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**University of Babylon  
College of Engineering  
Civil Department**

## **Design Model of Residential Water Demand in Al- Najaf City**

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وزارة التعليم  
العالي والبحث  
العلمي



جامعة بابل  
كلية الهندسة  
الهندسة المدنية

## تصميم موديل لطلب الماء المنزلي في مدينة النجف

رسالة

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

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2007



بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

﴿ أَلَمْ تَرَ أَنَّ اللَّهَ أَنْزَلَ مِنَ السَّمَاءِ مَاءً فَتُصْبِحُ  
الْأَرْضُ مُخْضَرَّةً إِنَّ اللَّهَ لَطِيفٌ خَبِيرٌ ﴾

صدق الله العلي العظيم  
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## الخلاصة

تتحرى هذه الدراسة تحليل طلب الماء المنزلي لمدينة النجف مع إيجاد العوامل المؤثرة على هذا الطلب للفترة من الأول من شهر تشرين الاول 2005 الى نهاية شهر آب -2006 .  
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، كما شملت هذه الأسر بالدراسة الاستفتائية للحصول على المعلومات التالية ( الخصائص الأسرية ) لكل دار والتي تعتبر من العوامل التي تؤثر كثيراً في طلب الماء المنزلي : حجم الأسرة ، مساحة البناء الكلي للدار ، مساحة الحديقة ، المستوى الثقافي، عدد غرف النوم ، المرافق الصحية، الدوشات في الحمام ، المغاسل ، الحنفيات في الحديقة ، مبردات الهواء ، مكيفات الهواء ، مكائن الغسيل ، عدد العوائل، عدد الاطفال والسيارات، و الضغط .

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 النجف وكانت 1221 لتر/ دار في اليوم (177 لتر/ شخص في اليوم ) لنموذج الطلب الكلي ، 745 لتر / دار في اليوم (108 لتر / شخص في اليوم ) لنموذج الطلب الشتائي ، 2754 لتر / دار في اليوم ( 399 لتر/ شخص في اليوم ) لنموذج الطلب الصيفي ، و 556 لتر / دار في اليوم ( 81 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 ل من نموذج الطلب الشتائي  
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إن الضغط هو متغير مهم في نموذج الطلب الشتائي والصيفي بينما عدد الدوشات هي من  
المتغيرات المهمة في نمودجي طلب الماء الكلي والصيفي .

# **TABLE 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 <sup>2</sup>           | Adjusted multiple determination coefficient                    |                          |
| ANOVA                         | Analysis of variance                                           |                          |
| b <sub>0</sub>                | Intercept coefficient                                          |                          |
| b <sub>1,2,3 ....</sub>       | Regression coefficients                                        |                          |
| $\hat{b}$                     | Estimated regression coefficient                               |                          |
| cuft                          | Cubic feet= 0.02834 m <sup>3</sup>                             |                          |
| df                            | Degree of freedom                                              |                          |
| e <sub>n</sub>                | Error term ( difference between Y and $\hat{Y}$ )              |                          |
| F $\alpha$                    | Tabulated F ( estimated from table )                           |                          |
| Gl                            | Giga liter =10 <sup>9</sup> 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                         |                                                                |                          |
| 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 <sup>2</sup>                | Coefficient of multiple determination                          |                          |

| <u><i>Symbol or Abbreviation</i></u> | <u><i>Description</i></u>                              |
|--------------------------------------|--------------------------------------------------------|
| 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                                             |
| $\alpha$                             | Significance level                                     |
| $\mu$                                | Mean of water consumption of population in l/h/d       |
| $\mu_0$                              | Population mean for water consumption (l/h/d)          |



# **CERTIFICATION**

We certify that the thesis, entitled "**Design Model of Residential Water Demand in Al-Najaf City**" was prepared by "**Abeer Ibraheem Al-Khazaly**" 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/ Environmental Engineering.

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# **Examination Committee Certification**

We certify that we have read this thesis, entitled "**Design Model of Residential Water Demand in Al-Najaf City**", and as examining committee, examined the student "**Abeer Ibraheem Al-Khazaly**" 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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# ***Abstract***

This study investigates the analysis of residential water demand for the city of Najaf along with determination the factors that affect such demand for the period from the 1<sup>st</sup> of October -2005 to the end of August – 2006.

The data used in this study 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. The households were supplemented by questionnaire survey to get the information (household characteristics) for each house which is considered 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, the pressure, education level , number of bedrooms , toilets , showers , washbasins, taps in garden , air-coolers , air-conditioners , washing machines ,families, children, 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 during the study period , but winter demand represented the water used for the in-house purposes during the period from the 1<sup>st</sup> 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 1<sup>st</sup> of July to the end of August.

Sprinkling water demand was estimated by subtracting winter water demand from summer water demand, which 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 models were fitted in log- linear form.

In this study , the average daily water demand for the city of Najaf was estimated to be 1221 l/h/d ( 177 l/c/d) for total demand , 745 l/h/d ( 108 l/c/d) for winter demand , 2754 l/h/d ( 399 l/c/d ) for summer demand , and 556 l/h/d (81 l/c/d ) for sprinkling demand .

The most significant factors effecting on the demand are appeared in the fitted equations. Household size was found to be the most significant variable in winter and sprinkling demand models, while the number of families was found to be the most significant variable in the total, and summer demand model.

The pressure was found to be the significant variable in winter and summer demand models, while the number of showers was found to be significant variable in the total and summer demand model.

# **CHAPTER ONE**

## **INTRODUCTION**

### **1.1 Introduction**

Water is vital for mans existence; without water there would be no life on earth. The body of a human being consists of 65 percent water. Apart from the day to day requirement, water is needed for irrigation, power generation, industrial production and receiving wastewater.

There is enormous amount of water on our planet, approximately  $1.4 \times 10^9$  cubic kilometers in the form of oceans, rivers, seas, lakes, ice, et... But only 3 percent of the total quantity of water on the earth is in the form of fresh water available in rivers, lakes, and ground water. Fresh water is limited, but the requirements for fresh water are ever on the increase, due to the increase of population and industrialization (Al-layla, M.A., Ahmed, S., and Middlebrooks, E.J., 1977)

In the design of any water-works project (such as treatment plant, water supply networks) it is necessary to estimate the amount of water that is required (Tebbutt, 1998). It is also important in wastewater-works project since the wastewater flow is assumed as a perentage of the supplied water quantity. Generally this involves determining the number of people who will be served and their per capita water consumption, together with an analysis of the factors that may operate to affect consumption (Steel and Meghee, 1979).

The basic human physiological requirement for water is about 2.5 liter per day (l/d), although when working hard in hot climates an intake up to 20 l/d may be necessary to prevent dehydration brought about by losses through perspiration( Tebbutt, 1998).

The “Basic Water Requirement (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 Fig. 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 Fig. (1-1) below (Qasim et al., 2000):

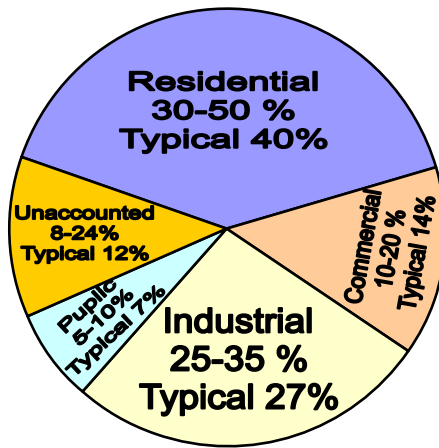


**Fig.(1-1):** Components of Municipal Water Demand ( Qasim et al., 2000).

1. Domestic Water Use. The residential water used 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. The present 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 such as (climate variables, socioeconomic, habits of dwellers, costs, and sewer services).

It has been widely accepted that the amount of water that people use in a country is the function of minimum needs for surviving, the availability of water resource, economic development and level of urbanization. It is difficult to estimate the amount of water needed to maintain accepted or minimum living standards though. Most of the data aggregated the residential (household) water use and consumption into domestic use- one of the three standard categories of fresh water use (Center for Communication Programs, 1998. P.6).

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 Najaf city.

For the purpose of this work, a sample of dwelling units was randomly chosen in different areas of Najaf city and supplied with new and identical charging meters. 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 1<sup>st</sup> of October of 2005 to the end of August, 2006.

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

Stepwise method reduces the number of variables initially presented 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 cases : case No.1 (total residential water demand), case No.2 (winter residential water demand), case No.3 (summer residential water demand), and case 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 1<sup>st</sup> of January to the end of February, 2006). Summer demand includes water consumed for in-house plus out-houses purposes in the summer season (from the 1<sup>st</sup> of July to the end of August, 2006).

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

These studies are very important for other Governorates of Iraq to know the change in water demand through seasons and months to provide the share for one person, and to identify domestic water use pattern in all Governorates and so we will know life style and social conditions that will effect on the water consumption and we will make a comparison between these Governorates, and provide objects to conservation the water resources.

## **1.2 Research Objectives**

The objectives of the present work are to:

1. Explain the major factors that affect such demand and define their effects.

2. Developing model of residential water demand in Al-Najaf city under the considerations total, winter, summer, and sprinkling.

### **1.3 Thesis Presentation**

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

- Chapter One presents introduction and research objectives.
- 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 studies.

# ***CHAPTER Two***

## **Literature Review**

### **2.1 Introduction**

Domestic water supplies are one of the fundamental requirements for human life. Without water, life cannot be sustained beyond a few days and the lack of access to adequate water supplies leads to the spread of disease. Children bear the greatest health burden associated with poor water and sanitation.

As the population continues to grow, measures must be taken to ensure that there is an adequate water supply to meet current and future demand. The capital investment, environmental concerns, and regulatory obstacles inherent in the development of new water supplies often make demand side management an attractive option. But what are the best and most effective measures to curb the use of such essential commodity as water?

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 by using multiple regression and time series methods.
2. Cross-sectional data which are arranged cross-sectional and analyzed by 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-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 -beta- 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 a 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 brakish 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 during rainless periods was closely related to air temperature once the maximum air temperature rise above( $21^{\circ}\text{C}$ ) in all cities studied. A greater than this temperature, seasonal use raised slowly at first, then more rapidly as air temperature rose beyond 29-32 centigrade 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 coefficients 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 coefficient;  $x_1, x_2$ , and  $x_n$ =values of 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  $48 \times 10^8$  cuft ( $=1.36 \times 10^8 \text{ m}^3$ ) in that year.

**Khalid (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.

### **2.1.2 analysis of water demand data arranged cross-sectionally**

**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 distributed billing and rates, water revenue, operating costs, and other financial information.

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

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 were:

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

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

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

$$R^2=0.9509, n=86$$

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

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

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

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

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

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

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= 3.787 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 is 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 by using an ordinary least squares method to fit the demand curve:

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

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 the higher price and the 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 the policy use.

**Hassan (1987)** randomly chose 50 households in Basrah city, in 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 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 the average of each air-cooler caused an increase of 46.89% in the seasonal demand which was equivalent to 284 liter per household per summer day 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 the domestic water consumption for two groups metered households and used to generate equations relating to these different variables were: the number of occupants, the number of children, the income level, the price of water, the lot size, the sprinkling area, the number of facilities consuming water including (washing cars, cleaning floors, air coolers, washing machines), the number of rooms, the number of taps in the courtyard for the first group and the 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:

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

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 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 a 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 by 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: the house type, the number and type of water-using appliances, the number of cars, the 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 quantity 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, when 200 dwelling were eliminated 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 the water demand was a function of: the number of fitments per dwelling unit, the number of occupants living in each house, the area of the house, lot price of each house, and the tap water pressure in the house-variables.

The number of fitments (number of toilets, washbasins, showers, air-coolers, and washing machines) 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 the 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 data of the case study of the city of Basrah, Iraq, in (1988) to fined the contributions of different types of fitments 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. While 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, Which consumed the larger quantity of water from each model (total, summer, and sprinkling) equal to 38%, 40%, and 47% 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 also analyzed by using primary data collected from telephone survey 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 household, which were visited from May 18 to June 28, 1999 in municipalities of Beijing and Tianjin, China. 11 samples were in Tianjin and 12 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 usually was 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 an empirical investigation and an 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.

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 generators.

**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 a stepwise multiple regression procedure to estimate the residential water demand as a function of (household size, No. of bedrooms, No. of toilets, No. of showers, No. of washbasins, No. of taps in the garden, total built-up area, No. of air-coolers, No. of air conditioner, and area of the garden). When 200 dwelling were randomly chosen from different areas in Baghdad, only 50 dwelling were found to be supplied with metered water. Only these dwelling were included in his study.

The 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.

The 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 equal 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, 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 the 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 the changes in the 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 un piped households, and the cost doubled since 1967. Water was the most expensive for un piped

households in urban areas, where dependency on vendors and other private suppliers was larger.

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

**WRC in 2001** carried out the use of method as a means of developing a national micro components monitor (Kowalski& Stimson 2001). The trial involve monitoring around 250 properties during a period of ‘normal’ (i.e. non-peak) demand and assessing domestic water use at the microcomponent level.

Typically these are the uses of devices such as toilets, showers, bath, washing machines, dishwashers, internal and external taps.

The average per household consumption (phc) for all households analysed was 367.4 litres/property/day. The volume per use results were in broad agreement with common knowledge.

The prevalence of newer washing machines was obvious in the sample with an average use volume of around 60 litres, much less than the consumption of machines more than, say, 10 years old. Bath events varied widely, from 50 to 150 litres, but with a mean value (around 80 litres) close to that anticipated.

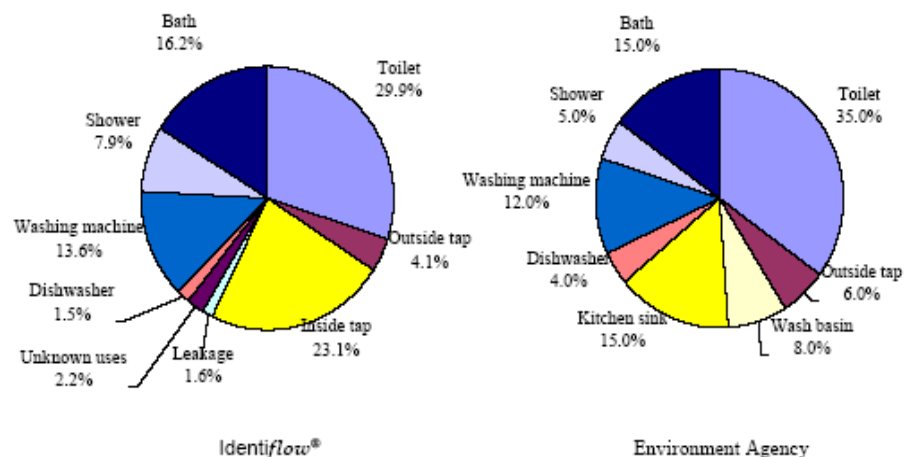


**Figure 2 – 1 Constituents of total household consumption by microcomponent**

Figure 2 compares microcomponent data from the WRC study with values commonly quoted by the UK Environment Agency (UK EA), which we believe to be the best estimates available in 2001. The figures show broad agreement, and that any differences are probably accounted for by differences in demography and sample size.

**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 period, 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 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)**

|                          | 1,000 gallons per house per year |        |         | %      | %       |
|--------------------------|----------------------------------|--------|---------|--------|---------|
| Study site               | 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. Indoor 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 indoor 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 gallon per capita per day (245.6 l/c/d and 261.9 l/c/d) respectively, 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=10<sup>9</sup>l), distributed as shown in Fig. (2-2) below:

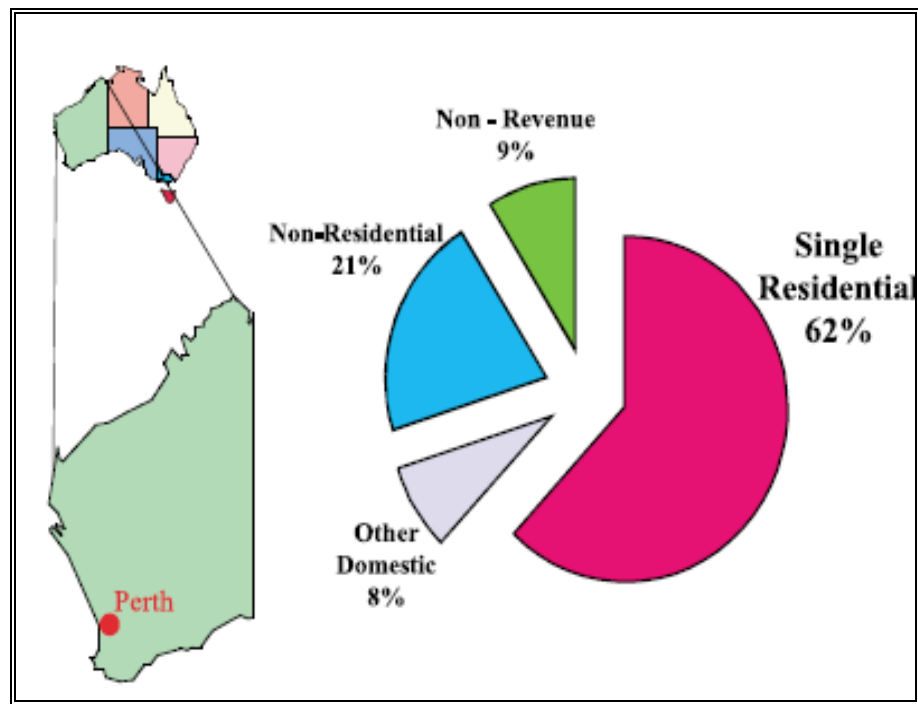


Fig.(2-2):Perth metropolitan water use 1999/2000(Loh and Coghlan, 2003).

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 (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 was 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 household, the study included a questionnaire survey 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 survey, 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 |
|-----------------|-------------|------------|
| <b>Ex-house</b> | 707         | 56         |
| <b>In-house</b> | 523         | 42         |
| <b>Leaks</b>    | 29          | 2          |
| <b>Total</b>    | 1259        | 100        |

And the component usage per household was set out in Fig. (2-3) below:

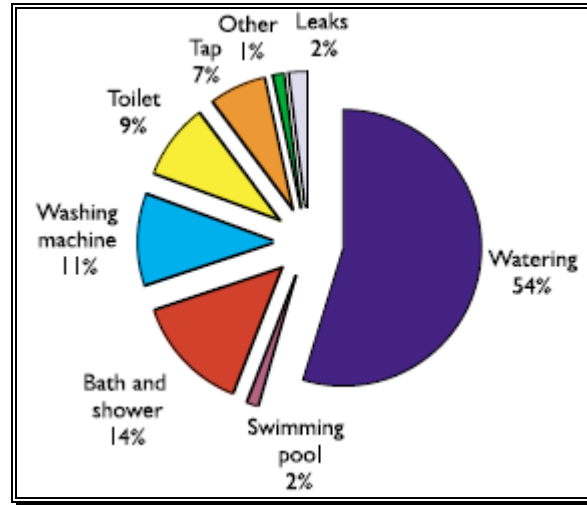


**Fig. (2-3): component usage of single residential household ( Loh and Coghlan, 2003)**

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

**Table (2-4): the average component usage 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, which means that 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 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 increase 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.

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            |
| <b>Total in-house</b> | <b>523</b>  | <b>100</b> | <b>42</b>  | <b>155</b>   |

**Samaka. I. S., (2004)** used the case study of the city of Hilla, Iraq, using metering of individual households were randomly chosen from different districts of the city.

The study investigated the analysis of the residential water demand with determining the factors that affect such demand for the period from the 1<sup>st</sup> of January to the end of august- 2004. These factors are the household size, the total built-up area of the house, the garden area, number of each bedrooms, the toilets, the showers, the washbasins, the taps in garden, the air coolers, the air-conditioners, the washing machines and cars.

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

The stepwise multiple linear regression for log-linear model in four forms of transformation were used for each one of four water demand studies.

The total 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 1<sup>st</sup> 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 out-house purposes for the period from 1<sup>st</sup> of July to the end of August. Sprinkling water demand was estimated by subtracting winter water consumption from summer water consumption which was equaled to the water used for the out-house purposes.

For the winter demand model, she found that the number of bedrooms explained most of the percentage contribution in prediction of water demand model 36.3 %, while the number of washbasins, household size, and the number of toilets variables explained 32.2 %, 16.1 %, and 15.4 % respectively.

The winter consumption was about 60.7 % of the total average daily demand. During the winter season, the minimum average daily consumption in the city happened in January.

For summer water consumption model indicated that independent variable (washbasins) explain most of the variation in percent prediction (44.1 %), while the household size, total built-up area of house, and the number of showers explain around 17.1 %, 2.4 %, and 18.45 % respectively. The maximum level of average daily consumption in the city during summer season occurred in the month of August.

### **2.1.3 Analysis of water demand data arranged chronologically and cross-sectionally**

**Danielson (1979)** estimated the residential water demand based upon the 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, and laundry rooms), and for outside purposes (e.g., for washing cars, and sprinkling lawns).

During the winter, the total residential demand was assumed to be equal in-house demand. During the summer season it was assumed to be 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.

The lot size was found to be collinear with the 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 of the 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. summary demand function:

East:

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

West:

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

where:

$q_s$ = 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 co-operation 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-square of 0.84 (indicating that 84 percent of the observed variation in water 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:

$$Q = 26.84 - 26.78 AP - 1.23 PO + 5.36 CH + 9.95 I + 0.185 SP + 0.0731 C \quad ..(2-15)$$

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

(R<sup>2</sup>=0.47; n=1031) Note: figures in parentheses are the t-values.

Where:

**Q**=per capita residential 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 population over 10000 conducted by the American Water Works Association (AWWA).

The monthly rainfall and temperature data were obtained from the National Oceanic and Atmospheric Administration Climatological data and the demographic data was taken from 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 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 test, 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) conserved 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 non price 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 non price 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, non price 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

statistically 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 the 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 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 non price conservation programs were effective.

In this research we evaluate the household water use and the identify water use pattern in Al-Najaf city and explain the major factors that affect such demand and define their effects.

## **CHAPTER Three**

### **Theoretical Background**

#### **3.1 Introduction**

This chapter is presented to give a theoretical background of 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 mode.

