 3-1, Table 3-2, and Table 3-3 respectively), (Kinnear, 1995; Ganeem and Sabri, 2000; Mason, 2000; Dancey, 2002).

A-The Model Summary Table

This table Includes an assessment of the adequacy of fit after fitting the model to a given body of data. The multiple determination coefficient R^2 is the most widely used measure, defined as:

A measure of the variation of the dependent variable that is explained by the regression line and the independent variables. It is computed by squaring the coefficient of correlation, R and it can assume any value between 0 and +1. Mathematically it is the sum of squares due to the regression divided by the total sum of squares (Wonnacott, T., and Wannacott, R.,1990; Mason, 2000; Dancey, 2002).

Table (3-1) :The Summary Model(Isehak,2001).

Model	R	R-square	Adjusted R square	Std. Error of Estimate
M ₁	$(R^2)^{1/2}$	SSR/SST	$adj.R^2 = 1 - \left(\frac{n-1}{n-k-1}\right)(1-R^2)$	$SE = [SSE / n - k - 1]^{1/2}$

$$R^2 = SSR / SST = 1 - (SSE / SST) \quad \dots (3.17)$$

Where;

R^2 = coefficient of multiple determination;

SSR = sum of squares for regression = $\sum (\hat{Y} - \bar{Y})^2$;

SST = sum of squares for total = $\sum (Y - \bar{Y})^2$;

SSE = sum of squares for error = $\sum (Y - \hat{Y})^2$;

\hat{Y} = values of dependent variable due to regression model;

\bar{Y} = the mean of given Y values = $\sum Y / n$; and

Y = is the observation.

The coefficient of correlation R is defined as a measure of the strength or the correlation between all X 's, and Y (Dancey, 2002). It can be obtained by taking square root of the value of R^2 (Bluman, 2001):

$$R = \sqrt{R^2} \quad \dots(3.18)$$

When the model fits the data well, the value of R^2 is close to unity, but if there is no relationship between the dependent variable and the independent variables, the linear model gives a poor fit, R^2 will be near zero.

When the Y values are entirely random, R^2 is corrected for this randomness by the adjusted R^2 and the later is considered a measure of a better goodness of fit . (Wonnacott, T., and Wonnacott, R., 1990; Bluman, 2001; www.unesco.org/webworld/idams/advguide/Chapt5-2.htm):

$$adj.R^2 = 1 - \left(\frac{n-1}{n-k-1}\right)(1-R^2) \quad \dots (3.19)$$

Where k is the number of independent variables in the model and n is the number of observations.

Multiple standard error of estimate measures the dispersion of the actual Y values about the regression line (Mason, 2000).

It is reported in the same units as the dependent variables, and is defined by (Keller, 1994; Mason, 2000):

$$SE = \left[\sum (Y - \hat{Y})^2 / n - k - 1 \right]^{1/2} = [SSE / n - k - 1]^{1/2} \quad \dots (3.20)$$

B-The ANOVA Table

The components of the variation of the dependent variable Y are represented by the analysis of variance table ANOVA.

When the model has k independent variables, the sum of squares due to regression has k degrees of freedom related with it.

When values of k coefficients and intercept have been estimated, the sum of squares due to residual has $n-(k+1)=n-k-1$ degrees of freedom related with it. Table (3-2) shows the mean squares for regression model with an intercept (constant). Then MSE will equal to $SSE/(n-k)$, MST will equal SST/n , and MSR will be the same when the model is without constant (Dancey, 2002).

Table (3-2): ANOVA Table (with constant)(Isehak,2001).

Model	Sum of squares	Degree of freedom	Mean squares	F value	Sig.
Regression	SSR	k	MSR=SSR/k	MSR/MSE	
Residual	SSE	n-k-1	MSE=SSE/(n-k-1)		
Total	SST	n-1			

The ANOVA table provides an F-statistic to test the significance of the results or to test whether the model fits the data (evaluating the significance of regression equation).

It is the basic ratio for testing the significance. In this test the resulting mean squares due to regression are divided by the mean squares due to the residual to obtain the value of F.

