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WATER SUPPLY DEMAND FORECASTING FOR VIENTIANE CAPITAL CITY LAO PDR TO 2029

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A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Engineering Program in Infrastructure in Civil Engineering
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บุญเสียง วิไลเชน: การพยากรณ์ความต้องการน้ำประปาสำหรับนครหลวงเวียงจันทน์ในปี ค.ศ. 2029 (WATER SUPPLY DEMAND FORECASTING FOR VIENTIANE CAPITAL CITY, Lao PDR TO 2029) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: รศ.ดร.ธเรศ ศรีสถิตย์, 115 หน้า.

การพยากรณ์ปริมาณการใช้น้ำของพื้นที่นครหลวงเวียงจันทน์ สาธารณรัฐประชาธิปไตยประชาชนลาว วิธีการศึกษาดังนี้ a) ศึกษาความเกี่ยวพันระหว่างความต้องการน้ำ และอิทธิพลของปัจจัยทั้งหมด b) ศึกษาการพยากรณ์ การทำนายความต้องการน้ำที่แท้จริงในนครหลวง โดยอาศัยปัจจัยที่มีอิทธิพลมาวิเคราะห์ ในรูปแบบของสมการเส้นตรง (Multiple linear regression) เป็นสูตรคำนวณ และตั้งสมการที่มีผลกระทบต่อปัจจัยในการใช้น้ำทั้งหมด ปัจจัยเหล่านั้นคือ 1) ขนาดของครอบครัว 2) จำนวนประชากรทั้งหมด 3) รายได้ต่อคน 4) เขตพื้นที่ 5) ความหนาแน่นของประชากร 6) ราคาของน้ำที่ใช้อุปโภคบริโภค 7) อุณหภูมิสูงสุด 8) อุณหภูมิต่ำสุด 9) อุณหภูมิโดยเฉลี่ย และ 10) ปริมาณน้ำฝนต่อปี ปัจจัยเหล่านี้ เกี่ยวพัน และมีอิธิพลต่อปริมาณความต้องการน้ำ พื้นฐานการใช้น้ำประเมินจากการใช้น้ำที่น้อยที่สุดของปี (The base consumption trend was) ทิศทางพื้นฐานการอุปโภคบริโภคได้ถูกนำเสนอโดยอาศัยปัจจัยหลายๆประการของช่วงเวลานั้นมาเป็น แบบจำ ลอง แบบจำลองที่ปรับปรุงแล้วนี้ได้ถูกนำไปทดสอบด้วยกระบวนการ cross validation และนำข้อมูลอิสระโดยกำหนดระยะเวลาตั้งแต่ปี ค.ศ. 1997 ถึง ค.ศ. 2007 โดยใช้การวิเคราะห์ และเครื่องมือทางสถิติ ทดสอบ และใช้โปรแกรม SPSS (V.6) แบบจำลองนี้สามารถนำไปประยุกต์ใช้ และดำเนินการวางแผนการจัดสรรน้ำอย่างถาวร และทำการพยากรณ์ความต้องการน้ำในอนาคตสำหรับนครหลวงเวียงจันทร์ หรือเมืองอื่น

ภาควิชา...วิศวกรรมโยธา.......................................ลายมือชื่อนิสิต..

สาขาวิชา.โครงสร้างพื้นฐานทางวิศวกรรมโยธา..........ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์หลัก.......................

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To forecast yearly water consumption, for service water use of area in Vientiane capital, Lao PDR, The study methods are following a). Study the correlation of water demand and influence all factors, b). Study proper prediction, forecasting of water demand in urban by using the influence factor. Analysing currency of a multiple linear regression model is formulated as a set of equations representing the effects of 10 factors on water use namely of all factor are 1). Number of family, 2). Total population, 3). Income per capita, 4). Area zone of district 5). Density of population, 6) Selling price of water, 7). Maximum temperature, 8). Minimum temperature 9).Average of temperature and 10). Total precipitation. These factors are correlation and influence to water demand consumptions. Base water use was estimated by the minimum water consumption year. The year-to-year long-term trend in base consumption was represented by a polynomial as a function of time water use was modelled. The model developed was tested using a cross-validation procedure, and an independent data set during period year from 1997 to 2007 use to analysising and using statistic tool was tested and run on the program computer by using a SPSS software V16 developed. This model can apply and operate water supply planning systems in a sustainable. And make to forecasting water demand in the future for Vientiane capital or other cities.

Department: Civil Engineering Student's signature..........
Field of Study: Infrastructure in Civil Engineering Advisor's signature..........
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Finally, to all readers, due to my intention to present this research pervasively, please accept my sincere apologies for my English usage in this research and any misunderstanding, which may arise from English language.

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CHAPTER 1
INTRODUCTION

1.1 Problem Statement

The Vientiane city is capital of Lao PDR, the past every years have had a problem of water supply demand, such as urban population increase every year, so that in the year 2007 had 725,820 people, that is the biggest city in Laos, high development and increasing of population high demand of water supply, lack of water in dry season even though located beside main basin, water supply distribution is not cover all of urban area. These include, changes in demographics, land use, types of water-using appliances and trends toward lower occupancy households and apartment living, particularly in inner city areas. At the same time, pressure on urban water supplies has increased, owing to declining yield of systems and increasing demands for water allocations to the environment. Therefore, the importance of and interest in demand management strategies has increased. This thesis project is designed to investigate research into factors that influence demand and demand management programs that have been undertaken by the Laotians water industry, particularly Water Services Association of Laos water supply Company.

This thesis is describes the water supply demand projections for Vientiane capital city as developed by Economic & Planning Systems, developed water supply demand forecasts for the land use alternatives that were being considered as part of the County General Plan process. These land use forecasts were developed for the Methodology model also developed water supply demand forecasts for the based on land use data provided by the Vientiane Water Supply Company. The water supply demand studies were prepared in an effort to comprehensively assess future demands on the Vientiane Capital Public Utilities Commission (VCPUC) regional water system. The currently implementing is a capital improvement program to improve the reliability of the Vientiane Capital Public Utilities Commission system and reduce its risk of failure. This study includes several projects to repair and replace existing distribution net work and storage facilities of the regional water system. These facilities are critical to supplying water to the Vientiane Capital Public Utilities Commission's retail and wholesale customer service area. Understanding the future demands on the regional water system is an important aspect to improve the system's reliability.

An urban area, water supply demand has increased rapidly. Greater pressure on water supplies, expansion of water supplies is usually the only means employed to meet the growing water demands; at the same time the economical and ecological limits of the water supplies have generally been ignored. The fact is that in many regions of the world, water consumption is nearing or surpassing the limits of natural systems. So there are a lot of factor which directly effect to water demand in mega cities e.g.; sell price of water, temperature of region & season, population quantities, Size of families in the cities, Precipitation in urban area. But how effect in each parameter. Which one should be strong considered or which parameter can be ignore. And how is the relationship between each factor. This thesis will identify in each parameter in order to find out the relation between each factors that influence with water demand in general city, in Vientiane capital as a model to be study. Result of this thesis may application to forecast the water supply demand in another city in Laos.

1.2 Research Objective

The objectives of this research are important for water planning in the year 2029. This project are purpose of the demand forecasts described in this is to provide data useful for the formulation of recommended actions as part of the Integrated Watershed and Resource Conservation Plan (IWRCP). Describing the existing and forecasted settings for which the plan is being developed is an early step in the integrated planning process. These forecasts help to predict the county's situation in the future. Using these forecasts, the IWRCP team can describe the county's future urban water needs and, through the planning process, develop and evaluate potential actions that can address the planning objectives, which include meeting the county's water needs in Vientiane city.

These forecasts were prepared for county specifically, and include water supply demand estimates for future planning 2009 to 2029. As described in this, this forecast is intended for use at the countywide level.

The objectives of this research were to:

1 Study the relationship of factors influencing on water supply demand in Vientiane capital city.

2 Develop urban water demand models by multiple linear regression equation.

3. Forecast water demand of Vientiane capital city in the next 20 years.

1.3 Scope of Research

This study has chosen at the Vientiane capital city, Lao PDR are scope research, this study use to develop water demand models and to forecast yearly urban water demand.

Limitations of this study include the following:

1. Literature review and study affected of water supply demand forecasting that has been processing before. Collecting all information as from water supply statistic data during the year 1997 - 2007.
2. Forecast the urban water demand in the study area, water consumption data is from water supply Company in Vientiane city year 1997-2007 and be used for this research.
3. Define scope area of study and family size that influence factor to water using was analysed. Other categories such as water use from domestic and commercial public service sectors.
4. In order to compare forecasting performance for different parameters, total volume of water used during the years such as temperature and rainfall in the forecasting period was assumed known as observed in historical records. Such as this model can use of multiple linear regression equations.
5. Study modeling use to forecasting of water demand by concerning on selling price of water. Not only must the yearly of population in Vientiane city be concern for this study but density of population in each district also:

a) Verification model by using data in the year 2008.

b) Data analysis will be use the SPSS programmer.

1.4 Main Contribution of this Research

The main contributions of this research to the scientific understanding of urban water use forecasting were:

To increase the understanding users of water. This research described and analysed variations in water use for each major component of community in Vientiane capital city.

To develop urban water demand models based on water users level of information to forecast residential water supply demand in Vientiane city. The models are able to explain the variations observed and the factors influencing the variations in domestic water use as well as the factors that can be manipulated to change water use behavior.

Recognising the lack of understanding on users of water and the need for improved demand forecasting models as well as the development and evaluation of conservation strategies, this research adopted a detailed investigation of water use known as user's analysis. It will also improve understanding on water use particularly at user's level and developed predictive models to forecast urban community water demand by making the most of the available data collected by Vientiane Water Supply Company (Nam Papa Vientiane).

This research will provide information to assist Water Authorities and the community to make informed decisions when they consider options to focus water conservation efforts. The result of this research can also be used as a tool for community education, to generate meaningful discussion on particular findings and to assist with planning and policy development for adopting particular strategies relating to water demand management. The forecast demands will also assist with accurate planning of infrastructure to service future growth.

Specifically, this research which involved analysis users of water will enable planners and water authorities. This research is forecasting of water demand in Vientiane city. Some of water consumption data is from Laos water supply company, especially consider factors which mainly effect to increasing using and this forecasting data will make an optimum to future planning of water demand in Vientiane city, therefore this forecasting is a mathematical model using with other urban city.

1.5 Benefit from the Research

The benefit from this research is:

Development of Water Demand Models is easy apply working, and easy understanding use to forecasts for urban water demand – describes development of a demand forecasting architecture, point models for demand prediction, and implementation of these models in generating a point forecast of water demand plan for 2009 to 2029.

Development of this model can apply method to study and operating our water planning systems in a sustainable. And make forecasting for water demand in the future for Vientiane capital city or other cities.

CHAPTER 2
LITERATURE REVIEW

This chapter focuses on literature review of the existing zone urban water use models: annual, demand models at the water supply distribution zone and at end use level of water usage. A general layout of a water supply distribution system consisting of three parts loosely defined as the storage or reservoir, the water supply distribution zone, and the end uses of water. The literature review covered the models developed in the Water Supply Distribution Zone of Vientiane capital.

2.1 Estimation of Water use

Water use data from water supply agency (i.e., water utility company) records can be used for examining historical trends in water use and disaggregating total use into seasons, sectors, and specific water uses within each sector. Water production records are a good source of data on total water demands in the area served by a public system. Water utilities usually have one or more production meters that are generally read at least daily. The usefulness of the production data for water supply demand analysis may include, but not be limited to: (1) the analysis of unaccounted water use (comparing production with water sales data), (2) the measurement of the aggregate effect of emergency conservation campaigns on water use.

2.2 Modelling Approaches

Demand models provide simplification, or abstraction, of complex physical reality and the processes involved in it, and serve as tools in the solution of demand forecasting problems. The choices of an appropriate approach to water demand modelling play a vital role in making planning and management decisions. The discussion here comprises the methodological framework for three broad approaches, namely: historical extrapolation, statistical techniques and mathematical programming (Khater, 1994).

2.2.1 Historical Extrapolation

The first step in the analysis of water demands in an area served by a public water-supply system is to determine average annual rates of water use. The simplest rate is the gross per capita water use that is determined by dividing the total annual amount of water delivered to the distribution system by the estimated population served. Although there are many types of forecasting approaches, they can be reduced to several prototypical methods that differ with respect to the level of disaggregation and the structural complexity of water-use equations. The simplest technique, known as time extrapolation, extrapolates the average change in past water use records into the future. The forecasting equation can be written as (Dziegielewski et al, 1996):

$$\mathbf{Q} = f(\mathbf{Q}_{hl\ldots}\mathbf{Q}_{hm}, t) \quad \text{.......... 2.1}$$

Where:

Q_t : water use in forecast year t

Q_{hl} ... Q_{hm} : historical time series of water use

A distinctive class of forecasting approaches introduces a simple water use relationship in which total water use is represented as the product of the number of users and an average rate of water use.

2.2.2. Statistical Techniques

In the statistical modelling of water demand relations, a water activity is conceptualized as a black box with input and output variables, and their associated costs or prices are defined. In the black box representation, inputs and outputs are known as explanatory variables and dependent variables, respectively. Among the explanatory variables one should distinguish the so called exogenous variables that have an effect on the dependent variables but are not explained by the model. These include variables such as administered prices, and environmental standards (Kindler and Russell, 1984).

A statistical model of a water demand relation can generally be expressed as

$$D = f(X_1, \mathrm{X}_2, \ldots X_n) + E \quad \text{.......... 2.2}$$

Where: **D** denotes demand, **f** ( ) the function of explanatory variables $\mathbf{X_1}$, $\mathbf{X_2}$, **.....**, $\mathbf{X_n}$ and **E** is a random error variable describing the effect on **D** of all factors other than those explicitly considered in the form of explanatory variables. In practical applications, the analytical form of function **f** is commonly assumed to be either additive, multiplicative, or a combination of the two. These possibilities translate into linear, full logarithmic, or semi logarithmic forms:

$$D = a_0 + a_1 X_1 + ... + a_n X_n + E \quad \text{..} 2.3$$

or

$$\ln D = b_0 + b_1 \ln X_1 + \ldots + b_n \ln X_n + E \quad \text{..} 2.4$$

or

$$D = c_0 + c_1 \ln X_1 + \ldots c_n \ln X_n + E \quad \text{..} 2.5$$

Where: **D** is the total unit amount of water demand; $\mathbf{a_0}$ **......**, $\mathbf{a_n}$, $\mathbf{b_0}$,**.........** $\mathbf{b_n}$ and $\mathbf{c_0}$ **,....** , $\mathbf{c_n}$ are the structural parameters of the alternative models, $\mathbf{X_1}$ **, ...** , $\mathbf{X_n}$ are explanatory variables, and **E** is the random error term. These forms are convenient because they allow for easy estimation of model parameters by use of multiple regression analysis (Taylor et al, 1987).

The identification of appropriate explanatory variables is closely connected with determination of a suitable model structure for each dependent variable. The ordinary least squares method is the most commonly used technique for estimation of model parameters under the assumptions mentioned about the random error term. In the modeling process, after estimating the model parameters, the next step that should proceed using the model is verification and validation of the model (Norusis, 1991).

2.2.3 Mathematical Programming

Mathematical programming techniques are concerned with establishing the best or optimal solutions to decision-making problems. Thus, they involve the use of optimisation methods such as linear, integer, dynamic, and multi-objective programming. A mathematical programming model of water use activity is a combination of unit processes written in the form of a set of inequality and equality constraints of the system, where the decision variables are the levels of operation of the process. The objective function for the model represents the criterion for choosing the optimum combination of unit processes, the measure that must be minimised or maximised. In water demand analysis, it is most common that the objective function represents cost. In such cases the problem is stated as follows (Khater, 1994; Hall and Dracup1970; Gupta and Hira 1997).

Find X that minimises f(X)

$D = f(X) + E$ ……………………………...……………………………………..2.6

Subject to constraints

$g_i(X) < 0, i = 1,2,\ldots\ldots.m$

and

$1_i(X) = 0, i = 12,\ldots,\ldots P$

Where **X** is an **n-** dimensional vector called the design vector, which denotes the levels of unit processes, **f (X) i**s the objective function to be minimised and **g_i (X) and l_i (X)** are respectively, the inequality **(g (X) < 0)** and equality constraints **(l_i (X) = 0)**. The number of variable n and the number of constraint m and / or p are not to be related in any way.

A linear programming model is applicable for the solution of problems in which the objective function and the constraints appear as linear functions of the decision variables. Integer programming is used when the variables are restricted to non-negative integer values. Dynamic programming technique is well suited for the optimisation of multi-stage decision problems when decisions have to be made sequentially at different points in time and space, and at different stages in the decision making process (Ossenbruggen, 1984).

The choice of objective function expressed in terms of decision variables is governed by the nature of the problem, being the criterion with respect to which the solution to the problem is optimised. In some situations, there may be more than one criterion to be satisfied simultaneously. An optimisation problem involving multiple objective functions is known as a multi-objective programming problem.

2.2.4 Choice of Modelling Approach

The choice between modelling approaches depends on such factors as data availability, data reliability, skills, and access to computational facilities. But this choice is also linked to the intended application of the model to be constructed. One way of summarising the links between application and model type is to look at combinations of two principal characteristics of a specific application: the level of analysis, and the problem to be addressed. However, the variety of situations under which demand analysis is required is so large that there is simply no way to provide a general recommendation of the best way to proceed (Khater, 1994; Kindler and Russell, 1984). The following discussion on the application of demand models for the various water use activities provides guidelines for the choice of modelling approach.

2.2.5 Domestic Water Demands

A criticism of the historical forecasting procedures is that they try to solve a complex problem with a simple solution procedure that ignores many factors that could affect the future demand. Statistical techniques are very helpful in identifying factors to account for variations in domestic water use. The most commonly used statistical technique has been regression analysis.

Domestic water demands have been the subject of considerable statistical modelling. In these model studies, per capita water use has been correlated with income, household size, price, number of occupants…etc. (e.g., Bhattacharya (1982) and Clarke and others (1997)).

In general, the following empirical relationship is most often used in practice to determine the domestic water demand in human settlements.

$$Q = K_l(k_d qP + Q_i) \quad \text{...2.7}$$

Where:

K_l is the coefficient denoting the water loss in the water supply network;

K_d the coefficient denoting the changes in the mean daily water consumption during 1 year;

P the number of inhabitants;

Q_i the required reserve amount of water for extinguishing potential fires.

q the specific daily water consumption per individual.

The future number of inhabitants can be calculated using the following formula:

1) Geometric Rate of Growth

$$P_{t+n} = P_t(1+r)^n \qquad 2.8$$

Where:

P_t the present number of inhabitants;

r population growth rate.

n the number of years for which the number of inhabitants needs to be calculated.

2) Exponential Rate of Growth

$$\mathbf{P_{t+n} = P_t\, e^{r.n}} \qquad 2.9$$

Where P_t , r and n are same as in equation (3.8)

2.2.6 Industrial Water Demands

Water is not a major input factor for industrial development, and the cost of water supply represents only a very small part (usually below 1%) of the total production cost or of the value of output. Because the purposes to which the water is used in industrial processes vary widely, and there are different uses of water within an industrial plant, the development of specific and accurate relationships explaining water use patterns is difficult. When the analysis is concerned with individual industrial plants, mathematical programming seems better suited. This is partly because the data problems of the statistical approach result in a rather crude average representation of the activity in question. When the problem at hand is of analysis beyond that of the individual activity, the model of choice is usually the statistical one (Khater, 1994).

The development of a sufficiently "realistic" industrial mathematical programming model requires specialised expertise and a great deal of cost and technological data. These necessary data are, of course, only a subset of the data required for constructing and operating the modelled facility anyway, but this does not mean that such data are easily collected. In addition, the development and operation of a model typically require considerable outlays in terms of both human and computer time (Stone and Whittington, 1984). In general, the total water demand of various industries can be computed using the following empirical relationship:

$$Q_i = \sum_{i-1}^{n} q_i p_i \quad \ldots\ldots 2.10$$

where:

q_i is the specific water consumption per unit product "i" of the branch of industry expressed in **m^3/unit** product;

P_i the total daily production "i" of a branch of industry in a given area; and

i the type of industrial production in a considered area.

2.2.7 Water Demand for Tourism

The water demand in tourism and sports depend on the type of facilities on offer, on the climatic conditions, on the time of year and on the number of individuals using the facilities. The general equation for calculating the water demand in this field is:

$$Q_t = k_d q_t N_t \quad \ldots\ldots 2.11$$

Where:

K_d is the fluctuation coefficient if the mean daily water consumption during the year;

q_t the average daily consumption of water per individual l/day; and

N_t the average number of tourists who use the facilities.

2.2.8 Examples and Case Studies

CDM (1997) used historical extrapolation to project domestic and industrial demands for the World Bank (see the training example in example 1) while a statistical approach was used to develop the domestic demand model for the Rammallah District (See example 2) to monitor the different factors affecting the domestic water demand.

Example 1: Case Study Historical Extrapolation to Project Domestic Water Demand in My City.

What is the projected water demand for "MY CITY" for the year 2025?

The first step for projecting water demand is to estimate the present domestic water demand. Estimates of the present water consumption rates for **"MY CITY"** is based on a questionnaire survey sent out to the responsible utilities. Based on the questionnaire response, the following is a summary for year 2002: the population is 234390 capita; network supply is 15980 x 10^3 m^3/y and billing records is 12944 x10^3 m/y.

From the above data, the per capita consumption for year 2002 is 186 l/c/d; the overall loss is 19%; the apparent consumption (without losses) is 151 l/c/d. For the purpose of projecting future domestic demands, three variables will be considered:

(1) Unaccounted for water and water losses in distribution systems

It is assumed that the target for the year 2025 is to reduce the percentage to 10% for **"MY CITY"** due to the new water infrastructure and distribution system that will be constructed by the coming years.

(2) Per Capita water consumption

On average, developing areas usually have a rate of increase of 2.0% per year for water demand.

(3) Population

Most population forecasting methods require the knowledge of past and present population concerned. These methods use the initial population (from Central Bureau of Statistics of the country) as a base for projecting into the future. Broadly speaking methods of population forecasting are graphical methods, ratio methods, and mathematical methods. Mathematical methods such as the geometric growth model are commonly used. The geometric model can be expressed as:

$$\mathbf{P_{t+n} = P_t (1+r)^n} \qquad \text{geometric growth model}$$

Where:

P_{t+n} : population at time (t+n)

P_t : population at present time

r : rate of growth per unit time

n : length of time for which the projection is made.

For **"MY CITY"**, it is assumed that the population growth rate is 2.5%. Based on the above assumptions and data the following can be concluded

- Population in 2030 = 467959 capita (r =2.5 %; n = 28; P_t = 234390)
- Projected per capita consumption for the year 2030 = 263 l/c/d (r = 2%, n=28; P_t= 151 l/c/d)
- Projected domestic demand for the year 2030 = 467959 capita x 263 l/c/d = 123073 m^3
- Adding the expected losses in the distribution networks = 123073 m^3 x 1.1 = 135381 m^3

Example 2: Case Study on Domestic Water demands Model

The water balance in the West Bank shows a severe deficit. Scenarios and strategies are formulated in order to overcome the deficit problem. These include horizons for better management of the existing water resources and the enhancement of new ones. This case focuses on demand modelling as one of the key issues for effective water management. The developed statistical domestic water demand model assesses the factors, which influence domestic water use, and determine the parameters that may help in demand management. Rammallah City is used as a case study to illustrate the proposed framework of the analysis. The developed model indicates that water authorities can use price as a tool to ration or encourage reduced water consumption in households only in rich water areas. The primary data source was a questionnaire survey sent out during summer of 1998, to 473 a random sample of consumers. The aim of the questionnaire is to gather information on personal characteristics, water use and consumption, economic activities and general housing conditions. The household variables assumed to have a reliable impact on domestic water consumption for Rammallah District household include: number of occupants, price of water, number of children, income level, lot size, number of cars, number of taps, and the number of rooms. Model was generated by multiple regression analysis. The variable symbols and somewhat abbreviated definitions for factors hypothesised as influencing domestic water consumption were:

q = average quantity consumed (l/c/d)

X_1 = number of cars per household

X_2 = number of children

X_3 = monthly income (U.S $)

X_4 = lot size in square meters

X_5 = number of occupants per dwelling

X_6 = the price of water that varies with individual household consumption (U.S $)

X_7 = number of rooms

X_8 = number of taps inside the house or in the courtyard

The linear equation of best fit generated by multiple regression models is:

$$q = 228.463 + 1.091 X_1 - 6.939 X_2 + 0.002 X_3 + 0.021 X_4 - 8.374 X_5 - 52.961 X_6 - 1.592 X_7 + 3.683 X_8$$

The price factor as often quoted in the literature is a very important management tool. Quantitative results can be produced from the above model by estimating the price elasticity of demand, which measures the willingness of consumers to give up water use as a result of rising prices, or conversely, the tendency to use more as price falls. In one sense, price elasticity reflects the availability of opportunities for water conservation, or for substituting other goods or services for water. The price elasticity for households in Rammallah derived from the model was -0.6, meaning that if other factors held constant, a 10 percent increase in price would lead to about 6 percent change (decrease) in the amount of water purchased. The water utility authorities can use price as a tool to ration or encourage reduced water consumption in households only if there is price elasticity and in rich water areas. Obviously, this is an acceptable practice and water resources will be conserved if it is applied taking the following points into account:

- The poorest of the society will be provided with basic minimum requirements of water at the minimum price.
- Factors such as “capacity to pay”, “benefits derived”, “proportionate cost of service” and “health impacts” have to be considered.

2.3 Thesis Theories

2.3.1 Data Regression

(Marques deSa, J.P. (2007). An important objective in scientific research and in more mundane data analysis tasks concerns the possibility of predicting the value of a dependent random variable based on the values of other independent variables, establishing a functional relation of a statistical nature. The study of such functional relations, known for historical reasons as regressions, goes back to pioneering works in Statistics.

Let us consider a functional relation of one random variable Y depending on a single predictor variable X, which may or may not be random:

$$Y = g(X).$$

We study such a functional relation, based on a dataset of observed values $\{(x_1, y1), (x_1, y_1), \ldots, (x_n, y_n)\}$, by means of a regression model, $\hat{Y}= \hat{g}(X)$, which is a formal way of expressing the statistical nature of the unknown functional relation, as illustrated in Figure 2.1. We see that for every predictor value x_i, we must take into account the probability distribution of Y as expressed by the density function f_Y (y). Given certain conditions the stochastic means of these probability distributions determine the sought for functional relation, as illustrated in Figure 2.1. In the following we always assume X to be a deterministic variable.

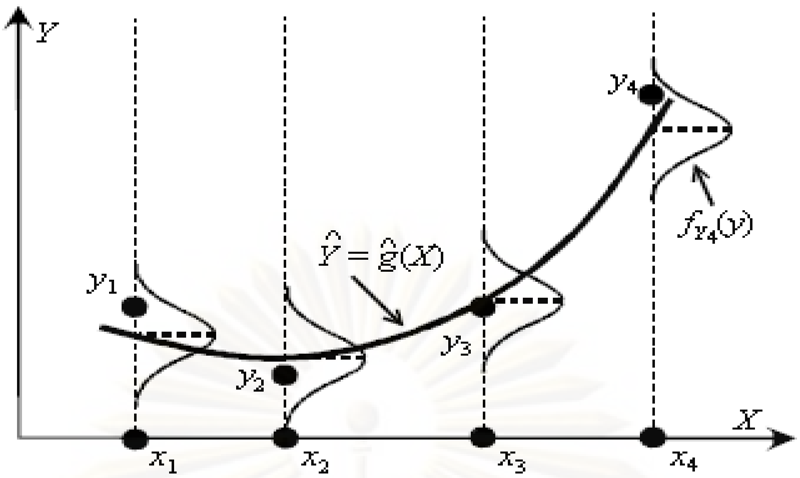


Figure 2-1 Statistical functional model in single predictor regression. The y_i are the observations of the dependent variable for the predictor values x_i.

Correlation differs from regression since in correlation analysis all variables are assumed to be random and play a symmetrical role, with no dependency assignment. As it happens with correlation, one must also be cautious when trying to infer causality relations from regression. As a matter of fact, the existence of a statistical relation between the response *Y* and the predictor variable *X* does not necessarily imply that *Y* depends causally on *X* .

2.3.2 Multiple Linear Regressions

In multiple linear regressions there is one in dependent (e.g., water sale) to predicted, but there are two or more independent variables. The predictor variable, *X*, and the functional relation is assumed to be linear. The only random variable is *Y* and the regression model.

The general form of multiple regression is

$$\boldsymbol{Y_i = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \cdots + \beta_{p-1} X_{i,p-1} + \varepsilon_i} \quad \text{2.12}$$

Where:

i. The Yi are random variables representing the observed values y_i for the predictor values x_i. The Y_i are distributed as f (y) Y_i . The linear regression parameters, β_0 and β_1, are known as *intercept* and *slope*, respectively.

ii. The ε are random *error* terms (variables), with:
$E[\varepsilon_i] = 0$; $V[\varepsilon\, i] = \sigma^2$; $V[\varepsilon_i\, \varepsilon_j] = 0$, $\forall\, i \neq j$.

Therefore, the errors are assumed to have zero mean, equal variance and to be uncorrelated among them (see Figure 2-1). With these assumptions, the following model features can be derived:

i. The errors are i.i.d. with:

$E[\varepsilon_i]= 0 \Rightarrow E[Y_i]= \beta_0 + \beta_1 x_i \Rightarrow E[Y]= \beta_0 + \beta_1 X$.

The last equation expresses the linear regression of Y dependent on X. The linear regression parameters β_0 and β_1 have to be estimated from the dataset. The density of the observed values, $f(y)\ Y_i$, is the density of the errors, $f\varepsilon(\varepsilon)$, with a translation of the means to $E[Y_i]$.

iii. $V[\varepsilon i]=\sigma^2 \Rightarrow V[Yi]=\sigma^2$.

iv. The Y_i and Y_j are uncorrelated.

The regression model in practice.

$$\boldsymbol{Y_i = b_0 + b_1X_{1i} + b_2X_{2i} + \ldots + b_kX_{ki} + e_i} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.13$$

for i = 1,2, . . . , N

Where $X_1 + X_2, \ldots, X_k$ are assumed measured without error,

$b_0, b_1, b_2, \ldots, b_k$ are least-squares estimate of $\beta_0, \beta_1, \beta_2, \ldots, \beta_k$ usually computed by statistical software and are all landom variables now, with a joint normal distribution.

e_i (i = 1,2, . . .,N) is and estimated error term, for the ith observation, and is assumed to be sampled independently from a normal distribution. The values fit by the equation $b_0 + b_1x_{i1} + \ldots + b_kx_{ik}$ are denoted $\hat{Y}_i$, and the residuals $\boldsymbol{e_i = Y_i - \hat{Y}_i}$, the difference between the observed.

2.3.3 Estimating the Regression Function

(A popular method of estimating the regression function parameters is to use a *least square error* (LSE) approach, by minimising the total sum of the squares of the errors (deviations) between the observed values y_i and the estimated values $b_0 + b_1x_i$:

$$E = \sum_{i=1}^{n} \varepsilon_i^2 = \sum_{i=0}^{n} (y_i - b_0 + b_1 x_i)^2 \quad \text{...2.14}$$

where b_0 and b_1 are estimates of β_0 and β_1, respectively.