#### **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 the 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 (Volk, 1969; Spiegel, 1972; Hayslett, 1981; 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 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 its 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 (McCuen, 1985; 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

$\mu$  = population mean for water consumption

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

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  $\alpha$ -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  $\mu$  of population is unknown.
5. Calculate  $Z$  from Equation (3.2).
6. Make the decision to reject or accept the null hypothesis.

When  $H_1: \mu > \mu_0$ . This is a one – tailed test. Refer to  $Z_\alpha$ , the critical region consists of all values greater than or equal to  $Z_\alpha$  as shown in Fig. (3-1).

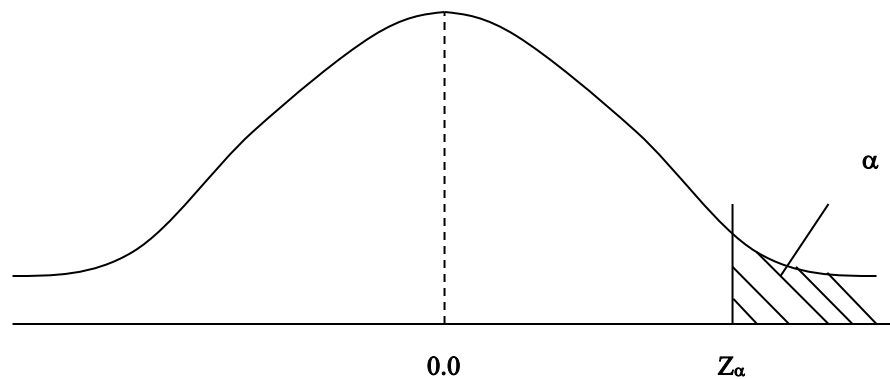


Fig.(3-1): Standard Normal Distribution Curve for Z-Test (One-tailed test)(Hayslett,1974).

Reject  $H_0$  if calculated  $Z$  is in the critical region. Accept  $H_0$  otherwise, this means that there is a significant difference between  $\mu$  and  $\mu_0$  (i.e.  $\mu > \mu_0$ ).

### 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 viewing 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

The general purpose of multiple\_regression (the term was first used by Pearson, 1908) is to quantify the relationship between a dependent or criterion variable  $Y$ , and several independent or predictor variables,  $x_1, \dots, x_k$ . When  $k=1$ , it is called simple regression but when  $k>1$  it is called multiple regression., multiple regression allows the researcher to ask (and hopefully answer) the general question "what is the best predictor of ..."

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

The *R-square* value is an indicator of how well the model fits the data (e.g., an *R-square* close to 1.0 indicates that we have accounted for almost all of the variability with the variables specified in the model)(Statsoft, Inc, 2003).

In general then, multiple regression procedures will estimate a linear equation of the form:

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

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

The most common method for fitting a regression line is the method of least-squares. This method calculates the best-fitting line for the observed data by minimizing the sum of the squares of the vertical deviations from each data point to the line (if a point lies on the fitted line exactly, then its vertical deviation is 0). Because the deviations are first squared, then summed, there are no cancellations between positive and negative values.

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:

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

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

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:

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

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:-

$$\begin{aligned}
nb_o + b_1 \sum x_1 + b_2 \sum x_2 + b_3 \sum x_3 + \dots + b_k \sum x_k &= \sum Y \\
b_o \sum x_1 + b_1 \sum x_1^2 + b_2 \sum x_1 x_2 + b_3 \sum x_1 x_3 + \dots + b_k \sum x_1 x_k &= \sum x_1 Y \\
b_o \sum x_2 + b_1 \sum x_2 x_1 + b_2 \sum x_2^2 + b_3 \sum x_2 x_3 + \dots + b_k \sum x_2 x_k &= \sum x_2 Y \\
b_o \sum x_3 + b_1 \sum x_3 x_1 + b_2 \sum x_3 x_2 + b_3 \sum x_3^2 + \dots + b_k \sum x_3 x_k &= \sum x_3 Y \\
\\ 
b_o \sum x_k + b_1 \sum x_1 x_k + b_2 \sum x_2 x_k + \dots + b_k \sum x_k^2 &= \sum x_k Y \\
&\dots (3.14)
\end{aligned}$$

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  $b_o$ . (Bryant, 1966; Volk, 1969; Spiegel, 1972; Mason, 2000; [www.public.iastate.edu/~mervyn/stat401/Trans/tr11-4.pdf](http://www.public.iastate.edu/~mervyn/stat401/Trans/tr11-4.pdf), John H. Walker, Ph.d., [www.informs-sim.org/Wsc04papers/281.pdf](http://www.informs-sim.org/Wsc04papers/281.pdf), statsoft, Inc, 2003).

#### 3.4.1.1.2 Multiple Regression Computations Using Matrix Notation.

The actual computations involved in solving regression problems can be expressed compactly and conveniently using matrix notation. Suppose that there are  $n$  observed values of  $Y$  and  $n$  associated observed values for each of  $k$  different  $X$  variables. Then  $Y_i, X_{ik}$ , and  $e_i$  can represent the  $i$ th observation of the  $Y$  variable, the  $i$ th observation of each of the  $X$  variables, and the  $i$ th unknown residual value, respectively. Collecting these terms into matrices we have

$$\mathbf{Y} = \begin{bmatrix} Y_1 \\ \vdots \\ Y_n \end{bmatrix}, \mathbf{X} = \begin{bmatrix} 1 & X_{11} & \cdots & \cdots & X_{1k} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ 1 & X_{n1} & \cdots & \cdots & X_{nk} \end{bmatrix}, \mathbf{e} = \begin{bmatrix} e_1 \\ \vdots \\ e_n \end{bmatrix}$$

The multiple regression model in matrix notation then can be expressed as

$$\mathbf{Y} = \mathbf{X}\mathbf{b} + \mathbf{e}$$

Where  $\mathbf{b}$  is a column vector of 1 (for the intercept) +  $k$  unknown regression coefficients. Recall that the goal of multiple regression is to minimize the sum of the squared residuals. Regression coefficients that satisfy this criterion are found by solving the set of normal equations

$$\mathbf{b} = \begin{bmatrix} b_o \\ b_1 \\ \vdots \\ b_k \end{bmatrix}$$

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

$$\mathbf{X}^T = \begin{bmatrix} 1 & 1 & 1 & \cdots & 1 \\ X_{11} & X_{21} & \cdots & \cdots & X_{n1} \\ X_{12} & X_{22} & \cdots & \cdots & X_{n2} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ X_{1k} & X_{2k} & \cdots & \cdots & X_{nk} \end{bmatrix}$$

Where  $\mathbf{X}^T$ =transpose of matrix  $\mathbf{X}$ , 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](http://www.public.iastate.edu/~mervyn/stat401/Trans/tr11-4.pdf);

[Lib.stat.cmu.edu/~kass/smn/notes/9/pdf](http://Lib.stat.cmu.edu/~kass/smn/notes/9/pdf);

[www.economics.utoronto.ca/benjamin/Lecture5pdf](http://www.economics.utoronto.ca/benjamin/Lecture5pdf); Faraway, 2000, Johnson, 2003, Abdi, 2003, statsoft, Inc 2003).

### 3.5 Computer Program, SPSS

SPSS is a comprehensive and flexible statistical analysis and data management system. SPSS can take data from almost any type of file and use them to generate tabulated reports, charts, and plots of distributions and trends, descriptive statistics, and conduct complex statistical analyses ([statmath/stat/spss/win/giant.html](http://statmath/stat/spss/win/giant.html)).

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. (Kinneer, 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 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), (Spiegel, 1972; Ganeem and Sabri, 2000; Mason, 2000; Dancey, 2002).

#### **A-The Summary Model 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).

| M<br>odel | R                           | R-<br>square | Adjusted R square                            | Std. Error of Estimate                  |
|-----------|-----------------------------|--------------|----------------------------------------------|-----------------------------------------|
| 1         | (<br>$R^2$ ) <sup>1/2</sup> | SSR<br>/SST  | $adj.R^2 = 1 - (\frac{n-1}{n-k-1})(1 - R^2)$ | SE=<br>[SSE / n - k - 1] <sup>1/2</sup> |

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

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;Bluman2001;  
[www.unesco.org/webworld/idams/advguide/Chapt5-2.htm](http://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 :

$H_0: b_1=b_2 = \dots b_k=0$  (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  $\alpha$  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  $\alpha$  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:

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

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 ( $b_0$ ) |                           | $b_0/SE(b)$ |      |

|                        |       |              |  |             |  |
|------------------------|-------|--------------|--|-------------|--|
| Variable k coefficient | $b_k$ | SE ( $b_k$ ) |  | $b_k/SE(b)$ |  |
|------------------------|-------|--------------|--|-------------|--|

### ***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,  $t_{\alpha/2} (n-2)$ .

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/advguide/Chapt5-2.htm](http://www.unesco.org/webworld/idams/advguide/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 Questionnaire Survey**

#### **4.1 Introduction**

The analysis of this study is based on the metered water consumption data for random sample of dwellings from different districts of Najaf city, observed cross-sectionally over the period from the 1<sup>st</sup> of October, 2005 to the end of August, 2006.

A sample of houses was selected by using a two – stage procedure. In the first stage, the houses supplemented by questionnaire surveys to obtain information related to the household size, the 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 is presented in Fig. (4-1) as a sample of the survey paper. There are many 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 was be adequate and continuous.

3. The water in each house was 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.

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

4. 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 collecting data, 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.

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.

Fig. (4-1): The Questionnaire Survey Paper

**استمارة استبيان الرسالة الموسومة**

**دراسة تحليلية في استهلاك الماء الصافي المنزلي لمدينة النجف**

**دراسة تحليلية لعينة من المنازل في النجف**

**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 النجف خدمة للصالح العام.

**المعلومات:**

|                                             |                                             |                                         |
|---------------------------------------------|---------------------------------------------|-----------------------------------------|
| 1- عدد الساكنين في الدار                    | 2- مساحة الأرض الكلية<br>(م <sup>2</sup> )  | 3- مساحة البناء الأول (م <sup>2</sup> ) |
|                                             |                                             |                                         |
| 4- مساحة البناء الثاني<br>(م <sup>2</sup> ) | 5- عدد غرف النوم                            | 6- عدد مبردات الهواء                    |
|                                             |                                             |                                         |
| 7- عدد مكيفات الهواء                        | 8- عدد الدوشات في الحمام                    | 9- عدد المرافق الصحية                   |
|                                             |                                             |                                         |
| 10- عدد المغاسل (عدى<br>مغسلة المطبخ)       | 11- عدد الحنفيات في<br>الحديقة<br>صافي خابط | 12- هل الدار مزود بماء<br>خابط          |
|                                             |                                             |                                         |
| 13- عدد مكائن<br>الغسيل                     | 14- عدد السيارات                            | 15- عدد العوائل                         |
|                                             |                                             |                                         |
| 16- عدد الاطفال                             |                                             |                                         |
|                                             |                                             |                                         |

ولكم جزيل الشكر

الباحثة:- عبير ابراهيم يحيى

Najaf lies in the middle of Iraq, with a population of about 541918 person, living in an area of 5.82 km<sup>2</sup> according to Central Committee of Statistics – Najaf Census Directorate – 1997. Najaf city may be classified into two distinguished areas; the old city (so called the city center) and the modern neighborhoods. The old city embraces the holy shrine of the Imam Ali Bin Abi Talib (peace be upon him) a great number of pilgrims visit the holy shrine every year that is estimated to be 7millions as total per year. This number is expected to be raised in the future. About 10000 human body of Moslems died people are buried annually in the area called Wadi Al-salam near the holy shrine. A great number of pilgrims that may reach 1-2million visit the holy shrine and the Wadi at special pilgrimage days. This gives a special character to the city and has a bearing influence on it's way of life, and characterized by old buildings and houses and narrow streets. The modern area consists of about 46 neighborhoods. Euphrates which passes through Kufa City east of Najaf City.

To achieve the aims of this study for a large society as Najaf city, it depends on a sample of ten districts(AL-Ghari(1),Al-Salam(2),AL-Eskan(3),AL-Karrama(4),Al-Ammer(5),AL-Zahraa(6),AL-Qadissya(7),AL-Nasir(8),Al-Makrama(9)),AL-Ghader(10) 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 Fig. (4-2)

The climatic conditions (temperature, rainfall, and evaporation) in Najaf for the period of study are shown in Table (4-1) with Temperature equal to 46.63 C° as maximum average daily value for the summer season.

**Table (4-1):** Climatic Conditions in Najaf City for the Period (from the 1<sup>st</sup> of October to the End of August, 2006)( *Source: Najaf Meteorological Station*)

| Variable        | Average daily |             |         |             |
|-----------------|---------------|-------------|---------|-------------|
|                 | Maximum       | Month's No. | Minimum | Month's No. |
| Temperature(C°) | 46.63         | 7,8         | 16.5    | 1,2         |
| Rainfall (mm)   | 8.7           | 1           | 0.0     | 6,7,8       |
| Evaporation(mm) | 23.00         | 8           | 7.8     | 1           |

### 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).



#### **4.3.1.1 Study No.1 (Total Residential Water Demand)**

This model represents the observed average daily of the 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 a non-seasonal demand which is the average daily demand for water during the period from the 1<sup>st</sup> of January to the end of February – 2006 and it includes in-house purposes when out-house purposes were hypothesized to be zero(Samaka. I. S,(2004)).

#### **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 1<sup>st</sup> of July to the end of August – 2006(Samaka. I. S,(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 (Samaka. I. S,(2004)).

### **4.3.2 The Independent Variables**

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

#### **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) m<sup>2</sup>.

#### 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) m<sup>2</sup>.

#### 4.3.2.4 Number of Bedrooms

The 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 Pressure:** A household water pressure regulator reduces the water pressure from the public water main to a pressure that is usable by the customer and compatible with normal household plumbing and fixtures. It also helps to prevent pressure surges from entering the household plumbing from the public main. High water pressure can result in dripping faucets and water pipes, and it can damage appliances.

In order to compute the water pressure the following equation was used:

$$P = \gamma h$$

**4.3.2.7 Education level:** the level of education is one of factors that may effect on the water demand in any city; hence, it was proposed that:

- ❖ Bad level of education denoted as 1.

❖ Medium level of education denoted as 2.

❖ High level of education denote as 3.

#### **4.3.2.8 Number of children**

#### **4.3.2.9 Number of families**

#### **4.3.2.10 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 except the number of air-coolers, air-conditioners, and taps in the garden.

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

#### **4.3.2.11 Raw Water Use**

The Raw water use is considered as a dummy variable ( $D$ ) in each house, which equals to 1 if the house was supplied with raw water, and zero if not.

## **CHAPTER FIVE**

### **RESULTS AND DISCUSSION**

#### **5.1 Introduction**

In this chapter, data of water demand arranged in four studies (total, winter, summer, and sprinkling) the residential water demand was analyzed to investigate the main objective of this research. Along with the data of factors (independent variables) that are assumed to have a reliable impact on domestic water use for metered households (household size, number of bedrooms, number of toilets, number of showers, number of washbasins, number of taps in the garden, number of air-coolers, number of air-conditioners, total built-up area, area of garden, number of washing machines, number of cars, and raw water as a dummy variable) are also analyzed to assess their effects on consumption.

#### **5.2 Descriptive Statistics for Independent Variables**

The most important statistical features of the independent variables investigated for four studies in this research are shown in Table (5-1).

The table presents the mean of each independent variable assumed to be influencing water demand in Al- Najaf city during the research period.

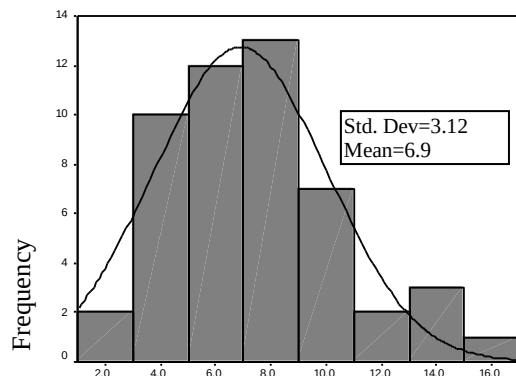
These statistics may be useful in the management of city needs for services.

**Table (5-1):** Descriptive Statistics for Independent Variables.

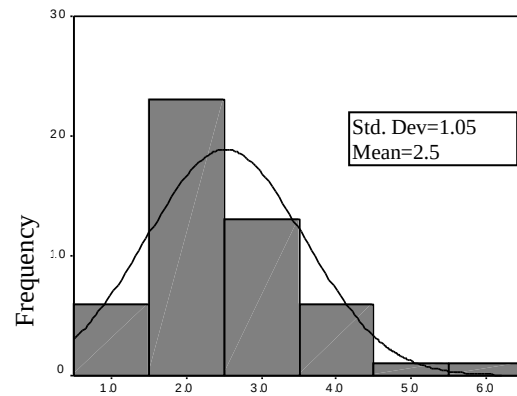
| Independent Variable                 | N         | Range     | Minimum   | Maximum   | Mean      | Std.      | Skewness  |            | Kurtosis  |            |
|--------------------------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|------------|-----------|------------|
|                                      | Statistic | Statistic | Statistic | Statistic | Statistic | Statistic | Statistic | Std. Error | Statistic | Std. Error |
| Household Size ( $x_1$ )             | 50        | 14.00     | 1.00      | 15.00     | 6.900     | 3.12495   | 0.665     | 0.337      | 0.196     | 0.662      |
| No. of Bedrooms ( $x_2$ )            | 50        | 5.00      | 1.00      | 6.00      | 2.520     | 1.05444   | 0.979     | 0.337      | 1.429     | 0.662      |
| No. of Toilets ( $x_3$ )             | 50        | 2.00      | 1.00      | 3.00      | 1.480     | 0.54361   | 0.479     | 0.337      | -0.979    | 0.662      |
| No. of Showers ( $x_4$ )             | 50        | 2.00      | 1.00      | 3.00      | 1.280     | 0.53605   | 1.805     | 0.337      | 2.514     | 0.662      |
| No. of Washbasins ( $x_5$ )          | 50        | 2.00      | 1.00      | 3.00      | 1.400     | 0.53452   | 0.835     | 0.337      | -0.457    | 0.662      |
| No. of Taps in Garden ( $x_6$ )      | 50        | 3.00      | 0.00      | 3.00      | 1.240     | 0.93808   | 0.419     | 0.337      | -0.592    | 0.662      |
| No. of Air-coolers ( $x_7$ )         | 50        | 5.00      | 0.00      | 5.00      | 1.520     | 0.97395   | 1.391     | 0.337      | 2.631     | 0.662      |
| No. of Air-conditioners ( $x_8$ )    | 50        | 4.00      | 0.00      | 4.00      | 1.280     | 1.01096   | 0.881     | 0.337      | 0.653     | 0.662      |
| Total Built-up Area ( $x_9$ )        | 50        | 405.00    | 45.00     | 450.00    | 236.24    | 90.54902  | 0.503     | 0.337      | 0.091     | 0.662      |
| Garden Area ( $x_{10}$ )             | 50        | 225.00    | 5.00      | 230.00    | 70.02     | 71.01609  | 1.041     | 0.337      | -0.442    | 0.662      |
| No. of Washing Machines ( $x_{11}$ ) | 50        | 3.00      | 0.00      | 3.00      | 0.880     | 0.52060   | 0.733     | 0.337      | 5.343     | 0.662      |
| No. of Cars ( $x_{12}$ )             | 50        | 3.00      | 0.00      | 3.00      | 0.480     | 0.61412   | 1.456     | 0.337      | 3.838     | 0.662      |
| The pressure ( $x_{13}$ )            | 50        | 6.75      | 3.90      | 10.65     | 6.8666    | 1.51942   | 0.636     | 0.337      | 0.955     | 0.662      |
| No. of Families ( $x_{14}$ )         | 50        | 2.00      | 1.00      | 3.00      | 1.5800    | 0.73095   | 0.854     | 0.337      | -0.599    | 0.662      |
| No. of Children ( $x_{15}$ )         | 50        | 4.00      | 0.00      | 4.00      | 1.2400    | 1.06061   | 0.457     | 0.337      | -0.528    | 0.662      |
| Education ( $x_{16}$ )               | 50        | 2.00      | 1.00      | 3.00      | 1.7800    | 0.93219   | 0.463     | 0.337      | -1.725    | 0.662      |
| Valid N (list wise)                  | 50        |           |           |           |           |           |           |            |           |            |

\*N : Number of selected houses

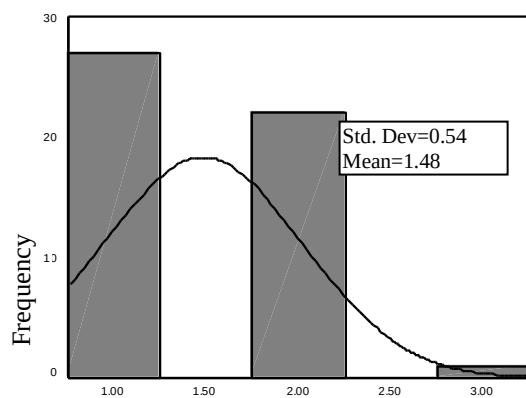
The frequency histogram graph for each independent variable is shown in Figs. (5-1) through (5-12) to explain the characteristics of the data sample as previous mentioned in Section (3-2-1).



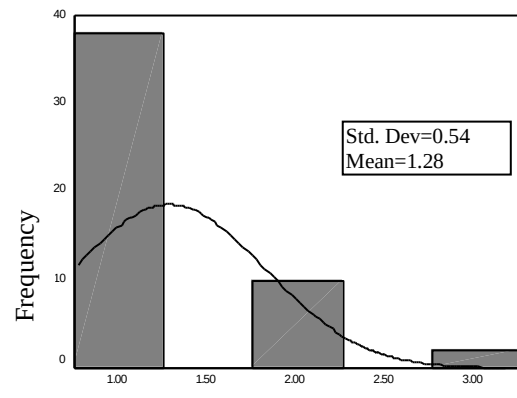
Household Size(X1)



Number of Bedrooms(X2)

**Fig. (5 – 1):** Frequency Histogram Distribution for Household Size.**Fig. (5 – 2):** Frequency Histogram Distribution for Number of Bedrooms Variable.