Procedure for F-Test

- 1- Formulate the hypothesis of null and alternative :

$$H_0: b_1=b_2 = \dots b_k=0 \quad (\text{null hypothesis});$$

H_1 : at least one of b_j is not equal to zero (i . e . there is at least one model regressor explains some of the response variation).

- 2- Find MSR and MSE from equations shown in Table (3-2).
- 3- Calculate F statistic using the following equation:

$$F = MSR/MSE \quad \dots (3.21)$$

- 4- Assume significance level (usually $\alpha=0.05$).
- 5- Find tabulated F, $[F_\alpha(k,n-k-1)]$, with α and degree of freedom related to regression and the error.

- 6- Compare the tabulated F with the value of F-statistic.
- 7- If the value of F-statistic is greater than F-table, then the regression equation is significant, and R^2 is significant with α chance of being wrong (Keller, 1994; Bluman, 2001).

C- The Coefficients Table

This table provides the values of coefficients of multiple regression model in addition to their standard error. The standardized coefficients (Beta coefficients)(percent prediction of independent variable in estimated dependent variable) are also found in this table to make comparisons between regression coefficients, and its equation is:

$$B_k = b \left[\frac{SX_k}{SY} \right] = b_k \left[\frac{\sum_{i=1}^n (X_{i_k} - \bar{X}_k)^2}{\sum_{i=1}^n (Y_i - \bar{Y})^2} \right]^{1/2} \quad \dots(3.22)$$

This table has the t-ratio which is based on the ratio of the regression coefficient to the standard error of the regression coefficient for the independent variable. This test is made to check the significance of the regression coefficients.

Table (3-3): Coefficients Table (Isehak,2001).

Model	Unstandardized coefficients		Standardized coefficients	t-values	Sig.
	B	Std. Error	Beta		
Constant	b_0	SE (b_0)		$b_0/SE(b_0)$	
Variable k coefficient	b_k	SE (b_k)		$b_k/SE(b_k)$	

Procedure for T-test to Test the Significance of the Regression Coefficients

- 1- Formulate the hypotheses of null and alternative:

$H_0: b_j=0$ (null hypothesis);

$H_1: b_j \neq 0$ (Alternative hypothesis).

- 2- Assume the significance level (usually $\alpha = 0.05$)
- 3- Compute the t-statistic value using the following equation (Wonnacott, T., and Wonnacott, R., 1990):

$$t = b / s(b) \quad \dots (3.23)$$

Where $s(b)$ is the standard error of the regression coefficient (b), and it is given by the following equation:

$$S^2(b) = MSE / \sum_{i=1}^n (x_i - \bar{x})^2 \quad \dots (3.24)$$

- 4- Estimate the t-table value related with $(n-2)$ degrees of freedom and the specified level of significance, $t_{\alpha/2} (n-2)$.
- 5- If $-t_{\alpha/2}(n-2) < t < t_{\alpha/2}(n-2)$, the null hypothesis is accepted and b is insignificant, and if $t \leq -t_{\alpha/2}(n-2)$, $t \geq t_{\alpha/2}(n-2)$, that means rejection of null hypothesis and the regression coefficient, b , is significant (Wonnacott, T., and Wonnacott, R., 1990; Kerller, 1994; Bluman, 2001).

3.8 Stepwise Regression Analysis Method

McCunce, 1985; Kinnear, 1995; Bluman, 2001; Dancey, 2002; explained multiple regression analysis as a type to develop a prediction equation relating a dependent variable to more than two predictors (or independent) variables, and calibrating a prediction equation. This method includes serial steps related with F-statistic to select which of the available independent variables will be included in the final regression equation.

For the F-test the following equations are used:

For total F-test (Bluman, 2001):

$$F = \frac{R_k^2 / k}{(1 - R_k^2) / (n - k - 1)} \quad \dots (3.25)$$

For partial F-test (McCune, 1985; www.unesco.org/webworld/idams/advgui.de/Chapt5-2.htm):

$$F = \frac{(R_k^2 - R_{k-1}^2)/q}{(1 - R_k^2)/(n - k - 1)} \quad \dots(3.26)$$

Where R_k is the multiple correlation coefficient for the equation which contains k predictor variables, and n is the number of observation on the dependent variable (Sample size). k is the number of the predictor variables and can vary from zero to q , q is the total number of the independent variables.