In order to apply the LSE method one starts by differentiating E in order to b_0 and b_1 and equalising to zero, obtaining the so-called *normal equations*:

$$\begin{cases} \Sigma y_i = nb_0 + b_1 \Sigma x_i \quad \text{..2.15} \\ \Sigma x_i y_i = b_0 \Sigma x_i + b_1 \Sigma x_i^{2,} \end{cases}$$

where the summations, from now on, are always assumed to be for the n predictor values. By solving the normal equations, the following parameter estimates, b_0 and b_1, are derived:

$$b_1 = \frac{\Sigma(x_i - \bar{x})(y_i - \bar{y})}{\Sigma(x_i - \bar{x})^2} \quad \text{..2.16}$$

$$b_0 = \bar{y} - b_1 \bar{x} \quad \text{..2.17}$$

The least square estimates of the linear regression parameters enjoy a number of desirable properties:

i. The parameters b_0 and b_1 are *unbiased estimates* of the true parameters β_0 and β_1 (E [b_0]=β_0, [b_1] E b_0 = β_0 , E[b_1] = β_1), and have *minimum variance* among all unbiased linear estimates.

ii. The *predicted* (or *fitted*) *values* $\hat{Y}_i = b_0 + b_1 X_{1i} + b_2 X_{2i} + \ldots + b_k X_{ki}$ are point estimates of the true, *observed* values, y_i. The same is valid for the whole relation $\hat{Y} = b_0 + b_1 X + b_2 X_2 + \ldots b_k X_k$, which is the point estimate of the *mean response* E[Y].

v. The regression line always goes through the point $(\bar{y}, \bar{x})$

iv. The computed errors $e_i = y_i - \hat{y}_i = yi - b_0 - b_1 x_i$, called the *residuals*, are point estimates of the error values ε_i. The sum of the residuals is zero: $\Sigma e_i = 0$.

v. The residuals are uncorrelated with the predictor and the predicted values: $\Sigma e_i x_i = 0$; $\Sigma e_i \hat{y}_i = 0$.

vi. $\Sigma\, y_i = \Sigma\, \hat{y}_i \;\Rightarrow\; y = \hat{y}$, i.e., the predicted values have the same mean as the observed values.

These properties are a main reason of the popularity of the LSE method. However, the reader must bear in mind that other error measures could be used. For instance, instead of minimising the sum of the squares of the errors one could minimise the sum of the absolute values of the errors: $E = \Sigma \varepsilon_i$. Another linear regression would then be obtained with other properties. In the following we only deal with the LSE method.

Example 3 Imagine that we wanted to predict the total area of the defects of a cork stopper (ART) based on their total perimeter (PRT), using a linear regression approach. Determine the regression parameters and represent the regression line.

A: Figure 2-2 shows the scatter plot obtained with STATISTICA of these two variables with the linear regression fit (Linear Fit box in Scatter plot), using equations 2.16 and 2.17 Figure 2-3 shows the summary of the regression analysis obtained with STATISTICA (see Commands 2-1). Using the values of the linear parameters (Column B in Figure 2-3) we conclude that the fitted regression line is:

ART = −64.5 + 0.547×PRT.

Note that the regression line passes through the point of the means of ART and PRT: (ART, PRT) = (324, 710).

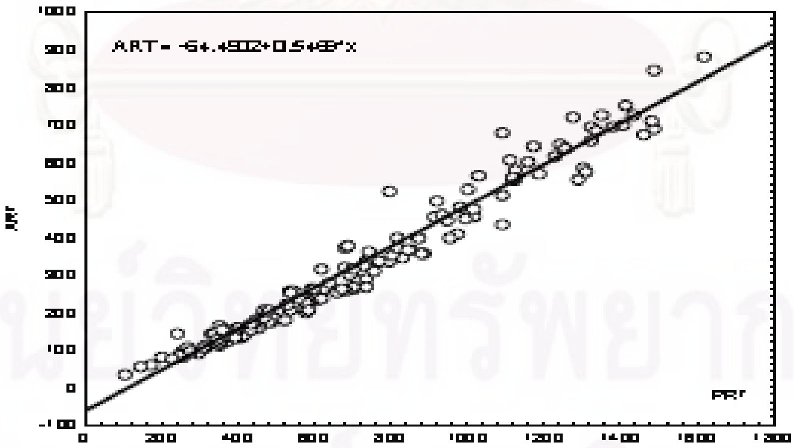


Figure 2-2 Scatter plot of variables ART and PRT (cork-stopper dataset), obtained with STATISTICA, with the fitted regression line.

N=150	R= .98114218 R²= .96263997 Adjusted R²= .96238754 F(1,148)=3813.5 p<0.0000 Std.Error of estimate: 39.050					
	Beta	Std.Err. of Beta	B	Std.Err. of B	t(148)	p-level
Intercept			-64.4902	7.053354	-9.14320	0.000000
PRT	0.981142	0.015888	0.5469	0.008857	61.75316	0.000000

Figure 2-3 Table obtained with STATISTICA containing the results of the simple linear regression for the Example 3.

The value of Beta, mentioned in Figure 2-3, is related to the so-called *standardised regression model*:

$$Y_i^* = \beta_1^* x_i^* + \varepsilon_i \quad \ldots\ldots 2.18$$

In equation 2.18 only one parameter is used, since Y_i^* and x_i^* are standardized variables (mean = 0, standard deviation = 1) of the observed and predictor variables, respectively. (By equation 2.17, $\beta_0 = E[Y] - \beta_1 x$ implies $(Yi - E[Y]) / \sigma Y = \beta_1^* (xi - x) / s X + \varepsilon_i$.) It can be shown that:

$$\beta_1 = \left(\frac{\acute{O}y}{Sx}\right) \beta^*_1 \quad \ldots\ldots 2.19$$

The standardised β^*_1 is the so-called *beta coefficient*, which has the point estimate value $b^*_1 = 0.98$ in the table shown in Figure 2-3

Figure 2-3 also mentions the values of R, R^2 and Adjusted R^2. These are measures of association useful to assess the goodness of fit of the model. In order to understand their meanings we start with the estimation of the error variance, by computing the *error sum of squares* or *residual sum of squares* (SSE)1, i.e. the quantity E in equation 2.14, as follows:

$$SST = \Sigma(y_i - \hat{y}_i)^2 = \Sigma e^2_i \quad \ldots\ldots 2.20$$

Note that the deviations are referred to each predicted value; therefore, SSE has $n - 2$ degrees of freedom since two degrees of freedom are lost: b_0 and b_1. The following quantities can also be computed:

- Meansqare error : $MSE = \frac{SSE}{n-2}$

- Root mean square error or standard error. $RMS = \sqrt{MSE}$

This last quantity corresponds to the "Std. Error of estimate" in Figure 2-3. The total variance of the observed values is related to the *total sum of squares*

(SST)1:

$$SST \equiv SSY = \Sigma\,(y_i - \hat{y}_i)^2. \qquad \ldots\ldots 2.21$$

The contribution of *X* to the prediction of *Y* can be evaluated using the following association measure, known as *coefficient of determination* or *R-square*:

$$R^2 = \frac{SST - SSE}{SST} \; E\; [0,1] \qquad \ldots\ldots 2.22$$

Therefore, "R-square", which can also be shown to be the square of the Pearson correlation between *xi* and y_i, measures the contribution of *X* in reducing the variation of *Y*, i.e., in reducing the uncertainty in predicting *Y*. Notice that:

1. If all observations fall on the regression line (perfect regression, complete certainty), then SSE = 0, $r^2 = 1$.
2. If the regression line is horizontal (no contribution of *X* in predicting *Y*), then SSE = SST, $r^2 = 0$.

However, as we have seen in 2.3.4 when discussing the Pearson correlation, "R-square" does not assess the appropriateness of the linear regression model.

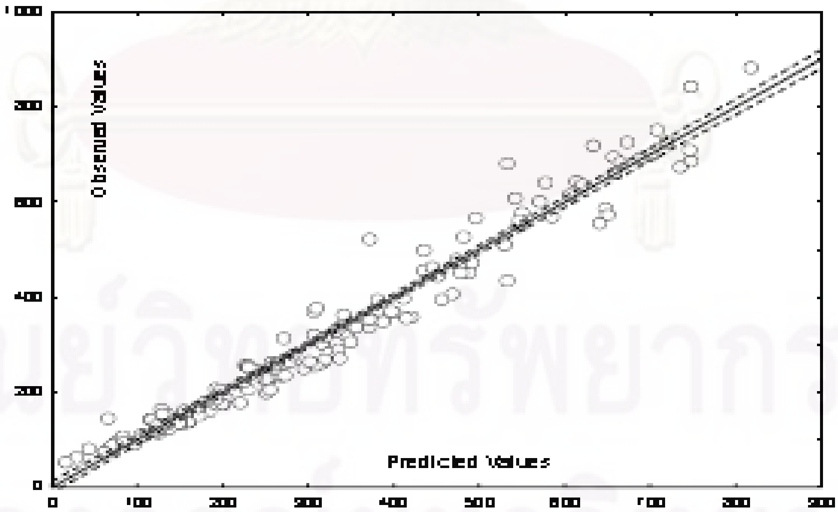


Figure 2-4 Scatter plot, obtained with STATISTICA, of the observed values versus predicted values of the ART variable (cork-stopper data) with the fitted line and the 95% confidence interval (dotted line).

Often the value of "R-square" is found to be slightly optimistic. Several authors propose using the following "Adjusted R-square" instead:

$r^2_a = r^2 - (1-r^2) / (n-2)$.

For the cork-stopper example the value of the "R square" is quite high, *r*2 = 0.96, as shown in Figure 2-3. STATISTICA highlights the summary table when this value is found to be significant, therefore showing evidence of a tight fit. Figure 2-4 shows the observed versus predicted values for the Example 3. A perfect model would correspond to a unit slope straight line.

Commands2-1. SPSS, STATISTICA and R commands used to perform simple linear regression.

SPSS	Analyze; Regression; Linear Statistics; Multiple regression
STATISTICA	Advanced Linear/Nonlinear Models; General Linear Models
R	lm(y~X)

SPSS and STATISTICA commands for regression analysis have a large number of options that the reader should explore in the following examples. With SPSS and STATISTICA, there is also the possibility of obtaining a variety of detailed listings of predicted values and residuals as well as graphic help, such as specialized scatter plots. For instance, Figure 2-4 shows the scatter plot of the observed versus the predicted values of variable ART (cork-stopper example), together with the 95% confidence interval for the linear fit.

2.3 4 ANOVA Tests

The analysis of variance tests are quite popular in regression analysis since they can be used to evaluate the regression model in several aspects. We start with a

basic ANOVA test for evaluating the following hypotheses:

H0: $\beta 1 = 0$; ……………………………………………………………..2.23a

H1: $\beta 1 \neq 0$. …………………………………………………………….2.23b

For this purpose, we break down the total deviation of the observations around the mean, given in equation 7.9, into two components:

$SST = \Sigma (y_i - y)^2 = \Sigma(\hat{y}_i - y)^2 + \Sigma(y_i - \hat{y}_i)^2$ ……………………………2.24

The first component represents the deviations of the fitted values around the mean, and is known as *regression sum of squares*, SSR:

$$SSR = \Sigma(\hat{y}i - y)^2 \quad \text{.........................2.25}$$

The second component was presented previously as the error sum of squares, SSE (see equation 7.8). It represents the deviations of the observations around the regression line. We, therefore, have:

$$SST = SSR + SSE. \quad \text{.........................2.26}$$

The number of degrees of freedom of SST is $n - 1$ and it breaks down into one degree of freedom for SSR and $n - 2$ for SSE. Thus, we define the *regression mean Square*

$$MSR = \frac{SSR}{1} = SSR$$

The number of degrees of freedom of SST is $n - 1$ and it breaks down into one degree of freedom for SSR and $n - 2$ for SSE. Thus, we define the *regression mean square*:

$$F * = \frac{MSR}{MSE} \sim F_{01,n-2} \quad \text{.........................2.27}$$

From the definitions of MSR and MSE we expect that large values of F support H_1 and values of F near 1 support H_0. Therefore, the appropriate test is an upper tail F test.

Example 4

Q: Apply the ANOVA test to the regression Example 3 and discuss its results.

A: For the cork-stopper Example 3, the ANOVA array shown in Table 2-1 can be obtained using either SPSS or STATISTICA. and R functions listed in Commands 7.1 return the same F and p values as in Table 2-1. The complete ANOVA table can be obtained in R with the anova function (see Commands 2-2).

Based on the observed significance of the test, we reject H_0, i.e., we conclude the existence of the linear component ($\beta 1 \neq 0$).

Table 2-1. ANOVA test for the simple linear regression example of predicting ART based on the values of PRT (cork-stopper data).

Model	Sum of Squares	df	Mean Square	F	p
SSR	5815203	1	3813453	1.868	0.000
SSE	225688	148			
SST	6040891				

Commands 2-2. SPSS, STATISTICA, and R commands used to perform the ANOVA test in simple linear regression.

SPSS	Analyze; Regression; Linear; Statistics; Model Fit
STATISTICA	Statistics; Multiple regressions; Advanced; ANOVA
R	anova(lm(y~X))

There are also specific ANOVA tests for assessing whether a certain regression observations at one or more *X* levels, the so-called *replicates*. function adequately fits the data. We will now describe the ANOVA *test for lack of fit*, which assumes that the observations of *Y* are independent, normally distributed and with the same variance. The test takes into account what happens to repeat observations at one or more *X* levels, the so-called *replicates*.

2.4 Summary

The process of projecting water demands should be directed towards analytical modelling approaches such as statistical techniques and mathematical programming if reliable and valid data are available. The superiority of analytical models over extrapolation methods lies not only in their greater accuracy but also in their capability of including economic factors and assessing the consequences of various policy options. One advantage of the mathematical programming approach over the statistical one is that the costs and prices may be allowed to vary beyond their values recorded in the past and the resulting predictions of the demand may be accepted with reasonable confidence.

Because of the diversity of local conditions under which demand analysis is required, general rules of standard solutions can only be of limited value in working out details of modelling procedures. However, based on the nature use of activities, mathematical programming as a planning tool seems well suited for the analysis of a wide range of demand forecasting problems in the industrial activities. On the other hand, the statistical approach appears to be most promising for modelling domestic water demands.

2.5 Maps for Development Plan of Vientiane Capital City.

The Vientiane capital city is one city in Lao PDR, and the city is developing and city have had development plan for town plan about infrastructure development, such as show on

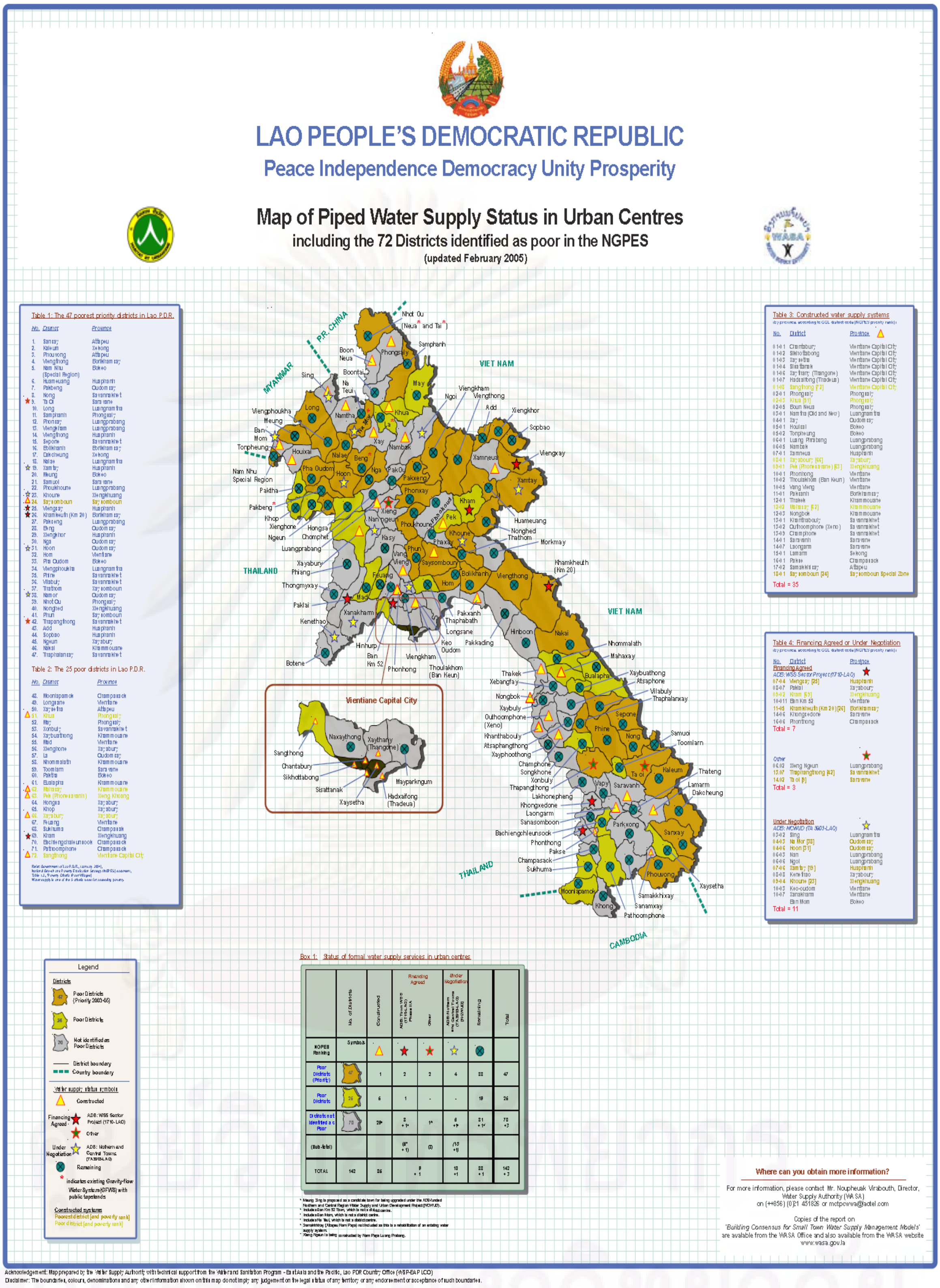


Figure 2-5 Map of pipe water supply status in centres

Source: Vientiane capital water supply Company (2005)