Number of Toilets (X3)



Number of Showers (X4)

**Fig. (5 – 3):** Frequency Histogram Distribution for Number of Toilets Variable.**Fig. (5 – 4):** Frequency Histogram Distribution for Number of Showers Variable.

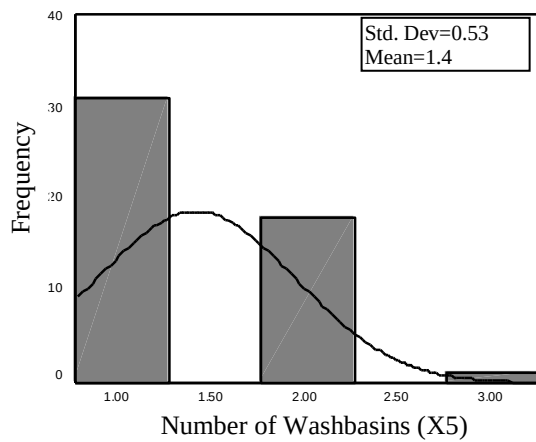


**Fig. (5 – 5):** Frequency Histogram Distribution for Number of Washbasins Variable.

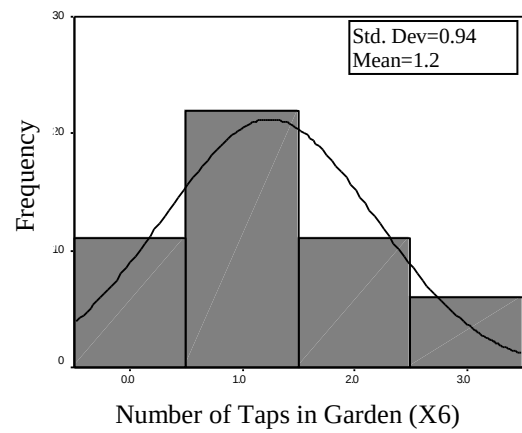


**Fig. (5 – 6):** Frequency Histogram Distribution for Number of Taps in Garden

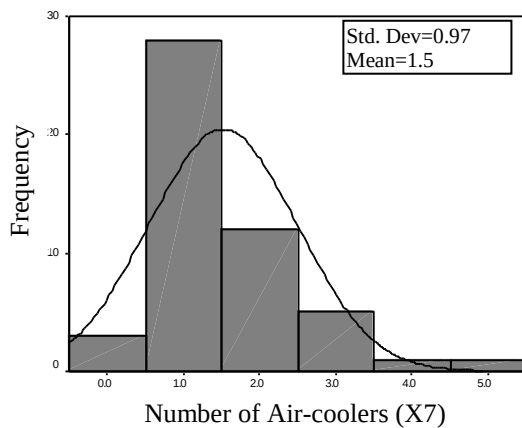


**Fig. (5 – 7):** Frequency Histogram Distribution for Number of Air-coolers Variable.

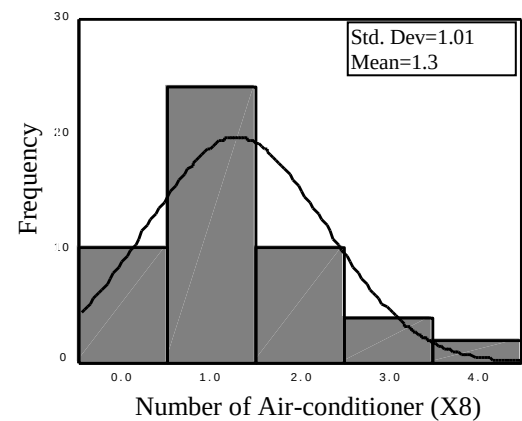


**Fig. (5 – 8):** Frequency Histogram Distribution for Number of Air-conditioners Variable.

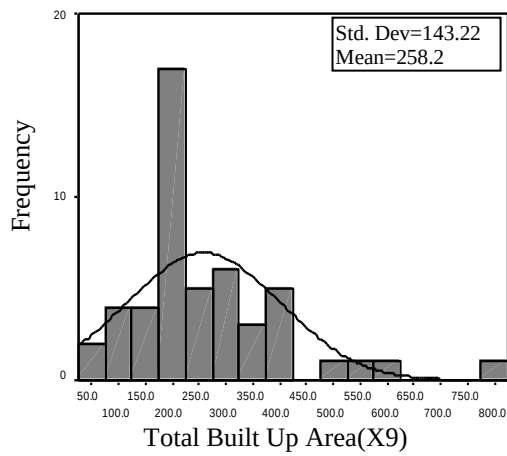


**Fig. (5 – 9):** Frequency Histogram Distribution for Total Built-Up Area of House Variable.

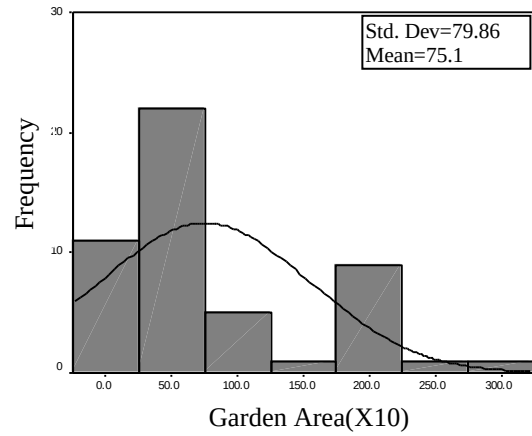


**Fig. (5–10):** Frequency Histogram Distribution for Garden Area Variable.

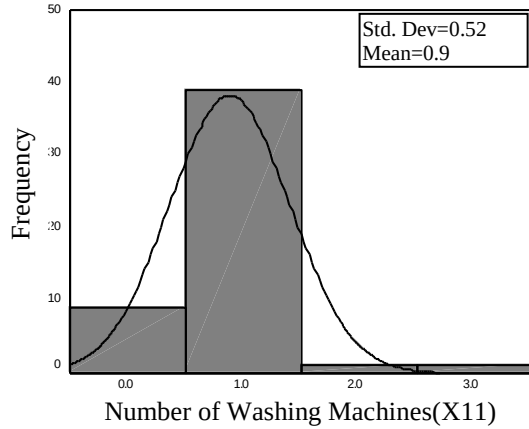


**Fig. (5 – 11):** Frequency Histogram Distribution for Number of Washing Machines Variable.

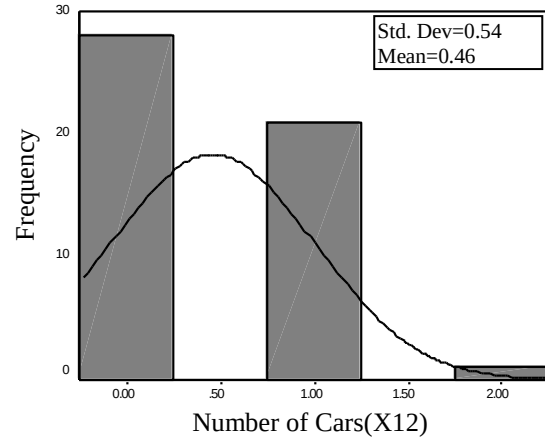


**Fig. (5 – 12):** Frequency Histogram Distribution for Number of Cars Variable.

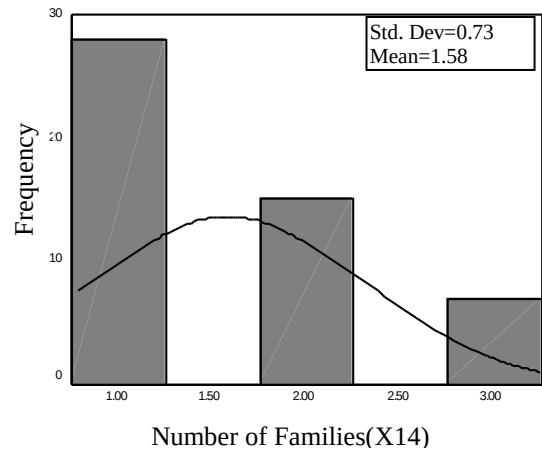
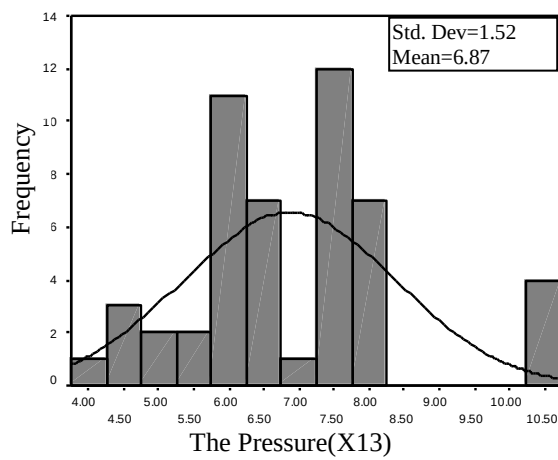


**Fig. (5 – 13):** Frequency Histogram Distribution for Pressure Variable. **Fig. (5 – 14):** Frequency Histogram Distribution for Number of Number of Families

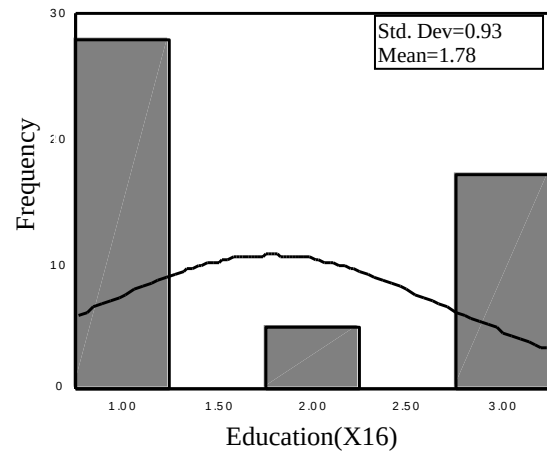
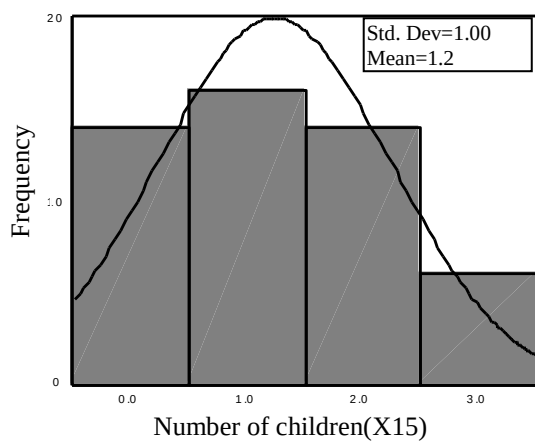


**Fig. (5 – 15):** Frequency Histogram Distribution for Number of children. **Fig. (5 – 16):** Frequency Histogram Distribution for Education.

### **5.3 Regression Models for Water Demand**

Stepwise multiple linear regression models in four forms of transformation were used for each one of four water demand studies (total, winter, summer and sprinkling) to investigate which form gives the best fitting of data (i.e. appropriate model).

It is very important to explain that the method of transformation are being used to reduce complex models to linear ones and use a regression model of simple form in the transformation variables, rather than a more complicated one in the original variables. Transforms are used to force all variables to normal distribution and to correct a positive skew distribution. Therefore, it should be noted that there are nonlinear models that are intrinsically linear (i.e. they seemed nonlinear only in their appearance, but they are intrinsically linear). Then, the nonlinear models can be divided into two types which can be called intrinsically linear and intrinsically nonlinear models. If a model is intrinsically linear it can be expressed by suitable transformation of the variables in the standard linear model form of Eq. (5.2). If a nonlinear model cannot be expressed in this form then it is intrinsically nonlinear (Draper and Smith, 1966; [www.chass.ncsu.edu/garson/pa765/regress.htm](http://www.chass.ncsu.edu/garson/pa765/regress.htm)). This study is interested in intrinsically linear models.

One of very general form for the linear model would be:

$$Q = f(x_1, x_2, \dots, x_q, D) \quad \dots(5.1)$$

Where  $f$  is unknown function,  $D$  is a dummy variable (if needed).

The following models were proposed and investigated:

## 1. Linear – linear model

$$Q = b_o + b_1 x_1 + b_2 x_2 + \dots + b_{12} x_{12} \quad \dots (5.2)$$

## 2- Log-log model (double log model)

$$\ln Q = b_o + b_1 \ln x_1 + b_2 \ln x_2 + \dots + b_{12} \ln x_{12} \quad \dots (5.3)$$

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

$$Q = b_o + b_1 \ln x_1 + b_2 \ln x_2 + \dots + b_{12} \ln x_{12} \quad \dots (5.4)$$

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

$$\ln Q = b_o + b_1 x_1 + b_2 x_2 + \dots + b_{12} x_{12} \quad \dots (5.5)$$

Where  $Q$  = average daily water demand (total, winter, summer, and sprinkling) in l/h/d (liter per house per day);  $x_1, x_2, \dots, x_{12}$  = the independent variables (as mentioned before in Section 5-2).

For the summer model, the function includes  $D$  as a dummy variable. Four types of models mentioned above represent the model of linear regression with constant ( $b_o$ ). If the model is carried out through the origin,  $b_o=0$  and the general relation according to (Snedecor, G., W., and Cochran, W., G., 1980; Legendre, P., and Desdevise, Y., 2002) is :-

$$\hat{Y} = b_1 x_1 + b_2 x_2 + b_3 x_3 + \dots + b_k x_k$$

Where:

$\hat{Y}$  : The predicted value of the dependent variable in L/h/d.

$x_1, x_2, x_3, \dots, x_k$  : the independent variable.

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

## 5.4 Results of Study No.1:

### A. Descriptive Statistics for Dependent Variable.

The most important statistical features of **total** water consumption (dependent variable) in Al-Najaf city during the study period can be explained by Table (5-2).

**Table (5-2):** Descriptive Statistics for Dependent Variable.

| Water Consumption |       | N         | Range     | Minimum   | Maximum   | Mean      | Std.      | Skewness  |           | Kurtosis  |           |
|-------------------|-------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
|                   |       | Statistic | Statistic | Statistic | Statistic | Statistic | Statistic | Statistic | Std Error | Statistic | Std Error |
| Total             | L/h/d | 50        | 1817.0    | 389.00    | 2206.00   | 1652.0570 | 447.59084 | -0.779    | 0.337     | -0.06     | 0.662     |
|                   | L/c/d | 50        | 297.43    | 140.07    | 437.50    | 271.5265  | 94.44452  | 0.296     | 0.337     | -1.186    | 0.662     |

Table (5-2) shows that the average daily of observed total water consumption during this period was about 1652 l/h/d with a standard deviation 447.59 (or 272 l/c/d with a standard deviation 94.44).

The total water consumption (indoor + outdoor) in the city ranged between a minimum of 389 to a maximum of 2206 l/h/d (or between 140.07 to 437.50 l/c/d).

Samaka, I.S. (2004), reported the total water consumption in Hilla city was 433.32 L/c/d.

The observed value of 272 l/c/d was found to be higher than that reported by Al-Samawi and Hassan (1988) for the city of Basrah back in (1977-1978). They reported a value of 137 lcd as an average daily taken over one year period.

Fig.(5-17) shows the histogram for the average daily water consumption per house .The frequency distributions of water consumption is negatively skewed; this is expected since most water demand distribution are skewed to the right and the mode is to the left of the mean value (i.e. the normal distribution curve is non symmetrical ),(Taofeek and AL-Rusafi ,1989)

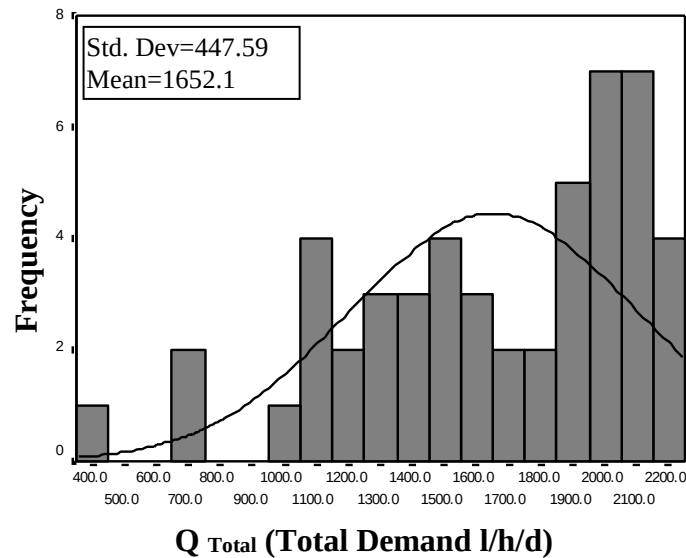


**Fig.(5-17):** Frequency Histogram Distribution for Total Water Demand ( l/h/d).

Figures(5-18) and (5-19) display the cumulative frequency and percentage graph for the average total demand per household .These figures indicate that 89% of houses in Al- Najaf city consume (2100 l/h or less)of water per day.

Isehak (2001) found that 87.8% of houses in Baghdad consume (2000 l/h or less) of water per day.

Samaka I, S (2004) fund that 90% of houses in Hilla consume (2077 l/h or less) of water per day.

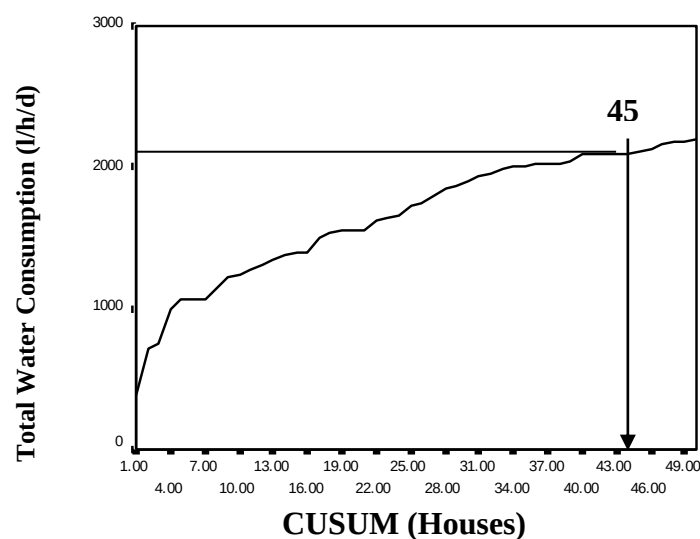


**Fig.(5-18):** Cumulative Frequency Histogram for Total Water Demand.

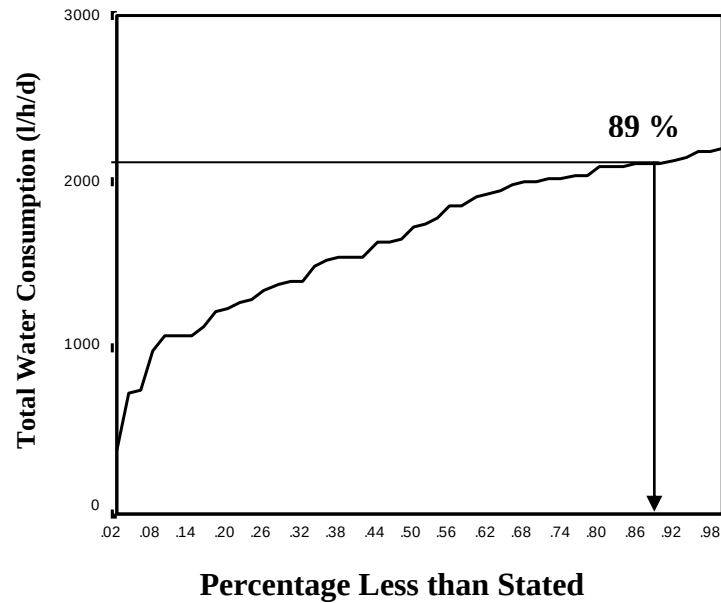


**Fig.(5-19):** Cumulative Frequency Histogram for Total Water Demand.

### **B. Pattern and Trend of Average Daily Total Water Demand in Al- Najaf City.**

Fig. (5-20) shows the pattern of average daily water consumption of households, weekly observed during the period of study.

Referring to this figure, the minimum water consumption occurred in winter time and the pattern increased with the increase of weather temperature and reached the maximum level at summer time.

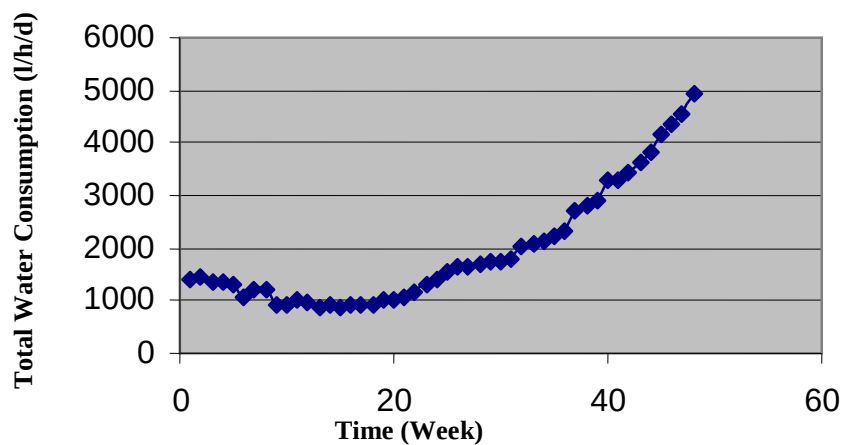


**Fig.(5-20):** Pattern of Average Daily Total Water Consumption Per House ( by Week ) for the Period (from the 1<sup>st</sup> of October to the End of August).

By using the best fitting data, the general trend of water consumption during the study period can be explained by Fig. (5-21). From this Fig., it can be noticed that there is a general upward trend with increasing variability (i.e. the level of consumption increased towards the end of winter and beginning of summer season and reached the maximum level at August (the average daily of winter temperature was 16.5 C° and 46.63 C° for summer)).