By stepwise regression method, the program is free to choose the best model with the suitable confidence for test (F-test)(lower than 5% for intering, and greater than 1% to remove the variable). Then, the independent variables are added to the predictive equation at serial steps, starting with an independent variable which has the highest value of correlation with dependent variable. The process of adding continues to maximize the total variation at each step.

At each step, and by the same time, the variables that are included in the equation are checked to see if they are still statistically significant, so that, a variable without longer significant is deleted.

CHAPTER FOUR

DATA COLLECTION AND QUESTIONNAIRES

4.1 Introduction

The analysis of this study is based on metered water consumption data for random sample of dwellings from different districts of Hilla city, observed cross-sectionally over the period from the 1st of January to the end of August, 2004.

A sample of houses was selected using a two – stage procedure. In the first stage, the houses supplemented by questionnaire surveys to obtain information related to household size, number and type of water – using appliances... etc which seemed necessary to estimate the per capita or per household daily consumption of domestic water.

The questionnaire survey are presented in Table (4-1) as a sample of the survey paper. There are some considerations which should be taken into account in selecting the dwelling:

1. The house should be provided with meter.
2. The water supply to each house should be adequate and continuous.
3. The water in each house should be supplied in adequate pressure to reach at least to the water tank on the first story of the house. That means the water pressure does not drop below 4.5 m.

Table (4-1): The Questionnaire Survey Paper

استمارة استبيان الرسالة الموسومة
دراسة تحليلية في استهلاك الماء الصافي المنزلي لمدينة الحلة
دراسة تحليلية لعينة من المنازل في الحلة

مقدمة:

إن هذا البحث للأغراض العلمية فقط، شاكرين تعاونك معنا مساهمة منك في إغناء هذه الرسالة بالمعلومات التي تهدف إلى تطوير استهلاك الفرد للماء الصافي في مدينة الحلة خدمة للصالح العام.

المعلومات:

1- عدد الساكنين في الدار	2- مساحة الأرض الكلية (م ²)	3- مساحة البناء الأول (م ²)
<input type="text"/>	<input type="text"/>	<input type="text"/>
4- مساحة البناء الثاني (م ²)	5- عدد غرف النوم	6- عدد مبردات الهواء
<input type="text"/>	<input type="text"/>	<input type="text"/>
7- عدد مكيفات الهواء	8- عدد الدوشات في الحمام	9- عدد المرافق الصحية
<input type="text"/>	<input type="text"/>	<input type="text"/>
10- عدد المغاسل (عدى مغسلة المطبخ)	11- عدد الحنفيات في الحديقة صافي خابط	12- هل الدار مزود بماء خابط
<input type="text"/>	<input type="text"/>	<input type="text"/>
13- عدد مكائن الغسيل	14- عدد السيارات	
<input type="text"/>	<input type="text"/>	

ولكم جزيل الشكر

الباحثة

إسراء سعدي عبد الأمير

4. The number of occupants in each dwelling should be almost the same during the period of analysis.

5. The researcher tried to confirm that the household did not leave the house during the period of analysis partially or otherwise.

If one or more of the above mentioned conditions was not found in any house, then the house was deleted from the list of questionnaire paper.

In the second stage of data collecting, the researcher worked hard to get new and identical charging meters to provide the main aims of the present study, and also to provide accurate results. The meters were supplied by Babylon Water Directorate and they were installed in the selected sites, and then removed after the study had been done.

In the present study , an additional number of dwellings have been chosen to have flexibility for excluding dwellings which have not the previous necessary conditions.

The readings of water consumption quantity for each house were taken **weekly** during the selected period. The readings of households water consumption quantities and questionnaire surveys were done by the researcher herself.