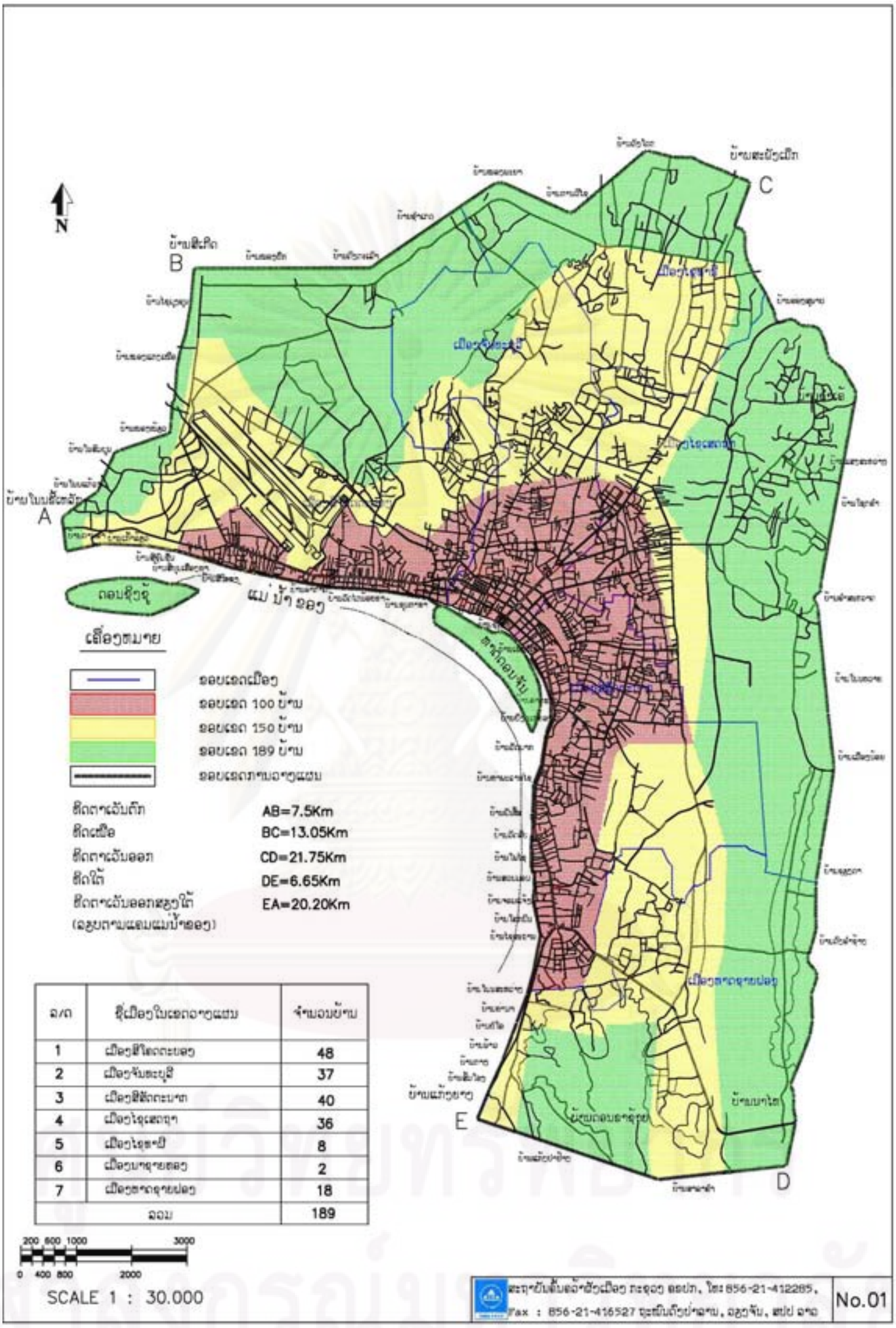


Figure 2-6 Map of the development area of Vientiane capital city since 200-2010

Source: Research Institute town plan, Vientiane capital city

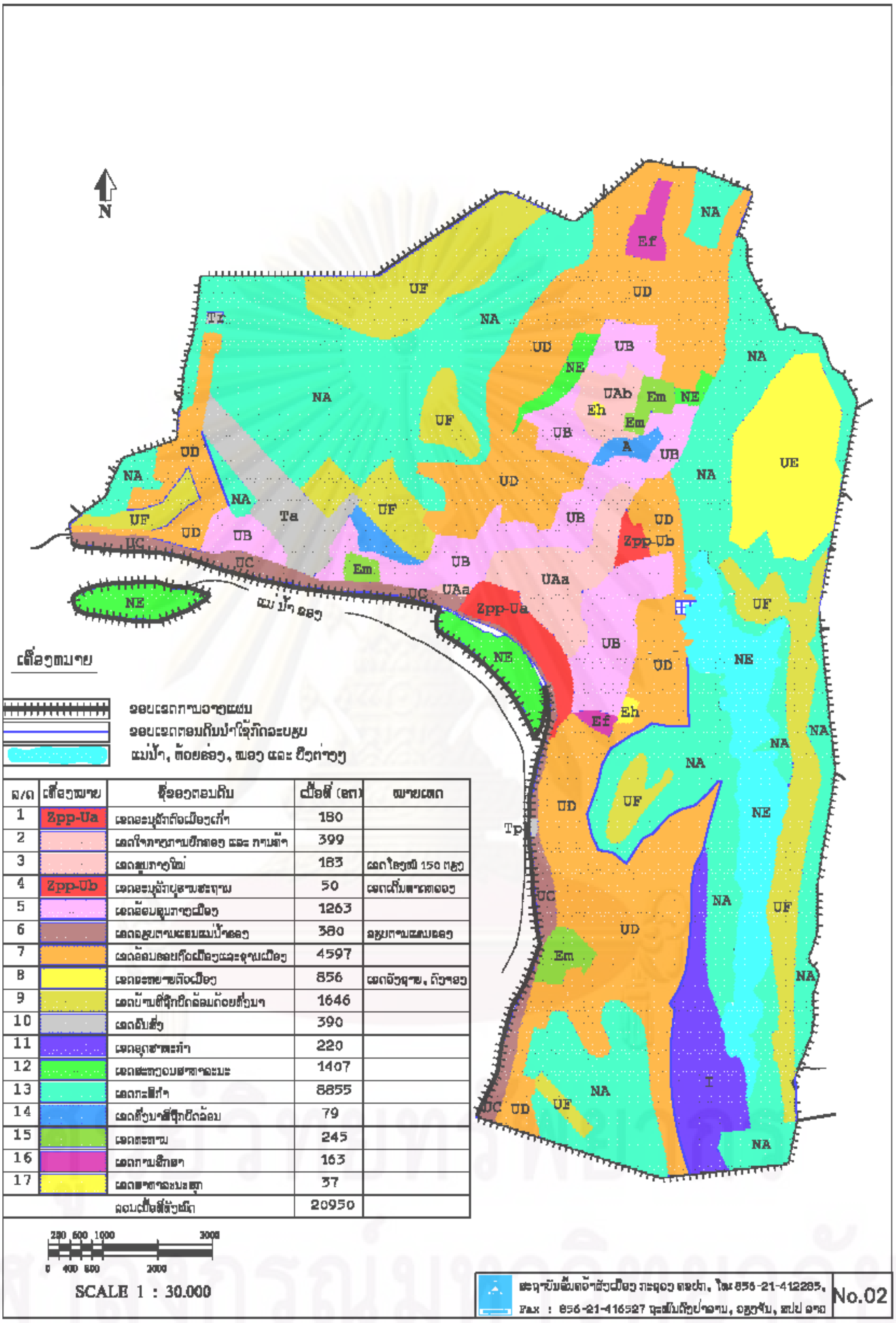


Figure 2-7 Maps of Land use and specified development area

Source: Research Institute town plan, Vientiane capital city

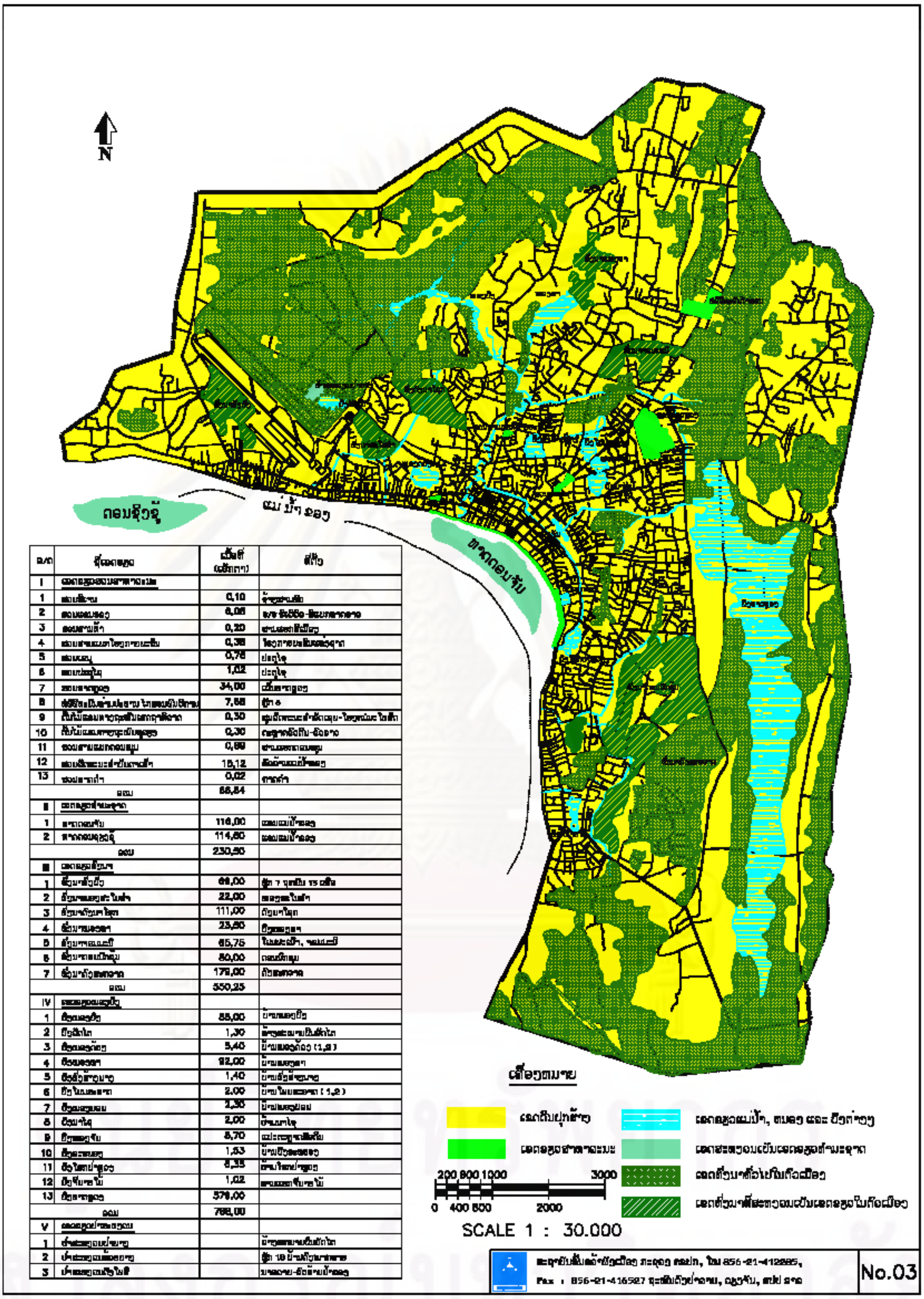


Figure 2-8 Maps of green areas and public parks

Source: Research Institute town plan, Vientiane capital city

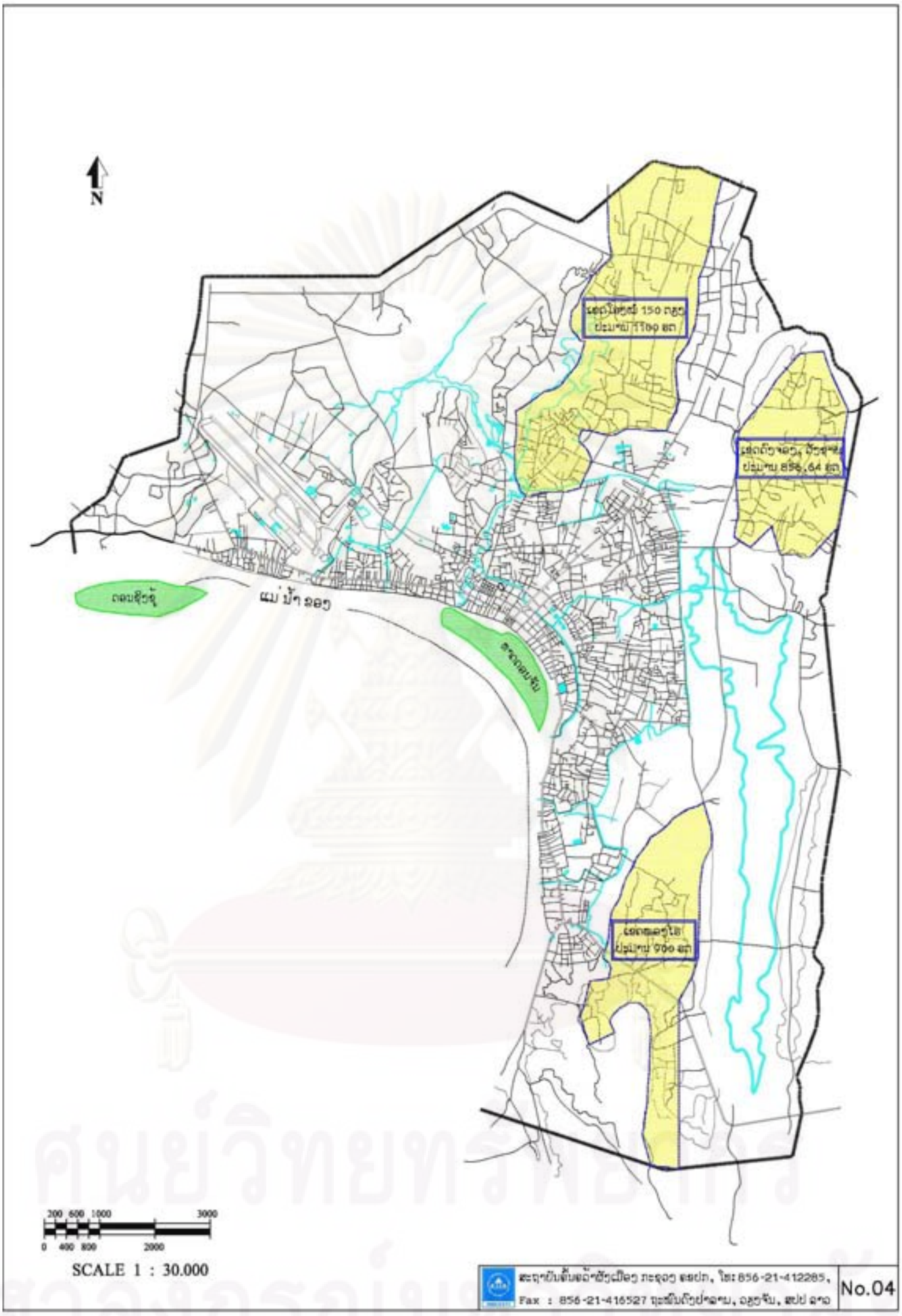


Figure 2-9 Maps of the growth directions and increasing the density

Source: Research Institute town plan, Vientiane capital city

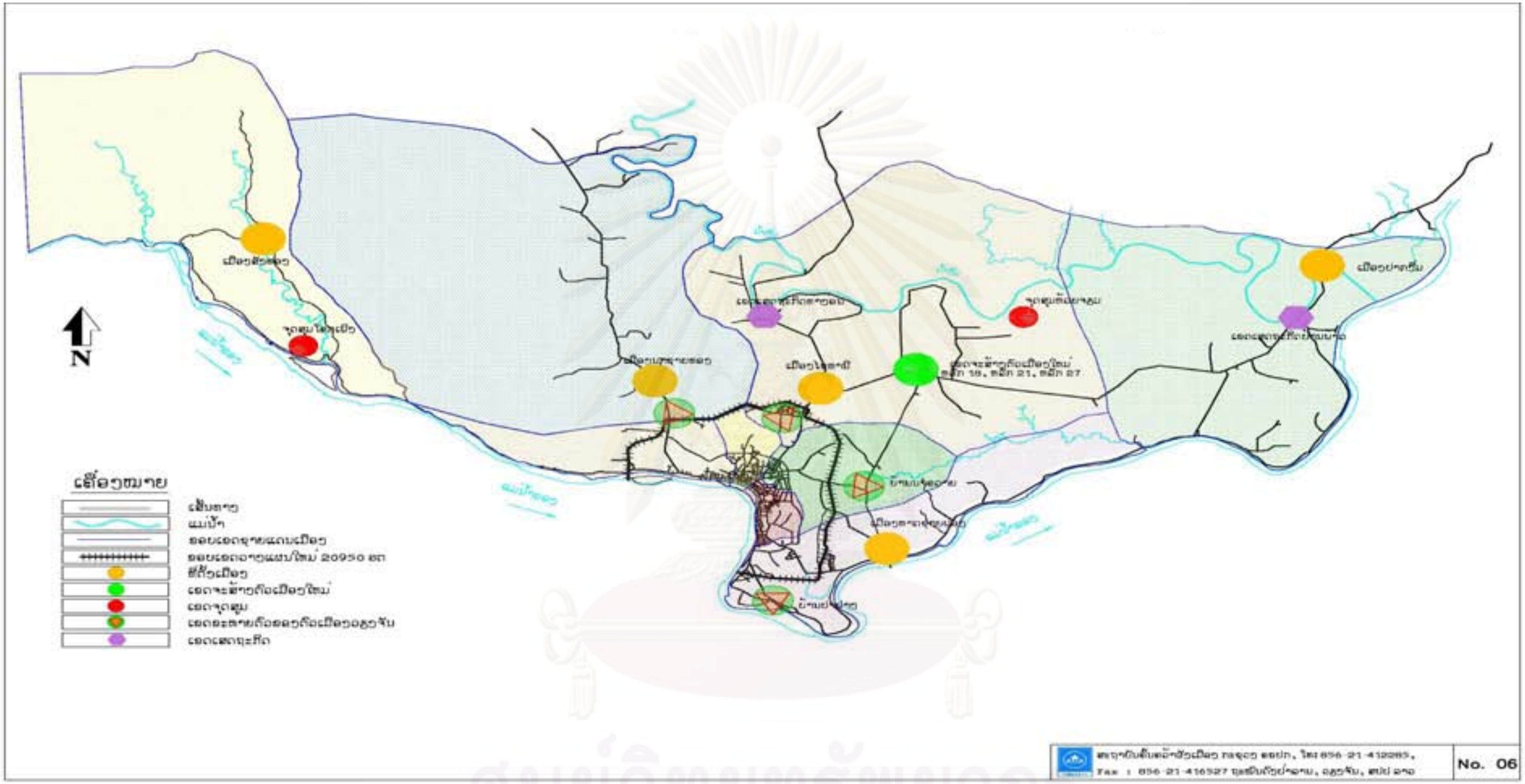


Figure 2-10 Maps of Vicinity districts of Vientiane capital city

Source: Research Institute town plan, Vientiane capital city

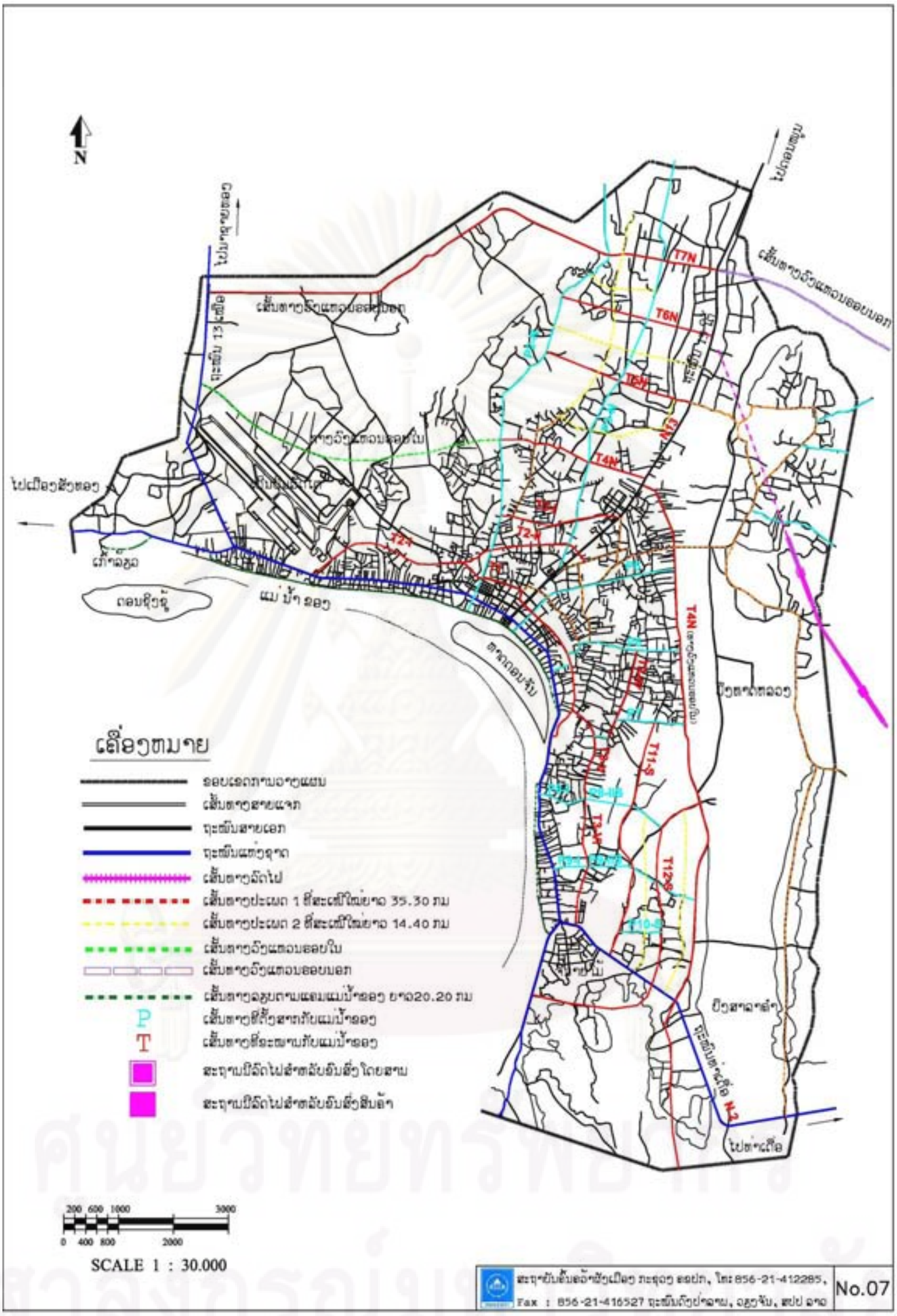


Figure 2-11 Maps of Road network system

Source: Research Institute town plan, Vientiane capital city

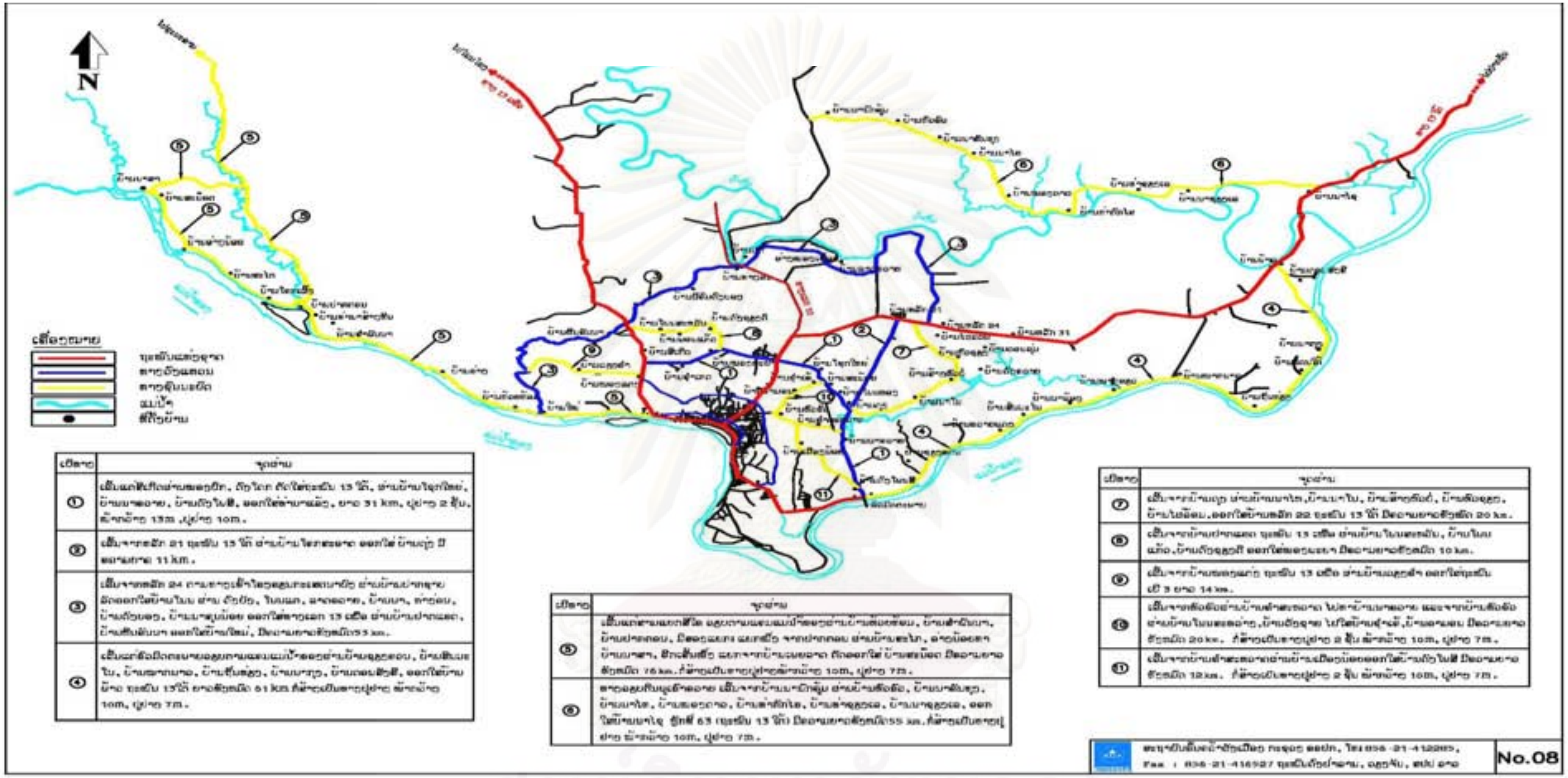


Figure 2-12 Maps of intercity road system

Source: Research Institute town plan, Vientiane capital city

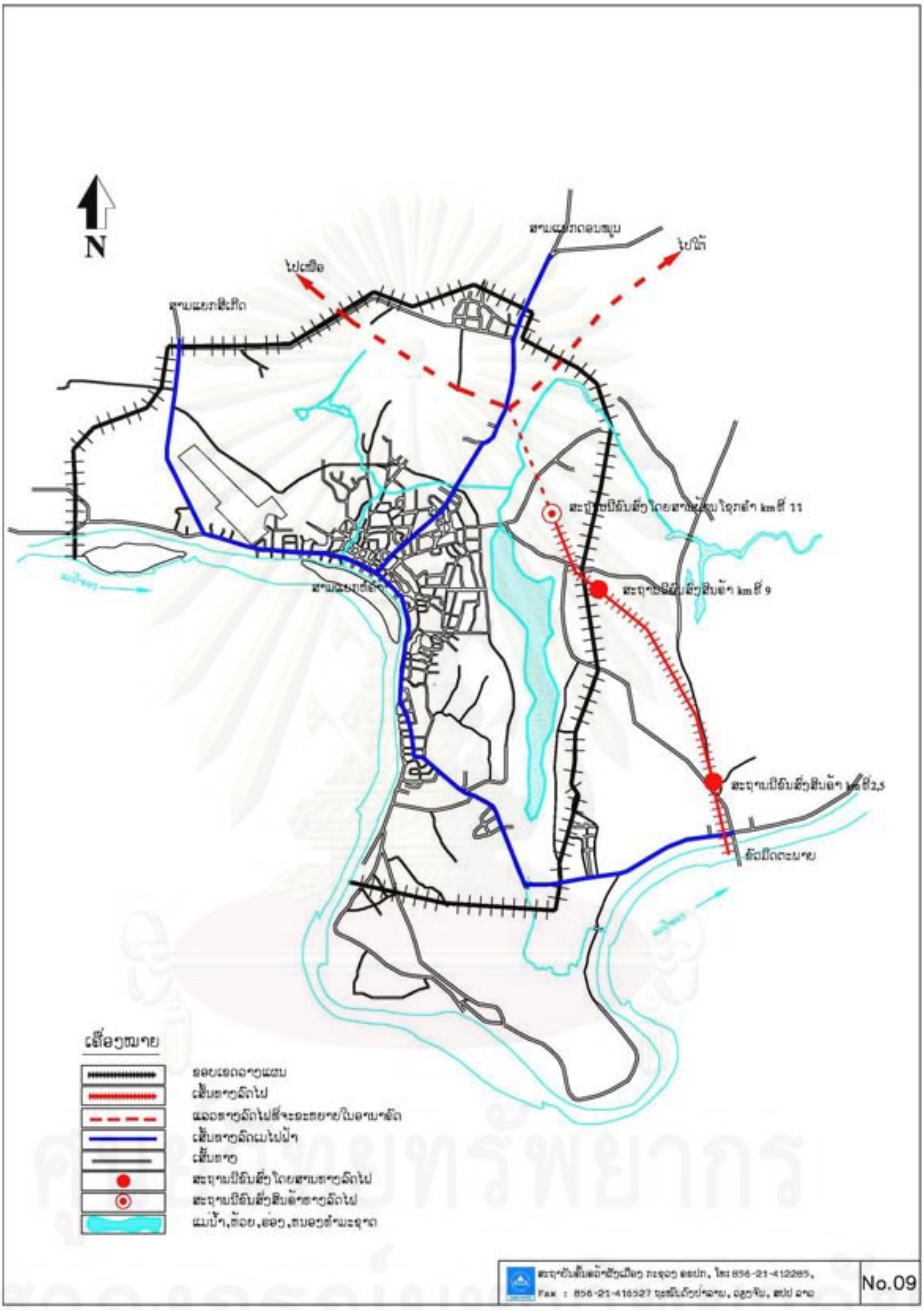


Figure 2-13 Maps of railway project and electrical bases project

Source: Research Institute town plan, Vientiane capital city

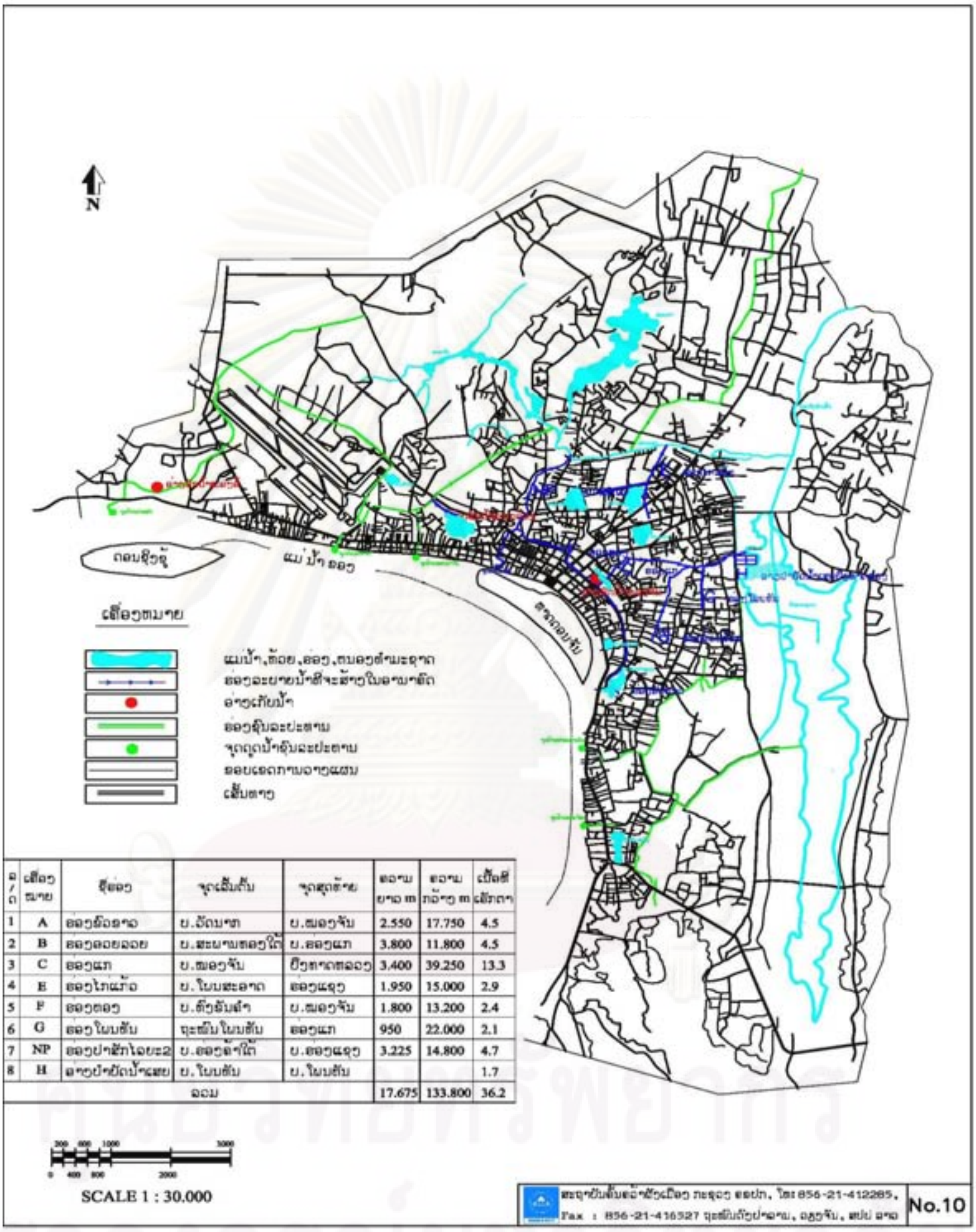


Figure 2-14 Maps of drainage systems and reservoirs

Source: Research Institute town plan, Vientiane capital city

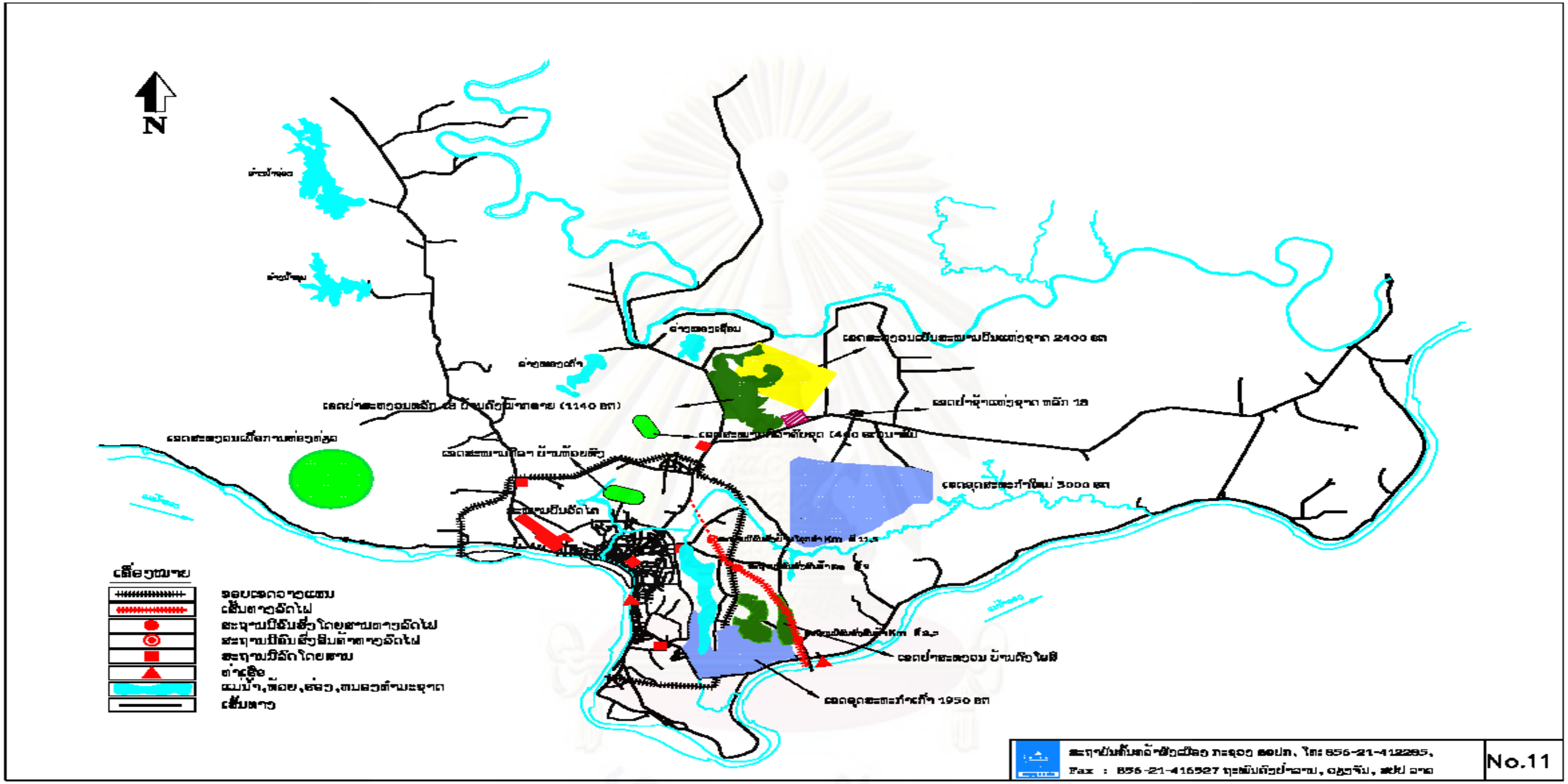


Figure 2-15 Maps of location of national government agencies

Source: Research Institute town plan, Vientiane capital city

CHAPTER 3
MEHTODOLOGY

The general process was first to contact water authorities around District zone of Vientiane capital city to determine the availability of data. This was followed by coordinating with the water authority that has data on Water consumption and the yearly data, analysing the data and developing urban water demand models. The methodology follows the layout shown by step below and chart diagram 3.4.

3.1 Methodology

The variation of water consumption over time arises in part from the effect of socioeconomic factors, in part from the effect of climatic factors, and from other factors, such as the activity over a year of a city's institutions and industries, and also as a result of restriction in water use because of supply limitations. In broad terms, approaches to water demand forecasting can be categorised as water consumption forecasting, econometric forecasting, and time series forecasting water consumption is an approach that bases the forecast of water demand on a forecast of uses for water. This approach requires tremendous amounts of data and assumptions. The econometric approach is based on statistically estimating historical relationships between different factors (independent variables) and water consumption (the dependent variable) assuming that those relationships will continue into the future, getting forecasts of the factors related to water consumption and basing the water forecast on those. Multiple linear regression approach forecasts water consumption directly, without having to forecast other factors on which water consumption depends. Based on the literature review and taking into account the requirements of Vientiane Water, the methodology adopted was based on time series analysis in which yearly water consumption is considered to be the sum of base consumption year.

3.2 Step and Research Methodology

The general process was first to contact water authorities around Greater Vientiane to determine the availability of data. This was followed by coordinating with the water authority that has data on users of water and the yearly data, analysing the data and developing urban water demand models. The methodology is follows by step are:

1. Collection the data related this research use data period of last 10 years for Vientiane city area, since 1997 to 2007).

- Water consumption volume (m^3/year).
- Number population in each district zones of Vientiane capital (capita/year)
- Number of family (family/year).
- Income per capita (Kip/capita/year) x 1000.
- Area of each districts (Km^2)
- Population density (Capita/ km^2/year).
- Selling price of water (Kip/m^3/year).
- Maximum temperature of Vientiane capital (degree Celsius).
- Minimum temperature of Vientiane capital (degree Celsius).
- Average temperature of Vientiane capital (degree Celsius).
- Precipitation volume (mm/year).
- Water production and water Distribution volume (m^3/year).
- Average of loss water (m^3/year).
- Service area of water supply are use the map of VWSC

2. Check and consider all data to be ready for model processing, and verification of model, in order to obtain the forecasting model by programmer SPSS.
3. Step of study and work process to prepare forecast model of urban water demand in the study area that divide in to 4 districts and report in the whole water demand of Vientiane city.
4. Process improves using work of forecasting model.
5. Forecast use statistic tools for water supply demand in the year 2009 – 2029.
6. The factors considered influencing water demand in this step include population, rainfall, temperature and water use. These factors will from part of the variables that will be used in developing and future planning of urban residential water supply demand model.

Numerous factors can directly or indirectly influence water demand. For the purpose of this study, they have been categorised as depicted in (Figure 4.1).

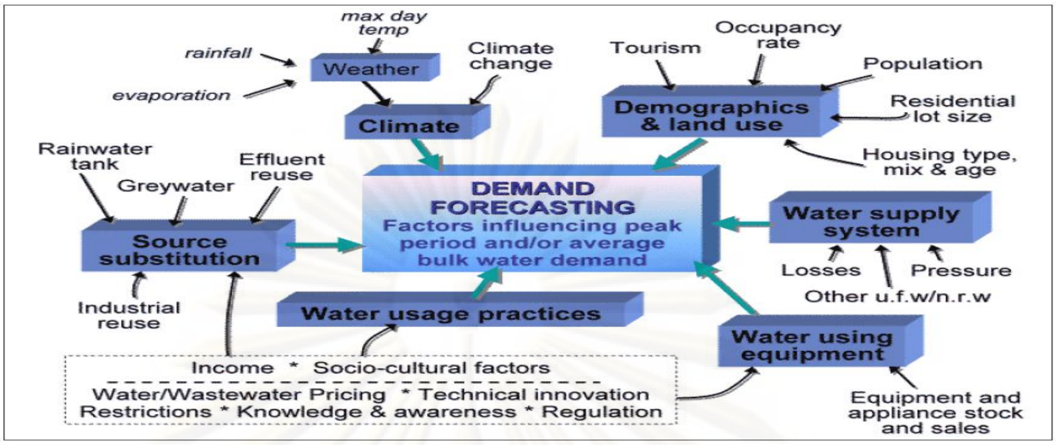


Figure 3.1 Direct and indirect factors influencing water demand.

Input all information as variables following the theories; the factor analysis to consider for correlation of each factors and the multiple linear regressions for determine the major influence factors.

For example for the multiple linear regression will use the format as follow

$$Y_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \ldots \beta_p x_{ip} + \varepsilon_i \quad \textbf{for} \quad i = 1,2, \ldots n.$$

Where:

Y_i	is water consumption	(m^3 /year)
X_i	is number of family	(family/year)
X_{i2}	is total population	(capita/year)
X_{i3}	is income per capita	(kip/capita/year) x 1000
X_{i4}	is Area	(Km^2)
X_{i5}	is population density	(capita/Km^2)
X_{i6}	is selling price of water	(kip/m^3)
X_{i7}	is minimum temperature	(Degree Celsius)
X_{i8}	is maximum temperature	(Degree Celsius)
X_{i9}	is Average temperature	(Degree Celsius)
X_{i10}	is total precipitation	(mm/year)

Using SPSS program for input variables and make a model process.

1. Find out independent and dependent variables
- Describe all parameter by factor analysis.
2. Using statistic tools e.g. F-test, T-test and Really-test. To decided the suitable forecast equation.
3. Find out all the validate factor which suitable for this study.
4. Forecast water supply demand in next 20 years (2009 to 2029).

3.3 Theory of Model in Database Table.

The area of table is a classify project area, the table area can call a grid and every grid, these grid can defined a schedule i and j, the i is follow a horizontal line axis (X) , the j is follow a vertical line axis (Y), the (X) can use A, B, C, D……is to replace i, the (Y) can use 1,2, 3 ,4……is to replace j, from this kind can save data other parameters of grid therefore this gird model can use program software calculate by **SPSS** program, and **EXCEL** program use forecast model.

Table 3-1 Table for database calculate in SPSS & Excel Software.

If A, B,….F,….i are the important Parameter, and 1,2,3,…..j are the yearly date value.

	i									
j		A	B	C	D	E	F	…	…	i
	1									
	2									
	3									
	4									
	5									
	⋮									
	j									

This table relates this research as use data period of last 10 years for Vientiane city area, since 1997 to 2007), and verification model by using data in the year 2008.