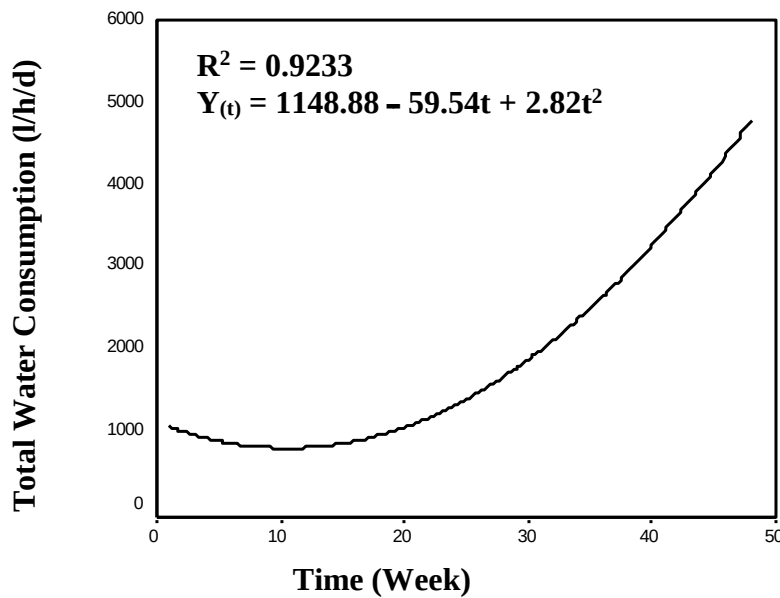


**Fig.(5-21):** Trend of Average Daily Total Water Consumption Per House (by Week) for the Period (from the 1<sup>st</sup> of October to End of August).

The existence of correlation between water demand and climatic variability is in agreement with the previous studies done on water consumption analysis (Metcalf and Eddy, 1974; Twort et al., 1974; Steel and McGhee, 1979). There is a logical fact when water demand is increased with increasing of weather temperature in different domestic activities.

Fig (5-22) shows the sample calculation for the Z- test.

Fig. (5-22) : Calculation of Z – test for the One Sample Test Mean.

Using the procedure mentioned in Sec.(3.3) with the Equation 3.2 and 3.3 the following values were obtained:

For total consumption;

$$S=448, \bar{X} =1652 \text{ l/h/d}$$

$\mu_0 =400 \text{ l/h/d}$  (the value was obtained from Al-Najaf Water Directorate).

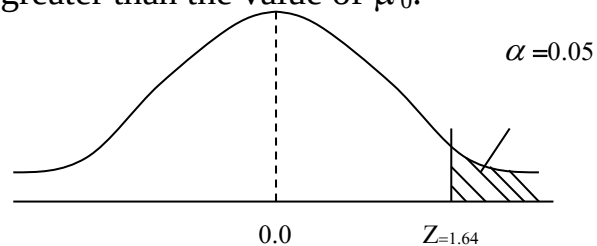
$$Z = \frac{1652-400}{1652/\sqrt{50}} = 5.3589$$

For one – side test at  $\alpha=0.05 \Rightarrow$  tabulated  $Z=1.645$

So calculated  $Z >$  tabulated  $Z \Rightarrow$  reject  $H_0 : \mu - \mu_0 = 0.0$

And accept the alternative hypothesis ( $H_1 : \mu > \mu_0$ ).

By the test (one-sample Z-test) which was carried out between the observed average daily of annual water consumption per house ( $\mu$ ) and standard level of annual water consumption per house ( $\mu_0$ ), it is very evident That the value of  $\mu$  is greater than the value of  $\mu_0$ .



### C. Total Water Demand Model

The findings of the present study are based on the results of the linear regression analysis summarized in Table (5-3 A, B and C) to choose the appropriate model. Model No. 6 (linear in logarithmic form) was found to be the most suitable model to express the total water demand.

The predicted model was as:

$$\ln Q_{total} = 1.354X_4 + 1.203X_5 + 0.009609X_9 + 0.899X_{14} \quad \dots(5-6)$$

Where:

$Q_{total}$  = average daily total water consumption in l/h/d.

In this model, four out of all independent variables assumed to have a reliable impact on demand: No. of showers( $X_4$ ), No. of washbasins( $X_5$ ), total built-up area of house ( $X_9$ ), and No. of families ( $X_{14}$ ), are the most significant variables.

The best fitting of data gives the best model which has the higher value of  $R^2$ , the smaller value of the standard error of the estimate, the least value mean squares errors, and the good values of each of (F) and (t) which are calculated by F-test and t-tests respectively. Then, the model gives a coefficient of determination of ( $R^2=0.945$ ,  $\text{adj.}R^2=0.940$ ) to show that 0.940 of the variation in dependent variable was explained by all independent variables appeared in regression equation, and the standard error of the estimate of 1.85566. Table (5-4) displays other details.

There is a positive correlation between the dependent variable and the four independent variables.

When the model is in log-linear form, the contribution of each one unit of showers, washbasins, total built-up area of house, and No. of families are 1.354, 1.203, 0.009609 and 0.899 L/d respectively for the natural logarithmic form of consumption.

On the other hand, this contribution takes the value of 225.17, 207.64, 1.65 and 159.24 L/d respectively for linear form of consumption.

The total built-up area of house explains most of the percent production power in water demand model (32%) due to the average daily total water consumption. While the variables of No. of washbasins, No. of showers and No. of families variables explain 23.8%, 23.6%, and 20.6% respectively as shown

in Fig.(5-28) or represented by the values of standardized coefficients(Beta) in Table(5-3 C).

The percent variation of showers variable in this study is lower than that reported for U.S.A. 21 %( World Wide Web, 2001).

Isehak (2001) found the percent prediction of the total built up area of house, household size, and number of showers is about 32%, 22%, and 17% respectively for the city of Baghdad.

Loh and Coghlan, 2003 reported the percentage contribution of showers variable of 14% which is lower than the estimated value here.

Samaka I, S (2004) found the percent prediction of number of showers equal to 18.6%.

The significance of the model was tested by conducting the F-test at 5% level of significance. The model shows F-value of 197.057 which exceeds a critical (F) of (2.5858)

The significance of regression coefficients was also tested by conducting the t-test as shown in Table (5-3 C). The value of (t) for each one of the most significant variables mentioned before is 3.080, 2.417, 2.704, and 2.337 respectively.

By regression model, the estimated average consumption in Najaf City is about 1221 l/h/d or is not far from 177 l/c/d).

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

The value of 177 l/c/d is lower than that forecasted by Haiste and Partners (1981) , who estimated average daily domestic consumption to be about 235 l/c/d for the city of Baghdad ,2000 .

Khadam (1988) estimated the average daily of annual water demand of 50.32 l/c/d for the Khartoum metropolitan area.

In U.S. (1998), the predicted average daily of total water use was 650.3 l/c/d which is higher than the value reported by this study ([www.environment.agency.gov.UK](http://www.environment.agency.gov.UK),1999).

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

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

Samaka I, S (2004) estimated the total demand in Hilla of 273.2 l/c/d, and such a value is considered to be higher than that estimated for Najaf.

**Table (5-3):** Linear Regression for Log-linear Total Water Demand Model (l/h/d).

**A- Model Summary**

| Model | R                  | R Square <sup>a</sup> | Adjusted R square | Std. Error of the Estimate |
|-------|--------------------|-----------------------|-------------------|----------------------------|
| 1     | 0.946 <sup>b</sup> | 0.895                 | 0.893             | 2.48105                    |
| 2     | 0.963 <sup>c</sup> | 0.928                 | 0.925             | 2.08081                    |
| 3     | 0.969 <sup>d</sup> | 0.938                 | 0.934             | 1.94171                    |
| 4     | 0.972 <sup>e</sup> | 0.945                 | 0.940             | 1.85566                    |

- a. For regression through the origin (the no-intercept model), R Square measures the proportion of the variability in the dependent variable about the origin explained by regression. This CANNOT be compared to R square for models which include an intercept.
- b. Predictors: Total Built-Up Area of House
- c. Predictors: Total Built-Up Area of House, No. of Washbasins
- d. Predictors: Total Built-Up Area of House, No. of Washbasins, No. of Showers
- e. Predictors: Total Built-Up Area of House, No. of Washbasins, No. of Showers, No. of Families

**B- ANOVA<sup>h,i</sup>**

|   | Model                           | Sum of Squares                               | df            | Mean Square       | F       | Sig.               |
|---|---------------------------------|----------------------------------------------|---------------|-------------------|---------|--------------------|
| 1 | Regression<br>Residual<br>Total | 2571.036<br>301.625<br>2872.661 <sup>b</sup> | 1<br>49<br>50 | 2571.036<br>6.156 | 417.673 | 0.000 <sup>a</sup> |
| 2 | Regression<br>Residual<br>Total | 2664.833<br>207.828<br>2872.661 <sup>b</sup> | 2<br>48<br>50 | 1332.416<br>4.330 | 307.735 | 0.000 <sup>c</sup> |
| 3 | Regression<br>Residual<br>Total | 2695.459<br>177.201<br>2872.661 <sup>b</sup> | 3<br>47<br>50 | 898.486<br>3.770  | 238.310 | 0.000 <sup>d</sup> |
| 4 | Regression<br>Residual<br>Total | 2714.260<br>158.401<br>2872.661 <sup>b</sup> | 4<br>46<br>50 | 678.565<br>3.443  | 197.057 | 0.000 <sup>e</sup> |

a. Predictors: Total Built-Up Area of House

b. This total sum of squares is not corrected for the constant because the constant is zero for regression through the origin.

c. Predictors: Total Built-Up Area of House, No. of Washbasins

d. Predictors: Total Built-Up Area of House, No. of Washbasins, No. of Showers

e. Predictors: Total Built-Up Area of House, No. of Washbasins, No. of Showers, No. of Families

**C- Coefficients<sup>a,b</sup>**

| Model                                                                                                     | Unstandardized coefficients                                      |                                                              | Standardized coefficients                                    | T                                                            | Sig.                                                     |
|-----------------------------------------------------------------------------------------------------------|------------------------------------------------------------------|--------------------------------------------------------------|--------------------------------------------------------------|--------------------------------------------------------------|----------------------------------------------------------|
|                                                                                                           | B                                                                | Std. Error                                                   | Beta                                                         |                                                              |                                                          |
| 1 Total Built-up Area                                                                                     | 2.838E-02                                                        | 0.001                                                        | 0.946                                                        | 20.437                                                       | 0.000                                                    |
| 2 Total Built-up Area<br>No. of Washbasins                                                                | 1.655E-02<br>2.196                                               | 0.003<br>0.472                                               | 0.552<br>0.434                                               | 5.922<br>4.654                                               | 0.000<br>0.000                                           |
| 3 Total Built-up Area<br>No. of Washbasins<br>No. of Showers                                              | 1.299E-02<br>1.498<br>1.484                                      | 0.003<br>0.504<br>0.521                                      | 0.433<br>0.296<br>0.271                                      | 4.491<br>2.972<br>2.850                                      | 0.000<br>0.005<br>0.006                                  |
| 4 <b>Total Built-up Area</b><br><b>No. of Washbasins</b><br><b>No. of Showers</b><br><b>No. of family</b> | <b>9.609E-03</b><br><b>1.203</b><br><b>1.354</b><br><b>0.899</b> | <b>0.003</b><br><b>0.498</b><br><b>0.501</b><br><b>0.385</b> | <b>0.320</b><br><b>0.238</b><br><b>0.236</b><br><b>0.206</b> | <b>3.080</b><br><b>2.417</b><br><b>2.704</b><br><b>2.337</b> | <b>.003</b><br><b>.020</b><br><b>.010</b><br><b>.024</b> |

a. Dependent Variable: Ln of Consumption

b. Linear Regression through the Origin

### D. Identification and Validation of the Total Water Demand Model

There are many ways to check the accuracy or validity of regression equation to show if it regarded as statistically. Some of them are used here.

The value of  $R^2$  is the most important indication of the model accuracy, so the model has high accuracy when  $R^2$  is equal 0.945.

The estimated versus observed values of the average daily water consumption for the total model can be shown in Figure (5-23).

This Fig. shows clearly that the model predicted consumption efficiently as shown by the slope of the best fit line (slope=0.945).

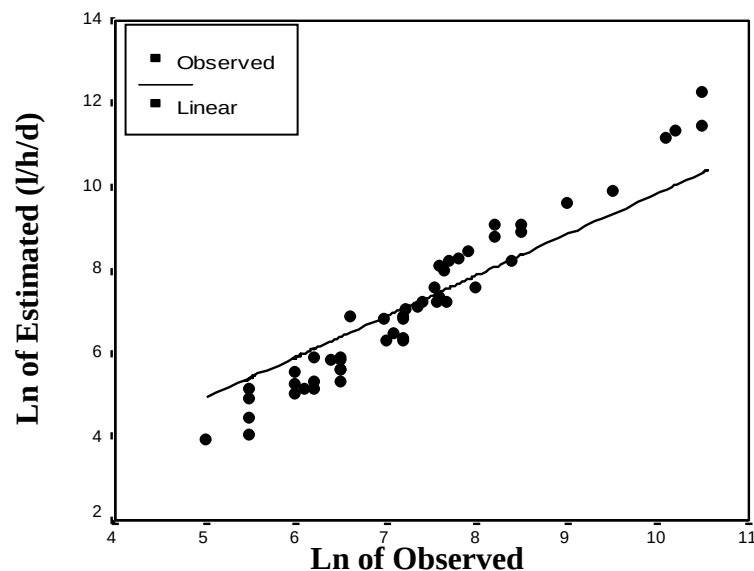


**Fig.(5-23):**Observed and Estimated Water Consumption Using Suitable Total Demand Model ( Log – Linear ) .

The adequacy of this model can be seen from Fig.(5-24),which shows the variation of the estimated and observed values of the average daily water consumption for each house.

The Fig. indicates that the fitted model is a good predictor of average daily water demand.

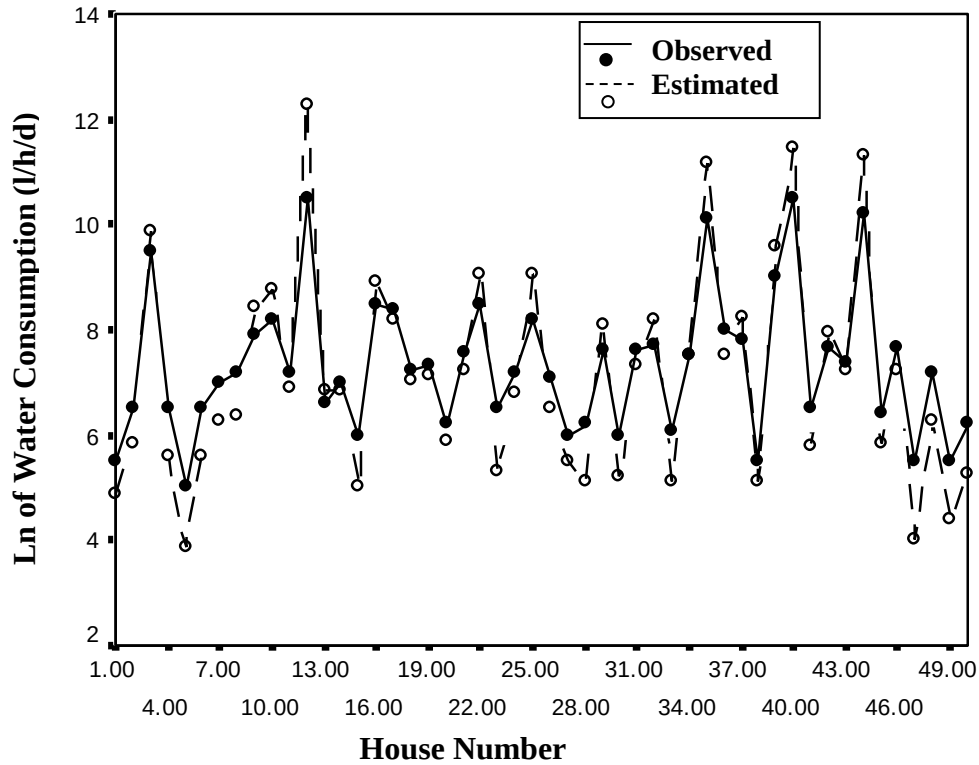


**Fig.(5-24):** Average Daily Observed and Estimated Water Consumption Using Appropriate Total Demand Model (Log-Linear ).

The regression equation was examined and the model was found to be correct when it adequately envelops observed water use with confidence limits of  $\pm 2SE$  (i.e. 95% of observations were enveloped by model).

According to the standard error of estimate, as a percentage of the observed mean demand, the model is acceptable because the value of standard error of estimate(1.85566) is considered in relation to demand(22% and it is lower than the maximum limit of 25%) .

Finally, residual analysis must be done to show the goodness of prediction when it was assume that the residuals should be normal distributed , have independence with mean equal to zero , and variance equal to  $\sigma_e^2$  {  $NID(0, \sigma_e^2)$  }.

A histogram of standardized residuals shows a roughly normal curve with zero value of mean. An alternative for the same purpose is the normal probability plot, with the observed cumulative probabilities of occurrence of the

standardized residuals on the Y axis, and of expected normal probabilities of occurrence on the X axis, such that a 45- degree line will appear when observed conforms to normality except. Ideally, the points should lie along the diagonal ([www2.chass.ncsu.edu/garson /pa765/regress.htm](http://www2.chass.ncsu.edu/garson/pa765/regress.htm)). Then the zero value of mean can be shown by Fig. (5-25) to explain the normality of residuals along with Fig. (5-26).

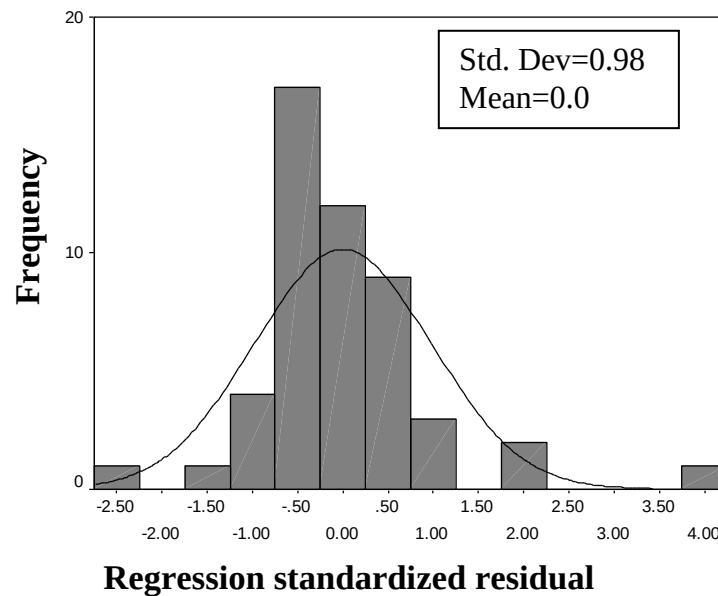


**Fig.(5-25):** The Histogram of Standardized residuals.

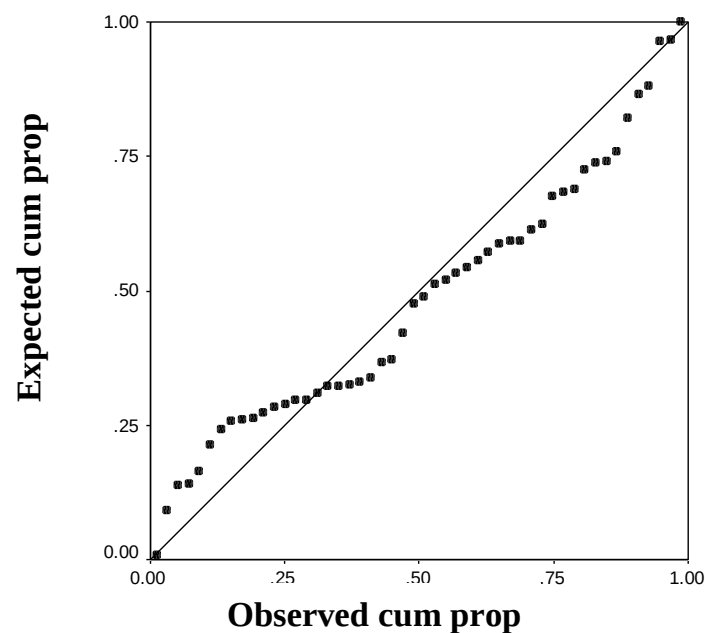


**Fig.(5-26) Cumulative Probability Plot of Standardized Residual**

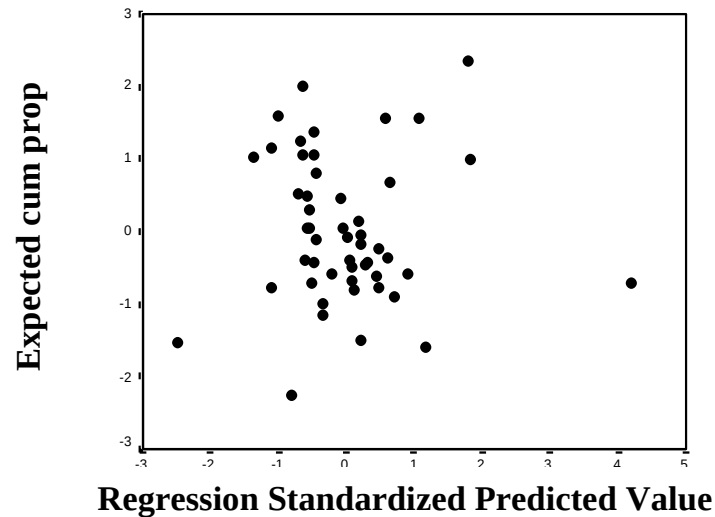


**Fig.(5-27): The Scatterplot of Predicted Against Residual Values**

The Durbin –Watson coefficient,  $d$ , tests for autocorrelation. The value of  $d$  ranges from 0 to 4. Values close to 0 indicate extreme positive autocorrelation; close to 4 indicates extreme negative autocorrelation; and closed to 2 indicates no serial autocorrelation. The value of  $d$  showed be between 1.5 and 2.5 to indicate independence of observations ([www2.chass.ncsu.edu/garson/pa765/regress.htm](http://www2.chass.ncsu.edu/garson/pa765/regress.htm)).