4.2 The Study Area

Hilla lies in the middle of Iraq, with a population of about 258568 person, living in an area of 55 km² according to Central Committee of Statistics – Babylon Census Directorate – 1997. Hilla river extends from the north to the south dividing the city into two parts: small eastern and large western part, the later consisted most of the urbanization expansions shown in Figure(4-1).

Hilla depends on surface water (specifically Hilla river which is a branch of the Euphrates river) to supply its growing population.

To achieve the aims of this study for a large society as Hilla city, it depends on a sample of nine districts(AL-Thawra(1),17 Tamooz(2),AL-Kerama(3),AL-Akrameen(4),Nadir1(5),AL-Iskan(6),AL-Theila(7),AL-Khusruyia(8),Hay-Babil(9)) to study this society in order to get the results. These districts were chosen with variety in the nature of construction, to reflect the environmental case of the city, and they lie in different parts of the city to include all of the sample as shown in Figure (4-2)

The climatic conditions (temperature, rainfall, and evaporation) in Hilla for the period of study are shown in Table (4-2) with temperature equalling to 42.74 C° as maximum average daily value for the summer season.

Table (4-2): Climatic Conditions in Hilla City for the Period (from the 1st of January to the End of August, 2004).

Variable	Average daily			
	Maximum	Month's No.	Minimum	Month's No.
Temperature(C°)	42.74	7,8	19.3	1,2
Rainfall (mm)	31	1	0.0	6,7,8
Evaporation(mm)	10.33	8	1.72	1

Source: Hilla Meteorological Station.

4.3 The Data

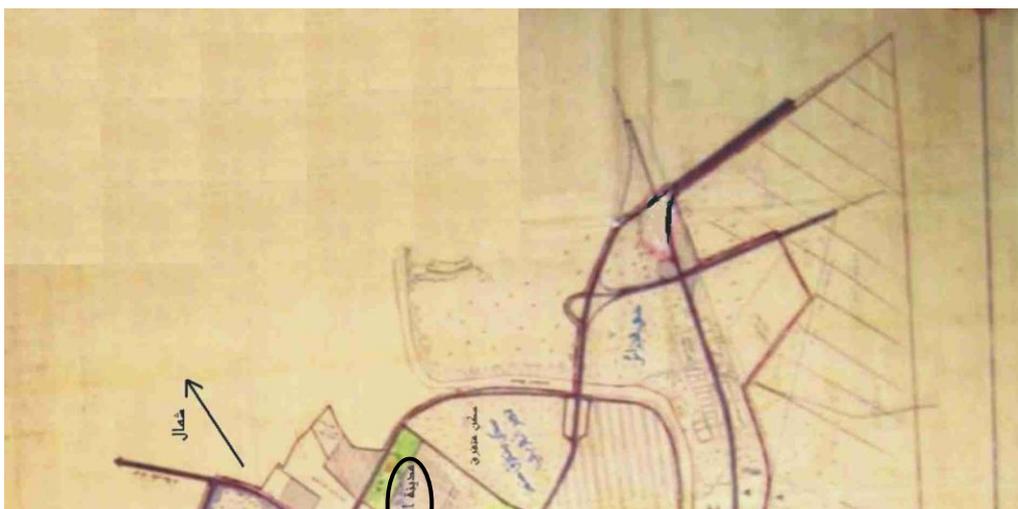
4.3.1 The Dependent Variable

In the present work, the quantity of water consumed was assumed to be the dependent variable and it varied by season. Therefore, in order to provide the main aims of the present study, the experimental works are divided into four separate main studies, each one deals with a specified model; (1) study no.1 (total residential water demand), (2) study no.2 (winter residential water demand), (3) study no.3 (summer residential water demand), and (4) study no. 4 (sprinkling residential water demand).