Table 3-2 Sample type of data calculate

Use data period of last 10 years													Verify data
Year 1997 to 2007													**2008**
	i												**i**
	yi	**yi1**	**yi2**	**yi3**	**yi4**	**yi5**	**yi6**	**yi7**	**yi8**	**yi9**	**yi10**		**yi11**
	X1												
	X2												
	X3												
j	**X4**												
	.												
	.												
	.												
	Xn												
Total													

3.4 Research Methodology Planning Diagram

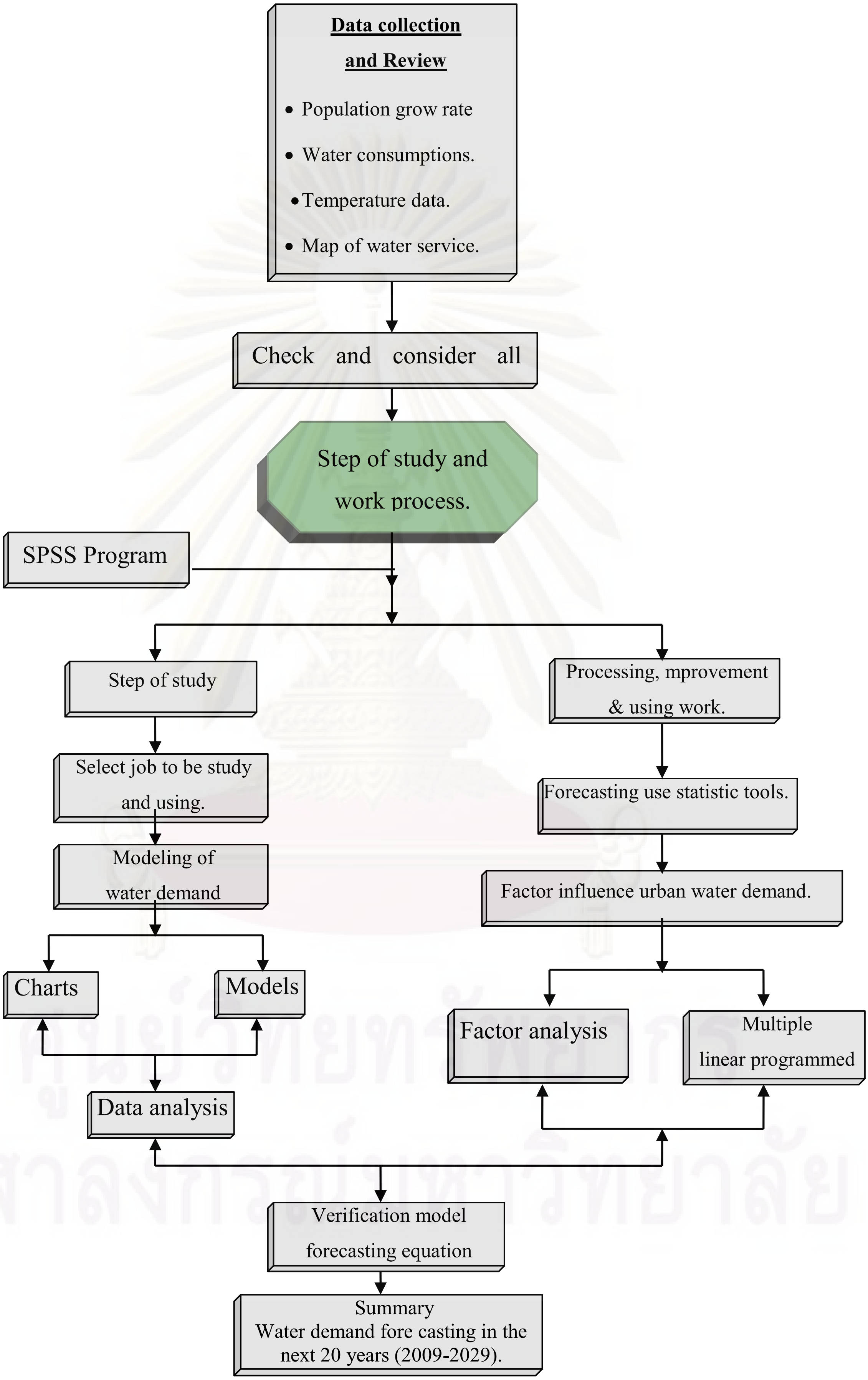
1. Collect all historical base data water use (period 10 years from Vientiane Water Supply Company a since, 1997-2007).

- Population volume: Collect information from the National Statistical office of Vientiane capital in Laos. (Registration Population and Non registration).
- Water supply consumption volume: Collect information from Water work of metropolitan Authority for 10 year recorded water consumption in Vientiane capital area.
- Precipitation volume for 10 year recorded from the Lao PDR Meteorological Department.
- Maximum, Minimum and Average of temperature record from Vientiane capital city Authority, from the Lao PDR Meteorological Department.
- Income per capita per year of Vientiane capital, from the National Statistical office of Lao PDR.
- Density of population per year at Vientiane from the National Statistical office of Lao PDR. Etc.

2. Consider and review all information by using SPSS program for model factor analysis.
3. Forecast population scope of area study in the future of the year 2009 to 2029.
4. Study kind of activity water using in scope of area study.
5. Study variable type of water supply demand volume.
6. Forecast model of water supply demand in the future.

It is important to note that the results of this study provide total water demand for the Vientiane capital city planning in the next 20 years

3.5 Research Planning Diagram



3.6 Base Data Collection

3.6.1. Project Area

The location of Vientiane capital city (Figure 3-2 and 3-3) has been recognised as having high quality drinking water, past Vientiane capital city its growing population means increasing water demand every year. In the Vientiane capital city, Lao PDR had all 9 districts zone, Area of responsibility 3,920 square kilometer, in that the population Vientiane capital had around 725,820 people in the year 2007, the population density is 190 people per square kilometer, with growth rate an increase of 3 % per year (table 3-4). The majority populations are Buddhism.

This study is focus four district zone is water demand forecasting model because urban population density had 4 district zones, Area responsibility 347 square kilometer in the year 2007, the total of population is 320,130 people, average of population density is 930 people per square kilometer, the detail is appendix table A-3 to table A-6.

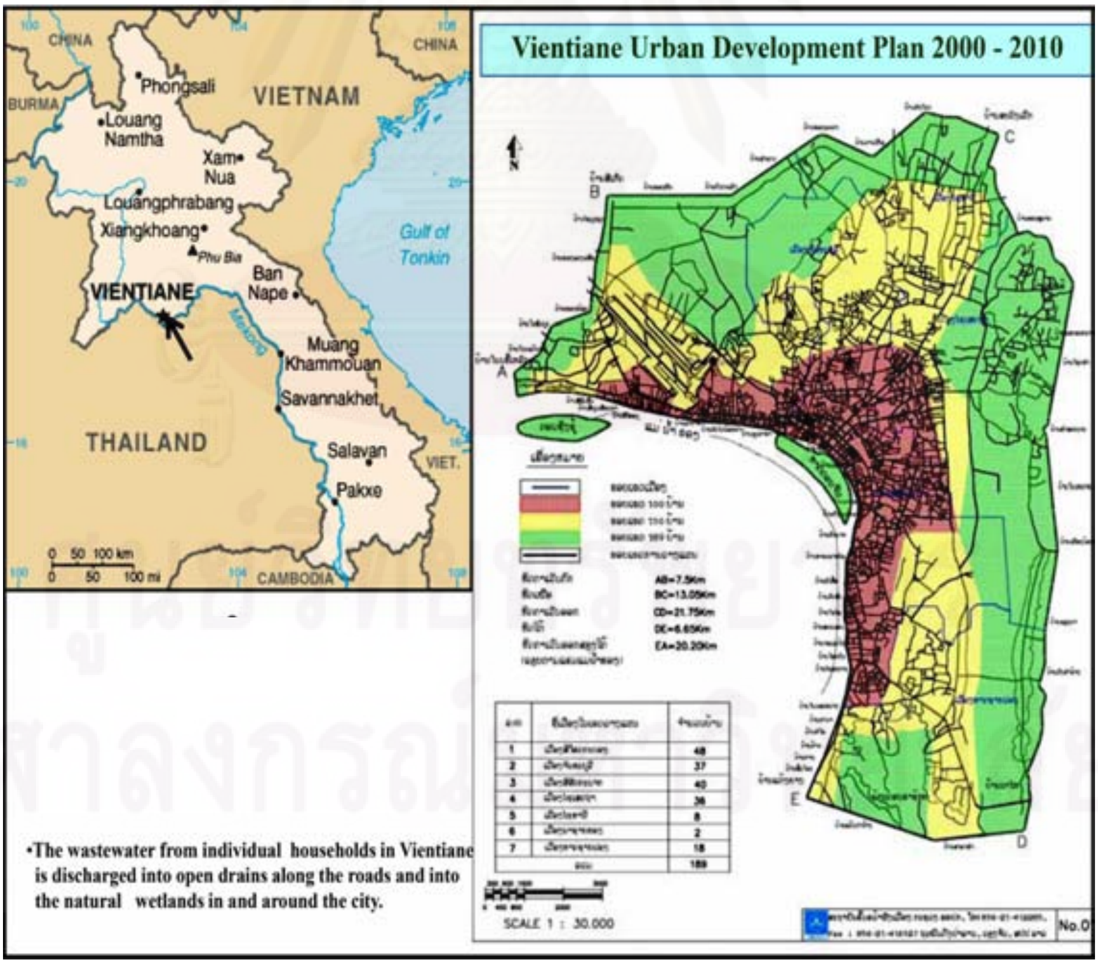


Figure 3-2 Nine district zone all of Vientiane capital city.

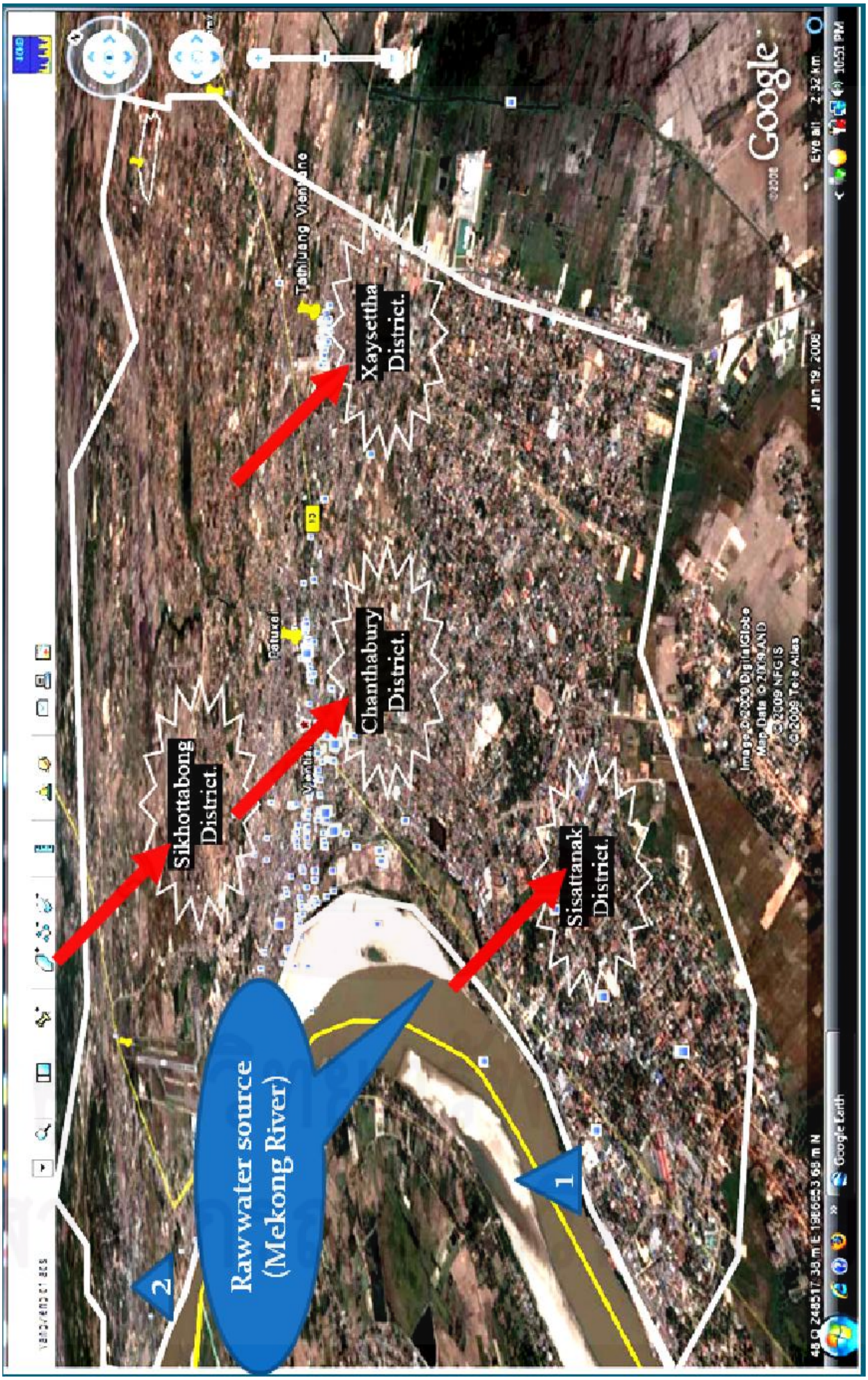


Figure 3-3 The four districts zones of population density year 2008

3.6.2. The Office and Treatment Plant

The present Vientiane capital water supply have had four plant station for distribution water supply to every district zone around at Vientiane capital such as show in the figure. 3-4, to 3-7. (Source: available from Google earth)

Figure 3-4 PhoneKeng water supply Plant and office centre

Figure 3-5 Kaoloe water supply distribution station

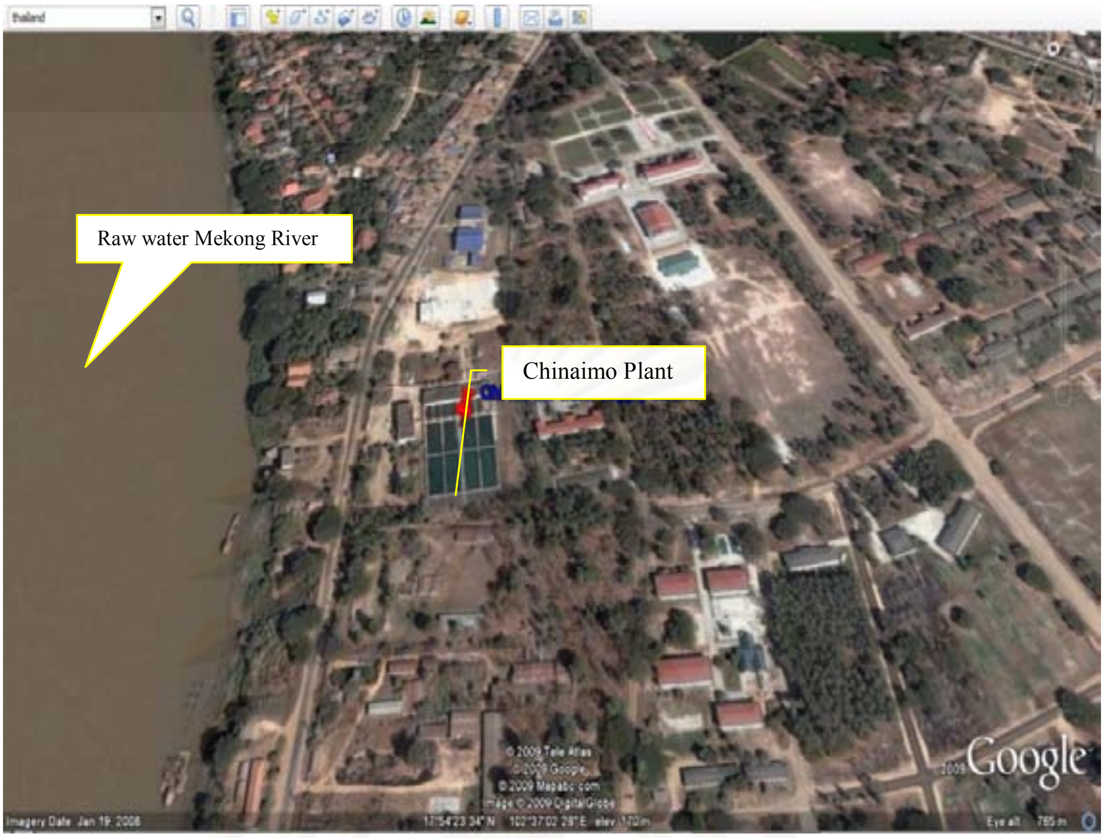


Figure 3-6 Chinaimo water supply distribution station

Figure 3-7 Dongmakkhai water supply distribution station, raw water is from Namngeum River

Figure 3-8 Water supply treatment plant, raw water is from Mekong and Namngeum River.

3.6.3 Water Consumption Data

This section presents the methodology adopted for water supply consumption data analysis from water supply data collection, consumption data disaggregation, survey development and implementation; and water use modelling. The aim of this section is to be able to answer the questions of how, how much, where and when water is used in the district zones. The results of the analysis of water consumption data is presented in Chapter 4.

Water Consumption Data Collection

Data collected from period 10 years, statistic were record from Vientiane capital water supply company of four district zone that use to this analysis and forecasting for water demand modeling in future.

Table 3-3 Statistic data of water use in Vientiane capital city

Year	Water Consumption m^3/year	Average of Loss water m^3/year	Selling Price of water Kip/m^3	Capacity of production m^3/year
1997	18,386,534	7,790,406	162	26,176,945
1998	20,861,567	9,728,691	195	30,590,258
1999	21,943,494	9,582,579	195	31,526,073
2000	24,992,460	11,280,830	195	36,273,290
2001	27,834,267	10,544,702	387	38,378,969
2002	28,829,294	12,536,121	550	41,365,415
2003	31,350,134	12,436,751	550	43,786,885
2004	30,484,816	12,720,883	950	43,205,699
2005	31,509,756	12,362,033	950	43,871,789
2006	31,679,467	11,760,729	950	43,440,196
2007	35,562,330	13,635,210	1,200	49,197,540
2008	36,177,870	13,603,375	1,200	49,781,245

3.6.4 Population Data Collection

The population is important for the water demand because population increase on the water consumption is increase follow too, that is influence factors for using data to forecasting water demand, and data is collection from period years during 1997 – 2008, that got from National statistic centre of Laos and Department of planning and investment of Vientiane capital, the statatistict was collected all 9 districts in Vientiane capital, the population had increased every year such as show in the table 3-4.

Table 3-4 Statistic data of population in the Vientiane capital.

Years	Number of population	Population density	Size of family	Number of family	Income per capita
	capita/yearly	capita/Km^2	capita/family/year	(family/year)	Kip/capita x1000
1997	556,431	139	6	99,163	6,285
1998	577,019	144	6	101,783	6,758
1999	581,062	148	6	101,450	7,266
2000	597,800	153	6	103,520	7,813
2001	616,160	157	6	105,633	8,401
2002	635,755	162	6	108,083	9,034
2003	650,600	163	6	117,561	9,714
2004	669,467	168	6	121,468	10,445
2005	698,138	177	6	126,669	11,231
2006	717,871	179	6	125,962	12,762
2007	725,820	190	6	120,447	14,041
2008	746,143	196	6	123,105	15,983

3.6.5 Temperature

Supplemental data was also collected to provide additional information about each district period (1997 to 2008). These data were used in the model estimation process and to qualify end use measurements.

Weather Data

The weather data including monthly minimum temperature, maximum temperature and measured rainfall were obtained from the Department of Meteorology, Laos at Vientiane capital station for the yearly period and for the period corresponding to the historic billing data. These data were used so that the relationship between weather and water use could be explored during the data yearly water consumption analysis and the water use model development. The weather data were incorporated into the database developed for each yearly period.

Table 3-5 Statistic data of temperature station at Vientiane capital station

Year	Max Temperature	Min Temperature	Average temperature	Total Precipitation
	°c	°c	°c	mm
1997	31.5	22.6	27.0	1,599.6
1998	32.5	23.2	27.9	1,477.4
1999	30.9	22.1	26.5	2,192.2
2000	31.4	22.2	26.8	1,499.8
2001	31.7	22.6	27.2	1,659.0
2002	31.6	22.5	27.1	1,846.7
2003	31.8	22.0	26.9	1,481.0
2004	31.2	22.1	26.6	1,629.6
2005	31.8	22.7	27.3	1,667.8
2006	31.7	22.7	27.2	1,930.3
2007	31.8	22.7	27.2	1,467.6
2008	30.5	22.0	26.3	1,717.5

3.7 Step of Research Modelling

Once the data collection and analysis was complete, all of the assembled information was used to develop analytical tools and relationships to explain yearly water use in Vientiane capital.

3.7.1 Development Water Demand Models

Water consumption data was combined with yearly survey to develop models of water demand at the water use level. These models were designed exclusively to search for and reveal year characteristics that explain, from a statistical perspective, variation in water use from year to year.

Using yearly data and surveys for the district monitored in year 2008, water consumption models for districts were developed. These models were validated using the data for 2008 and 1997-2007 monitoring periods.

Multiple regression analysis was used to estimate each of the water consumption demand models. Multiple regression analysis is commonly used to estimate a direct and quantifiable numeric relationship between a variable of interest (the dependent variable) and a set of independent variables that are hypothesized to affect or explain changes in the variable of interest.

3.7.2 Water Use Model Performance Criteria

Water use model performances were evaluated according to two criteria: standard error, SE, and the coefficient of determination, R^2. A favorable model is the one with high R^2, but low residual standard error.

All parameters considered in the water use modelling were tested of its statistical level of significance by its *P*-value. The *P*-value is the smallest level of significance at which the parameter is significant (Devore 1990). Conventionally (and arbitrarily) a p-value of 0.05 (5%) is generally regarded as sufficiently small. The 5% value is called the significance level of the test (Campbell and Machin 1999). In this study, a *P*-value lower than 0.05 is considered statistically significant.

3.7.3 Analysis of Variance

Analysis of variance (ANOVA) was performed to determine the extent to which variation could be found among the mean values of each water use components covering the three monitoring periods. ANOVA is a set of statistical procedure for the analysis of quantitative data. Multiple comparisons in ANOVA are techniques which allow ranking the means of various treatments with 95% confidence so that all confidence intervals comparing the means contain the true differences between the treatment means year 1997 -2007. According to Devore (1991), Tukey developed a procedure specifically for pair wise comparisons when the sample sizes of the treatments are equal. Tukey's procedure involves the use of a probability distribution called the Studentized range distribution and the result is a collection of simultaneous confidence statements about the true values of all differences between true treatment means (Devore 1991).

In order to determine which differences in water uses were statistically significant, multiple comparison tests for significance using Tukey's procedure were performed on the per capita consumption for each end use in each logging period at the 95% level of confidence. This multiple comparisons procedure provided a relatively simple methodology for developing simultaneous confidence statements from multiple sets of data such as the different daily per capita water use found for each logging period. As reported by Mayer et al. (1999), Tukey's procedure may not be as sensitive in detecting differences in some situations as other methods such as those of Bonferroni's or Scheffe's, but it offered an appropriate and effective methodology to use for this study on per capita usage data. Booth

3.7.4 Extending Water Consumption Models to Predict Yearly Use

In order to adjust the system of end use models for the effects of weather and time of the year, water use billing data and weather data were combined with predictions from the end use models to develop a model that is capable of producing better estimates of total average year daily water use in any given monthly/bimonthly billing period. In this context, predictions from the end use models were arrayed with billing period water use and weather conditions to estimate the model. Because the process was to broaden to billing data, the model was termed the “extended” model for predicting billing period use. The model provides estimates of average total single family household water in any given billing period in terms of usage per day (ML/day). These extended models could also be used to develop estimates of indoor and outdoor use.

Monthly billing data for the entire sample of single-family households was modelled using predictions from the reduced form models as inputs and variables denoting weather conditions and time of year. This two-step procedure resulted in water use predictions for total yearly water use, in the water consumption at Vientiane. These predictions were compared with actual water forecasting and yearly billing data for the water distribution in district to test the general performance of the models in reproducing actual water use.

3.8 Data Analysis

The following analyses were undertaken on yearly water consumption data of Vientiane capital water supply distribution zone data received from Vientiane water supply company:

• Basic statistical analysis to determine the average, maximum, minimum, and standard deviation values was undertaken for all the data collected. Demand profiles from yearly data over the 10-year period were developed. Yearly water consumption was also determined based on the calculated average values.

• Analysis every data is influence factor for urban water use including the effects of significant water demand increase, of consecutive in water use of each district significant importance factor

3.9 Sector Planning and Development Water Supply in LAO P.D.R

The Department of Housing and Urban Planning (DHUP) is responsible for setting of development strategies and plans, planning of staff training, and drafting regulations and technical standards of water supply systems. DHUP also has the task of managing the Government’s ambitious long-term capital investment program in urban water supply systems, which aims to achieve 80% coverage by 2020(MDG).

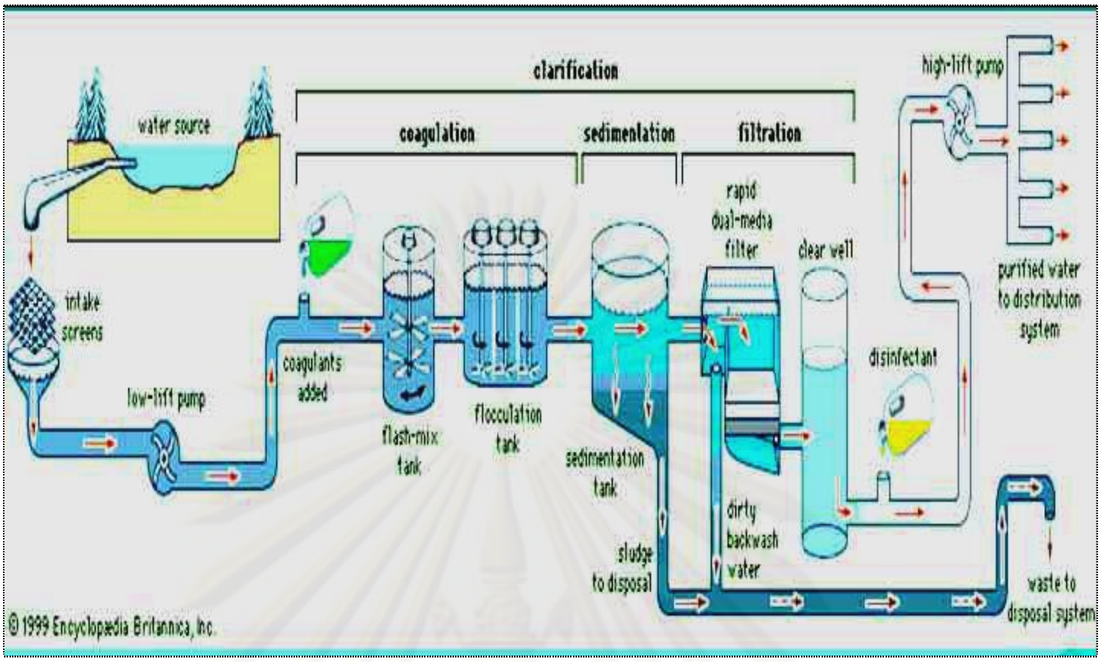


Figure 3.9 Step of Water supply system

Source: Water supply division of housing and urban planning in LAO P.D.R. (2007)

CHAPTER 4
DATA ANALYSIS AND RESULT

4.1 Introduction

The objectives in this chapter is order specifically to development of a yearly urban water demand model, the analysis of a yearly urban water supply distribution zone data was undertaken adopting the methodology to analysis water use and water demand. The analysis presented in this chapter was also undertaken to show that there are variation in yearly urban water demand that could be better explained through water consumption data which further provide a valuable tool for assessing the effectiveness of water consumption demand planning.

This chapter is presents some of the fundamental findings from the water consumption data analysis part of the study. These findings provide some information data for analysis water consumption model. Specifically, these include the average water consumption cubic met per year (m^3/year) the water supply consumption is different zone water using. This study is analyses for each zone of the participating and uses only four district zones of Vientiane capital city because these zone suitable for analysis. Show (Figure 4-1) and can available information data for analysis statistic data use periods; year 1997 to 2007. This study is using model for water consumption of Vientiane capital city.

4.2 Yearly Water Consumption Data Analysis

The analysis for yearly water consumption was undertaken based on average yearly water consumption per year, and total per year. This analysis was undertaken to determine the factors influencing urban water demand.

4.3 Total Yearly Water Consumption Data Analysis

The average yearly water consumption per year and the average total usage per year were determined by grouping all available daily data into yearly categories. For the total yearly water consumption, the years with missing data were removed from the analysis and the average values for each year was calculated (e.g., 2007 - 2008 average over the 10-year period). Basic statistical analysis was undertaken to determine the mean, minimum, maximum and standard deviation of daily water consumption and total consumption per month (Table 4.1). Using the mean values from the analysis, a 10 years demand profile was generated (Figure 6-13). Based on this analysis

The yearly water supply consumption data for 1997 to 20007 were obtained from Vientiane water supply. The data set contains 10 years. There was data recorded from staff Vientiane Water Supply Company. Basic statistical analysis was undertaken to determine the mean, minimum, maximum and standard values across each time interval (e.g.10 years,). The results of the basic statistical analysis undertaken are presented in Table 4-1.

The annual consumption was calculated by summing all the yearly data for the particular year. A year with missing data was excluded from the analysis.

Based on the analysis, the average annual water use in Vientiane water supply distribution zone was around 5,120,286 m^3 per year. The annual level of demand and the average yearly water consumption per year have been gradually increasing from 1997 to 2007.