The Durbin –Watson confinement for the total model is equal to 1.775.

### **E. Component Usage for Total Water Demand Model**

Figure (5-28) displays the split of the components of the estimated average daily household water consumption which it is obtained by the regression model and it was found about 1221 l/h/d or close to 177.01 l/c/d.

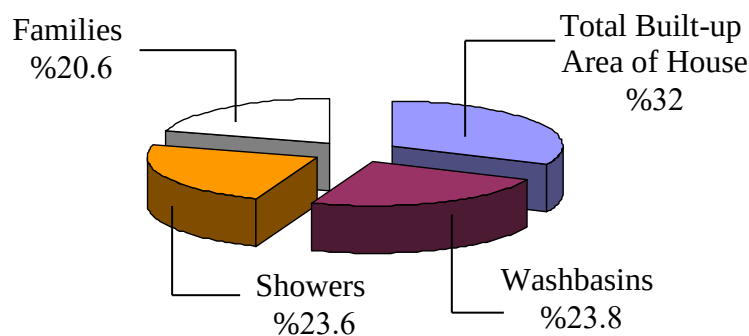


**Fig.(5-28): Percent Water Consumption for Total Demand Model**

The total water consumption is highly dependent on the rate of total built-up area during the study period.

Table (5-4) lists other details which indicate the average component usages for total demand per house per day (l/h/d) or per capita per day (l/c/d).

**Table (5-4):** Average Component Usage for Total Water Demand Model per House or Per Capita per Day

| Component of Model           | l/house/day | % Total use | l/c*/d | l/c/d  |
|------------------------------|-------------|-------------|--------|--------|
| Total Built-up Area of House | 390.9       | 32          | 1.65   | 56.65  |
| Washbasins                   | 290.7       | 23.8        | 207.64 | 42.13  |
| Showers                      | 288.22      | 23.6        | 225.17 | 41.77  |
| Families                     | 251.6       | 20.6        | 159.24 | 36.46  |
| Total Use                    | 1221.42     | 100         |        | 177.01 |

l/c\*/d refers to the value of regression coefficient of each independent variable or it refers to the contribution of each one unit of independent variable in dependent variable (water consumption, Q) .

## F. Correlation Matrix Analysis

Table (5-5) lists the correlation values for the dependent variable and different independent variables that affect total water demand.

**Table (5-5):** Correlation Matrix for Total Water Demand

|                                        | Q Total (l/h/d) | No. of Showers (X <sub>4</sub> ) | No. of Washbasins (X <sub>5</sub> ) | Total Built-up Area (X <sub>9</sub> ) | No. of Families (X <sub>14</sub> ) |
|----------------------------------------|-----------------|----------------------------------|-------------------------------------|---------------------------------------|------------------------------------|
| Q Total                                | 1               | 0.264                            | 0.402                               | 0.465                                 | 0.117                              |
| No. of Showers (X <sub>4</sub> )       | 0.264           | 1                                | 0.313                               | 0.268                                 | 0.15                               |
| No. of Washbasins (X <sub>5</sub> )    | 0.402           | 0.313                            | 1                                   | 0.275                                 | 0.23                               |
| Total Built- up Area (X <sub>9</sub> ) | 0.465           | 0.268                            | 0.275                               | 1                                     | 0.39                               |
| No. of Families (X <sub>14</sub> )     | 0.117           | 0.15                             | 0.23                                | 0.39                                  | 1                                  |

## 5.5 Results of study No.2:

### A. Descriptive Statistics for Dependent Variable

Table (5-6) shows the most important statistical features of **winter** water consumption (from the 1<sup>st</sup> of January to the end of February).

The table explains that the average daily of the observed water demand during winter time was about 1018.1334 l/h/d with a standard deviation of 1051.1162(or 137.4 l/c/d with a standard deviation of equal to 91.339).

Al-Samawi and Hassan (1988) reported a lower value for average daily consumption during winter for Basrah city in (1977-1978) when their figure was 88 lcd.

Samaka, I. S.(2004) reported the value for average daily consumption during winter season for Hilla city 137 l/c/d.

The winter water consumption in Najaf City is about 46.3% of the total average daily demand. Hammer reported the value of 80% in 1975.

**Table (5-6):** Descriptive Statistics for Dependent Variable.

| Water Consumption |       | N         | Range     | Minimum   | Maximum   | Mean      | Std.      | Skewness  |            | Kurtosis  |            |
|-------------------|-------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|------------|-----------|------------|
|                   |       | Statistic | Statistic | Statistic | Statistic | Statistic | Statistic | Statistic | Std. Error | Statistic | Std. Error |
| Winter            | L/h/d | 50        | 4576.67   | 40.00     | 4616.67   | 1018.133  | 1051.1162 | 2.507     | 0.337      | 6.455     | 0.662      |
|                   | L/c/d | 50        | 502.96    | 10.00     | 512.96    | 137.4058  | 91.33987  | 1.958     | 0.337      | 4.980     | 0.662      |

Fig. (5-29) shows the histogram for the average daily winter water consumption per household. The graph explains that the frequency distributions of the water consumption are positively skewed. This is accepted since most water consumption distributions are skewed to the right.

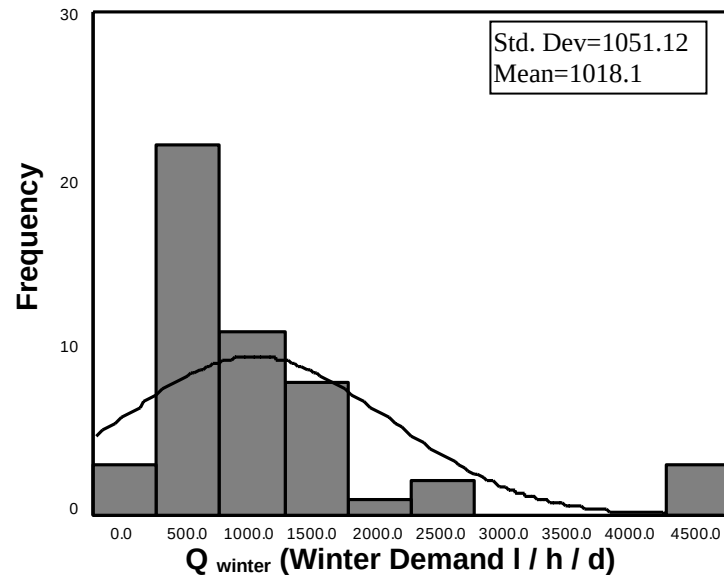


**Fig. (5–29):** Frequency Histogram Distribution for Winter Water Demand (l / h / d).

Figs. (5-30) and (5-31) display the cumulative frequency and percentage graph for the average daily winter demand per household and they indicate that 88% of the houses in Al-Najaf city consume (1.5 m<sup>3</sup>/h or less) of water per day.

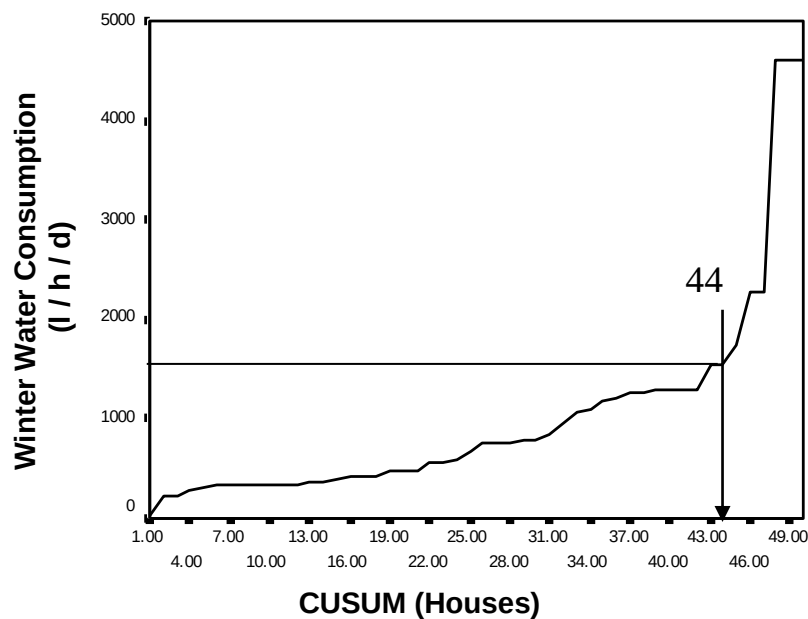


**Fig. (5–30):** Cumulative Frequency Histogram for Winter Water Demand.

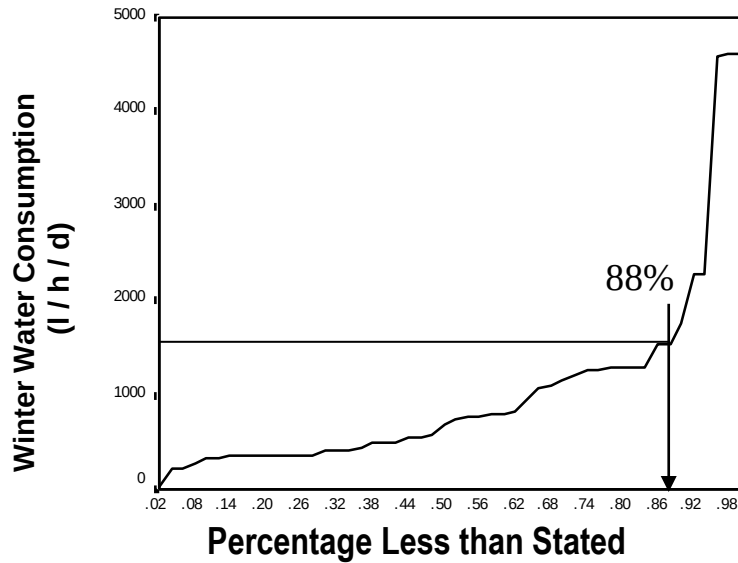


Fig. (5-31): Cumulative Frequency Histogram for Winter Water Demand.

### B. Pattern of Average Daily Winter Water Usage in Najaf City

Fig. (5-32) shows the pattern of the average daily water consumption of the households, weekly observed during winter season.

Referring to this Fig., it can be seen that the minimum water consumption happened in January and the pattern increased towards the end of this season (the average daily temperature of January was 18.5 C° and of February was 21.5 C°).

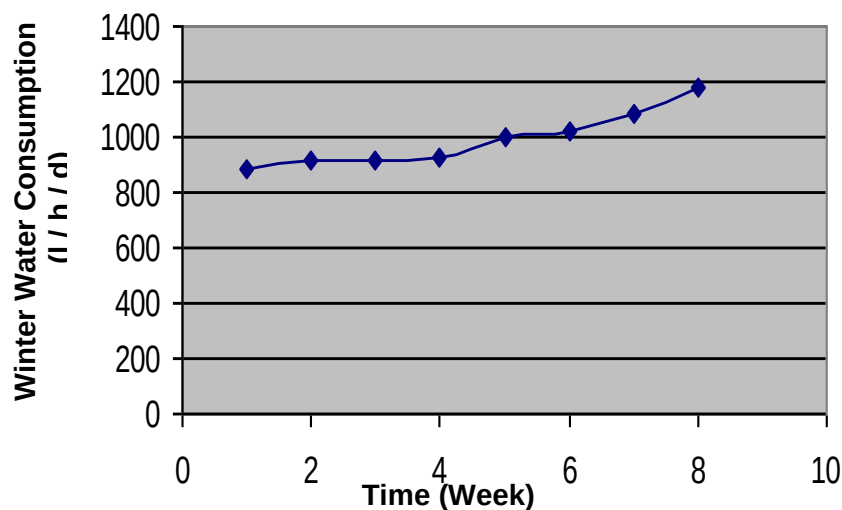


Fig. (5-32): Pattern of Average Daily Winter Water Consumption Per House (by Week) for the Period (from the 1<sup>st</sup> of January to the End of February).

### C. Winter Water Demand Model

The results of the regression analysis can be summarized in Table (5-7A, B, and C) to choose the appropriate model. The table shows that model number 4 (linear in logarithmic form) was found to be the most suitable to represent the winter water demand.

The model was predicted as:

$$\ln Q_{win.} = 0.24 X_1 + 0.692 X_2 + 0.468 X_{13} \quad \dots (5-7)$$

where  $Q_{win.}$  = average daily winter water consumption in l/h/d.

In this model, household size ( $x_1$ ), No. of bedrooms ( $x_2$ ) and the pressure ( $x_{13}$ ) are the most significant independent variables. When the data was fitted very well, then the explanatory power of the model is measured by coefficient of multiple determination  $R^2 = 0.974$  (adj. $R^2=0.972$ ), and the standard error of estimate was 1.14749; Table (5-6) displays other details.

There is a positive correlation between the dependent variable and the three independent variables.

When the model is in log-linear form, then the contribution of each one unit of household size, No. of bedrooms, and pressure are 0.24, 0.692, 0.468, and l/d respectively for natural logarithmic form of consumption, but it equals to about 27.53, 80.99 and 51.1 l/d respectively for the linear form of consumption.

The pressure explains most of the percentage contribution in prediction of water demand model 47.1%, while the household size and the No. of bedrooms variables explain 25.5% and 27.4% respectively as shown in Fig. (5-38) or represented by the values of standardized coefficients (Beta) in Table (5-7C).

Samaka I, S (2004) reported the percent of bedrooms variable of Hilla city 36.3%, which is higher than the value for Najaf.

The significance of the model was tested by conducting the F-test at 5% level of significance. The model shows F-value of 577.134 which exceeds a critical F of (2.5858). The regression coefficients are significant when their significance was tested by conducting the t-test as shown in Table (5-6C). The value of t for each one of the most significant variables mentioned before is 3.824, 3.735 and 8.805 respectively.

By the model, the estimated average consumption (nearly 745 l/h/d or about 107.97 l/c/d) was within range of observed values.

Twort et al. (1985) suggested a value of 160 l/c/d for winter water demand.

In Canada (1996) and U.S. (1998), the average daily indoor water use (winter) was 326 and 262.3 l/c/d respectively which is higher than the value reported by this study

([www.chs.ubc.ca/china/pdf%20Files/Zhang/Ch%202%20%20Lit%Review.pdf](http://www.chs.ubc.ca/china/pdf%20Files/Zhang/Ch%202%20%20Lit%Review.pdf));([www.environment.agency.gov.UK](http://www.environment.agency.gov.UK), 1999).

Darmody et al. (1998, pp. 286) found the values for three cities: Sydney, Bangkok, and East Bay Municipal Utility District (EBMUD) which were 184, 190, 244 l/c/d respectively.

Loh and Coghlan (2003) estimated the water demand for the in-house purposes in Perth/Western Australia to be 155 l/c/d; this value is higher than that reported for Al-Najaf city. Heaney et al. (2002) reported the value of 262.32 L/c/d (640.9 l/h/d) for 12 cities of North America, but Maddaus (1987) reported it 227.1 l/c/d for the same areas. Both two values are higher than the estimated value of Al- Najaf city.

**Table (5-7):** Linear Regression for Log-linear Winter Water Demand Model (L/h/d).**A- Model Summary**

| Model | R                  | R Square <sup>a</sup> | Adjusted R square | Std. Error of the Estimate |
|-------|--------------------|-----------------------|-------------------|----------------------------|
| 1     | 0.959 <sup>b</sup> | 0.920                 | 0.918             | 1.9573                     |
| 2     | 0.983 <sup>c</sup> | 0.966                 | 0.964             | 1.29301                    |
| 3     | 0.987 <sup>d</sup> | 0.974                 | 0.972             | 1.14749                    |

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

b. Predictors: The pressure

c. Predictors: The pressure, Household size

d. Predictors: The pressure, Household size, No. of Bedrooms

**B- ANOVA<sup>f,g</sup>**

| Model        | Sum of Squares        | Df | Mean Square | F       | Sig.               |
|--------------|-----------------------|----|-------------|---------|--------------------|
| 1 Regression | 2153.953              | 1  | 2153.953    | 562.234 | 0.000 <sup>a</sup> |
| Residual     | 187.722               | 49 | 3.831       |         |                    |
| Total        | 2341.675 <sup>b</sup> | 50 |             |         |                    |
| 2 Regression | 2261.425              | 2  | 1130.712    | 676.310 | 0.000 <sup>c</sup> |
| Residual     | 80.251                | 48 | 1.672       |         |                    |
| Total        | 2341.675 <sup>b</sup> | 50 |             |         |                    |
| 3 Regression | 2279.789              | 3  | 759.930     | 577.134 | 0.000 <sup>d</sup> |
| Residual     | 61.886                | 47 | 1.317       |         |                    |
| Total        | 2341.675 <sup>b</sup> | 50 |             |         |                    |

a. Predictors: The pressure

b. This total sum of squares is not corrected for the constant because the constant is zero for regression through the origin.

c. Predictors: The pressure, Household size

d. Predictors: The pressure, Household size, No. of Bedrooms

e. Linear Regression through the Origin

**C- Coefficients<sup>a,b</sup>**

| Model           | Unstandardized coefficients |            | Standardized coefficients | t      | Sig.  |
|-----------------|-----------------------------|------------|---------------------------|--------|-------|
|                 | B                           | Std. Error | Beta                      |        |       |
| 1 The pressure  | 0.934                       | 0.039      | 0.959                     | 23.711 | 0.000 |
| 2 The pressure  | 0.553                       | 0.054      | 0.568                     | 10.207 | 0.000 |
| Household size  | 0.404                       | 0.050      | 0.446                     | 8.018  | 0.000 |
| 3 The pressure  | 0.468                       | 0.053      | 0.471                     | 8.805  | 0.000 |
| Household size  | 0.240                       | 0.063      | 0.255                     | 3.824  | 0.000 |
| No. of bedrooms | 0.692                       | 0.185      | 0.274                     | 3.735  | 0.001 |

a. Dependent Variable: Ln of Consumption

b. Linear Regression through the Origin

### D. Identification and Validation of the Winter Water Demand Model

In addition to the high value of  $R^2$  (0.974) which reflects the good predication of model.

Fig. (5-33) shows a plot of estimated versus the observed values of average daily water consumption for the winter model.

It is clear from this Fig. that the model predicted consumption efficiently as shown by the slope of the best fit line (slope = 0.974).

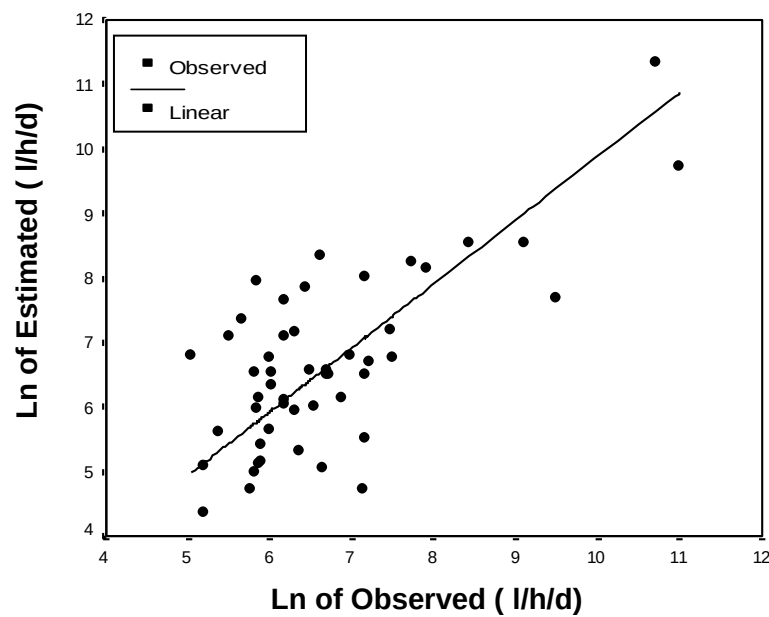


**Fig. (5-33):** Observed and Estimated Water consumption Using Suitable Winter Model (Log – Linear).

The adequacy of this model can be seen from Figure (5-34), which shows the variation of the estimated and observed values of the average daily water consumption for each house. The figure indicates that the fitted model is a good predictor of average daily water demand.

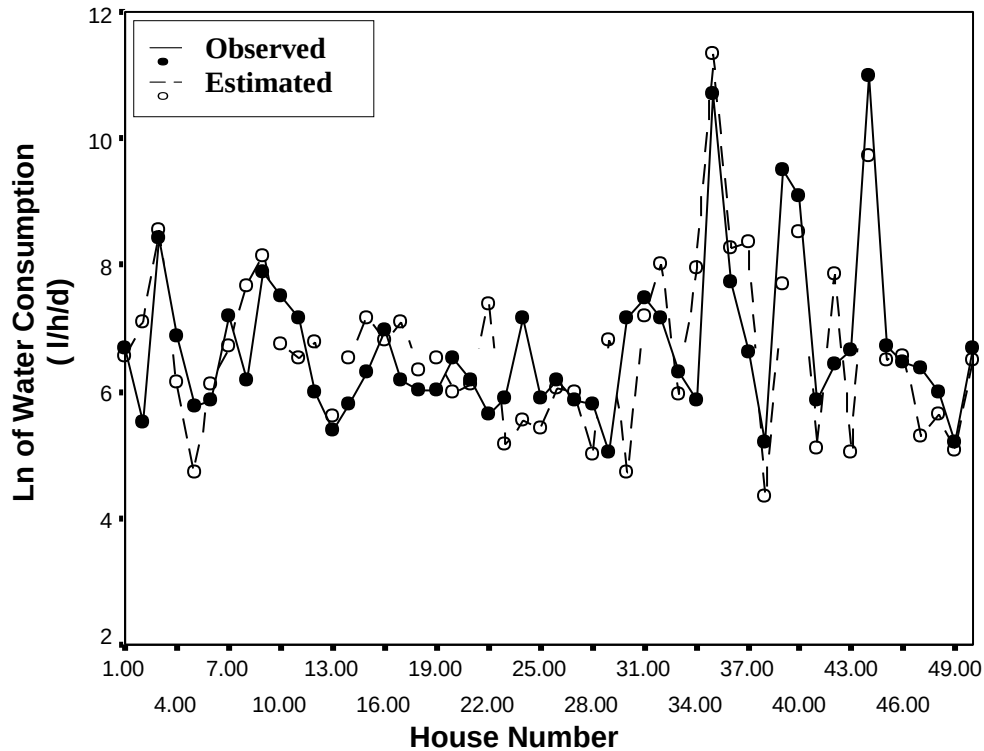


**Fig. (5-34):** Average Daily Observed and Estimated Water Consumption Using Appropriate Winter Model (Log – Linear).

The regression equation was examined and it was found that the model adequately envelops observed water use with confidence limits of  $\pm 2SE$ .