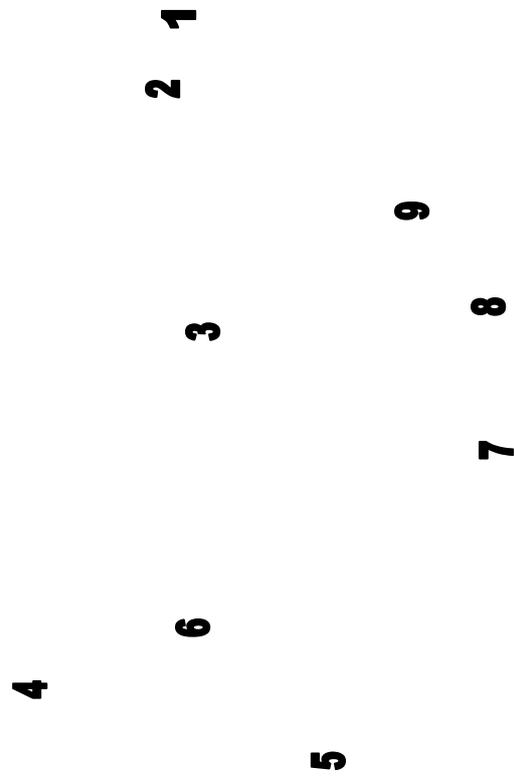


Fig.(4-1): The Main Design Chart of Hilla City Including the Locations of the Study Areas .

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



Hilla City.



4.3.1.1 Study No.1 (Total Residential Water Demand)

This model represents the observed average daily of total quantity of water consumed per house over all the period for all purposes (in-house; bathrooms, kitchens,... etc and out-house; sprinkling Lawn...etc).

4.3.1.2 Study No.2 (Winter Residential Water Demand)

It is also defined as non-seasonal demand which is the average daily demand for water during the period from the 1st of January to the end of February – 2004 and it includes in-house purposes when out-house purposes were hypothesized to be zero.

4.3.1.3 Study No.3 (Summer Residential Water Demand)

It includes the average daily water consumed for in-house purposes plus out-house (sprinkling) purposes from the 1st of July to the end of August – 2004.

4.3.1.4 Study No.4 (Sprinkling Residential Water Demand)

This model can be calculated by subtracting the observed winter water demand from the observed summer water demand for each house. It represents the water used for the out-house purposes only.

4.3.2 The Independent Variables

They are also named as explanatory variables or predictors. Each one of the four studies have specified independent variables which are assumed to have a reliable impact on domestic water consumption.

4.3.2.1 Number of Occupants (Household Size)

Number of occupants per dwelling unit represents the number of persons living in each house; it is also named as household size.

For the data sample used in this study, the household size per dwelling unit ranged between (1-11).

4.3.2.2 Total Built-Up Area of House

The total built up area of each house was measured in square meters and it varied between (95-650) m².

4.3.2.3 Area of Garden (Courtyard)

In this study, it is hypothesized to include the sprinkling area also, and was measured for each house by subtracting the built-up area of the first story of the house from the area of land.

It was measured in square meters and ranged between (10-462) m².

4.3.2.4 Number of Bedrooms

Number of bedrooms per dwelling unit was recorded and ranged between (1-4) bedrooms.

4.3.2.5 Number of Cars

It was recorded per dwelling unit and it varied between (0-2) in the data sample of this study.

4.3.2.6 Number of Fixtures

Number of fixtures per dwelling unit consists of :

1. Number of toilets;
2. Number of showers;
3. Number of washbasins;
4. Number of air-coolers;
5. number of air-conditioners;
6. number of taps in the garden;
7. number of washing machines.

All the above mentioned fixtures contribute in study no.1 and no.3 (total and summer residential water demand), while study no.2 (winter residential water demand) includes all the fixtures without the number of air-coolers, air-conditioners, taps in the garden variables and the rest can be defined as winter fixtures.

Sprinkling fixtures included in study no.4 (sprinkling residential water demand) are: air – coolers, air – conditioners, taps in the garden.

4.3.2.7 Raw Water Use

Raw water use is used as a dummy variable in each house, D , which equals 1 if the house was supplied with raw water, and zero if not.