Table 4-1 Total annual statistic water supply consumption of each district zones

Year	Chanthabury	Sikhottabong	Xaisettha	sisatanak	Total
	Water consumption	Water consumption	Water consumption	Water consumption	Water consumption
	m^3	m^3	m^3	m^3	m^3
	Y	Y	Y	Y	Σ Y=Y+Y+Y+Y
1997	3,845,489	3,734,540	4,861,687	4,891,926	17,333,641
1998	3,987,764	3,872,711	5,041,559	5,072,917	17,974,952
1999	4,015,714	3,899,854	5,076,895	5,108,472	18,100,934
2000	4,130,734	4,011,555	5,222,310	5,254,792	18,619,391
2001	4,319,522	4,215,889	5,383,547	5,478,411	19,397,369
2002	4,294,303	4,226,926	5,636,213	5,577,147	19,734,589
2003	4,717,803	4,753,900	6,100,123	5,938,548	21,510,374
2004	4,702,820	4,765,779	5,885,797	5,935,245	21,289,641
2005	4,986,707	5,003,934	6,129,808	6,161,510	22,281,959
2006	4,958,843	5,330,359	6,288,396	6,367,261	22,944,859
2007	5,358,739	5,391,710	8,344,209	7,010,211	26,104,869
2008	5,407,891	5,411,064	8,559,280	7,513,307	26,891,542

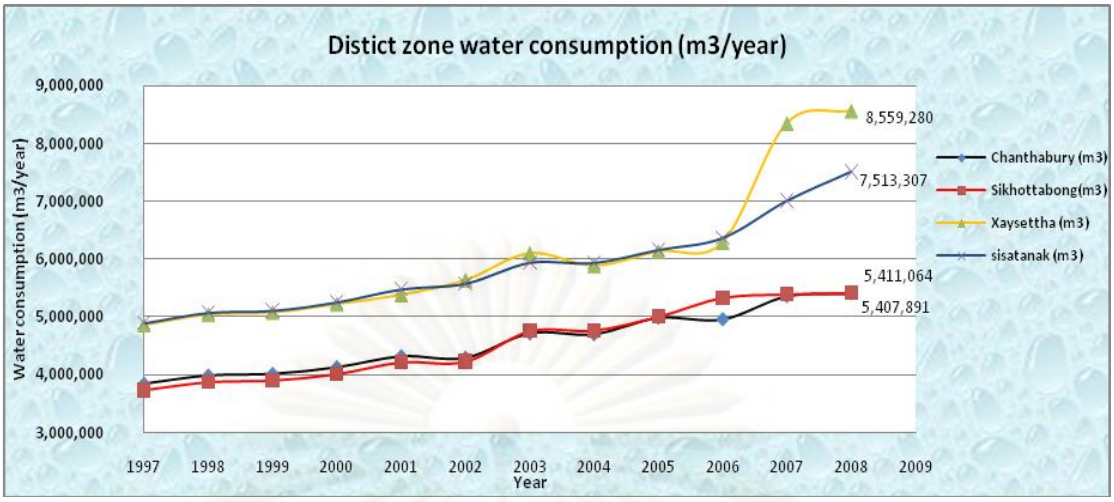


Figure 4-1 Average water supply consumption of district (1997 to 2008)

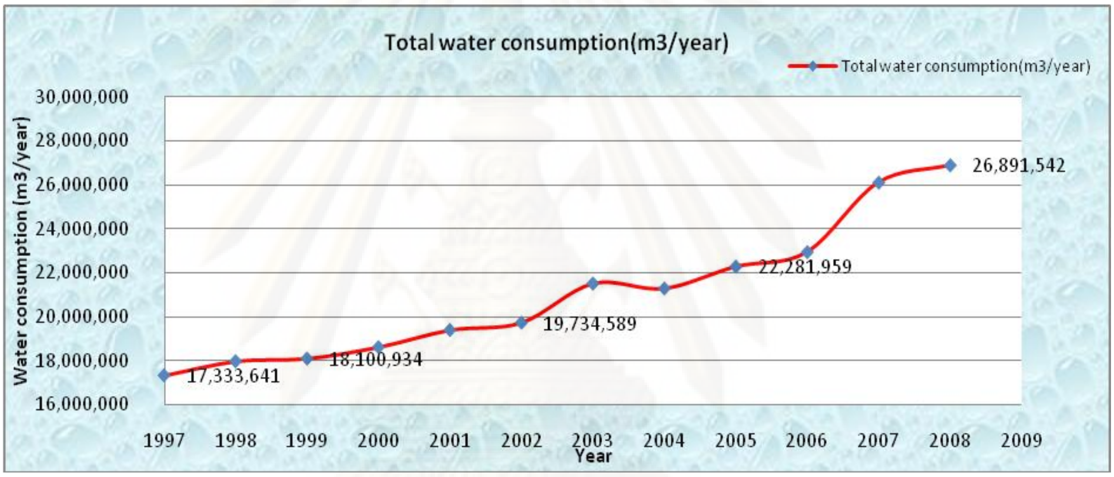


Figure 4-2 Average total water supply consumption of each district zone (1997 to 2008)

4.3 Factor Influencing Water Consumption Demand

The following sections present some of the factors that influence urban water supply demand. The factors considered influencing water demand in this section include these factor groups as: number of family, population, income per capita, Area of each district, population density, selling price of water, minimum temperature, maximum temperature, Average temperature and total precipitation of the yearly. These factors will form part of the variables that will be used in developing the yearly urban water demand model as discussed in data variables that to used indicator without adjustment for forecast water consumption.

4.4 Theoretical Consideration

There are a lot of papers dealing with forecasting urban water demands consider annual or monthly data such as general paper like to use multiple linear regression attempts to model the relationship between two or more explanatory variables and a response variable by fitting a linear equation to observed data. Every value of the independent variable *X* is associated with a value of the dependent variable *Y*. Simple linear regression was presented as formal statistical model.(white etal (2003). We do so now for general multiple linear regression model, one dependent at least two independent variables. Makridakis S, Wheelwright, S.C and McGee V.E. 1983., Department of Hydrology Lao PDR. (2008)., National Statistic Centre Lao PDR. (2007)., Vientiane Water Supply Co., Ltd. (2008)., and Vientiane Capital Department of Planning and Investment. (2007).

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_k X_k + \varepsilon$$

Where

Y is dependent variable of water consumption cubicmet per year (m^3 /year)

$\beta_0, \beta_1, \beta_2, \ldots, \beta_k$ are ceofficients of poly nomial function for base water consumtion,

X_1 X_1 . . . X_k are independent factor availables of base consumption,

k are independent to dependent variable

ε is a error difference between actual value (Y) and predicted($\hat{Y}$) value

4.5 Study Area

4.5.1 Water Consumption in Vientiane Capital City

Vientiane capital in the years (2007) had Population around 725,820 peoples, average of population density is 190 capita per square kilometer, with growth rate an increase of 3 % per year. There is a historical annual increase in water consumption of 2.9% but four district zones had population density consumption that is the total volume of water supplied to the metropolitan area from service reservoirs, increased at about 3.2% per year between years 2006 to 2007. Scope of study has chosen four these districts are modeling of this research.

4.5.2 Base Consumption

Base consumption is weather-insensitive and characterised by the water use during the years 1997 to 2007, but it may exhibit trends, upward or downward, through time. Trends in base water consumption may result from the effect of socioeconomic factors such as city population, household income, and water price. Water consumption responds to these factors on different time scales. Population and income change slowly over time and their effects on water consumption are appropriately measured by annual average values. Water price usually changes in a step function to which water consumption may show a short-run adjustment in successive years, accumulating to form a long-run adjustment in successive years. Various methods are available for estimating base consumption including regression against independent socio-economic variables such as population, household income, water price and water use.

To eliminate the effect of water use variation, the unit of cubic meter per year (m^3/year) for water consumption was used in this study. Population data for Vientiane metropolitan area were obtained from the department planning of Vientiane capital and water supply Company of Vientiane capital, Lao PDR. The water base consumption was estimated by fitting a polynomial function of time to during years of water consumption in each year, expressed as regression modle in practice.

$$Y_i = b_0 + b_1X_{1i} + b_2X_{2i} + \ldots + b_kX_{ki} + e_i \qquad \text{for } i = 1,2, \ldots , N$$

Where $X_1 + X_2 , \ldots , X_k$ are assumed measured without error,

$b_0, b_1, b_2 ,\ldots , b_k$ are least-squares estimate of $\beta_0, \beta_1,\beta_2 , \ldots , \beta_k$ usually computed by statistical software and are all landom variables now, with a joint normal distribution.

e_i (i = 1,2, . . .,N) is and estimated error term, for the ith observation, and is assumed to be sampled independently from a normal distribution

.The values fit by the equation $b_0 + b_1x_{i1} + \ldots + b_kx_{ik}$ are denoted $\hat{Y}_i$, and the residuals $e_i = Y_i - \hat{Y}_i$, the difference between the observed and fitted values. $R^2 = \frac{SSR}{SST}$, also known as the mean-squared error and coefficient determination, that is available from use statistic tool analysis SPSS software (Vanichbuncha 2008).

4.5.3 Water Demand Forecasting Model

The development of a yearly water demand is one of the objectives of this study as stated to develop a model that would forecast yearly urban water consumption demand. The yearly urban water consumption model was developed in this study is based to planning water supply For service each zone for Vientiane capital. The data for use to forecast water consumption is available from office relate with this research at Vientiane capital city. This research is us data of four district zone is model simple for other city, such as Chanthabury dstrict zone, Sikhottabong district zone, Xaisettha district zone and Sisattanak district zone. The water consumption model is separateness of each zone; the calculate of each district zone by using influence factor data available use to this forecasting this model.

4.6 Data and Results

4.6.1 Data sets

A complete set of Y= water consumption (m^3 /year) data from 1997 to was used for this study. Concurrent data sets of X_{i1} is number of family (family), X_{i2} is total of population (capita/year), X_{i3} is income per capita (Kip/capita) x 1000, X_{i4} is Area (m^2), X_{i5} is population density (capita/Km^2), X_{i6} is selling price of water (kip/m^3), X_{i7} is minimum temperature (°**c**), X_{i8} maximum temperature (°**c**), X_{i9} is Average temperature (°**c**) and X_{i10} is total precipitation (mm/year) recorded yearly at Vientiane capital were used as data variables that to used indicator without adjustment for forecast water consumption factor.

The times of measurement of water consumption data by the respective authorities are different. Yearly water consumption on year was recorded from year 1997 to 2009 was recorded in 10 years after that use to forecasting water supply demand of every year. However, the data were used in the model as recorded. After using the statistic tool program (SPSS) and (Excel) software to analyze them by factor analysis and multiple linear regression method, the result are following.

4.6.2 Independent factor data of each district zone

The independent factor data use to forecast water consumption demand year 2009 to 2029 is available from independent factor data by year 1997 to 2008, by using linear equation calculate such as (X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, X_9, & X_{10}) available from Appendix A-3 Linear equation forecasting is: $Y= a_0 + b_1X_{1i}$, where X is time of years

Table.4-2 Data independent factor available from linear (chanthaburi district zone)

Year	Number of family	Number of population	Income per capita	Area	Population density	Selling price of water	Max Temperature	Min Temperature	Average temperature	Total Precipitation
	family/year	capita/yearly	Kip/capita x1000)	Km^2	capita/Km^2	Kip/m^3	°c	°c	°c	mm
	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
2009	12,516	68,321	15,309	29	2,356	1,333	31.3	22.3	26.8	1,675
2010	12,710	69,334	16,130	29	2,391	1,442	31.3	22.2	26.8	1,674
2011	12,904	70,347	16,950	29	2,426	1,551	31.2	22.2	26.7	1,674
2012	13,098	71,360	17,770	29	2,461	1,660	31.2	22.2	26.7	1,673
2013	13,292	72,373	18,590	29	2,496	1,770	31.2	22.2	26.7	1,672
2014	13,486	73,386	19,411	29	2,531	1,879	31.1	22.1	26.6	1,671
2015	13,681	74,399	20,231	29	2,565	1,988	31.1	22.1	26.6	1,670
2016	13,875	75,412	21,051	29	2,600	2,097	31.1	22.1	26.6	1,669
2017	14,069	76,425	21,872	29	2,635	2,206	31.0	22.1	26.5	1,669
2018	14,263	77,438	22,692	29	2,670	2,315	31.0	22.0	26.5	1,668
2019	14,457	78,451	23,512	29	2,705	2,424	30.9	22.0	26.5	1,667
2020	14,651	79,464	24,332	29	2,740	2,533	30.9	22.0	26.4	1,666
2021	14,845	80,477	25,153	29	2,775	2,643	30.9	21.9	26.4	1,665
2022	15,040	81,490	25,973	29	2,810	2,752	30.8	21.9	26.4	1,664
2023	15,234	82,503	26,793	29	2,845	2,861	30.8	21.9	26.3	1,664
2024	15,428	83,516	27,613	29	2,880	2,970	30.8	21.9	26.3	1,663
2025	15,622	84,529	28,434	29	2,915	3,079	30.7	21.8	26.3	1,662
2026	15,816	85,542	29,254	29	2,950	3,188	30.7	21.8	26.3	1,661
2027	16,010	86,555	30,074	29	2,985	3,297	30.7	21.8	26.2	1,660
2028	16,204	87,568	30,894	29	3,020	3,406	30.6	21.8	26.2	1,659
2029	16,398	88,581	31,715	29	3,055	3,516	30.6	21.7	26.2	1,659

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Table.4-3 Data independent factor available from linear (Sikhottabong district zone)

Year	Number of family	Number of population	Income per capita	Area	Population density	Selling price of water	Max Temperature	Min Temperature	Average temperature	Total Precipitation
	family/year	capita/yearly	Kip/capita (X 1000)	Km^2	capita/Km^2	Kip/m^3	°c	°c	°c	mm
	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
2009	19,840	103,953	15,309	140	764	1,333	31.3	22.3	26.8	1,675
2010	20,416	106,932	16,130	140	785	1,442	31.3	22.2	26.8	1,674
2011	20,993	109,911	16,950	140	806	1,551	31.2	22.2	26.7	1,674
2012	21,570	112,891	17,770	140	828	1,660	31.2	22.2	26.7	1,673
2013	22,146	115,870	18,590	140	849	1,770	31.2	22.2	26.7	1,672
2014	22,723	118,849	19,411	140	870	1,879	31.1	22.1	26.6	1,671
2015	23,300	121,828	20,231	140	891	1,988	31.1	22.1	26.6	1,670
2016	23,876	124,807	21,051	140	913	2,097	31.1	22.1	26.6	1,669
2017	24,453	127,786	21,872	140	934	2,206	31.0	22.1	26.5	1,669
2018	25,030	130,765	22,692	140	955	2,315	31.0	22.0	26.5	1,668
2019	25,606	133,744	23,512	140	977	2,424	30.9	22.0	26.5	1,667
2020	26,183	136,723	24,332	140	998	2,533	30.9	22.0	26.4	1,666
2021	26,760	139,702	25,153	140	1,019	2,643	30.9	21.9	26.4	1,665
2022	27,336	142,682	25,973	140	1,040	2,752	30.8	21.9	26.4	1,664
2023	27,913	145,661	26,793	140	1,062	2,861	30.8	21.9	26.3	1,664
2024	28,490	148,640	27,613	140	1,083	2,970	30.8	21.9	26.3	1,663
2025	29,066	151,619	28,434	140	1,104	3,079	30.7	21.8	26.3	1,662
2026	29,643	154,598	29,254	140	1,126	3,188	30.7	21.8	26.3	1,661
2027	30,220	157,577	30,074	140	1,147	3,297	30.7	21.8	26.2	1,660
2028	30,796	160,556	30,894	140	1,168	3,406	30.6	21.8	26.2	1,659
2029	31,373	163,535	31,715	140	1,189	3,516	30.6	21.7	26.2	1,659

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Table.4.-4 Data independents factor available from linear (Xaisettha district zone)

Year	Number of family	Number of population	Income per capita	Area	Population density	Selling price of water	Max Temperature	Min Temperature	Average temperature	Total Precipitation
	family/year	capita/yearly	Kip/capita (x 1000)	Km^2	capita/Km^2	Kip/m^3	°c	°c	°c	mm
	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
2009	18,214	99,906	15,309	147	680	1,333	31.3	22.3	26.8	1,675
2010	18,628	102,262	16,130	147	696	1,442	31.3	22.2	26.8	1,674
2011	19,043	104,618	16,950	147	712	1,551	31.2	22.2	26.7	1,674
2012	19,458	106,974	17,770	147	728	1,660	31.2	22.2	26.7	1,673
2013	19,873	109,330	18,590	147	744	1,770	31.2	22.2	26.7	1,672
2014	20,288	111,686	19,411	147	760	1,879	31.1	22.1	26.6	1,671
2015	20,703	114,042	20,231	147	776	1,988	31.1	22.1	26.6	1,670
2016	21,118	116,398	21,051	147	792	2,097	31.1	22.1	26.6	1,669
2017	21,533	118,754	21,872	147	808	2,206	31.0	22.1	26.5	1,669
2018	21,947	121,110	22,692	147	824	2,315	31.0	22.0	26.5	1,668
2019	22,362	123,466	23,512	147	840	2,424	30.9	22.0	26.5	1,667
2020	22,777	125,822	24,332	147	856	2,533	30.9	22.0	26.4	1,666
2021	23,192	128,178	25,153	147	872	2,643	30.9	21.9	26.4	1,665
2022	23,607	130,534	25,973	147	888	2,752	30.8	21.9	26.4	1,664
2023	24,022	132,890	26,793	147	904	2,861	30.8	21.9	26.3	1,664
2024	24,437	135,246	27,613	147	920	2,970	30.8	21.9	26.3	1,663
2025	24,852	137,602	28,434	147	936	3,079	30.7	21.8	26.3	1,662
2026	25,267	139,958	29,254	147	952	3,188	30.7	21.8	26.3	1,661
2027	25,681	142,314	30,074	147	968	3,297	30.7	21.8	26.2	1,660
2028	26,096	144,670	30,894	147	984	3,406	30.6	21.8	26.2	1,659
2029	26,511	147,026	31,715	147	1,000	3,516	30.6	21.7	26.2	1,659

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Table.4.5 Data independents factor available from linear (Sisattanak district zone)

Year	Number of family	Number of population	Income per capita	Area	Population density	Selling price of water	Max Temperature	Min Temperature	Average temperature	Total Precipitati on
	family/year	capita/yearly	Kip/capita (X 1000)	Km^2	capita/Km^2	Kip/m^3	°c	°c	°c	mm
	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
2009	11,047	61,660	15,309	31	1,989	1,333	31.3	22.3	26.8	1,675
2010	11,186	61,946	16,130	31	1,998	1,442	31.3	22.2	26.8	1,674
2011	11,326	62,233	16,950	31	2,007	1,551	31.2	22.2	26.7	1,674
2012	11,466	62,519	17,770	31	2,017	1,660	31.2	22.2	26.7	1,673
2013	11,605	62,806	18,590	31	2,026	1,770	31.2	22.2	26.7	1,672
2014	11,745	63,092	19,411	31	2,035	1,879	31.1	22.1	26.6	1,671
2015	11,885	63,378	20,231	31	2,044	1,988	31.1	22.1	26.6	1,670
2016	12,025	63,665	21,051	31	2,054	2,097	31.1	22.1	26.6	1,669
2017	12,164	63,951	21,872	31	2,063	2,206	31.0	22.1	26.5	1,669
2018	12,304	64,238	22,692	31	2,072	2,315	31.0	22.0	26.5	1,668
2019	12,444	64,524	23,512	31	2,081	2,424	30.9	22.0	26.5	1,667
2020	12,583	64,811	24,332	31	2,091	2,533	30.9	22.0	26.4	1,666
2021	12,723	65,097	25,153	31	2,100	2,643	30.9	21.9	26.4	1,665
2022	12,863	65,384	25,973	31	2,109	2,752	30.8	21.9	26.4	1,664
2023	13,003	65,670	26,793	31	2,118	2,861	30.8	21.9	26.3	1,664
2024	13,142	65,957	27,613	31	2,128	2,970	30.8	21.9	26.3	1,663
2025	13,282	66,243	28,434	31	2,137	3,079	30.7	21.8	26.3	1,662
2026	13,422	66,530	29,254	31	2,146	3,188	30.7	21.8	26.3	1,661
2027	13,561	66,816	30,074	31	2,155	3,297	30.7	21.8	26.2	1,660
2028	13,701	67,103	30,894	31	2,165	3,406	30.6	21.8	26.2	1,659
2029	13,841	67,389	31,715	31	2,174	3,516	30.6	21.7	26.2	1,659

4.7 Model Efficiency Criteria

The methods commonly used to compare agreement between estimated and measured water consumption can be classified into two groups: graphical plots and statistical parameters including description of the characteristics of the two time series and dimensionless coefficients. The choice of appropriate graphical plots is important as they can enhance or discredit the model simulations. The statistical parameters of describing time series, e.g. mean, standard deviation, can be used to compare the agreement between the estimated and measured consumption. Dimensionless coefficients are very useful indicator in assessing model adequacy.

The measure adopted in this study describes directly the difference between the simulated and recorded consumption. Using terms and methodology from Analysis of Variance for four district zones.

Yearly average base consumption was identified from the lowest year's water consumption (usually 1997 and 2007) for Vientiane. A order polynomial function of time (years) was fitted. The yearly equivalent by using data 2008 validate to forecasting water consumption.

Yearly average base consumption was identified from the lowest year's water consumption (usually 1997 and 2007) for Vientiane. A order polynomial function of time (years) was fitted. The yearly equivalent by using data 2008 validate to forecasting water consumption.

4.7.1 Result model of Chanthaburi district zone water consumption demand forecasting by equations as:

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.996[a]	.991	.972	82661.165	2.934

a. Predictors: (Constant), X10=Total precipitation volume(mm./year), X3=Income per capita (Kip/capita) X 1000, X8=Min Temperature (degree celsius), X5=Density of Population (Capita/Km2)., X1=Number of House (Rung), X7=Max Temperature (degree Celsius), X6=Selling price of water (Kip/m3)

b. Dependent Variable: Y= Water sale (m3)

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2.386E12	7	3.409E11	49.895	.004[a]
	Residual	2.050E10	3	6.833E9		
	Total	2.407E12	10			

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	531698.019	2.863E6		.186	.865
X1=Number of House (Rung)	300.055	158.176	.469	1.897	.154
X3=Income per capita (Kip/capita) X 1000	116.813	68.019	.594	1.717	.184
X5=Density of Population (Capita/Km2).	-65.710	746.248	-.017	-.088	.935
X6=Selling price of water (Kip/m3)	-50.185	363.805	-.039	-.138	.899
X7=Max Temperature (degree Celsius)	-41880.911	272925.697	-.034	-.153	.888
X8=Min Temperature (degree Celsius)	58674.477	281265.801	.043	.209	.848
X10=Total precipitation volume(mm./year)	-202.504	200.499	-.094	-1.010	.387

a. Dependent Variable: Y= Water sale (m3)

Excluded Variables[b]

Model	Beta In	t	Sig.	Partial Correlation	Co linearity Statistics
					Tolerance
X2=Number of population volume in district register (capita/year)	.[a]	.	.	.	.000
X9=Average of temperature (degree celsius)	.[a]	.	.	.	.000

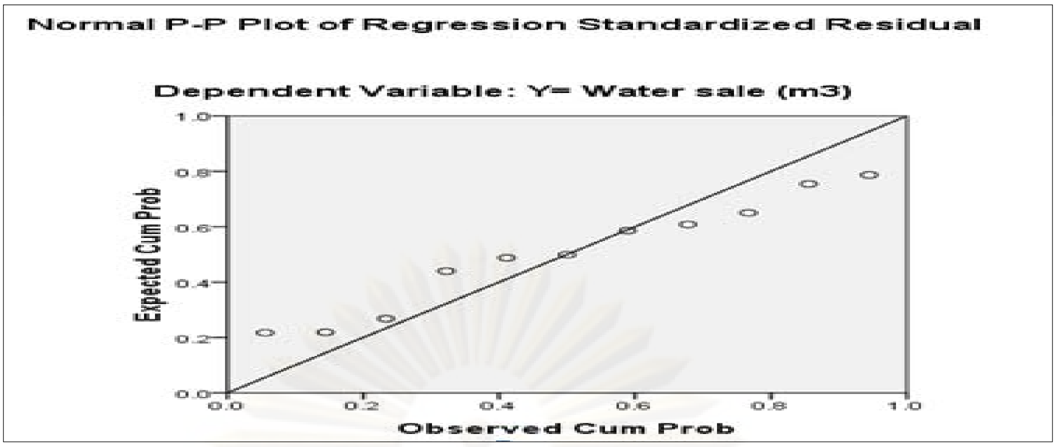
a. Predictors in the Model: (Constant), X10=Total precipitation volume(mm./year), X3=Income per capita (Kip/capita) X 1000, X8=Min Temperature (degree celsius), X5=Density of Population (Capita/Km2)., X1=Number of House (Rung), X7=Max Temperature (degree celsius), X6=Selling price of water (Kip/m3)

b. Dependent Variable: Y= Water sale (m3)

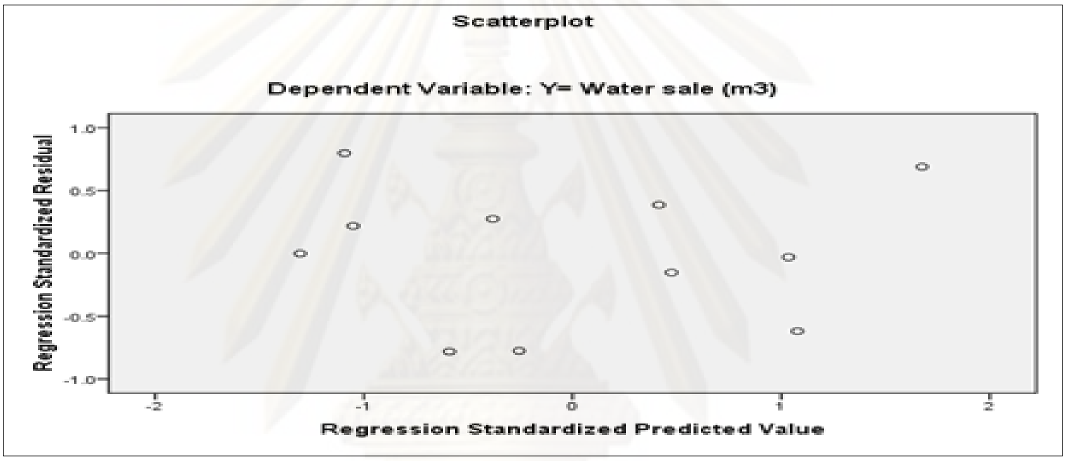
Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	3.85E6	5.30E6	4.48E6	488515.800	11
Residual	-6.459E4	6.586E4	.000	45275.384	11
Std. Predicted Value	-1.306	1.675	.000	1.000	11
Std. Residual	-.781	.797	.000	.548	11

a. Dependent Variable: Y= Water sale (m3)



Charts



Yearly average base consumption was identified from the lowest year's water consumption (usually 1997 and 2007) for Vientiane. A order polynomial function of time (years) was fitted. The yearly equivalent by using data 2008 validate to forecasting water consumption.

The forecasting equation of water demand of Chanthaburi zone is using coefficient after run program SPSS software had equation is: g

$\hat{Y}=(531698.019 + 300.055X_{1i} + 116.813X_{3i} -65.710X_{5i} - 50.185X_{6i} - 41880.911X_{7i} + 58674.477 X_{8i} - 202.504X_{10i}) + \mathbf{e}$

Table Forecasting water consumption $\hat{Y}$ using data 2008

Year	District Zone	Water consumption	Estimated using the regression model	Residual
		m3	m3	error
		Y	$\hat{Y}$	$e = Y - \hat{Y}$
2008	Chanthabury	5,407,891	5,382,119	25,772

After that using linear equation are forecasting factor independent data available X_{1i}, X_{2i}, X_{3i}….X_{ni} of years 2009 to 2029 and use these independent forecast water consumption demand by using equation from data analysis of year 2007 to 2007 available to forecasting water consumption demand of yearly.

$$\hat{Y}=(531698.019 + 300.055X_{1i} + 116.813X_{3i} -65.710X_{5i} - 50.185X_{6i} - 41880.911X_{7i}\ 58674.477\ X_{8i} - 202.504X_{10i}) + \mathbf{25{,}772}$$

Table 4-6 Forecasted water demand Chanthaburi district (2009-2029)

Year	Forecasting water consumption m3/year	Forecasting + residual water consumption m3/year
	$\hat{Y}$	$Y=\hat{Y} + e$
2009	5,509,935	5,535,707
2010	5,656,307	5,682,079
2011	5,802,679	5,828,451
2012	5,949,051	5,974,823
2013	6,095,423	6,121,195
2014	6,241,795	6,267,567
2015	6,388,168	6,413,940
2016	6,534,540	6,560,312
2017	6,680,912	6,706,684
2018	6,827,284	6,853,056
2019	6,973,656	6,999,428
2020	7,120,028	7,145,800
2021	7,266,400	7,292,172
2022	7,412,772	7,438,544
2023	7,559,144	7,584,916
2024	7,705,516	7,731,288
2025	7,851,888	7,877,660
2026	7,998,260	8,024,032
2027	8,144,632	8,170,404
2028	8,291,004	8,316,776
2029	8,437,376	8,463,148

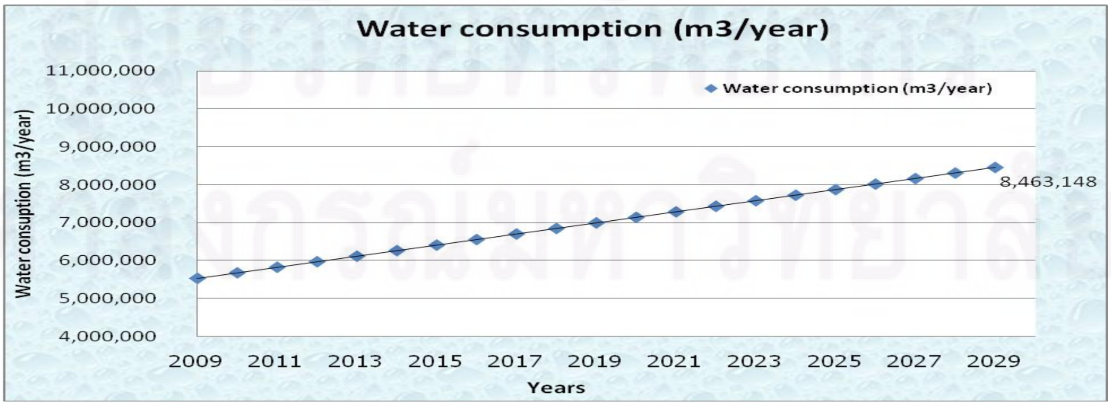


Figure 4-3 Water demand forecasting for Chanthaburi zone

4.7.2 Result model of Sikhottabong district zone use to forecasting Water consumption demand by equations as:

Model Summary[b]

R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
.999[a]	.997	.991	57595.682	2.460

a. Predictors: (Constant), X10=Total precipitation volume(mm./year), X3=Income per capita (Kip/capita) X 1000, X8=Min Temperature (degree celsius), X7=Max Temperature (degree celsius), X1=Number of House (Rung), X6=Selling price of water (Kip/m3), X5=Density of Population (Capita/Km2).

b. Dependent Variable: Y= Water sale (m3)

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
1 (Constant)	-4.184E6	2.659E6		-1.573	.214
X1=Number of House (Rung)	175.835	133.630	.590	1.316	.280
X3=Income per capita (Kip/capita) X 1000	206.097	43.883	.857	4.697	.018
X5=Density of Population (Capita/Km2).	2277.198	3435.702	.284	.663	.555
X6=Selling price of water (Kip/m3)	-1092.520	426.722	-.694	-2.560	.083
X7=Max Temperature (degree celsius)	-131407.516	150037.178	-.088	-.876	.446
X8=Min Temperature (degree celsius)	324680.404	170597.022	.193	1.903	.153
X10=Total precipitation volume(mm./year)	8.055	120.206	.003	.067	.951

a. Dependent Variable: Y= Water sale (m3)

Excluded Variables[b]

Model	Beta In	t	Sig.	Partial Correlation	Co linearity Statistics
					Tolerance

1 X2=Number of population volume in district register, (capita/year)	.[a]	.	.	.	.000
X9=Average of temperature (degree celsius)	.[a]	.	.	.	.000

a. Predictors in the Model: (Constant), X10=Total precipitation volume(mm./year), X3=Income per capita (Kip/capita) X 1000, X8=Min Temperature (degree celsius), X7=Max Temperature (degree celsius), X1=Number of House (Rung), X6=Selling price of water (Kip/m3), X5=Density of Population (Capita/Km2).

b. Dependent Variable: Y= Water sale (m3)

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	3.70E6	5.40E6	4.47E6	599116.927	11
Residual	-4.791E4	5.049E4	.000	31546.454	11
Std. Predicted Value	-1.292	1.549	.000	1.000	11
Std. Residual	-.832	.877	.000	.548	11

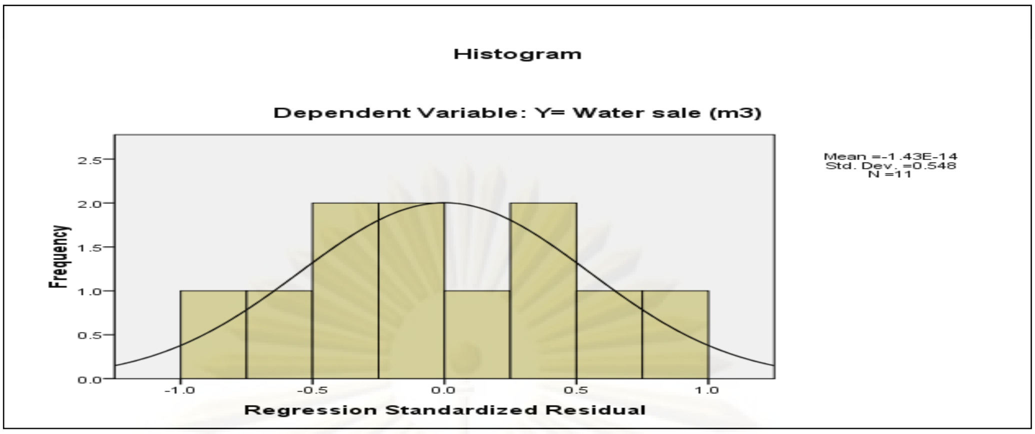
a. Dependent Variable: Y= Water sale (m3)

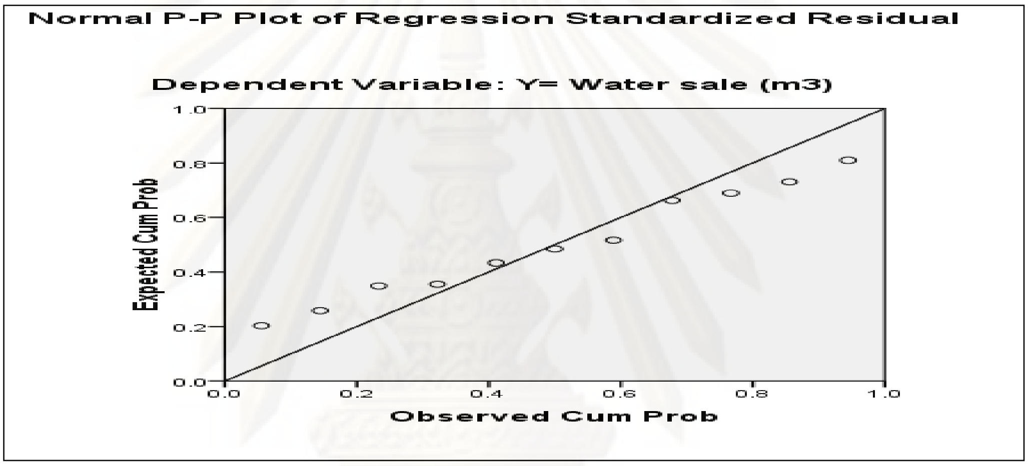
Residuals Statistics[a]

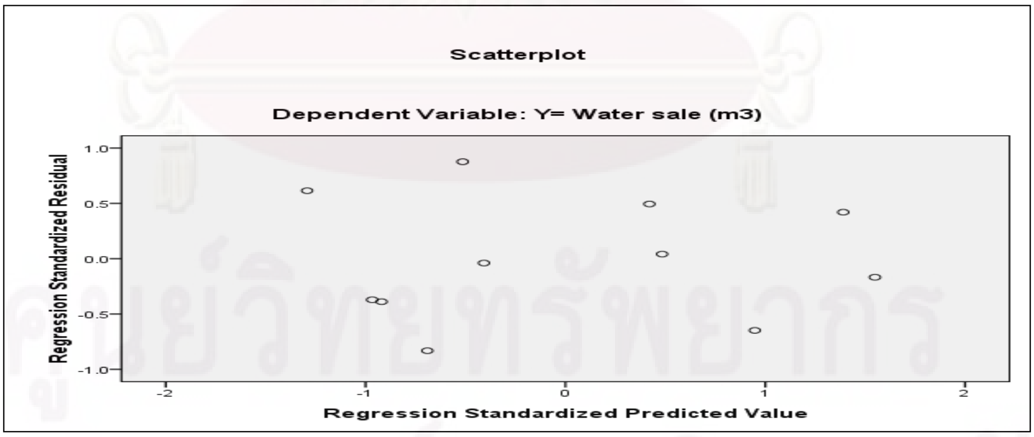
	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	3.70E6	5.40E6	4.47E6	599116.927	11
Residual	-4.791E4	5.049E4	.000	31546.454	11
Std. Predicted Value	-1.292	1.549	.000	1.000	11
Std. Residual	-.832	.877	.000	.548	11

a. Dependent Variable: Y= Water sale (m3)

Charts







The forecasting equation of water demand of Sikhotabong district zone is using coefficient after run program SPSS software had equation is:

$\hat{Y}=(-4.184E6 + 175.835X_{1i} + 206.097X_{3i} + 2277.198X_{5i} - 1092.520X_{6i} - 131407.516X_{7i} + 324680.404X_{8i}+8.055X_{10i}) + e$

Table Forecasting water consumption Ŷ using data 2008

Year	District Zone	Water consumption	Estimated using the regression model	Residual
		m3	m3	error
		Y	Ŷ	e = Y - Ŷ
2008	Sikhottabong	5,411,064	6,014,798	- 603,734

After that using linear equation are forecasting factor independent data available X_{1i}, X_{2i}, X_{3i}….X_{ni} of years 2009 to 2029 and use these independent forecast water consumption demand by using equation from data analysis of year 2007 to 2007 available to forecasting water consumption demand of yearly.