According to the standard error of estimate, as a percentage of the observed mean demand, the model is considered to be acceptable because the value of standard error of estimate (1.14749) is considered in relation to demand (17% and it is less than the maximum limit of 25%)

Figures (5-35) and (5-36) verify the normality assumption. Both figures indicate that the distribution of the residuals is normal, as required in the assumptions.

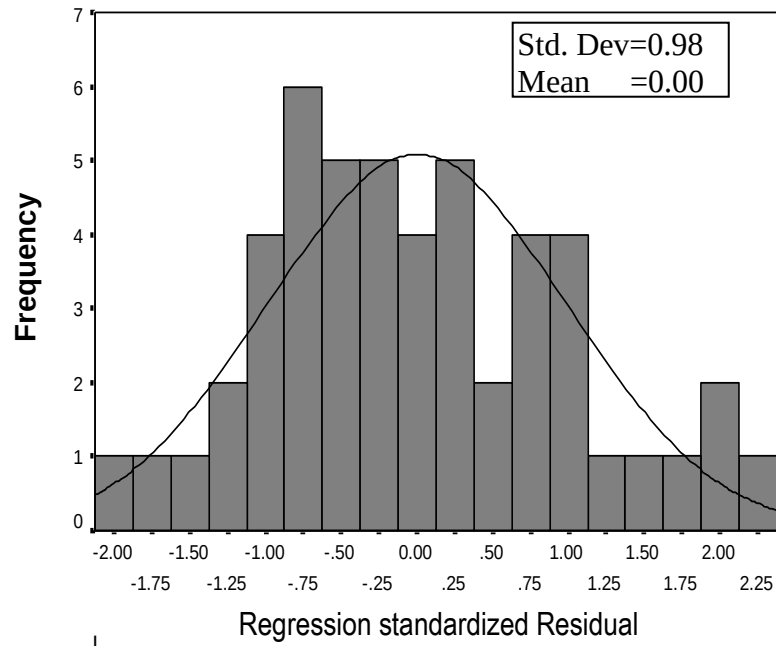


**Fig.(5-35):** The Histogram of standardized Residuals

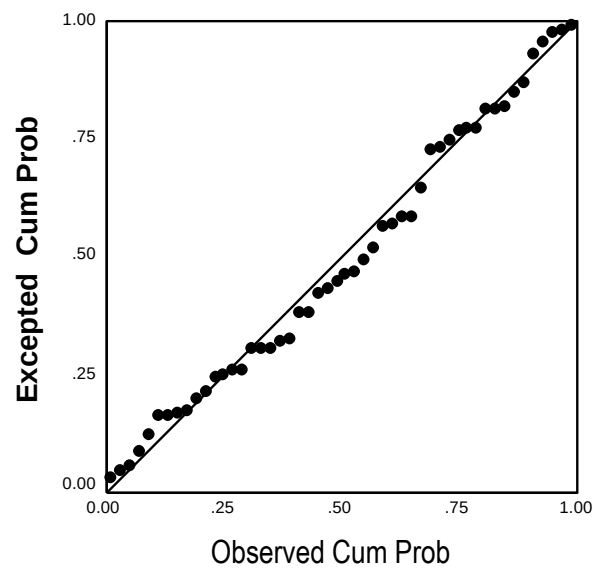


**Fig.(5-36):** Cumulative Probability Plot of Standardized Residuals

The residuals are plotted against the predicted values of demand by Figure (5-37). No clear systematic pattern appears in this figure, indicating the adequacy of the model and that the predicted values are not correlated with the residuals.

The Durbin- Watson coefficient,  $d$ , is equal to 1.828.

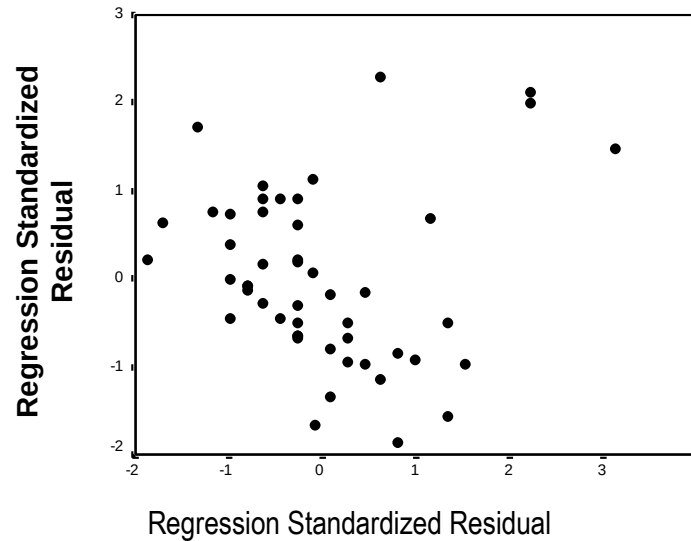


**Fig.(5-37):** The Scatterplot of Predicted against Residuals Values

### **E. Component Usage for Winter Water Demand Model**

By regression model, the average daily household water consumption was estimated and it was found to be 745 l/h/d or nearly 107.97 l/c/d. The split of the components is as shown in Figure (5-38) below:

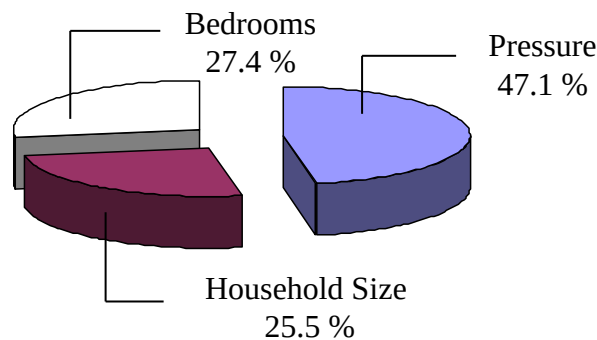


**Fig. (5 – 38):** Percent Water Consumption for Winter Demand Model.

Winter water consumption is highly dependent on the rate of number of the pressure during the winter period in this study. The average daily water use per person with bedroom can be estimated of 29.58 L/c/d, which is less than that reported by Samaka I, S (2004) for Hilla city which is 33.8 L/c/d.

Other details are explained in Table (5-7), which shows the average component usages for winter demand per house per day (l/h/d) or per capita per day (l/c/d).

**Table (5-8):** Average Component Usage for Winter Water Demand Model Per House or Per Capita Per Day.

| Component of Model     | l/house/day | %Total use | %Total model | l/c*/d | l/c/d  |
|------------------------|-------------|------------|--------------|--------|--------|
| Pressure               | 350.9       | 47.1       | 28.73        | 51.1   | 50.855 |
| Household size         | 190         | 25.5       | 15.55        | 27.53  | 27.53  |
| No. of Bedrooms        | 204.1       | 27.4       | 16.71        | 80.99  | 29.58  |
| Total Winter Water Use | 745         | 100        | 60.99        |        | 107.97 |

## F. Correlation Matrix Analysis

Table (5-9) lists the correlation values for the dependent variable and different independent variables that affect winter water demand.

**Table (5-9):** Correlation Matrix for Winter Water Demand

|                                   | Q Winter<br>(l/h/d) | Household<br>Size<br>(X <sub>1</sub> ) | No. of<br>Bedrooms<br>(X <sub>2</sub> ) | Pressure<br>(X <sub>13</sub> ) |
|-----------------------------------|---------------------|----------------------------------------|-----------------------------------------|--------------------------------|
| Q Winter                          | 1                   | 0.620                                  | 0.04                                    | 0.623                          |
| Household Size (X <sub>1</sub> )  | 0.620               | 1                                      | 0.586                                   | 0.163                          |
| No. of Bedrooms (X <sub>2</sub> ) | 0.04                | 0.586                                  | 1                                       | 0.119                          |
| Pressure (X <sub>13</sub> )       | 0.623               | 0.163                                  | 0.119                                   | 1                              |

## 5.6 Results of study No.3:

### A. Descriptive Statistics for Dependent Variable.

Descriptive statistics for **summer** water consumption in study area (from the 1<sup>st</sup> of July to the end of August) are explained by Table (5-10) below:

**Table (5-10):** Descriptive Statistics for Dependent Variable.

| Water Consumption |       | N         | Range     | Minimum   | Maximum   | Mean      | Std.      | Skewness  |            | Kurtosis  |            |
|-------------------|-------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|------------|-----------|------------|
|                   |       | Statistic | Statistic | Statistic | Statistic | Statistic | Statistic | Statistic | Std. Error | Statistic | Std. Error |
| Summer            | L/h/d | 50        | 3551.50   | 748.50    | 4300.00   | 2196.21   | 8586.36   | 0.5       | 0.337      | 0.08      | 0.662      |
|                   | L/c/d | 50        | 525.17    | 223.33    | 748.50    | 334.8     | 99.48531  | 1.86      | 0.337      | 4.792     | 0.662      |

From this table, it can be noticed that the observed average daily water demand during summer season was very close to 1852 L/h/d with a standard deviation of nearly 632.15(or around 331 L/c/d with a standard deviation of about 270.86).

Al-Samawi and Hassan (1988) found a value of 180 Lcd for average daily consumption during the summer season for the period (1977-1978) in Basrah City, Iraq . This value indicates that a significant increase in trend of water demand occurred in Iraq during the last two decades.

Samaka, I. S. (2004) found a value of 307 L/c/d for average daily consumption during the summer season in Hilla city.

The average daily summer consumption in Al-Najaf city is (69.62%) higher than the total average daily demand. In 1975, Hammer reported a value of 30%.

Al-Adawi (1983) concluded a peak factor value of 1.2-1.6 for maximum seasonal domestic water demand. In the present study, the peak factor is found to be 1.6 .

Fig. (5-39) explains the histogram for the average daily water demand per house. The frequency distributions of water consumption are positively skewed when most water demand distributions are skewed to the right.

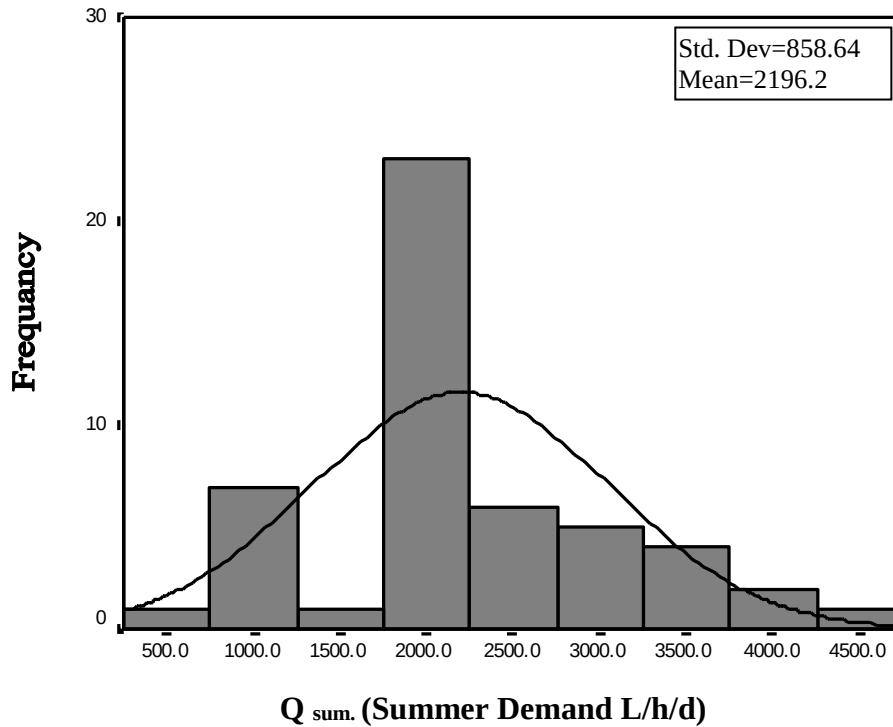


**Fig.(5-39):** Frequency Histogram Distribution for Study No.3 (L/h/d).

Figs. (5-40) and (5-41) show the cumulative frequency and percentage graph for the average summer demand per household. These figures indicate that 87% of houses in Najaf consume (3400 l/h or less) of water per day.

Isehak (2001) concluded that 81.3% of houses in Baghdad consume (2000 l/h or less) of water.

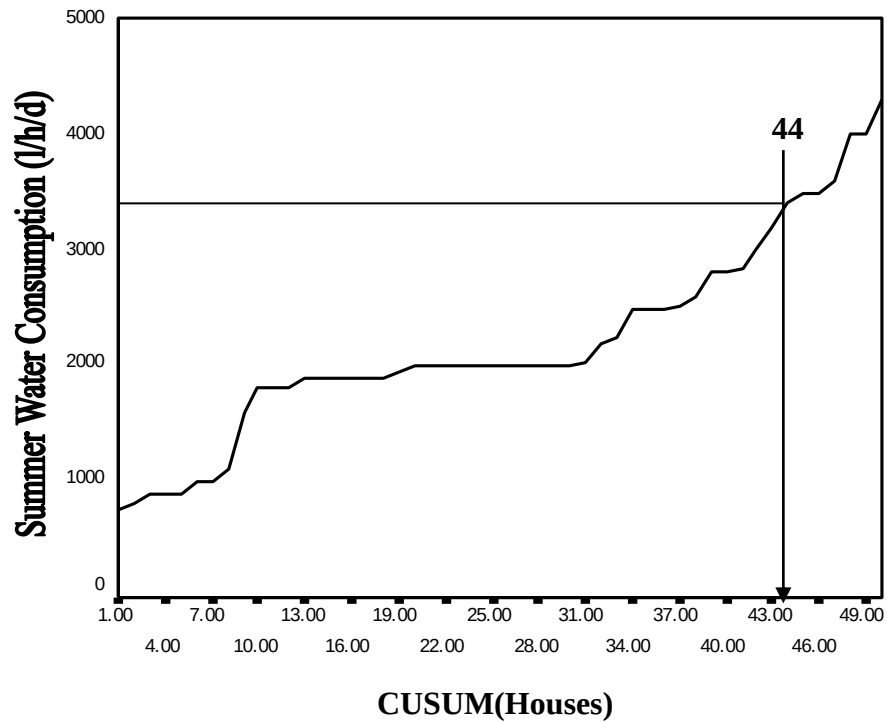


Fig.(5-40): Cumulative Frequency Histogram for Study No.3.

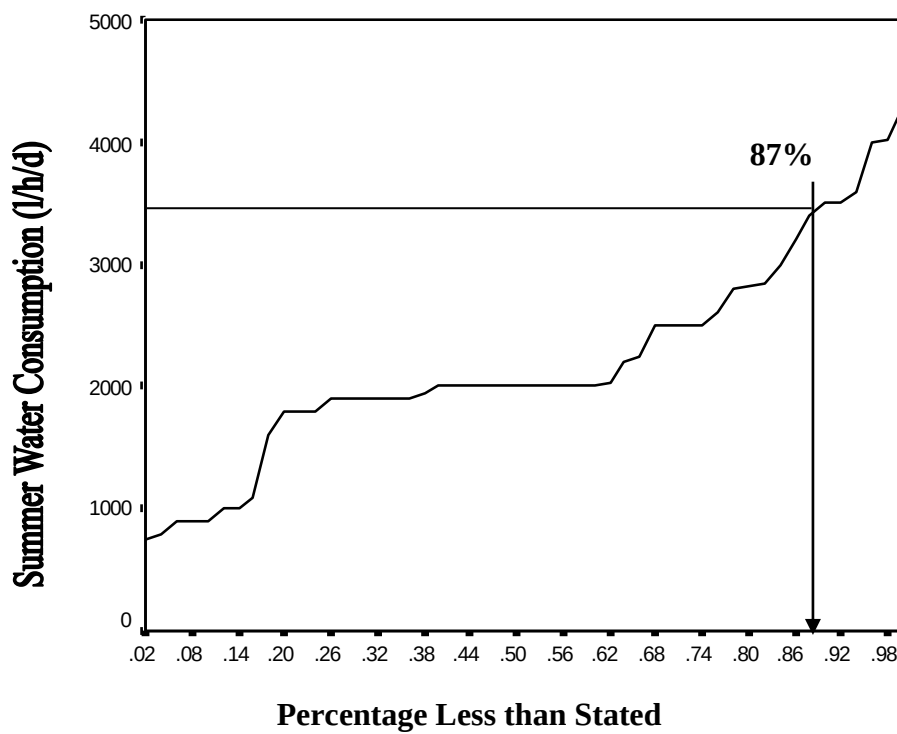


Fig.(5-41): Cumulative Frequency Histogram for Study No.3

## B. Pattern of Average Daily Summer Water Demand in Najaf City.

The pattern of the average daily household water consumption which was weekly observed during the summer season are presented through Fig.(5-42). According to the results of this figure, one can conclude that the maximum level of water demand occurred in August because temperature reaches to its maximum value.

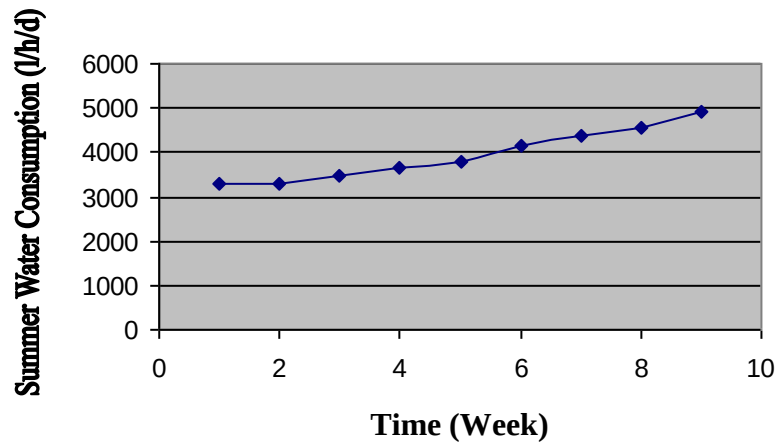


**Fig.(5-42):** Pattern of Average Daily Summer Water Consumption Per House (by Week ) for the Period (from the 1<sup>st</sup> of July to the End of August).

## C. Summer Water Demand Model.

Table (5-11 A, B, and C) shows a summary of the results of the linear regression for the average daily summer water demand per house.

The final suitable model (model no. 4) which is linear in logarithmic form is :

$$\ln Q_{sum.} = 0.731X_4 + 1.097X_7 + 0.693X_{12} + 0.61X_{13} + 0.504X_{14} \dots (5-8)$$

Where:

$Q_{sum.}$  =average daily summer water consumption in l/h/d

In this model, No. of showers( $X_4$ ), No. of air-coolers( $X_7$ ), No. of cars ( $X_{12}$ ), the pressure( $X_{13}$ ), and No. of families( $X_{14}$ ), are the most significant independent variables.

The best fitting of data can be measured by the high value of coefficient of determination of  $R^2=0.981$ (adj. $R^2=0.979$ ), and the standard error of the estimate of 1.16898. Table (5-11) lists other details.

It can be noticed from the above-mentioned model that there is a positive correlation between the dependent variable and four independent variables.

The contribution of each one unit of No. of showers, No. of air-coolers, No. of cars, the pressure, and No. of families are 0.731, 1.097, 0.504, 0.693, and 0.61 l/d respectively for natural logarithmic form of consumption. On the other hand, the value of this contribution is nearly 455.8, 402.17, 176,183.75, and 210.13 l/d respectively for linear form of consumption.

The model indicates that the independent variable (the pressure) explains most of the variation in percent prediction (52.4%) in the summer demand model, while number of air coolers, number of families, number of cars, and number of showers explain around 22.2%, 10.1%,3.2% and 12.1% respectively. Isehak(2001) estimated the percent prediction power of built-up area of house, household size, and number of showers for the city of Baghdad of about 31%, 22.6%, and 15.7% respectively for summer model.

The significance of model was tested by conducting the F-test at 5% level of significance. The value of (F) is 472.856 which exceed the critical value of (F).

The test of significance of regression coefficients was also done by conducting the t-test as shown in Table (5-11 C).

The value of (t) for each one of the most significant variables previously mentioned is 9.377, 4.392, 2.125, 2.457, and 2.339 respectively.

By this study, the estimated average consumption, which was about (2753.7 l/h/d) or not far from (399.08 l/c/d), was within the range of observed water use.

Loh and Coghlan (2003) estimated the value of 1230 l/h/d in Perth/Western Australia, and this value is lower than the estimated value for Al-Najaf city.