CHAPTER

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE STUDIES

6.1 Conclusions

By the results analysis of the present study which was based on using stepwise multiple linear regression analysis, it was concluded that the most suitable predicting model for four types of residential water demand is a linear relation in (log-linear) form. This form is one of the transformation forms. Other conclusions can be drawn in the following four considerations:

6.1.1 Study No.1 (Total Residential Water Demand).

1. The most appropriate model with the most significant independent variables is:

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

The regression model shows that there is a positive impact of the four independent variables on total water demand and the contribution of each one unit for each previous independent variables is 2.042, 0.201, 0.00809, and 1.22 respectively for natural logarithmic transformation of dependent variable, while the percentage contribution power of x_5 , x_1 , x_9 , and x_4 in estimated demand is 36.2%, 17%, 28.2%, and 18.6% respectively.

2. It was found that the four predictors helped to predict annual water demand during the study period with high efficiency because ($t=6.005$, Sig. < 0.05 for number of washbasins , $t=3.047$, Sig. < 0.05 for household size , $t=4.626$, Sig. < 0.05 for total built-up area of house , $t=3.437$, Sig. < 0.05 for number of showers) .
3. It was found that 90% Of houses in the city consume (2077 L/h or less) of water per day .
4. During the total period of study , the minimum level of average daily consumption in the city occurred in winter time especially in the month of January , but the maximum level happened in summer season(August)

6.1.2 Study No.2 (Winter Residential Water Demand)

1. The most appropriate model with the most significant independent variables is:

$$\ln Q_{win..} = 0.884x_2 + 1.553x_5 + 0.162x_1 + 0.695x_3$$

Through regression equation , it can be seen that there is a positive impact of the four independent variables on winter water demand with contribution 0.884 , 1.553 , 0.162 , and .0695 for each one unit of each of previous independent variables respectively for natural logarithmic scale of water demand , while $x_2, x_5, x_1,$ and x_3 contributed in predication of water demand of a percent power of 36.3 % , 32.2 % , 16.1% , and 15.4 % respectively.

2. It was noticed that the four predictors helped to predict water consumption during winter season because ($t=5.6901$, Sig. <0.05 for number of bedrooms, $t=7.671$, Sig. <0.05 for number of washbasins, $t=3.191$, Sig. <0.05 for household size, $t=2.830$, Sig. <0.05 for number of toilets).

3. It was found that 90% of houses in Hilla consume (1.25 m³/h or less) of water per day.
4. The average daily winter water consumption in the city was found 60.7% of the total average daily consumption.
5. During the winter season, the minimum average daily consumption in the city happened in January.

6.1.3 Study No.3(Summer Residential Water Demand)

1. The final suitable model with the most significant independent variables is :

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

There is a positive impact of the four independent variables on Summer water demand . Each one unit on each independent variables appeared in regression model contributed by 2.609 , 0.211,0.006135 ,and 1.264 respectively for natural logarithmic scale of demand , while the percent prediction power of each independent variable in demand model was 44.1% , 17.05 % , 20.4% , and 18.45% respectively .

2. The four predictors helped to predict summer water demand during the summer season with high efficiency because($t=7.051$, Sig. <0.05 for number of washbasins, $t=2.848$, Sig. < 0.05 for household size, $t=3.229$, Sig. < 0.05 for total built-up area of house, $t=3.139$, Sig. <0.05 for number of showers).
3. It was noticed that 90% of houses in Hilla consume (3130 L/h or less) of water per day.
4. The average daily summer water consumption in the city was 42.66% higher than the total average daily consumption .

5. The maximum level of average daily consumption in the city during summer season occurred in the month of August.

6.1.4 Study No.4 (Sprinkling Residential Water Demand)

1. The most appropriate model with the most significant independent variables is :

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

The regression model explains that there is a positive impact of the three independent variables on sprinkling water demand.

The contribution of each one unit of each independent variable appeared in regression is 0.496, 0.0133, and 0.737 respectively for natural logarithmic form of demand.