$\hat{Y}$=(-4.184E6 + 175.835X_{1i} + 206.097X_{3i} + 2277.198X_{5i} - 1092.520X_{6i} - 131407.516X_{7i} + 324680.404X_{8i}+8.055X_{10i}) – 603,734

Table 4-7 Forecasted water demand Sikhottabong district (2009-2029)

Year	Forecasting water consumption m3/year	Forecasting water consumption + residual m3/year
	Ŷ	Y=Ŷ - e
2009	5,872,908	5,269,174
2010	6,068,429	5,464,695
2011	6,263,950	5,660,216
2012	6,459,472	5,855,738
2013	6,654,993	6,051,259
2014	6,850,514	6,246,780
2015	7,046,035	6,442,301
2016	7,241,556	6,637,822
2017	7,437,077	6,833,343
2018	7,632,598	7,028,864
2019	7,828,119	7,224,385
2020	8,023,640	7,419,906
2021	8,219,161	7,615,427
2022	8,414,682	7,810,948
2023	8,610,203	8,006,469
2024	8,805,724	8,201,990
2025	9,001,246	8,397,512
2026	9,196,767	8,593,033
2027	9,392,288	8,788,554
2028	9,587,809	8,984,075
2029	9,783,330	9,179,596

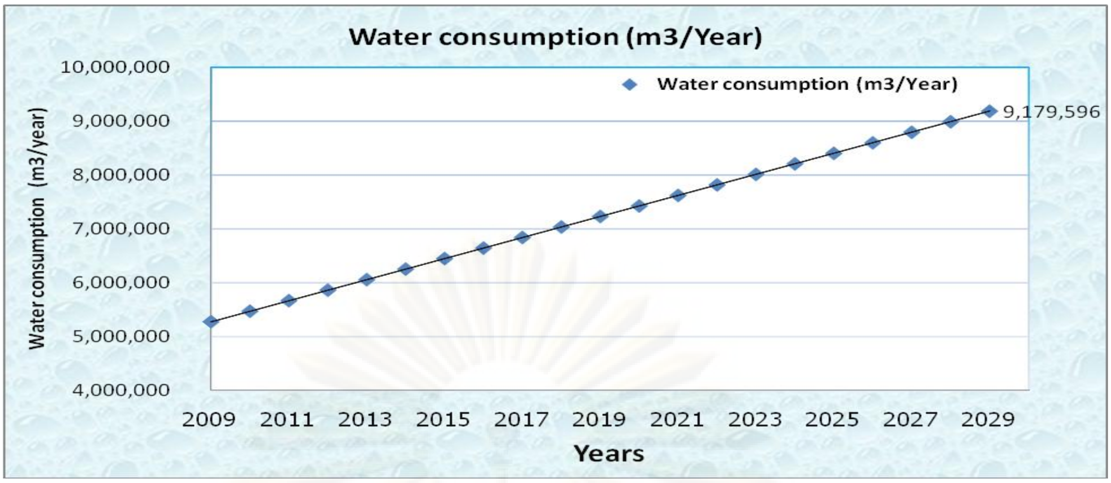


Figure 4.4 Water demand forecasting for Sikhottabong district zone

4.7.3 Result model of Xaisettha district zone use to forecasting water demand consumption by equations as:

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.960[a]	.922	.742	493563.276	3.099

a. Predictors: (Constant), X10=Total precipitation volume(mm./year), X1=Number of House (Rung), X8=Min Temperature (degree celsius), X7=Max Temperature (degree celsius), X3=Income per capita (Kip/capita) X 1000, X6=Selling price of water (Kip/m3), X2=Number of population volume in district register, (capita/year)

b. Dependent Variable: Y= Water sale (m3)

ANOVA[b]

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	8.697E12	7	1.242E12	5.100	.104[a]
Residual	7.308E11	3	2.436E11		
Total	9.428E12	10			

a. Predictors: (Constant), X10=Total precipitation volume(mm./year), X1=Number of House (Rung), X8=Min Temperature (degree Celsius), X7=Max Temperature (degree Celsius), X3=Income per capita (Kip/capita) X 1000, X6=Selling price of water (Kip/m3), X2=Number of population volume in district register, (capita/year)

b. Dependent Variable: Y= Water sale (m3)

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
1 (Constant)	1.152E7	1.726E7		.668	.552
X1=Number of House (Rung)	-448.647	601.444	-.724	-.746	.510
X2=Number of population (capita/year)	-38.291	270.574	-.307	-.142	.896
X3=Income per capita (Kip/capita) X 1000	549.774	608.430	1.413	.904	.433
X6=Selling price of water (Kip/m3)	1172.936	2379.753	.460	.493	.656
X7=Max Temperature (degree celsius)	322523.152	1.426E6	.134	.226	.836
X8=Min Temperature (degree celsius)	-471354.222	1.507E6	-.173	-.313	.775
X10=Total precipitation volume(mm./year)	-643.350	1085.232	-.151	-.593	.595

a. Dependent Variable: Y= Water sale (m3)

Excluded Variables[b]

Model	Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
					Tolerance
1 X5=Density of Population (Capita/Km2).	.[a]	.	.	.	.000
X9=Average of temperature (degree celsius)	.[a]	.	.	.	.000

a. Predictors in the Model: (Constant), X10=Total precipitation volume(mm./year), X1=Number of House (Rung), X8=Min Temperature (degree celsius), X7=Max Temperature (degree celsius), X3=Income per capita (Kip/capita) X 1000, X6=Selling price of water (Kip/m3), X2=Number of population volume in district register, (capita/year)

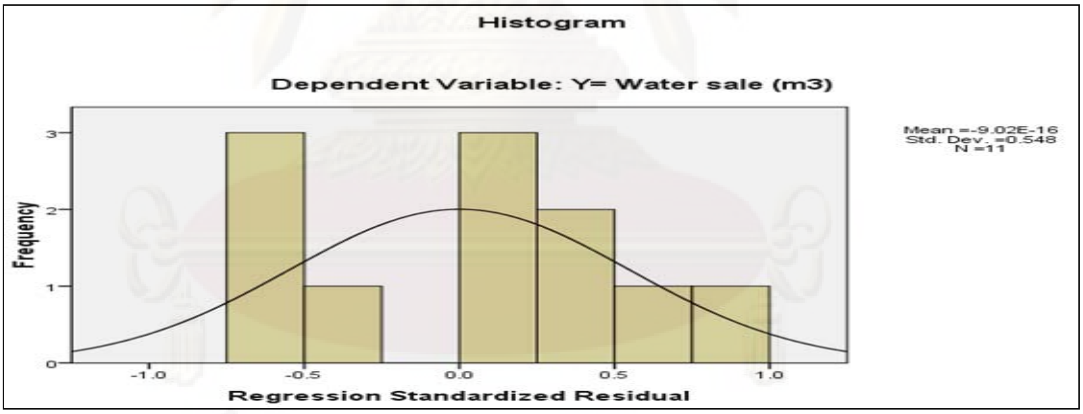
b. Dependent Variable: Y= Water sale (m3)

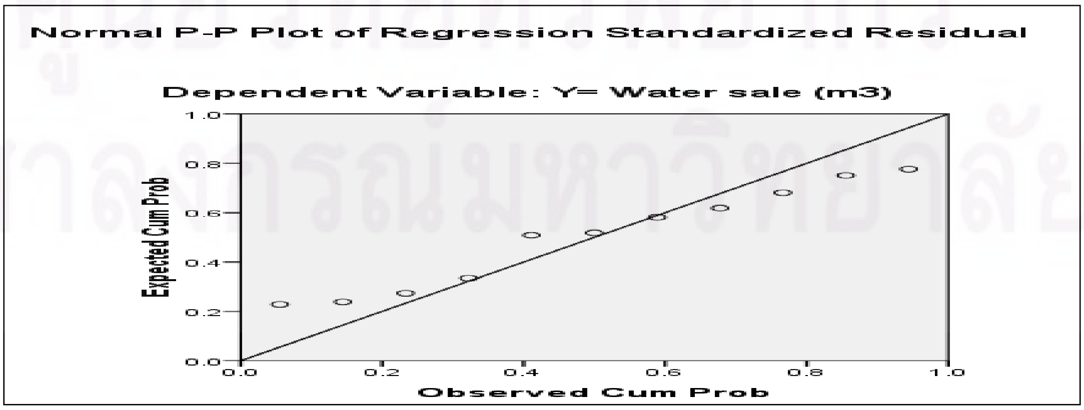
Residuals Statistics[a]

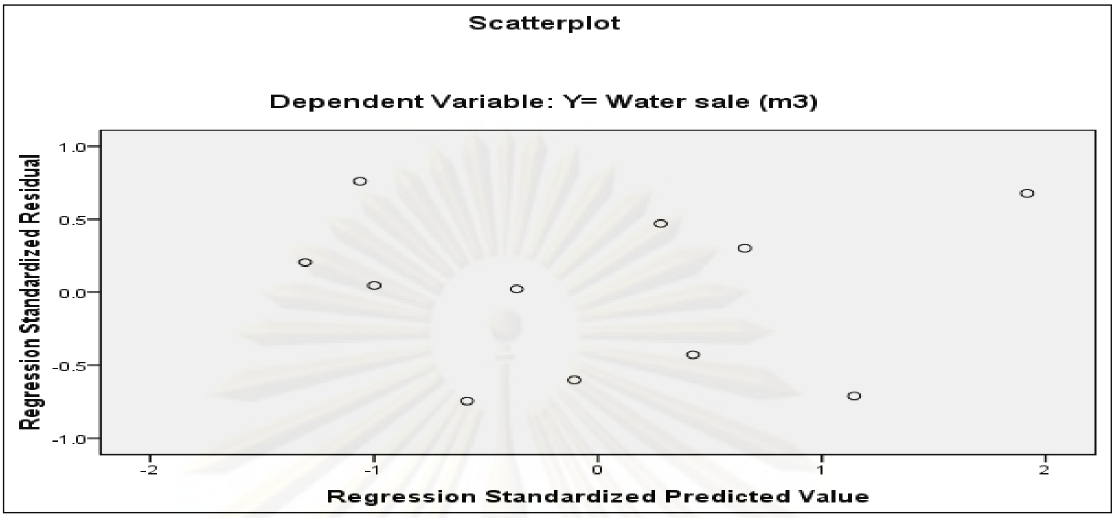
	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	4.73E6	7.97E6	5.82E6	932566.948	11
Residual	-4.836E5	3.776E5	.000	270335.740	11
Std. Predicted Value	-1.163	2.307	.000	1.000	11
Std. Residual	-.980	.765	.000	.548	11

a. Dependent Variable: Y= Water sale (m3)

Charts







The forecasting equation of water demand of Xaisettha district zone is using coefficient after run program SPSS software had equation is:

$\hat{Y}$=(1.152E7 - 448.647X_{1i} -38.291X_{2i} + 549.774X_{3i} + 1172.936 X_{6i} + 322523.152 X_{7i} - 471354.222 X_{8i} - 643.350 X_{10i}) + e

Table Forecasting water consumption $\hat{Y}$ using data 2008

Year	District Zone	Water consumption	Estimated using the regression model	Residual
		m3	m3	error
		Y	$\hat{Y}$	e = Y - $\hat{Y}$
2008	Xaisettha	8,559,280	8,648,549	- 89,269

After that using linear equation are forecasting factor independent data available X_{1i}, X_{2i}, X_{3i}….X_{ni} of years 2009 to 2029 table 4.4 and use these independent forecast water consumption demand by using equation from data analysis of year 2007 to 2007 available to forecasting water consumption demand of yearly.

$\hat{Y}$=(1.152E7 - 448.647X_{1i} -38.291X_{2i} + 549.774X_{3i} + 1172.936 X_{6i} + 322523.152 X_{7i} - 471354.222 X_{8i} - 643.350 X_{10i}) - 89,269

Table 4-8 Forecasted water demand Xaisettha district (2009-2029)

Year	Forecasting water consumption m3/year	Forecasting + residual water consumption m3/year
	$\hat{Y}$	$Y=\hat{Y} - e$
2009	8,025,954	7,936,685
2010	8,330,380	8,241,111
2011	8,634,807	8,545,538
2012	8,939,233	8,849,964
2013	9,243,659	9,154,390
2014	9,548,086	9,458,817
2015	9,852,512	9,763,243
2016	10,156,939	10,067,670
2017	10,461,365	10,372,096
2018	10,765,791	10,676,522
2019	11,070,218	10,980,949
2020	11,374,644	11,285,375
2021	11,679,071	11,589,802
2022	11,983,497	11,894,228
2023	12,287,923	12,198,654
2024	12,592,350	12,503,081
2025	12,896,776	12,807,507
2026	13,201,202	13,111,933
2027	13,505,629	13,416,360
2028	13,810,055	13,720,786
2029	14,114,482	14,025,213

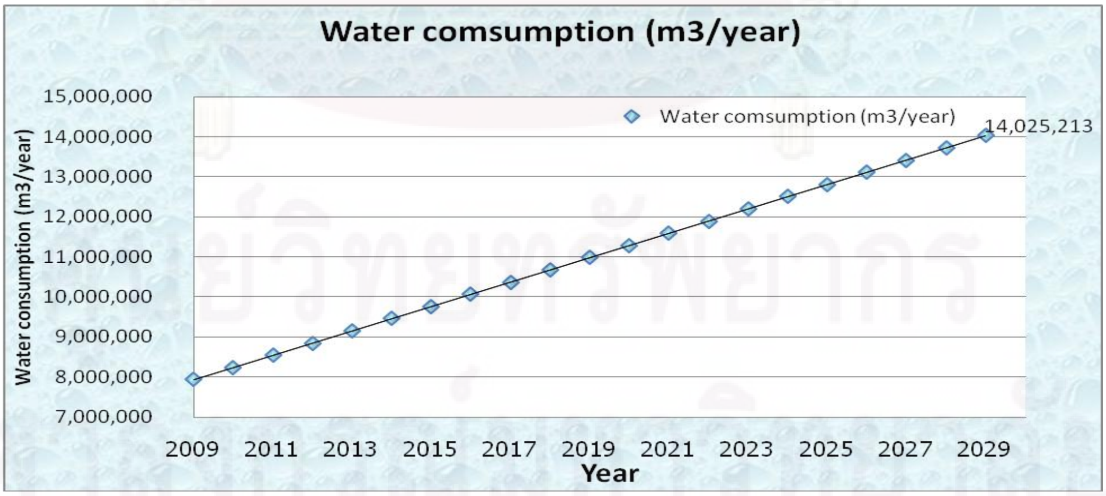


Figure 4-5 Water demand forecasting for Xaisettha zone

4.7.4 Result of model Sisattanak district zone use to forecasting water consumption demand by equations as:

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.996[a]	.992	.973	106405.718	3.073

a. Predictors: (Constant), X10=Total precipitation volume(mm./year), X3=Income per capita (Kip/capita) X 1000, X8=Min Temperature (degree Celsius), X5=Density of Population (Capita/Km2)., X7=Max Temperature (degree Celsius), X1=Number of House (Rung), X6=Selling price of water (Kip/m3)

b. Dependent Variable: Y= Water sale (m3)

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	4.111E12	7	5.873E11	51.868	.004[a]
	Residual	3.397E10	3	1.132E10		
	Total	4.145E12	10			

a. Predictors: (Constant), X10=Total precipitation volume(mm./year), X3=Income per capita (Kip/capita) X 1000, X8=Min Temperature (degree Celsius), X5=Density of Population (Capita/Km2)., X7=Max Temperature (degree Celsius), X1=Number of House (Rung), X6=Selling price of water (Kip/m3)

b. Dependent Variable: Y= Water sale (m3)

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
1 (Constant)	3.223E6	3.644E6		.885	.442
X1=Number of House (Rung)	-176.818	189.168	-.170	-.935	.419
X3=Income per capita (Kip/capita) X 1000	273.968	70.325	1.062	3.896	.030

X5=Density of Population (Capita/Km2).	747.891	939.718	.108	.796	.484
X6=Selling price of water (Kip/m3)	49.748	451.976	.029	.110	.919
X7=Max Temperature (degree celsius)	60600.953	242536.963	.038	.250	.819
X8=Min Temperature (degree celsius)	-62323.395	256575.006	-.035	-.243	.824
X10=Total precipitation volume(mm./year)	-177.410	220.245	-.063	-.806	.479

a. Dependent Variable: Y= Water sale (m3)

Excluded Variables[b]

Model	Beta In	t	Sig.	Partial Correlation	Co linearity Statistics
					Tolerance
1 X2=Number of population (capita/year)	.[a]	.	.	.	.000
X9=Average of temperature (degree celsius)	.[a]	.	.	.	.000

a. Predictors in the Model: (Constant), X10=Total precipitation volume(mm./year), X3=Income per capita (Kip/capita) X 1000, X8=Min Temperature (degree Celsius), X5=Density of Population (Capita/Km2)., X7=Max Temperature (degree Celsius), X1=Number of House (Rung), X6=Selling price of water (Kip/m3)

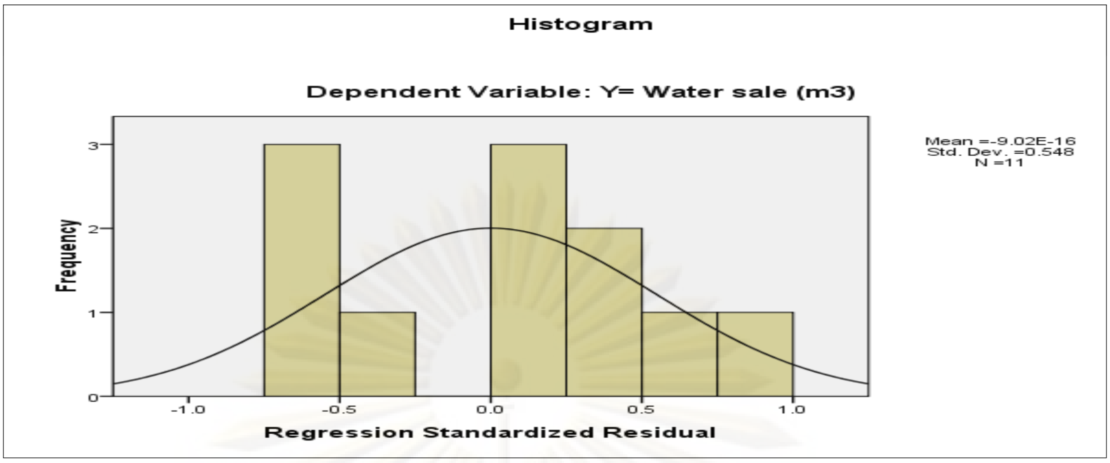
b. Dependent Variable: Y= Water sale (m3)

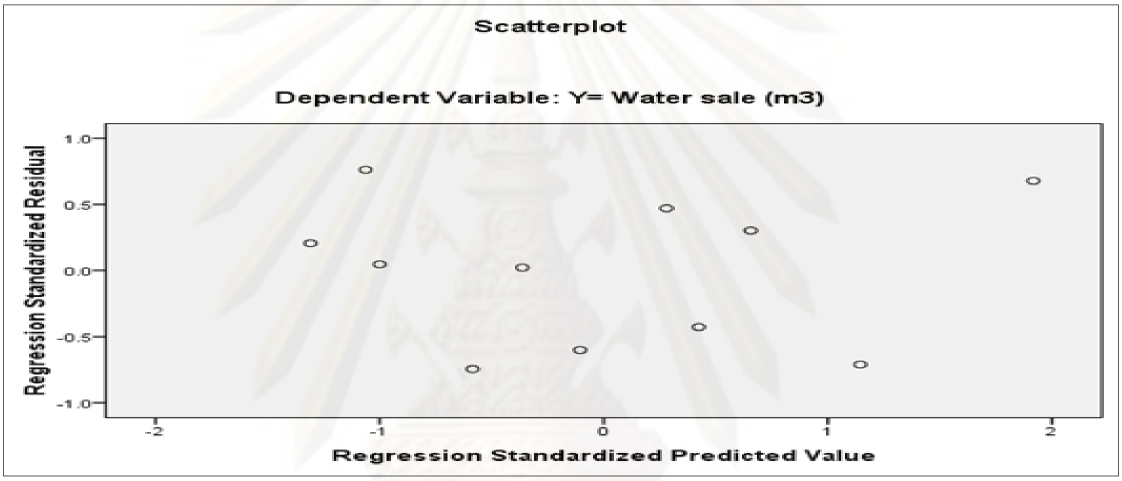
Residuals Statistics[a]

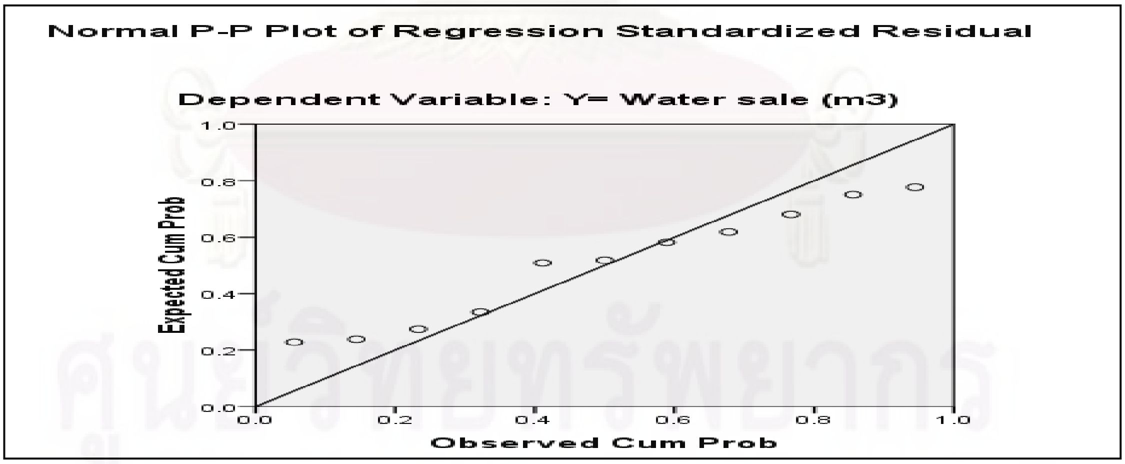
	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	4.87E6	6.94E6	5.71E6	641158.458	11
Residual	-7.924E4	8.101E4	.000	58280.812	11
Std. Predicted Value	-1.308	1.917	.000	1.000	11
Std. Residual	-.745	.761	.000	.548	11

a. Dependent Variable: Y= Water sale (m3)

Charts







The forecasting equation of water demand of Xaisettha district zone is using coefficient after run program SPSS software have had equation is:

$\hat{Y}$=(3.223E6- -176.818X_{1i} + 273.968X_{3i} + 747.891X_{5i}+ 49.748X_{6i} + 60600.953X_{7i} -62323.395X_{8i} -177.410X_{10i}) + **e**

Table1 Forecasting water consumption Ŷ using data 2008

Year	District Zone	Water consumption	Estimated using the regression model	Residual
		m3	m3	error
		Y	Ŷ	e = Y - Ŷ
2008	Sisattanak	7,513,307	7,780,843	- 267,536

After that using linear equation are forecasting factor independent data available X_{1i}, X_{2i}, X_{3i}….X_{ni} of years 2009 to 2029 and use these independent forecast water consumption demand by using equation from data analysis of year 2007 to 2007 available to forecasting water consumption demand of yearly.

$\hat{Y}$=(3.223E6- -176.818X_{1i} + 273.968X_{3i} + 747.891X_{5i}+ 49.748X_{6i} + 60600.953X_{7i} - 62323.395X_{8i} -177.410X_{10i}) – 267,536

Table 4-9 Forecasted water demand Sisattanak district (2009-2029)

Year	Forecasting water consumption m3/year	Forecasting + residual water consumption m3/year
	Ŷ	Y=Ŷ - e
2009	7,572,278	7,304,742
2010	7,784,140	7,516,604
2011	7,996,002	7,728,466
2012	8,207,864	7,940,328
2013	8,419,726	8,152,190
2014	8,631,588	8,364,052
2015	8,843,451	8,575,915
2016	9,055,313	8,787,777
2017	9,267,175	8,999,639
2018	9,479,037	9,211,501
2019	9,690,899	9,423,363
2020	9,902,761	9,635,225
2021	10,114,623	9,847,087
2022	10,326,486	10,058,950
2023	10,538,348	10,270,812
2024	10,750,210	10,482,674
2025	10,962,072	10,694,536
2026	11,173,934	10,906,398
2027	11,385,796	11,118,260
2028	11,597,658	11,330,122
2029	11,809,521	11,541,985

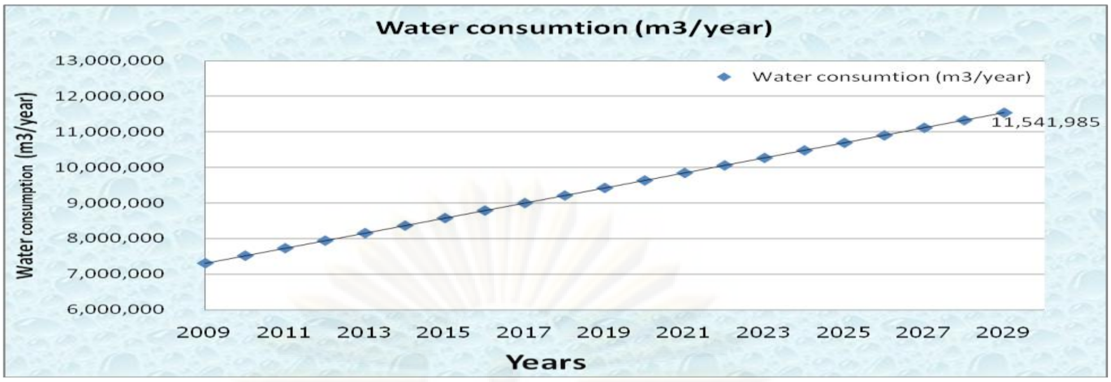


Figure 4-6 Water demand forecasting for Sisattanak zone

4.8 Total Water Demand Forecasting (2009-2029)

The yearly total water demand forecasting for Vientiane capital city, Lao PDR water supply distribution zone was then calculated as the sum of the estimated yearly base use and daily seasonal use of water. This included the following equations and variables derived on the analysis of the yearly data over the 10-year period (1997 – 2007) for Vientiane capital city of each zone

- **For Chanthaburi district zone**

$\hat{Y}$=(531698.019 + 300.055X_{1i} + 116.813X_{3i} -65.710X_{5i} - 50.185X_{6i} - 41880.911X_{7i} 58674.477 X_{8i} - 202.504X_{10i}) + **25,772**

Where $\hat{Y}$ is the estimated yearly base water consumption demand forecasting; X1=Number of family (family), X3=Income per capita (Kip/capita) X 1000, X5=Density of Population (Capita/Km2)), X6=Selling price of water (Kip/m3), X7=Max Temperature (degree Celsius), X8=Min Temperature (degree Celsius), X10=Total precipitation volume(mm./year).

- **For Sikhottabong district zone**

$\hat{Y}$=(-4.184E6 + 175.835X_{1i} + 206.097X_{3i} + 2277.198X_{5i} - 1092.520X_{6i} - 131407.516X_{7i} + 324680.404X_{8i}+8.055X_{10i}) – 603,734

Where $\hat{Y}$ is the estimated yearly base water consumption demand forecasting; X1=Number of family (family), X3=Income per capita (Kip/capita) X 1000, X5=Density of Population (Capita/Km2)), X6=Selling price of water (Kip/m3), X7=Max Temperature (degree Celsius), X8=Min Temperature (degree Celsius), X10=Total precipitation volume(mm./year).