**Table (5-11):** Linear Regression for Log-linear Summer Water Demand Model (L/h/d).**A- Model Summary**

| Model | R                  | R Square <sup>a</sup> | Adjusted R square | Std. Error of the Estimate |
|-------|--------------------|-----------------------|-------------------|----------------------------|
| 1     | 0.973 <sup>b</sup> | 0.947                 | 0.945             | 1.89492                    |
| 2     | 0.985 <sup>c</sup> | 0.971                 | 0.969             | 1.41917                    |
| 3     | 0.988 <sup>d</sup> | 0.977                 | 0.975             | 1.27915                    |
| 4     | 0.989 <sup>e</sup> | 0.979                 | 0.977             | 1.22447                    |
| 5     | 0.991 <sup>f</sup> | 0.981                 | 0.979             | 1.16898                    |

- a. For regression through the origin (the no-intercept model), R Square measures the proportion of the variability in the dependent variable about the origin explained by regression. This CANNOT be compared to R square for models which include an intercept.
- b. Predictors: The pressure
- c. Predictors: The pressure, No. of air-coolers
- d. Predictors: The pressure, No. of air-coolers, No. of families
- e. Predictors: The pressure, No. of air-coolers, No. of families, No. of cars
- f. Predictors: The pressure, No. of air-coolers, No. of families, No. of cars, NO. Of showers

**B- ANOVA<sup>f,g</sup>**

| Model        | Sum of Squares        | df | Mean Square | F       | Sig.               |
|--------------|-----------------------|----|-------------|---------|--------------------|
| 1 Regression | 3116.357              | 1  | 3116.357    | 867.892 | 0.000 <sup>a</sup> |
| Residual     | 175.945               | 49 | 3.591       |         |                    |
| Total        | 3292.302 <sup>b</sup> | 50 |             |         |                    |
| 2 Regression | 3195.629              | 2  | 1597.814    | 793.342 | 0.000 <sup>c</sup> |
| Residual     | 96.673                | 48 | 2.014       |         |                    |
| Total        | 3292.302 <sup>b</sup> | 50 |             |         |                    |
| 3 Regression | 3215.400              | 3  | 1071.800    | 655.044 | 0.000 <sup>d</sup> |
| Residual     | 76.903                | 47 | 1.636       |         |                    |
| Total        | 3292.302 <sup>b</sup> | 50 |             |         |                    |
| 4 Regression | 3223.334              | 4  | 805.833     | 537.467 | 0.000 <sup>e</sup> |
| Total        | 68.969                | 46 | 1.499       |         |                    |
| Residual     | 3292.302 <sup>b</sup> | 50 |             |         |                    |
| 5 Regression | 3230.809              | 5  | 646.162     | 472.856 | 0.000 <sup>f</sup> |
| Total        | 61.493                | 45 | 1.367       |         |                    |
| Residual     | 3292.302 <sup>b</sup> | 50 |             |         |                    |

- a. Predictors: No. of Washbasins
- b. This total sum of squares is not corrected for the constant because the constant is zero for regression through the origin.
- c. Predictors: The pressure, No. of air-coolers
- d. Predictors: The pressure, No. of air-coolers, No. of families
- e. Predictors: The pressure, No. of air-coolers, No. of families, No. of cars
- f. Predictors: The pressure, No. of air-coolers, No. of families, No. of cars, NO. of showers
- g. Dependent Variable : Ln of Consumption
- h. Linear Regression through the Origin

**C- Coefficients <sup>a,b</sup>**

| Model |                           | Unstandardized coefficients |              | Standardized coefficients | t            | Sig.         |
|-------|---------------------------|-----------------------------|--------------|---------------------------|--------------|--------------|
|       |                           | B                           | Std. Error   | Beta                      |              |              |
| 1     | The pressure              | 1.123                       | 0.038        | 0.973                     | 29.460       | 0.000        |
| 2     | The pressure              | 0.775                       | 0.062        | 0.672                     | 12.430       | 0.000        |
|       | No. of air-coolers        | 1.656                       | 0.264        | 0.339                     | 6.274        | 0.000        |
| 3     | The pressure              | 0.681                       | 0.062        | 0.590                     | 10.925       | 0.000        |
|       | No. of air-coolers        | 1.258                       | 0.264        | 0.257                     | 4.764        | 0.000        |
|       | No. of families           | 0.823                       | 0.237        | 0.176                     | 3.476        | 0.001        |
| 4     | The pressure              | 0.683                       | 0.060        | 0.592                     | 11.442       | 0.000        |
|       | No. of air-coolers        | 1.248                       | 0.253        | 0.255                     | 4.937        | 0.000        |
|       | No. of families           | 0.627                       | 0.242        | 0.134                     | 2.589        | 0.013        |
|       | No. of cars               | 0.680                       | 0.295        | 0.065                     | 2.300        | 0.026        |
| 5     | <b>The pressure</b>       | <b>0.610</b>                | <b>0.065</b> | <b>0.524</b>              | <b>9.377</b> | <b>0.000</b> |
|       | <b>No. of air-coolers</b> | <b>1.097</b>                | <b>0.250</b> | <b>0.222</b>              | <b>4.392</b> | <b>0.000</b> |
|       | <b>No. of families</b>    | <b>0.504</b>                | <b>0.237</b> | <b>0.101</b>              | <b>2.125</b> | <b>0.039</b> |
|       | <b>No. of cars</b>        | <b>0.693</b>                | <b>0.282</b> | <b>0.032</b>              | <b>2.457</b> | <b>0.018</b> |
|       | <b>No. of showers</b>     | <b>0.731</b>                | <b>0.313</b> | <b>0.121</b>              | <b>2.339</b> | <b>0.024</b> |

a. Dependent Variable: Ln of Consumption

b. Linear Regression through the Origin

**D. Identification and Validation of the Summer Water Demand Model.**

The explanatory power of the model is measured by  $R^2$ , which is the most important indication of the model accuracy. So that, the result is good when the value of  $R^2 = 0.981$ .

The efficiency of model is shown through Fig. (5-43), which plots the estimated versus observed values of average daily water consumption for summer model. It can be found that the model predicted consumption efficiently when the slope of the best fit line is 0.981.

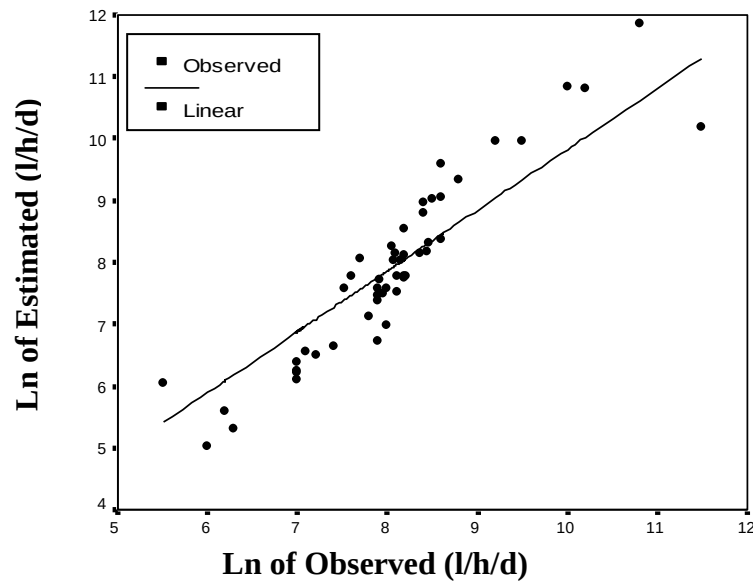


**Fig.(5-43):** Observed and Estimated Water Consumption Using Suitable Summer Demand Model ( Log – Linear )

Fig. (5-44) shows the adequacy of summer model when the variation of the estimated and observed values of the average daily water consumption for each house was plotted.

The figure indicates that the model is a good predictor of summer water demand.

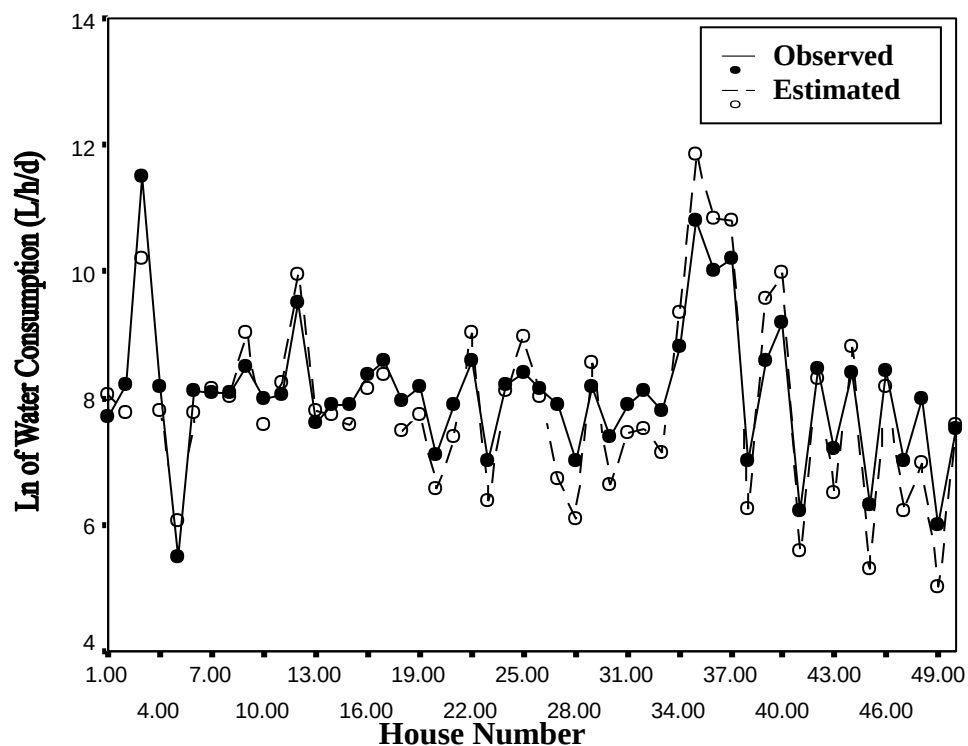


**Fig.(5-44):** Average Daily Observed and Estimated Water Consumption Using Appropriate Summer Demand Model (Log-Linear ).

The summer model has a good efficiency in predicting the water demand when its regression equation was examined and it was in agreement with the measurements which indicate the accuracy of model. These measurements are previously presented with the two previous models.

The residuals from this model were plotted in Figs. (5-45) and (5-46). The data seemed to be in normal distribution with a mean level of zero.

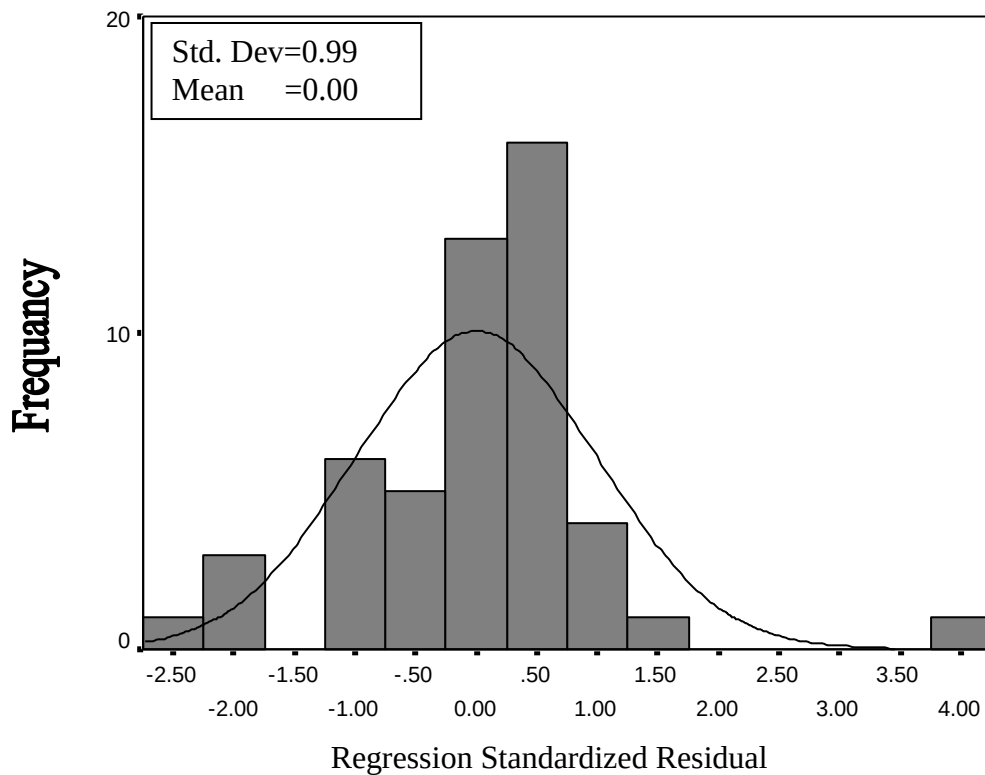


**Fig.(5-45):** The Histogram of Standardized Residuals

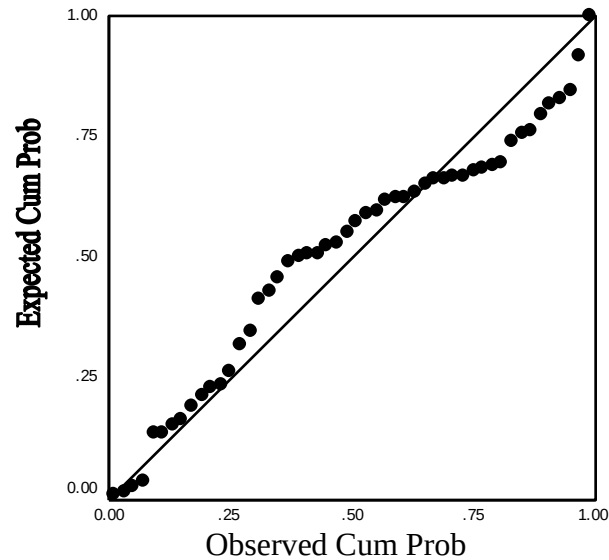


**Fig.(5-46):** Cumulative Probability Plot of Standardized Residuals

The adequacy of summer model is further proved by the Figure (5-47), which shows a scatterplot of the residuals versus the predicted values. No clear systematic pattern appears in this figure, indicating the adequacy of the model.

Durbin – Watson coefficient for summer model is equal to 1.92.

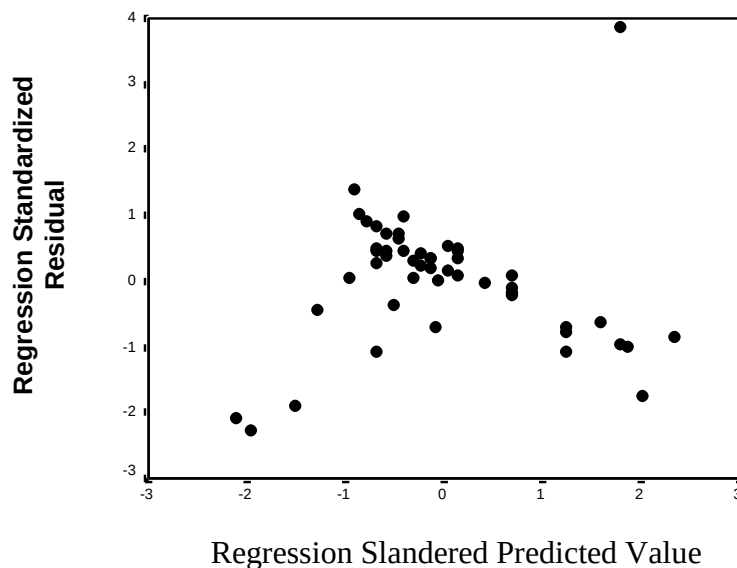


**Fig.(5-47):** The Scatter plot of Predicted against Residuals Value

It was planned to introduce the dummy variable (D) which refers to the use of raw water and added to the independent variables of summer demand to show its contribution in reducing domestic water use. Then the raw water was not supplied to the houses at the study period, so the idea of dummy variable was eliminated from this research.

### E . Component Usage for Summer Water Demand Model.

The summer water demand is highly dependent on the rate of component of number of washbasins. Figure(5-48) shows the split of the other components of the estimated average daily water demand which is obtained by regression equation has the value of 2753 l/h/d or about 399.08 l/c/d.

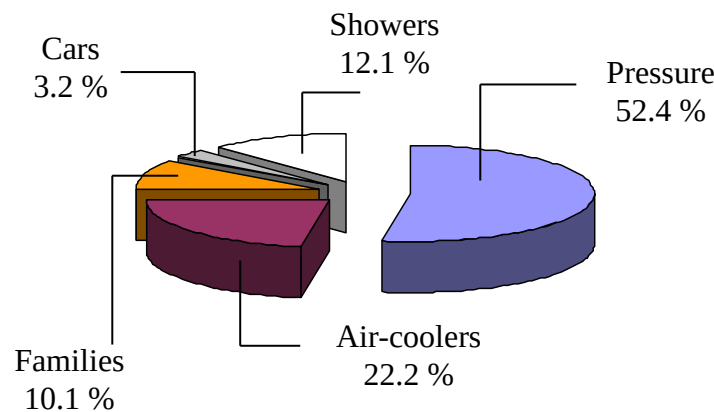


**Fig.(5-48):** Percent Water Consumption for Summer Model.

Table (5-12) explains other details such as average component usages for summer demand per house per day or per capita per day.

**Table (5-12):** Average Component Usage for Summer Demand Model Per House or Per Capita Per Day.

| Component of Model | l/house/day | % Total use | %Total model | l/c*/d | l/c/d  |
|--------------------|-------------|-------------|--------------|--------|--------|
| The pressure       | 1442.9      | 52.4        | 118.13       | 210.13 | 209.11 |
| Air-coolers        | 611.3       | 22.2        | 50.04        | 402.17 | 88.59  |
| Families           | 278.1       | 10.1        | 22.77        | 176.01 | 40.3   |
| Cars               | 88.2        | 3.2         | 7.22         | 183.75 | 12.78  |
| Showers            | 333.2       | 12.1        | 27.28        | 455.8  | 48.29  |
| Total Summer Use   | 2753.7      | 100         | 225.44       |        | 399.08 |

## F. Correlation Matrix Analysis

Table (5-13) lists the correlation values for the dependent variable and different independent variables that affect summer water demand.

**Table (5-13):** Correlation Matrix for Summer Water Demand

|                                      | Q Summer | No. of Showers (X <sub>4</sub> ) | No. of Air-coolers (X <sub>7</sub> ) | No. of Cars (X <sub>12</sub> ) | Pressure (X <sub>13</sub> ) | No. of Families (X <sub>14</sub> ) |
|--------------------------------------|----------|----------------------------------|--------------------------------------|--------------------------------|-----------------------------|------------------------------------|
| Q Summer                             | 1        | 0.064                            | 0.307                                | 0.242                          | 0.618                       | 0.272                              |
| No. of Showers (X <sub>4</sub> )     | 0.064    | 1                                | 0.209                                | 0.045                          | 0.051                       | 0.15                               |
| No. of Air-coolers (X <sub>7</sub> ) | 0.307    | 0.209                            | 1                                    | 0.026                          | 0.054                       | 0.244                              |
| No. of Cars (X <sub>12</sub> )       | 0.242    | 0.045                            | 0.26                                 | 1                              | 0.217                       | 0.276                              |
| Pressure (X <sub>13</sub> )          | 0.618    | 0.051                            | 0.54                                 | 0.217                          | 1                           | 0.173                              |
| No. of Families (X <sub>14</sub> )   | 0.272    | 0.15                             | 0.244                                | 0.276                          | 0.173                       | 1                                  |

## 5.7 Results of Study No.4:

### A. Descriptive Statistics for Dependent Variable.

Table (5-14) lists the descriptive statistics for *sprinkling* water consumption.

**Table (5-14):** Descriptive Statistics for Dependent Variable.

| Water Consumption |       | N         | Range     | Minimum   | Maximum   | Mean      | Std.      | Skewness  |            | Kurtosis  |            |
|-------------------|-------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|------------|-----------|------------|
|                   |       | Statistic | Statistic | Statistic | Statistic | Statistic | Statistic | Statistic | Std. Error | Statistic | Std. Error |
| Sprinkling        | L/h/d | 50        | 1732.53   | 62.80     | 1795.33   | 951.2020  | 443.86099 | -0.157    | 0.337      | -0.788    | 0.662      |
|                   | L/c/d | 50        | 1790.50   | 4.83      | 1795.33   | 201.9859  | 255.76253 | 5.140     | 0.337      | 31.700    | 0.662      |

The observed maximum value is thought to be due to the use of air-coolers and the large house gardens.

The table shows that the average daily of observed sprinkling water demand was very close to 951.20 l/h/d with a standard deviation of about 493.86 (or around 202 l/c/d with a standard deviation of nearly 255.7).

Al-Samawi and Hassan (1988) reported a lower value for average daily sprinkling demand for the city of Basrah back in (1977-1978). They reported a value of 92 Lcd.

For the city of Baghdad 2001, Isehak reported a lower value of (458.66 lhd ) and ( 89.31 lcd) .

Samaka, I. S. (2004), reported a lower value of (192 L/c/d) for the city of Hilla.

The sprinkling demand is about 32.76% which is higher the total average daily.

Fig. (5-49) shows the histogram for the average daily water demand per house. It is clear that the Frequency distributions of water demand are positively skewed when most demand distributions are skewed to the right.

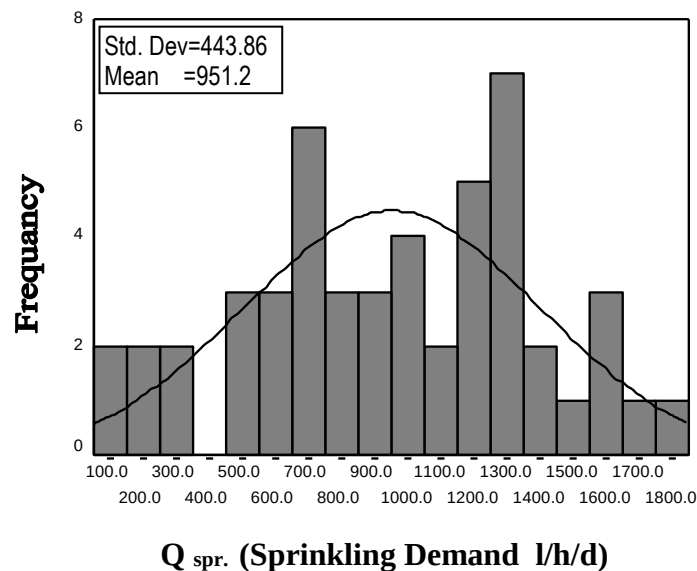


**Fig.(5-49):** Frequency Histogram Distribution for Study No.4(L/h/d).

Figs. (5-50) and (5-51) present the cumulative frequency and percentage graph for the average daily sprinkling demand per house . The figures indicate that 90% of the houses in Al-Najaf city consume (about 1500 l/h or less ) of water per day.

Isehak (2001) found that 50 % of houses in Baghdad use (500 l/h or less ) of water per day .