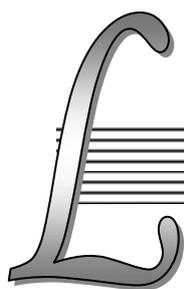
The percent prediction power of each independent variable in estimated demand was 50.5%, 31.9%, and 17.6% respectively.

2. The three predictors helped to predict sprinkling water demand with high efficiency because ($t = 7.459$, $\text{Sig.} < 0.05$ for household size , $t = 8.419$, $\text{Sig.} < 0.05$ for garden area , $t = 2.322$, $\text{Sig.} < 0.05$ for number of air-coolers).
3. It was found that 90 % of houses in the city consume (1609 L/h or less) of water per day .
4. The average daily sprinkling water demand was 86.4% of the total average daily .

6.2 Recommendations for Future Studies

Some further developments should be extended beyond this research study. The extension of this research should be focused on the following directions:

1. A future study is needed to construct residential water consumption models which include additional variables (such as water price, climatic variables, age of dwellers, household income, ..., etc.).
2. A further study is needed to record water consumption rate for all governorates of Iraq. Such a study assists in providing evaluation for the water consumption rate for the whole country.
3. Constructing models of water consumption for different uses of water, (industrial and commercial), is needed in a further study.
4. A future study should be done to apply multiple regression models to evaluate the effect of the different household fixtures demands only.
5. A future study should be carried out to estimate the loss rate in supplied water for Hilla and other Iraqi cities.
6. An additional model including raw water as a dummy variable should be investigated in a future study to show the contribution of raw water in the reduction of domestic water use for summer model.
7. It is important to carry out a future study with regard to the additional future factors which governed Iraqi society after war (such as the increasing of living standard, high use of air-conditioners instead of air-coolers, ..etc.).
8. Such a study must be done in all Iraqi cities for every ten years to check and follow the water demand with the development of living standard....etc.



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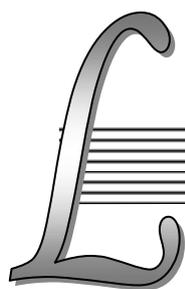
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IST OF SYMBOLS AND ABBREVIATIONS

Most of common symbols and abbreviations are listed below;
others are defined where they appear in the research.

<u>Symbol or Abbreviation</u>	<u>Description</u>
adj. R^2	Adjusted multiple determination coefficient
ANOVA	Analysis of variance
b_0	Intercept coefficient
$b_{1,2,3} \dots$	Regression coefficients
\hat{b}	Estimated regression coefficient
cuft	Cubic feet= 0.02834 m ³
df	Degree of freedom
e_n	Error term (difference between Y and \hat{Y})
F_α	Tabulated F (estimated from table)
GL	Giga liter =10 ⁹ liter
gpcd	Gallon per capita per day
K	Number of independent variables entered in regression equation
L/c*/d	Liter per one unit of independent variable per day
L/c/d	} Liter per capita per day
Lcd	
L/d	Liter per day
L/h/d	} Liter per household per day
Lhd	
MSE	Mean square for error
MSR	Mean square for regression
MST	Mean square for total
n	Sample size
pcm	Per cubic meter
q	The total number of the independent variables
Q	Denotes the residential water demand in L/h/d .
R	Coefficient of multiple correlation
R^2	Coefficient of multiple determination

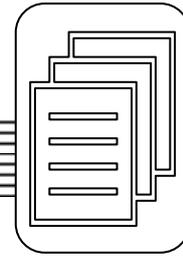
Symbol or Abbreviation

Description

S	Standard deviation
S_e	Sum of squares of errors
SE	Standard error of the estimate
SPSS	Statistical package for social science
SSE	Sum of squares for error
SSR	Sum of squares for regression
SST	Sum of squares for total
t	For t-test of regression coefficient
X	The independent variable
\bar{X}	Mean of sample
Y	The value of dependent variable in L/h/d
\bar{Y}	The mean of the given Y values
\hat{Y}	The predicted value of the dependent variable in L/h/d
Z	For Z-test
α	Significance level
μ	Mean of water consumption of population in L/h/d
μ_0	Population mean for water consumption (L/h/d)

R

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