- **For Xaisettha district zone**

$\hat{Y}$=(1.152E7 - 448.647X_{1i} -38.291X_{2i} + 549.774X_{3i} + 1172.936 X_{6i} + 322523.152 X_{7i} - 471354.222 X_{8i} - 643.350 X_{10i}) - 89,269

Where $\hat{Y}$ is the estimated yearly base water consumption demand forecasting; X1=Number of family (family), X3=Income per capita (Kip/capita) X 1000, X5=Density of Population (Capita/Km2)), X6=Selling price of water (Kip/m3), X7=Max Temperature (degree Celsius), X8=Min Temperature (degree Celsius), X10=Total precipitation volume(mm./year).

- **For Sisattanak district zone**

$\hat{Y}$=(3.223E6-176.818X_{1i} + 273.968X_{3i} + 747.891X_{5i}+ 49.748X_{6i} + 60600.953X_{7i} - 62323.395X_{8i} -177.410X_{10i}) – 267,536

Table 4-10 Summary 4 district Forecasted water demand (2009-2029)

Years	Chanthaburi	Sikhottabong	Xaisettha	Sisattanak	Total
	Water consumption	Water consumption	Water consumption	Water consumption	Water consumption
	m^3	m^3	m^3	m^3	m^3
	$Y=\hat{Y} + e$	$Y=\hat{Y} - e$	$Y=\hat{Y} + e$	$Y=\hat{Y} + e$	ΣY
2009	5,535,707	5,269,174	7,936,685	7,304,742	26,046,308
2010	5,682,079	5,464,695	8,241,111	7,516,604	26,904,490
2011	5,828,451	5,660,216	8,545,538	7,728,466	27,762,671
2012	5,974,823	5,855,738	8,849,964	7,940,328	28,620,853
2013	6,121,195	6,051,259	9,154,390	8,152,190	29,479,035
2014	6,267,567	6,246,780	9,458,817	8,364,052	30,337,216
2015	6,413,940	6,442,301	9,763,243	8,575,915	31,195,398
2016	6,560,312	6,637,822	10,067,670	8,787,777	32,053,580
2017	6,706,684	6,833,343	10,372,096	8,999,639	32,911,761
2018	6,853,056	7,028,864	10,676,522	9,211,501	33,769,943
2019	6,999,428	7,224,385	10,980,949	9,423,363	34,628,125
2020	7,145,800	7,419,906	11,285,375	9,635,225	35,486,306
2021	7,292,172	7,615,427	11,589,802	9,847,087	36,344,488
2022	7,438,544	7,810,948	11,894,228	10,058,950	37,202,670
2023	7,584,916	8,006,469	12,198,654	10,270,812	38,060,851
2024	7,731,288	8,201,990	12,503,081	10,482,674	38,919,033
2025	7,877,660	8,397,512	12,807,507	10,694,536	39,777,215
2026	8,024,032	8,593,033	13,111,933	10,906,398	40,635,396
2027	8,170,404	8,788,554	13,416,360	11,118,260	41,493,578
2028	8,316,776	8,984,075	13,720,786	11,330,122	42,351,760
2029	8,463,148	9,179,596	14,025,213	11,541,985	43,209,941

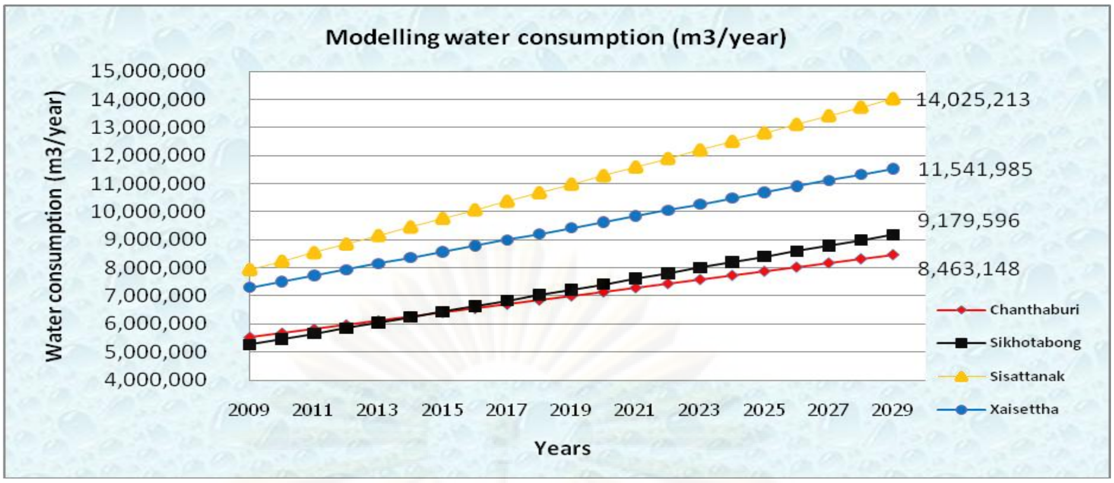


Figure 4-7 Water demands forecasting of each district (2009-2029)

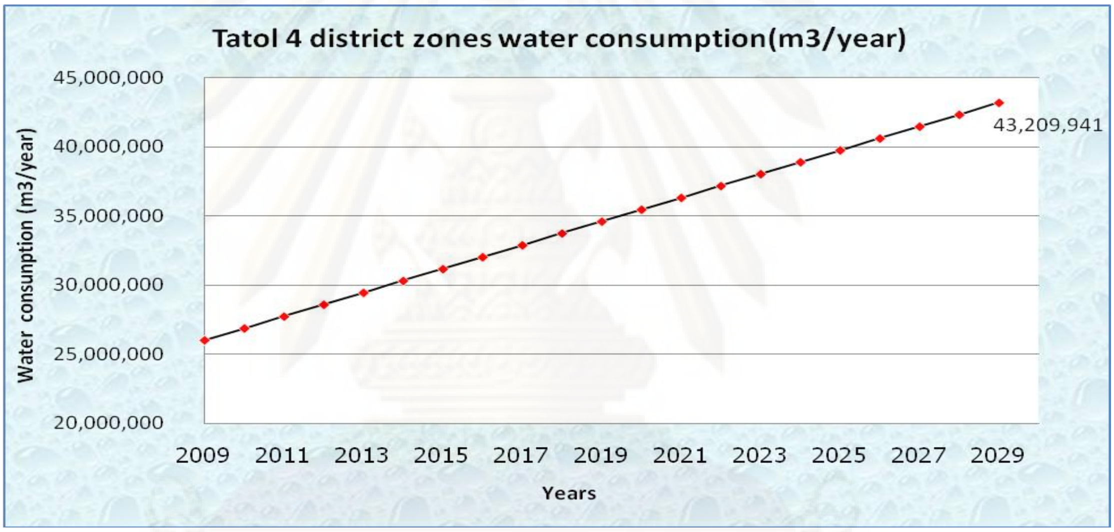


Figure 4-8 Summary model average water consumption demands forecasting for 4 district zones

4.9 Summary

This chapter presents the results of the analysis for water consumption data collected for each of the participating in each district by using data analysis of data water use before during period's year (1997 -2029). The total water demand in Vientiane capital for the next 20 years o is 43,209,941 m^3.

CHAPTER 5
SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

The Water Resources Strategy has been developed for Vientiane capital, which serve as the basis for the Laos Government to set per yearly consumption in each districts. The strategy is developed to ensure a continuation of a safe, reliable and cost effective water supply that is environmentally sustainable in the long term. This is in recognition that population growth and water consumption will eventually require additional supplies of water to each areas of district zone at Vientiane capital city in the years 2029.

The districts of Vientiane capital in Lao PDR is like other urban cities in the world, its growing population means increasing water demand. Vientiane is also already on its ten eight year of dry climatic conditions and is currently experiencing a drought that has forced water authorities to impose water restrictions after 20 years of unrestricted supply. The current drought, dwindling supplies and possible impact of climate change highlight the importance of making better use of this precious resource.

Recognising the lack of understanding about water consumption and the need for improved demand forecasting models as well as the development and evaluation of conservation strategies, this research adopted a detailed investigation of water use known as water consumption analysis. It improved understanding on water use particularly at water use level and developed models to forecast urban yearly water demand by using the available relevant data collected by Vientiane capital water supply Company.

This research on water consumption measurement and analysis provided information to assist Water Authorities and the community to:

- make informed decisions when they consider options to focus water conservation efforts.

- serve as a tool for community education, to generate meaningful discussion on particular findings and to support with planning and policy development for adopting particular strategies relating to water demand management. The forecast demands will assist with accurate planning of infrastructure to service future growth.
- improve the understanding of where and how water is being used within the district zone which will increase awareness and educate all consumers, planners and water authorities on what component of water consumption.

The objectives of this research were to:

- Identify average daily urban water consumption model per year on a yearly basis for the total water use, and for the major components of water demand forecasting. Etc.
- Identify variations in water consumption for each water-using appliance according to influencing factors such as population, temperature, rainfall and number of family.
- Develop models that would:
    - Explain yearly water use among major water commotion of population.
    - Forecast yearly urban water demand.

5.2 Conclusions

Based on the analysis of all the data in this study, the following conclusions have been drawn. The conclusions are presented in Water Demand Forecasting Model, which is a combination of yearly consumption model from water consumption data and from water supply distribution data.

- Yearly Water Demand Forecasting Model:

In modelling yearly water use, consumption was split into components: base yearly water supply consumption uses. For Vientiane capital, base water use was estimated by the lowest years of water consumption. The year-to-year long-term trend in base consumption was represented by a polynomial as a function of time.

For the Vientiane capital data the models developed with a square root function of API (Antecedent Precipitation Index) showed improvement over models with a linear relation of API. As well the models that considered the statistic data water use during years 1997 to 2007 of four districts at Vientiane and to separate ranges exhibited considerable improvement over a single model.

Based on a series of validation runs, the recommended model was found to perform very satisfactorily. The model efficiency of each district zones as namely Chanthaburi R^2 = 99,1%, Sikhottabong R^2 = 99,1%, Xaisettha R^2 = 92,2%, and Sisattanak R^2 = 99,2%, these coefficient is considered acceptable. The model also performed satisfactorily when tested in a forecast mode using independent data for 10 years during the period of years 1997 to 2007.

The demand is simulation model developed in this study comprises a yearly module. Total water consumption is base forecasting water demand for the next 20 years of each district zone; Conclusions total water consumption demand forecasting model was 43,209,941 m^3

5.3 Recommendations

The analysis of the water consumption data and the water supply distribution zone data for Vientiane capital city as well as the modelling process undertaken reveals some important areas for further research:

- Additional research should be undertaken to check or improve the regression equations of the water consumption. Specifically;
    - Increase of the water consumption in this study are conducted in only water consumption use analysis and in the zone level analysis, water use fluctuates yearly seasonally. Thus, the four district zones considered in this study is insufficient to accurately model and predict total water use.
    - A computer package that would estimate the average total yearly water use and for each major component of water uses and water should be developed. The computer model should incorporate possible water savings by converting or using water efficient appliances.
- For the daily urban water demand at water supply distribution zone, the validity and generality of the proposed methodology should be tested by applying the model to different water supply distribution zone from other water authorities, other cities with different sizes and different weather conditions.
- Yearly water demand at different water supply distribution zones should be monitored, recorded and collected. Based on the experience of collecting yearly

demand data, it has found out that there is scarcity of yearly demand data recorded over period of years in water authorities in Vientiane capital Lao PDR.

- A computer package with high computational efficiency should be developed for the proposed yearly urban water demand forecasting model.

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APPENDICES

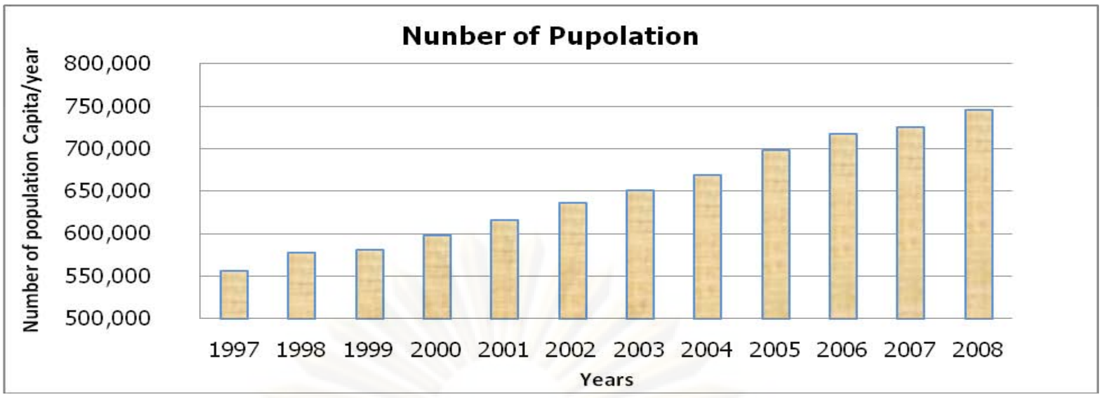
Appendix A. Survey Questionnaire form

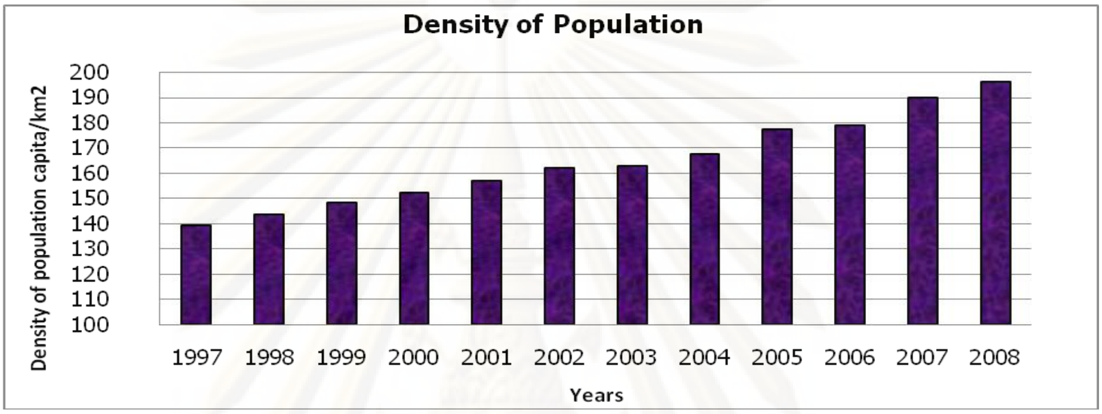
Table A-1 : Form Collection data information at Vientiane Capital

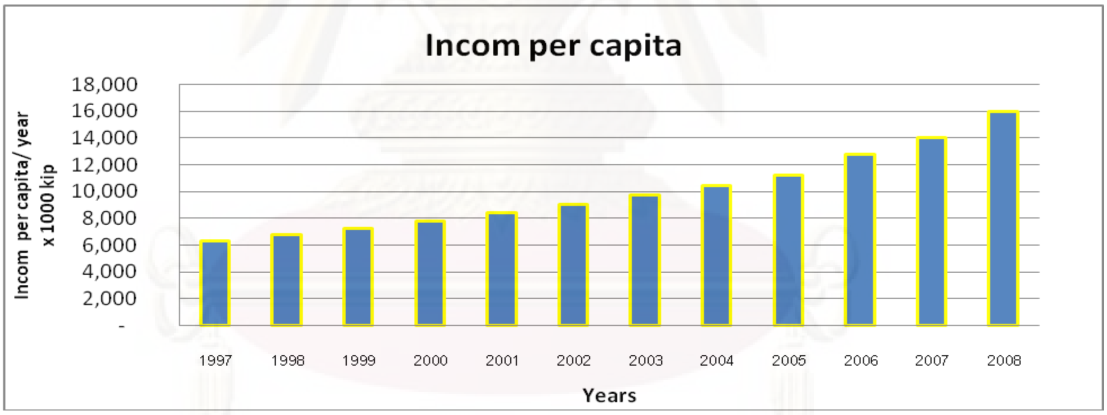
Year	Water sale	Number of family	Number of population	Income per capita (x1000)	Area	Population density	Selling price of water	Max Temperature	Min Temperature	Average temperature	Total Precipitation
	m3	family/year	capita/yearly	Kip/capita	Km^2	capita/Km^2	Kip/m^3	°c	°c	°c	mm/year
	y	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
1997											
1998											
1999											
2000											
2001											
2002											
2003											
2004											
2005											
2006											
2007											
2008											

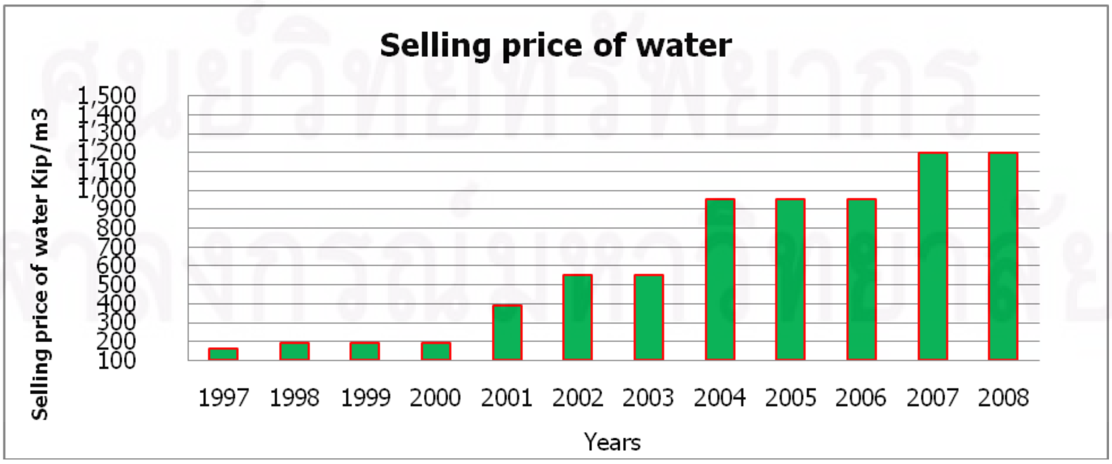
Table A-2. Data Information at Vientiane Capital City Year 1997 to 2008 (9 District zone)

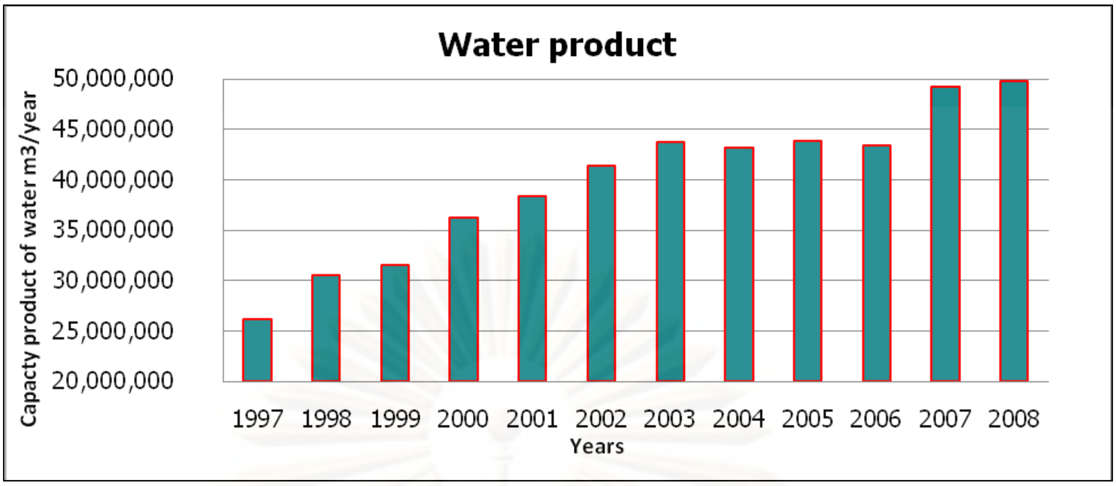
Years	water consumption	Number of population	Population density	Size of family	Income per capita	Capacity of product	Average of loss water	Selling price of water	Max temperature of VT	Min temperature of VT	Temperature of VT	Precipitation volume
	m^3/year	capita/yearly	capita/Km^2	Size of family/year	Kip/capita x 1000	m^3/year	m^3/year	Kip/m^3	Degree Celsius	Degree Celsius	Degree Celsius	mm/year
1997	18,386,534	556,431	139	6	6,285	26,176,945	7,790,406	162	31	23	27	1,600
1998	20,861,567	577,019	144	6	6,758	30,590,258	9,728,691	195	33	23	28	1,477
1999	21,943,494	581,062	148	6	7,266	31,526,073	9,582,579	195	31	22	27	2,192
2000	24,992,460	597,800	153	6	7,813	36,273,290	11,280,830	195	31	22	27	1,500
2001	27,834,267	616,160	157	6	8,401	38,378,969	10,544,702	387	32	23	27	1,659
2002	28,829,294	635,755	162	6	9,034	41,365,415	12,536,121	550	32	23	27	1,847
2003	31,350,134	650,600	163	6	9,714	43,786,885	12,436,751	550	32	22	27	1,481
2004	30,484,816	669,467	168	6	10,445	43,205,699	12,720,883	950	31	22	27	1,630
2005	31,509,756	698,138	177	6	11,231	43,871,789	12,362,033	950	32	23	27	1,668
2006	31,679,467	717,871	179	6	12,762	43,440,196	11,760,729	950	32	23	27	1,930
2007	35,562,330	725,820	190	6	14,041	49,197,540	13,635,210	1,200	32	23	27	1,468
2008	36,177,870	746,143	196	6	15,983	49,781,245	13,603,375	1,200	31	22	26	1,717

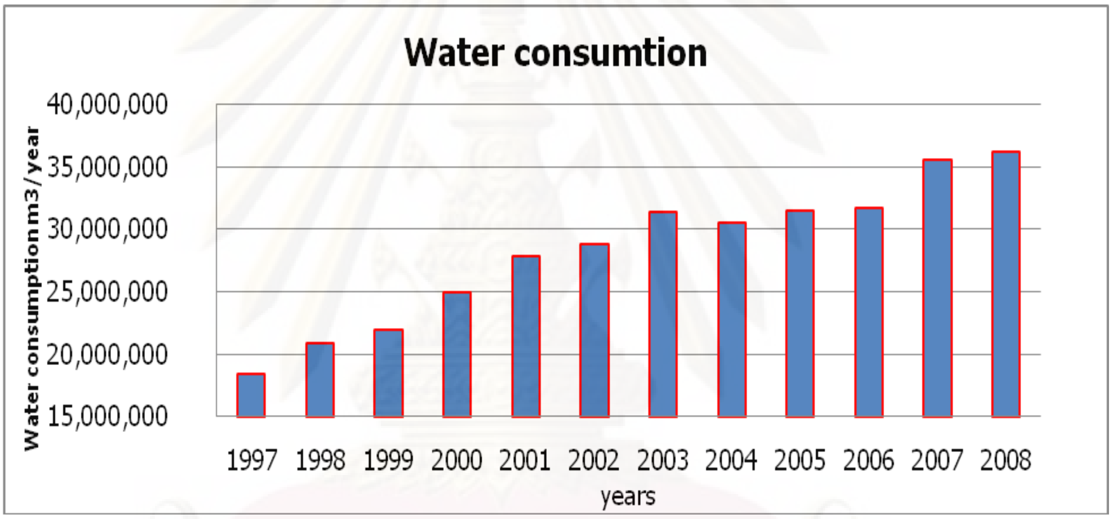

Nunber of Pupolation
Number of population Capita/year
800,000
750,000
700,000
650,000
600,000
550,000
500,000
1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008
Years

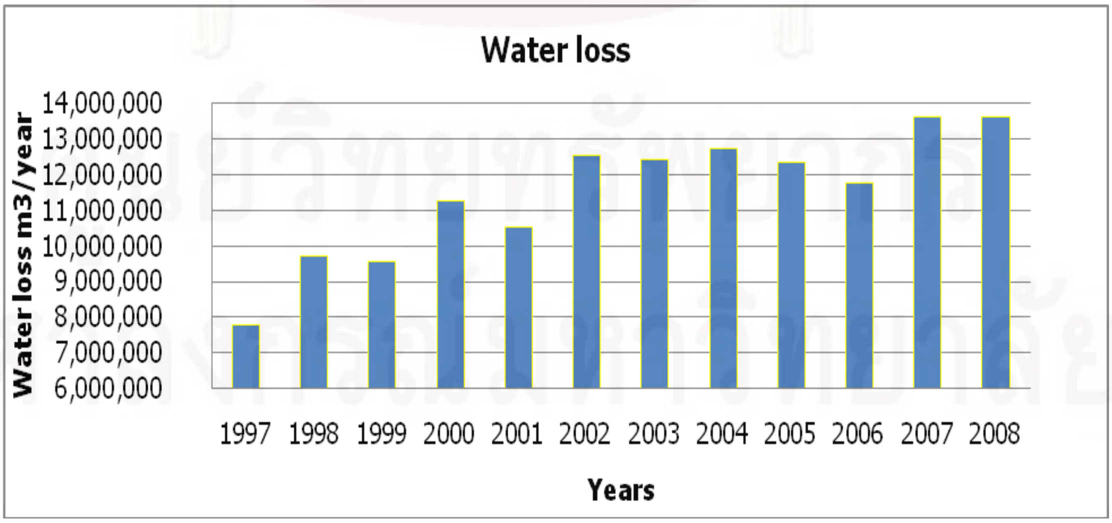

Density of Population
Density of population capita/km2
200
190
180
170
160
150
140
130
120
110
100
1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008
Years

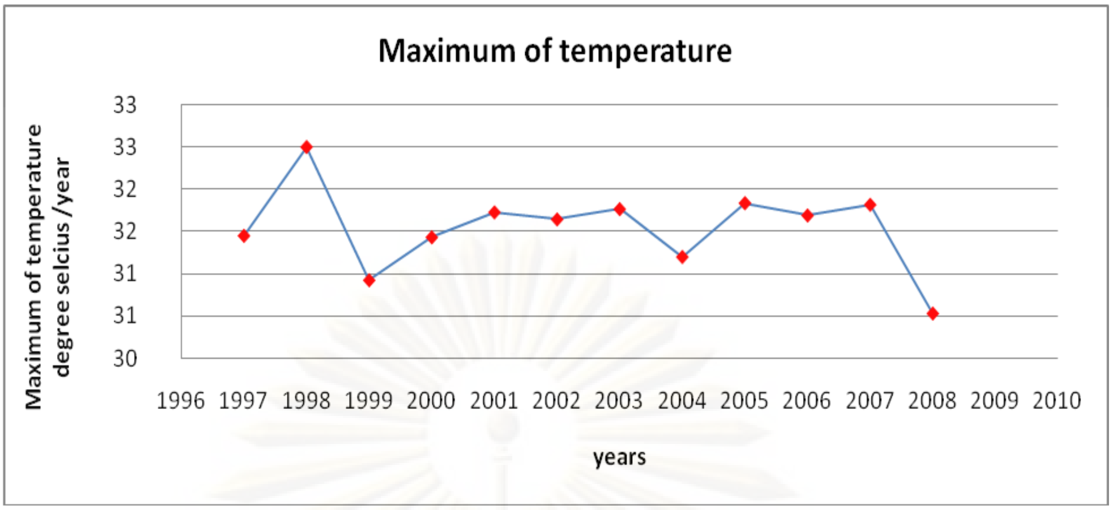

Incom per capita
Incom per capita/ year
x 1000 kip
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
-
1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008
Years

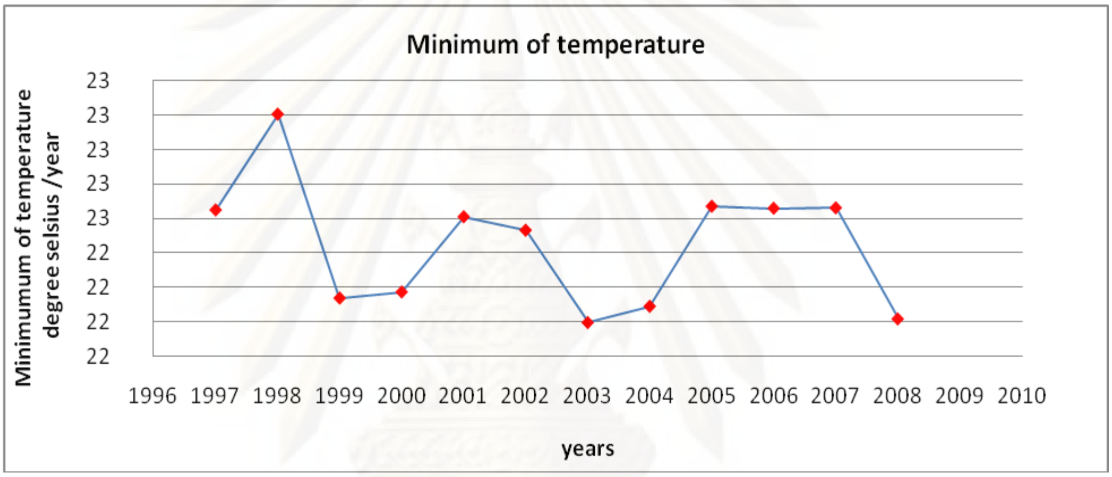

Selling price of water
Selling price of water Kip/m3
1,500
1,400
1,300
1,200
1,100
1,000
900
800
700
600
500
400
300
200
100
1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008
Years


Water product
Capacty product of water m3/year
50,000,000
45,000,000
40,000,000
35,000,000
30,000,000
25,000,000
20,000,000
1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008
Years


Water consumtion
Water consumption m3/year
40,000,000
35,000,000
30,000,000
25,000,000
20,000,000
15,000,000
1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008
years


Water loss
Water loss m3/year
14,000,000
13,000,000
12,000,000
11,000,000
10,000,000
9,000,000
8,000,000
7,000,000
6,000,000
1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008
Years


Maximum of temperature
Maximum of temperature degree selcius /year
33
33
32
32
31
31
30
1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010
years


Minimum of temperature
Minimum of temperature degree selsius /year
23
23
23
23
23
22
22
22
22
1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010
years