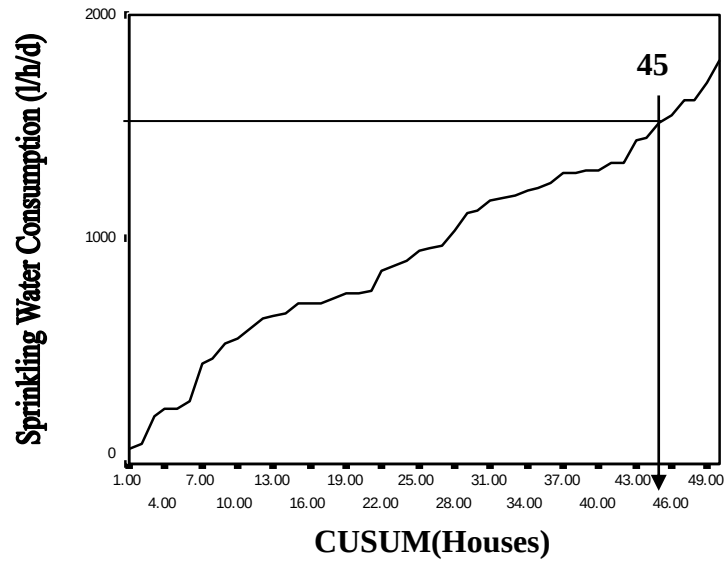


Fig.(5-50): Cumulative Frequency Histogram for Study No.4.

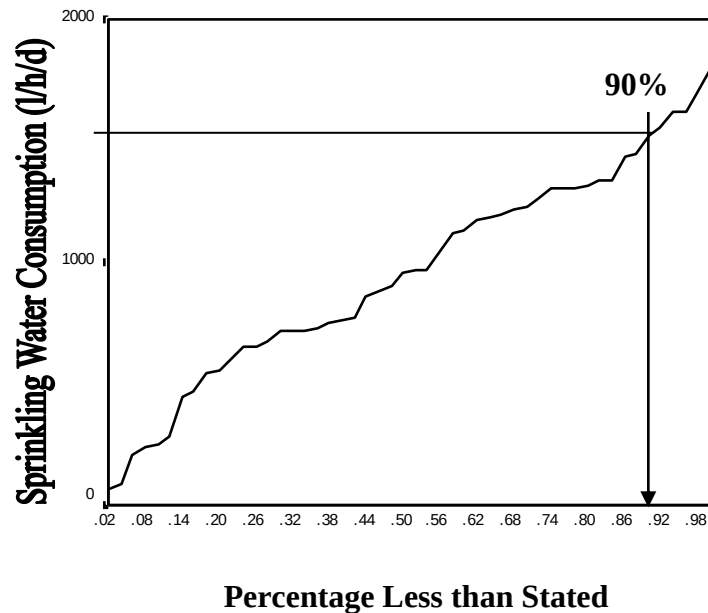


Fig.(5-51): Cumulative Frequency Histogram for Study No.4.

### B. Sprinkling Water Demand Model.

The results of the linear regression for the average daily sprinkling water demand per house are summarized by Table (5-15).

The appropriate model is model number 3 (linear in logarithmic form). The predicated model is as:

$$\ln Q_{spr.} = 0.536 X_1 + 1.231 X_6 + 0.01565 X_{10} \quad \dots (5-9)$$

Where:

$Q_{spr.}$  = average daily sprinkling water demand in l/h/d.

The model shows that the explanatory variables; household size ( $X_1$ ), No. of taps in garden ( $X_6$ ), garden area ( $X_{10}$ ) in each house were the most significant variables.

The model provides a high value of coefficient of determination of  $R^2 = 0.907$  (adj.  $R^2 = 0.901$ ) to notice the best fitting of data. The standard error of the estimate is 2.21693, Table (5-15) displays other details.

There is a positive correlation between the dependent variable and three independent variables.

The contribution of each one unit of household size, number of taps in garden, and garden area is 0.536, 1.231, and 0.01565 l/d respectively for natural logarithmic form of consumption, but the value equals to 43.5, 107.6, and 1.746 l/d respectively for the linear form of consumption.

Al-Samawi and Hassan (1989) reported a value of 285 l/h/d of contribution of air-cooler for the city of Basrah.

Isehak (2001) reported the contribution of each one unit of air-coolers and household size of 90.03 and 36.55 l/d respectively for the city of Baghdad.

The household size explains most of the percent prediction power (54%). On the other hand, number of taps in garden and garden area explains 24 % and 22% of the variation respectively as shown in Figure (5-57). The values of relative prediction can also be represented by the values of standardized coefficients (Beta) in Table (5-15 C).

Isehak (2001) found that the number of air-coolers explains most of the relative power of prediction (39.8%), while the household size explains 39.7%.

The F-test at 5% level of significance was done to test the significance of the model. The value of (F) is 152.635. The t-test was also done to test the significance of regression coefficients. The values of (t) are listed in Table (5-15 C).

The estimated average daily consumption (about 555.93 l/h/d or about 80.56 l/c/d) for Al-Najaf city was within the range.

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

Loh and Coghlan (2003) estimated the values of 707 l/h/d, and 211 l/c/d, and both values are higher than the estimated value for Al- Najaf city.

**Table (5-15):** Linear Regression for Log-linear Sprinkling Water Demand Model (l/h/d).  
**A- Model Summary**

| Model | R                  | R Square <sup>a</sup> | Adjusted R square | Std. Error of the Estimate |
|-------|--------------------|-----------------------|-------------------|----------------------------|
| 1     | 0.886 <sup>b</sup> | 0.784                 | 0.780             | 3.30489                    |
| 2     | 0.944 <sup>c</sup> | 0.891                 | 0.886             | 2.37698                    |
| 3     | 0.952 <sup>d</sup> | 0.907                 | 0.901             | 2.21693                    |

- a. For regression through the origin (the no-intercept model), R Square measures the proportion of the variability in the dependent variable about the origin explained by regression. This CANNOT be compared to R square for models which include an intercept.
- b. Predictors: Household size
- c. Predictors: Household size , No. of taps in garden
- d. Predictors: Household size , No. of taps in garden, Garden area

**B- ANOVA<sup>e,f</sup>**

| Model        | Sum of Squares        | df | Mean Square | F       | Sig.               |
|--------------|-----------------------|----|-------------|---------|--------------------|
| 1 Regression | 1946.308              | 1  | 1946.308    | 178.196 | 0.000 <sup>a</sup> |
| Residual     | 535.193               | 49 | 10.922      |         |                    |
| Total        | 2481.501 <sup>b</sup> | 50 |             |         |                    |
| 2 Regression | 2210.298              | 2  | 1105.149    | 195.600 | 0.000 <sup>c</sup> |
| Residual     | 271.203               | 48 | 5.650       |         |                    |
| Total        | 2481.501 <sup>b</sup> | 50 |             |         |                    |
| 3 Regression | 2250.507              | 3  | 750.169     | 152.635 | 0.000 <sup>d</sup> |
| Residual     | 230.994               | 47 | 4.915       |         |                    |
| Total        | 2481.501 <sup>b</sup> | 50 |             |         |                    |

- a. Predictors: Household size
- b. This total sum of squares is not corrected for the constant because the constant is zero for regression through the origin.
- c. Predictors: Household size, No. of taps in garden .
- d. Predictors: Household size, No. of taps in garden, Garden area
- e. Dependent Variable: Ln of Consumption
- f. Linear Regression through

C- Coefficients <sup>a,b</sup>

| Model |                       | Unstandardized coefficients |            | Standardized coefficients | t      | Sig.  |
|-------|-----------------------|-----------------------------|------------|---------------------------|--------|-------|
|       |                       | B                           | Std. Error | Beta                      |        |       |
| 1     | Household size        | 0.825                       | 0.062      | 0.886                     | 13.349 | 0.000 |
| 2     | Household size        | 0.554                       | 0.060      | 0.595                     | 9.296  | 0.000 |
|       | No. Of taps in garden | 1.988                       | 0.291      | 0.437                     | 6.835  | 0.000 |
|       | Area                  |                             |            |                           |        |       |
| 3     | Household size        | 0.536                       | 0.056      | 0.54                      | 9.577  | 0.000 |
|       | No. Of taps in garden | 1.231                       | 0.379      | 0.24                      | 3.249  | 0.002 |
|       | Area                  |                             |            |                           |        |       |
|       | Garden Area           | 1.565E-02                   | 0.005      | 0.220                     | 2.860  | 0.006 |

a. Dependent Variable: Ln of Consumption

b. Linear Regression through the Origin

### C. Identification and Validation of the Sprinkling Water Demand Model .

The model has a high value of the explanatory power (  $R^2 = 0.907$ ), then the model accuracy is good.

Fig. (5-52) shows the model efficiency. It can be noticed that the model predicted the water demand efficiently as shown by the slope of the best fit line (slope =0.907).

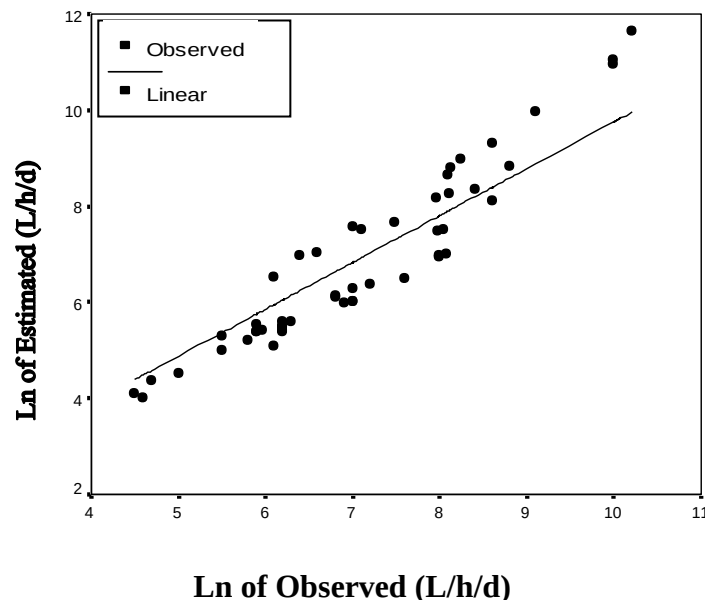


**Fig.(5-52):** Observed and Estimated Water Consumption Using Suitable Sprinkling Demand Model ( Log – Linear ) .

Fig. (5-53) reflects the adequacy of model. The results of figure indicate that the model is a good predictor of sprinkling water demand.

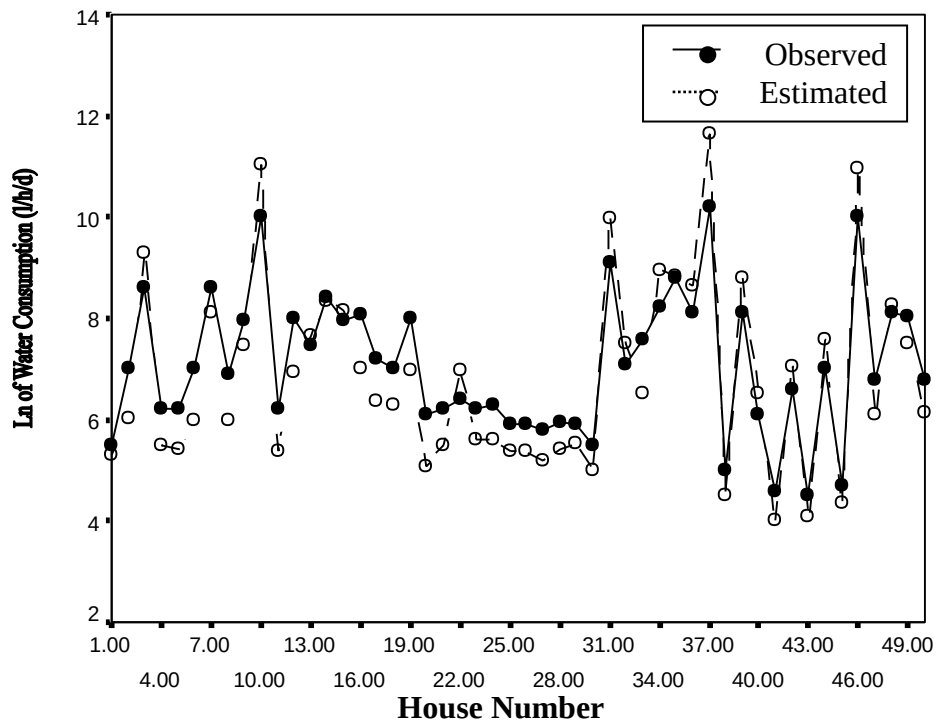


**Fig.(5-53):**Average Daily Observed and Estimated Water Consumption Using Appropriate Sprinkling Demand Model (Log-Linear ).

The regression equation was examined to check the accuracy of model and it gave agreement with measurements explained for the last models.

A histogram a cumulative probability plot of standardized residuals can be explained by Figures (5-54) and (5-55) to show the normal distribution of errors with mean level of zero.

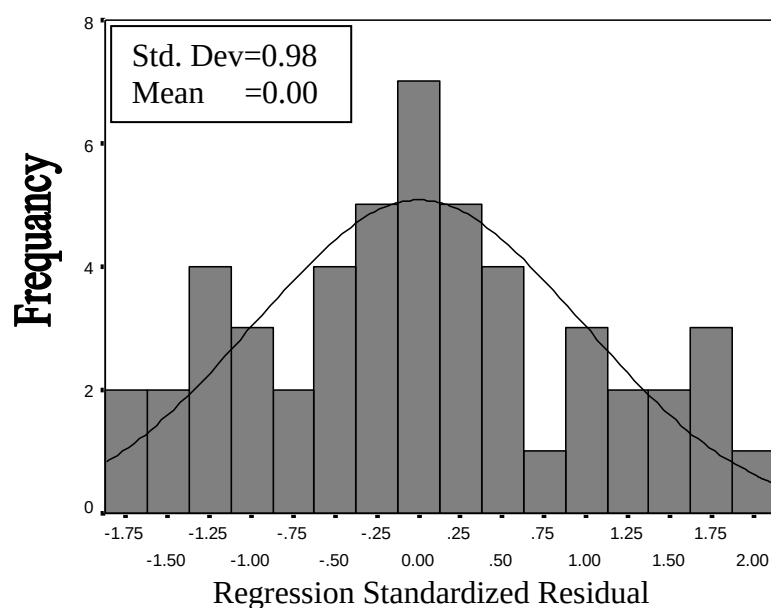


**Fig.(5-54):**The Histogram of Standardized Residuals.

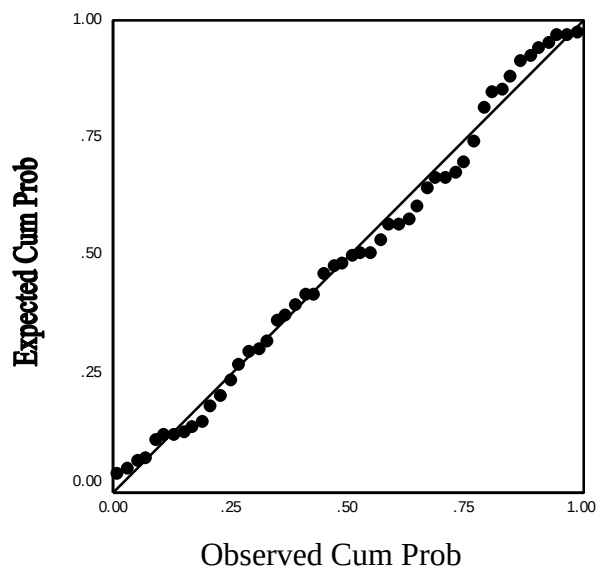


**Fig.(5-55):**Cumulative Probability Plot of Standardized Residuals .

Through Figure (5-56) which is a scatter plot, it is noted that there is no pattern, thereby confirming that the assumptions of linearity and homogeneity of variance have been met.

Durbin –Watson coefficient,  $d$ , is equal to 1.8.

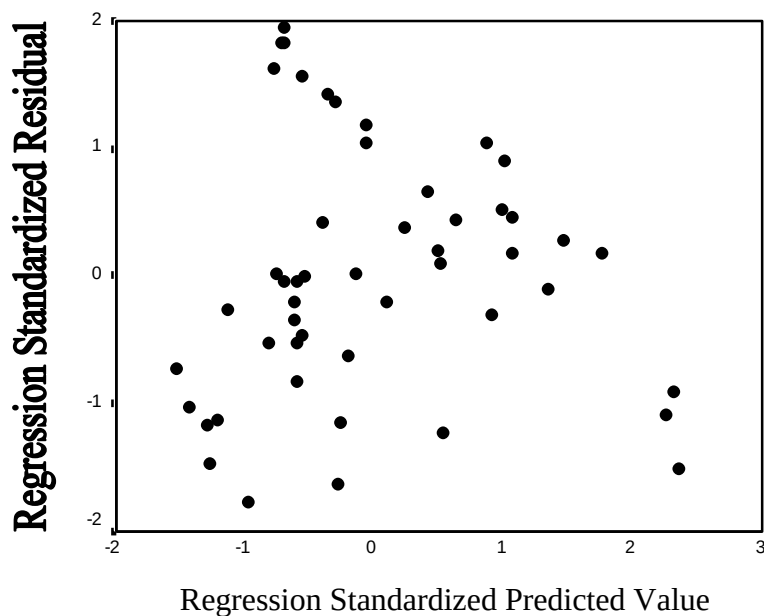


**Fig.(5-56):** The scatter plot of Predicted against Residuals Values .

### D. Component Usage for Sprinkling Water Demand Model.

Through the regression model, the split of the components of the estimated average daily water demand per house (about 555.93 l/h/d or around 80.56 l/c/d) can be explained by Fig. (5-57) below:

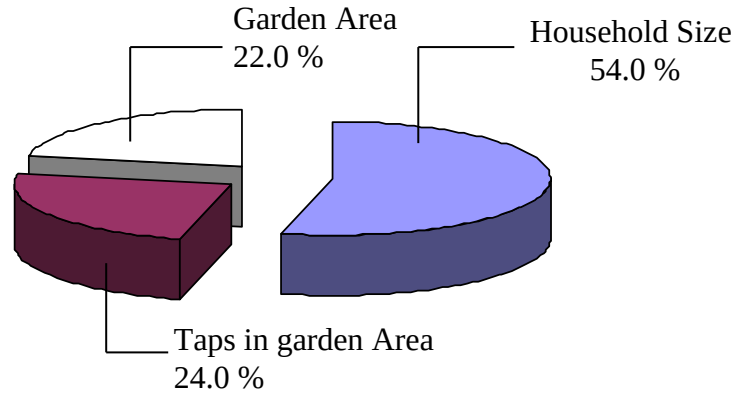


**Fig.(5-57): Percent Water Consumption for Sprinkling Model.**

Through the figure, the model seemed to be highly dependent on the household size .

Table (5-16) lists other details of the average component usages for sprinkling demand per house per day or per capita per day.

**Table (5-16): Average Component Usage for Sprinkling Demand Model per House or Per Capita Per Day**

| Component of Model   | l/house/day | %Total use | % Total model | l/c*/d | l/c/d |
|----------------------|-------------|------------|---------------|--------|-------|
| Household size       | 300.20      | 54         | 24.57         | 43.5   | 43.5  |
| Garden Area          | 133.43      | 24         | 10.92         | 107.6  | 19.34 |
| Air-coolers          | 122.3       | 22         | 10.01         | 1.746  | 17.72 |
| Total sprinkling Use | 555.93      | 100        | 45.5          |        | 80.56 |

## F. Correlation Matrix Analysis

Table (5-17) lists the correlation values for the dependent variable and different independent variables that affect sprinkling water demand.

**Table (5-17):** Correlation Matrix for Sprinkling Water Demand

|                                       | <b>Q Sprinkling</b> | <b>Household Size (X<sub>1</sub>)</b> | <b>No. of Taps (X<sub>6</sub>)</b> | <b>Garden Area (X<sub>10</sub>)</b> |
|---------------------------------------|---------------------|---------------------------------------|------------------------------------|-------------------------------------|
| <b>Q Sprinkling</b>                   | 1                   | 0.644                                 | 0.12                               | 0.411                               |
| <b>Household Size (X<sub>1</sub>)</b> | 0.664               | 1                                     | 0.263                              | 0.182                               |
| <b>No. of Taps (X<sub>6</sub>)</b>    | 0.12                | 0.263                                 | 1                                  | 0.586                               |
| <b>Garden Area (X<sub>10</sub>)</b>   | 0.411               | 0.182                                 | 0.586                              | 1                                   |

# **CHAPTER SIX**

## **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:

1. the most appropriate model with the most significant independent

Variables is:

For total water demand model:

$$\ln Q_{total} = 1.354X_4 + 1.203X_5 + 0.009609X_9 + 0.899X_{14}$$

For winter water demand model:

$$\ln Q_{win.} = 0.24 X_1 + 0.692 X_2 + 0.468 X_{13}$$

For summer water demand model:

$$\ln Q_{sum.} = 0.731X_4 + 1.097X_7 + 0.693X_{12} + 0.61X_{13} + 0.504X_{14}$$

For sprinkling water demand model:

$$\ln Q_{spr.} = 0.536 X_1 + 1.231X_6 + 0.01565X_{10}$$

Where:

$X_1$ : household size. ,  $X_2$ : No. of bedrooms. ,  $X_4$ : No. of showers.

$X_6$ : No. of taps in garden. ,  $X_7$ : No. of air-coolers.

$X_9$ : total built-up area of house. ,  $X_{10}$ : garden area

$X_{12}$ : No. of cars. ,  $X_{13}$ : the pressure and  $X_{14}$ : No. of families.

2. In this study , the average daily water demand for Al- Najaf city was estimated to be 1221 l/h/d ( 177 l/c/d) for total demand , 745 l/h/d ( 108 l/c/d) for winter demand , 2754 l/h/d ( 399 l/c/d ) for summer demand , and 556 l/h/d (81 l/c/d ) for sprinkling demand .
3. During the period of study, the minimum level of the 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).

## **6.2 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. 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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