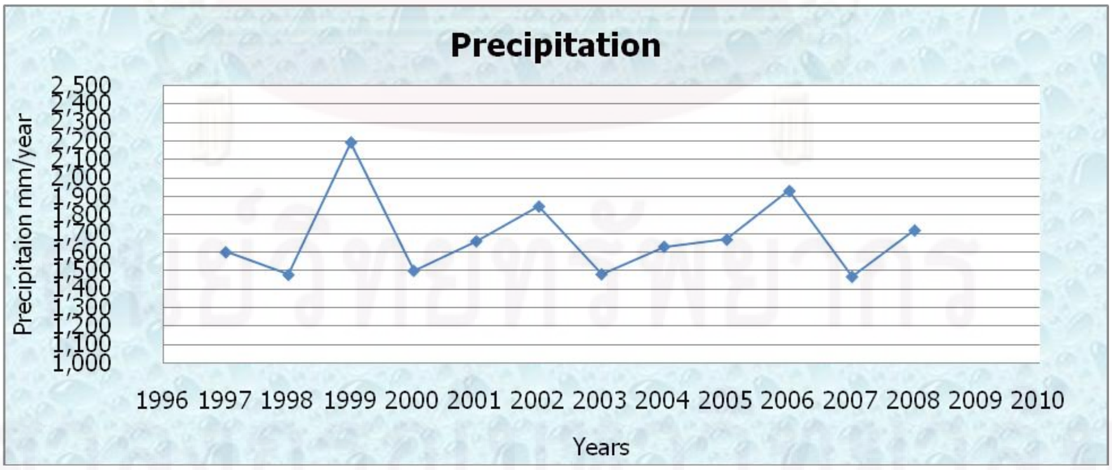
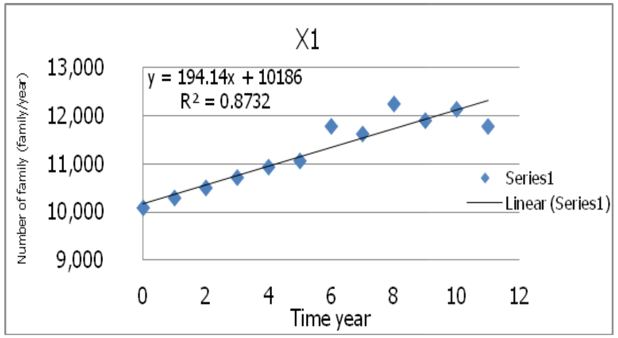
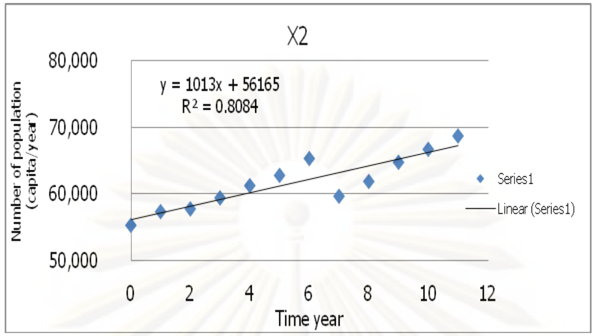

Precipitation
Precipitaion mm/year
2,500
2,400
2,300
2,200
2,100
2,000
1,900
1,800
1,700
1,600
1,500
1,400
1,300
1,200
1,100
1,000
1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010
Years

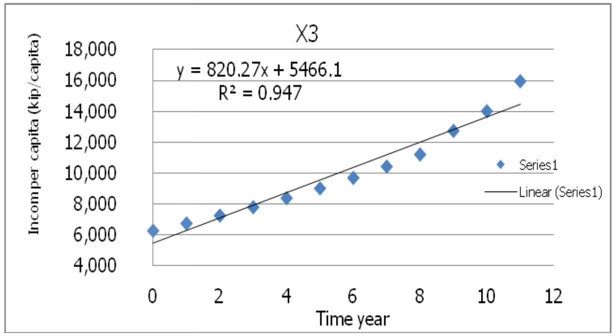
Table A-3 Statistic of data water use at Vientiane 1997 to 2008 (Chanthabury district)

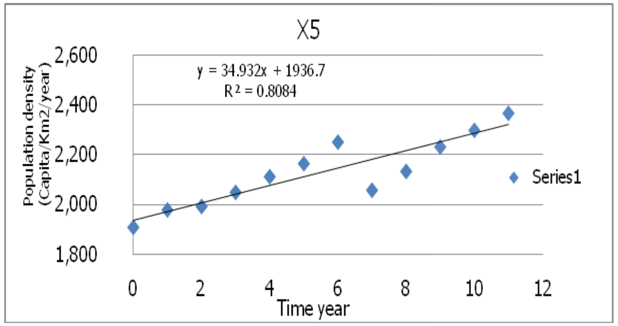
X	Year	Water sale	Number of family	Number of population	Income per capita(x1000)	Area	Population density	Selling price of water	Max Temperature	Min Temperature	Average temperature	average Precipitation
		m^3	family/year	capita/year	Kip/capita	Km^2	capita/Km^2	Kip/m^3	°c	°c	°c	mm
		Y	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
		y = 146784x + 4E+06 R^2 = 0.9658	y = 194.14x + 1018 R^2 = 0.8732	y = 1013x + 56165 R^2 = 0.8084	y = 820.27x + 5466.1 R^2 = 0.947		y = 34.932x + 1936.7 R^2 = 0.8084	y = 109.13x + 23.436 R^2 = 0.9383	y = -0.0361x + 31.743 R^2 = 0.0681	y = -0.0274x + 22.6 R^2 = 0.0723	y = -0.0317x + 27.171 R^2 = 0.0781	y = -0.8347x + 1685.3 R^2 = 0.0002
0	1997	3,845,489	10,083	55,315	6,285	29	1,907	162	31	23	27	1,600
1	1998	3,987,764	10,289	57,362	6,758	29	1,978	195	33	23	28	1,477
2	1999	4,015,714	10,499	57,764	7,266	29	1,992	195	31	22	27	2,192
3	2000	4,130,734	10,713	59,418	7,813	29	2,049	195	31	22	27	1,500
4	2001	4,319,522	10,932	61,253	8,401	29	2,112	387	32	23	27	1,659
5	2002	4,294,303	11,060	62,782	9,034	29	2,165	550	32	23	27	1,847
6	2003	4,717,803	11,781	65,307	9,714	29	2,252	550	32	22	27	1,481
7	2004	4,702,820	11,622	59,668	10,445	29	2,058	950	31	22	27	1,630
8	2005	4,986,707	12,246	61,875	11,231	29	2,134	950	32	23	27	1,668
9	2006	4,958,843	11,900	64,737	12,762	29	2,232	950	32	23	27	1,930
10	2007	5,358,739	12,136	66,679	14,041	29	2,299	1,200	32	23	27	1,468
11	2008	5,407,891	11,778	68,679	15,983	29	2,368	1,200	31	22	26	1,717

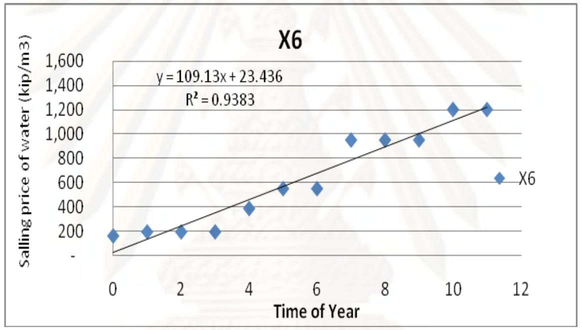
The eqaution of linear regession use forecast future year show on figure of the graph X_1 to X_{10}

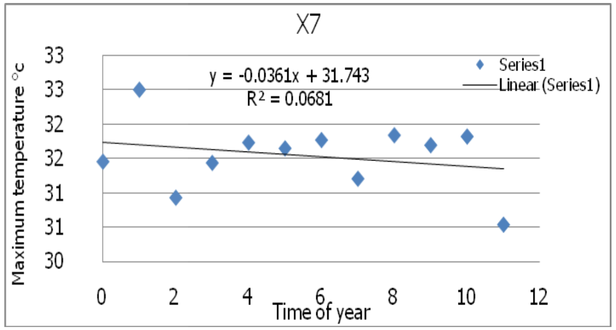

X1
y = 194.14x + 10186
R² = 0.8732
Number of family (family/year)
13,000
12,000
11,000
10,000
9,000
0 2 4 6 8 10 12
Time year
Series1
Linear (Series1)

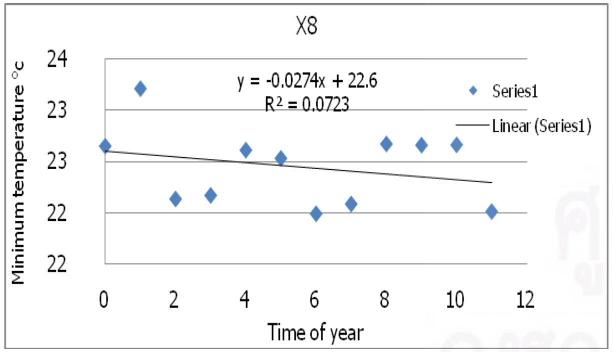

X2
y = 1013x + 56165
R² = 0.8084
Number of population (capita/year)
80,000
70,000
60,000
50,000
0 2 4 6 8 10 12
Time year
Series1
Linear (Series1)

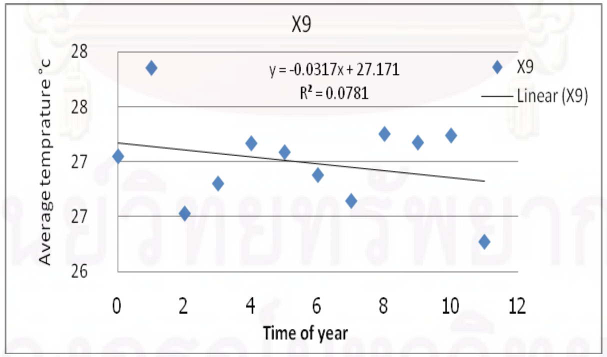

X3
y = 820.27x + 5466.1
R² = 0.947
Incomper capita (kip/capita)
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
0 2 4 6 8 10 12
Time year
Series1
Linear (Series1)


X5
y = 34.932x + 1936.7
R² = 0.8084
Population density (Capita/Km2/year)
2,600
2,400
2,200
2,000
1,800
0 2 4 6 8 10 12
Time year
Series1


X6
y = 109.13x + 23.436
R² = 0.9383
Salling price of water (kip/m3)
1,600
1,400
1,200
1,000
800
600
400
200
-
0 2 4 6 8 10 12
Time of Year
X6


X7
y = -0.0361x + 31.743
R² = 0.0681
Series1
Linear (Series1)
Maximum temperature °c
33
33
32
32
31
31
30
0 2 4 6 8 10 12
Time of year


X8
y = -0.0274x + 22.6
R² = 0.0723
Series1
Linear (Series1)
Minimum temperature °c
24
23
23
22
22
0 2 4 6 8 10 12
Time of year


X9
y = -0.0317x + 27.171
R² = 0.0781
X9
Linear (X9)
Average temprature °c
28
28
27
27
26
0 2 4 6 8 10 12
Time of year

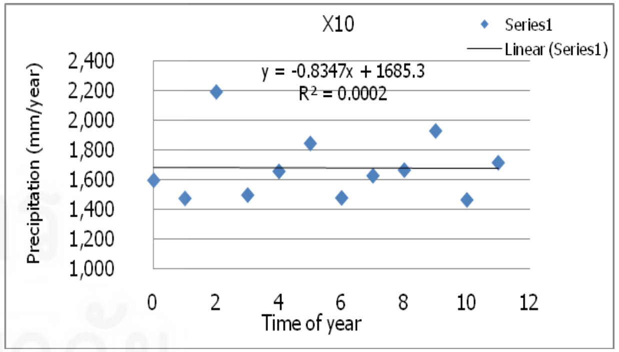

X10
Series1
Linear (Series1)
y = -0.8347x + 1685.3
R² = 0.0002
Precipitation (mm/year)
2,400
2,200
2,000
1,800
1,600
1,400
1,200
1,000
0 2 4 6 8 10 12
Time of year

Table A-3-1 Data independent factors year 2009 to 2029 (Chanthaburi district)

X	Year	Water sale	Number of family	Number of population	Income per capita	Area	Population density	Selling price of water	Max Temperature °c	Min Temperature °c	Average temperature °c	Total Precipitation
		m3	Family/year	capita/yearly	Kip/capita (X 1000)	Km^2	capita/Km^2	Kip/m^3	°c	°c	°c	mm
		Y	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
12	2009	5,761,408	12,516	68,321	15,309	29	2,356	1,333	31.3	22.3	26.8	1,675
13	2010	5,908,192	12,710	69,334	16,130	29	2,391	1,442	31.3	22.2	26.8	1,674
14	2011	6,054,976	12,904	70,347	16,950	29	2,426	1,551	31.2	22.2	26.7	1,674
15	2012	5,989,660	13,098	71,360	17,770	29	2,461	1,660	31.2	22.2	26.7	1,673
16	2013	6,131,424	13,292	72,373	18,590	29	2,496	1,770	31.2	22.2	26.7	1,672
17	2014	6,273,188	13,486	73,386	19,411	29	2,531	1,879	31.1	22.1	26.6	1,671
18	2015	6,414,952	13,681	74,399	20,231	29	2,565	1,988	31.1	22.1	26.6	1,670
19	2016	6,556,716	13,875	75,412	21,051	29	2,600	2,097	31.1	22.1	26.6	1,669
20	2017	6,698,480	14,069	76,425	21,872	29	2,635	2,206	31.0	22.1	26.5	1,669
21	2018	6,840,244	14,263	77,438	22,692	29	2,670	2,315	31.0	22.0	26.5	1,668
22	2019	6,982,008	14,457	78,451	23,512	29	2,705	2,424	30.9	22.0	26.5	1,667
23	2020	7,123,772	14,651	79,464	24,332	29	2,740	2,533	30.9	22.0	26.4	1,666
24	2021	7,265,536	14,845	80,477	25,153	29	2,775	2,643	30.9	21.9	26.4	1,665
25	2022	7,407,300	15,040	81,490	25,973	29	2,810	2,752	30.8	21.9	26.4	1,664
26	2023	7,549,064	15,234	82,503	26,793	29	2,845	2,861	30.8	21.9	26.3	1,664
27	2024	7,690,828	15,428	83,516	27,613	29	2,880	2,970	30.8	21.9	26.3	1,663
28	2025	7,832,592	15,622	84,529	28,434	29	2,915	3,079	30.7	21.8	26.3	1,662
29	2026	7,974,356	15,816	85,542	29,254	29	2,950	3,188	30.7	21.8	26.3	1,661
30	2027	8,116,120	16,010	86,555	30,074	29	2,985	3,297	30.7	21.8	26.2	1,660
31	2028	8,257,884	16,204	87,568	30,894	29	3,020	3,406	30.6	21.8	26.2	1,659
32	2029	8,399,648	16,398	88,581	31,715	29	3,055	3,516	30.6	21.7	26.2	1,659

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Graph forecasting independent factors year 2009 - 2029

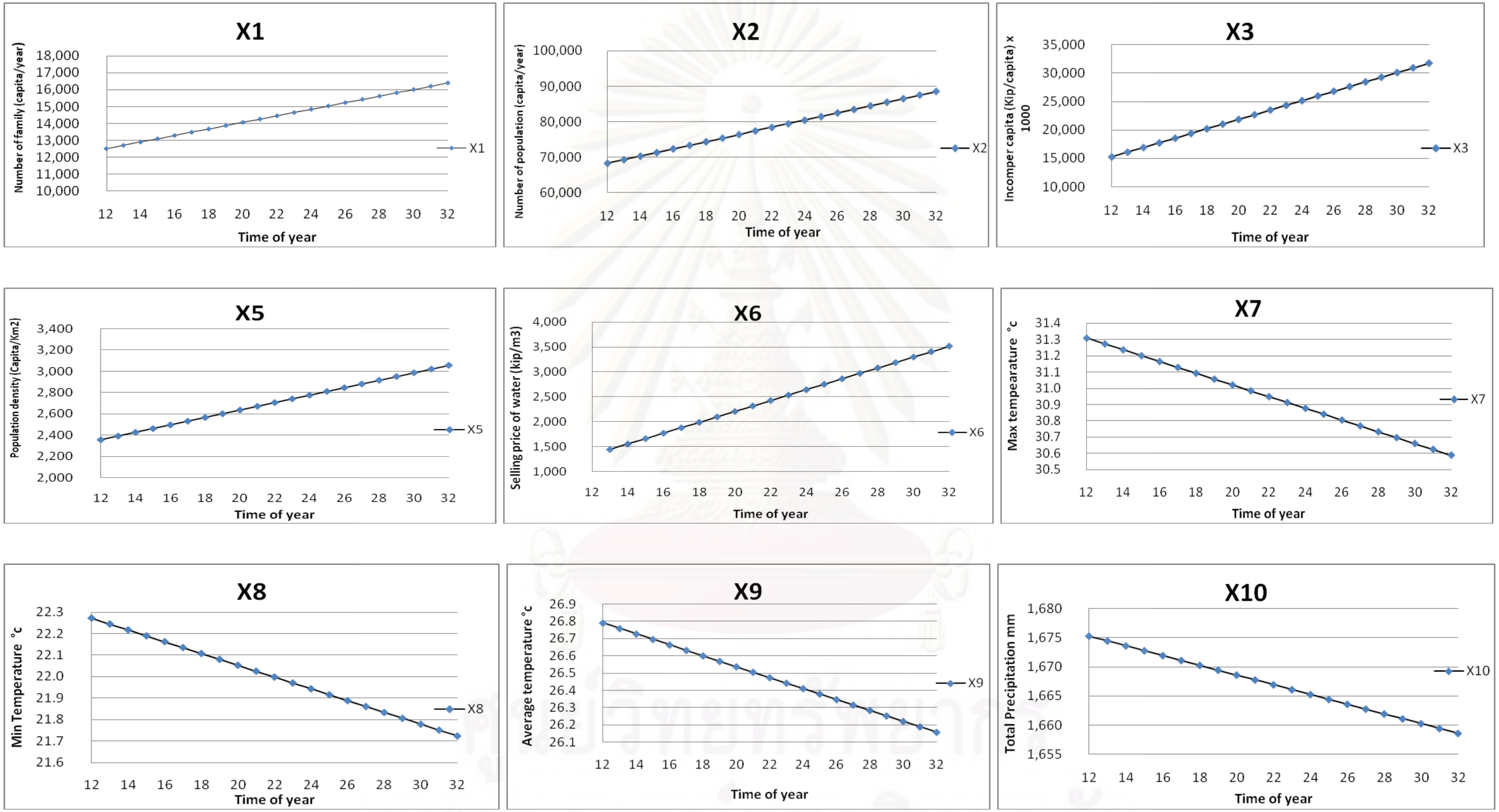

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Table A-4 Statistics of data water use at Vientiane 1997 to 2008 (Sikhottabong district)

X	Year	Water sale	Number of family	Number of population	Income per capita(x1000)	Area	Population density	Selling price of water	Max Temperature	Min Temperature	Average temperature	Total Precipitation
		m^3	Family/year	capita/yearly	Kip/capita	Km^2	capita/Km^2	Kip/m^3	°c	°c	°c	mm
		y	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
		y = 172255x + 4E+06 R^2 = 0.9632	y = 576.65x + 12920 R^2 = 0.9171	y = 2979.1x + 68204 R^2 = 0.9417	y = 820.27x + 5466.1 R^2 = 0.947		y = 21.279x + 508.45 R^2 = 0.9417	y = 109.13x + 23.436 R^2 = 0.9383	y = -0.0361x + 31.743 R^2 = 0.0681	y = -0.0274x + 22.6 R^2 = 0.0723	y = -0.0317x + 27.171 R^2 = 0.0781	y = -0.8347x + 1685.3 R^2 = 0.0002
0	1997	3,734,540	13,361	72,677	6,285	140	519	162	31	23	27	1,600
1	1998	3,872,711	13,634	75,366	6,758	140	538	195	33	23	28	1,477
2	1999	3,899,854	13,912	75,894	7,266	140	542	195	31	22	27	2,192
3	2000	4,011,555	14,196	78,068	7,813	140	558	195	31	22	27	1,500
4	2001	4,215,889	14,486	80,478	8,401	140	575	387	32	23	27	1,659
5	2002	4,226,926	15,044	82,096	9,034	140	586	550	32	23	27	1,847
6	2003	4,753,900	17,089	93,761	9,714	140	670	550	32	22	27	1,481
7	2004	4,765,779	18,225	94,894	10,445	140	678	950	31	22	27	1,630
8	2005	5,003,934	17,959	98,404	11,231	140	703	950	32	23	27	1,668
9	2006	5,330,359	17,720	96,794	12,762	140	691	950	32	23	27	1,930
10	2007	5,391,710	18,159	99,698	14,041	140	712	1,200	32	23	27	1,468
11	2008	5,411,064	19,313	102,689	15,983	140	733	1,200	31	22	26	1,717

Table A-4-1 Data independent factors year 2009 to 2029 (Sikhottabong district)

X	Year	Number of family	Number of population	Income per capita	Area	Population density	Selling price of water	Max Temperature	Min Temperature	Average temperature	Total Precipitation
		Family/year	capita/yearly	Kip/capita (X 1000)	Km2	capita/Km2	Kip/m3	°c	°c	°c	mm
		X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
12	2009	19,840	103,953	15,309	140	764	1,333	31.3	22.3	26.8	1,675
13	2010	20,416	106,932	16,130	140	785	1,442	31.3	22.2	26.8	1,674
14	2011	20,993	109,911	16,950	140	806	1,551	31.2	22.2	26.7	1,674
15	2012	21,570	112,891	17,770	140	828	1,660	31.2	22.2	26.7	1,673
16	2013	22,146	115,870	18,590	140	849	1,770	31.2	22.2	26.7	1,672
17	2014	22,723	118,849	19,411	140	870	1,879	31.1	22.1	26.6	1,671
18	2015	23,300	121,828	20,231	140	891	1,988	31.1	22.1	26.6	1,670
19	2016	23,876	124,807	21,051	140	913	2,097	31.1	22.1	26.6	1,669
20	2017	24,453	127,786	21,872	140	934	2,206	31.0	22.1	26.5	1,669
21	2018	25,030	130,765	22,692	140	955	2,315	31.0	22.0	26.5	1,668
22	2019	25,606	133,744	23,512	140	977	2,424	30.9	22.0	26.5	1,667
23	2020	26,183	136,723	24,332	140	998	2,533	30.9	22.0	26.4	1,666
24	2021	26,760	139,702	25,153	140	1,019	2,643	30.9	21.9	26.4	1,665
25	2022	27,336	142,682	25,973	140	1,040	2,752	30.8	21.9	26.4	1,664
26	2023	27,913	145,661	26,793	140	1,062	2,861	30.8	21.9	26.3	1,664
27	2024	28,490	148,640	27,613	140	1,083	2,970	30.8	21.9	26.3	1,663
28	2025	29,066	151,619	28,434	140	1,104	3,079	30.7	21.8	26.3	1,662
29	2026	29,643	154,598	29,254	140	1,126	3,188	30.7	21.8	26.3	1,661
30	2027	30,220	157,577	30,074	140	1,147	3,297	30.7	21.8	26.2	1,660
31	2028	30,796	160,556	30,894	140	1,168	3,406	30.6	21.8	26.2	1,659
32	2029	31,373	163,535	31,715	140	1,189	3,516	30.6	21.7	26.2	1,659

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Table A-5 Statistic of data water use at Vientiane 1997 to 2008 (Xaisettha district)

X	Years	Water sale	Number of family	Number of population	Income Per capita (x1000)	Area	Population density	Selling price of water	Max Temperature	Min Temperature	Average temperature	Total Precipitation
		m^3	Family/year	capita/yearly	Kip/capita	Km^2	capita/Km^2	Kip/m^3	°c	°c	°c	mm
		y	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
		y = 298553x + 4E+06 $R^2 = 0.7806$	y = 414.88x + 13235 $R^2 = 0.9038$	y = 2356x + 71634 $R^2 = 0.9806$	y = 820.27x + 5466.1 $R^2 = 0.947$		y = 16.027x + 487.31 $R^2 = 0.9806$	y = 109.13x + 23.436 $R^2 = 0.9383$	y = -0.0361x + 31.743 $R^2 = 0.0681$	y = -0.0274x + 22.6 $R^2 = 0.0723$	y = -0.0317x + 27.171 $R^2 = 0.0781$	y = -0.8347x + 1685.3 $R^2 = 0.0002$
0	1997	4,861,687	13,368	72,594	6,285	147	494	162	31	23	27	1,600
1	1998	5,041,559	13,641	75,280	6,758	147	512	195	33	23	28	1,477
2	1999	5,076,895	13,919	75,807	7,266	147	516	195	31	22	27	2,192
3	2000	5,222,310	14,203	77,978	7,813	147	530	195	31	22	27	1,500
4	2001	5,383,547	14,493	80,386	8,401	147	547	387	32	23	27	1,659
5	2002	5,636,213	15,155	80,724	9,034	147	549	550	32	23	27	1,847
6	2003	6,100,123	15,842	87,661	9,714	147	596	550	32	22	27	1,481
7	2004	5,885,797	16,593	87,577	10,445	147	596	950	31	22	27	1,630
8	2005	6,129,808	17,785	90,816	11,231	147	618	950	32	23	27	1,668
9	2006	6,288,396	17,021	92,621	12,762	147	630	950	32	23	27	1,930
10	2007	8,344,209	17,093	95,400	14,041	147	649	1,200	32	23	27	1,468
11	2008	8,559,280	17,093	98,262	15,983	147	668	1,200	31	22	26	1,717

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Table A-5-1 Data independent factors year 2009 to 2029 (Xaisettha district)

X	Year	Number of family	Number of population	Income per capita	Area	Population density	Selling price of water	Max Temperature	Min Temperature	Average temperature	Total Precipitation
		Family/year	capita/yearly	Kip/capita (X 1000)	Km^2	$capita/Km^2$	Kip/m^3	°c	°c	°c	mm
		X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
12	2009	18,214	99,906	15,309	147	680	1,333	31.3	22.3	26.8	1,675
13	2010	18,628	102,262	16,130	147	696	1,442	31.3	22.2	26.8	1,674
14	2011	19,043	104,618	16,950	147	712	1,551	31.2	22.2	26.7	1,674
15	2012	19,458	106,974	17,770	147	728	1,660	31.2	22.2	26.7	1,673
16	2013	19,873	109,330	18,590	147	744	1,770	31.2	22.2	26.7	1,672
17	2014	20,288	111,686	19,411	147	760	1,879	31.1	22.1	26.6	1,671
18	2015	20,703	114,042	20,231	147	776	1,988	31.1	22.1	26.6	1,670
19	2016	21,118	116,398	21,051	147	792	2,097	31.1	22.1	26.6	1,669
20	2017	21,533	118,754	21,872	147	808	2,206	31.0	22.1	26.5	1,669
21	2018	21,947	121,110	22,692	147	824	2,315	31.0	22.0	26.5	1,668
22	2019	22,362	123,466	23,512	147	840	2,424	30.9	22.0	26.5	1,667
23	2020	22,777	125,822	24,332	147	856	2,533	30.9	22.0	26.4	1,666
24	2021	23,192	128,178	25,153	147	872	2,643	30.9	21.9	26.4	1,665
25	2022	23,607	130,534	25,973	147	888	2,752	30.8	21.9	26.4	1,664
26	2023	24,022	132,890	26,793	147	904	2,861	30.8	21.9	26.3	1,664
27	2024	24,437	135,246	27,613	147	920	2,970	30.8	21.9	26.3	1,663
28	2025	24,852	137,602	28,434	147	936	3,079	30.7	21.8	26.3	1,662
29	2026	25,267	139,958	29,254	147	952	3,188	30.7	21.8	26.3	1,661
30	2027	25,681	142,314	30,074	147	968	3,297	30.7	21.8	26.2	1,660
31	2028	26,096	144,670	30,894	147	984	3,406	30.6	21.8	26.2	1,659
32	2029	26,511	147,026	31,715	147	1,000	3,516	30.6	21.7	26.2	1,659

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Table A-6 Statistic of data water use at Vientiane 1997 to 2008 (Sisattanak district)

X	Years	Water sale	Number of family	Number of population	Income per capita (x 100)	Area	Population density	Selling price of water	Max Temperature	Min Temperature	Average temperature	Total Precipitation
		m^3	Family/year	capita/yearly	Kip/capita	Km^2	capita/Km^2	Kip/m^3	°c	°c	°c	mm
		Y	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
		y = 214503x + 5E+06	y = 139.71x + 9370.1	y = 286.47x + 58222	y = 820.27x + 5466.1		y = 9.2408x + 1878.1	y = 109.13x + 23.436	y = -0.0361x + 31.743	y = -0.0274x + 22.6	y = -0.0317x + 27.171	y = -0.8347x + 1685.3
		$R^2 = 0.9228$	$R^2 = 0.707$	$R^2 = 0.1401$	$R^2 = 0.947$		$R^2 = 0.1401$	$R^2 = 0.9383$	$R^2 = 0.0681$	$R^2 = 0.0723$	$R^2 = 0.0781$	$R^2 = 0.0002$
0	1997	4,891,926	9,225	55,429	6,285	31	1,788	162	31	23	27	1,600
1	1998	5,072,917	9,413	57,480	6,758	31	1,854	195	33	23	28	1,477
2	1999	5,108,472	9,605	57,883	7,266	31	1,867	195	31	22	27	2,192
3	2000	5,254,792	9,801	59,541	7,813	31	1,921	195	31	22	27	1,500
4	2001	5,478,411	10,001	61,379	8,401	31	1,980	387	32	23	27	1,659
5	2002	5,577,147	9,840	60,911	9,034	31	1,965	550	32	23	27	1,847
6	2003	5,938,548	10,316	62,550	9,714	31	2,018	550	32	22	27	1,481
7	2004	5,935,245	10,655	62,486	10,445	31	2,016	950	31	22	27	1,630
8	2005	6,161,510	11,322	64,797	11,231	31	2,090	950	32	23	27	1,668
9	2006	6,367,261	10,502	56,654	12,762	31	1,828	950	32	23	27	1,930
10	2007	7,010,211	10,491	58,354	14,041	31	1,882	1,200	32	23	27	1,468
11	2008	7,513,307	10,491	60,104	15,983	31	1,939	1,200	31	22	26	1,717

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Table A-6-1 Data independent factors year 2009 to 2029 (Sisattanak district)

X	Year	Number of family	Number of population	Income per capita	Area	Population density	Selling price of water	Max Temperature	Min Temperature	Average temperature	Total Precipitation
		Family/year	capita/yearly	Kip/capita (X 1000)	Km^2	capita/Km^2	Kip/m^3	°c	°c	°c	mm
		X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
12	2009	11,047	61,660	15,309	31	1,989	1,333	31.3	22.3	26.8	1,675
13	2010	11,186	61,946	16,130	31	1,998	1,442	31.3	22.2	26.8	1,674
14	2011	11,326	62,233	16,950	31	2,007	1,551	31.2	22.2	26.7	1,674
15	2012	11,466	62,519	17,770	31	2,017	1,660	31.2	22.2	26.7	1,673
16	2013	11,605	62,806	18,590	31	2,026	1,770	31.2	22.2	26.7	1,672
17	2014	11,745	63,092	19,411	31	2,035	1,879	31.1	22.1	26.6	1,671
18	2015	11,885	63,378	20,231	31	2,044	1,988	31.1	22.1	26.6	1,670
19	2016	12,025	63,665	21,051	31	2,054	2,097	31.1	22.1	26.6	1,669
20	2017	12,164	63,951	21,872	31	2,063	2,206	31.0	22.1	26.5	1,669
21	2018	12,304	64,238	22,692	31	2,072	2,315	31.0	22.0	26.5	1,668
22	2019	12,444	64,524	23,512	31	2,081	2,424	30.9	22.0	26.5	1,667
23	2020	12,583	64,811	24,332	31	2,091	2,533	30.9	22.0	26.4	1,666
24	2021	12,723	65,097	25,153	31	2,100	2,643	30.9	21.9	26.4	1,665
25	2022	12,863	65,384	25,973	31	2,109	2,752	30.8	21.9	26.4	1,664
26	2023	13,003	65,670	26,793	31	2,118	2,861	30.8	21.9	26.3	1,664
27	2024	13,142	65,957	27,613	31	2,128	2,970	30.8	21.9	26.3	1,663
28	2025	13,282	66,243	28,434	31	2,137	3,079	30.7	21.8	26.3	1,662
29	2026	13,422	66,530	29,254	31	2,146	3,188	30.7	21.8	26.3	1,661
30	2027	13,561	66,816	30,074	31	2,155	3,297	30.7	21.8	26.2	1,660
31	2028	13,701	67,103	30,894	31	2,165	3,406	30.6	21.8	26.2	1,659
32	2029	13,841	67,389	31,715	31	2,174	3,516	30.6	21.7	26.2	1,659

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Appendixes B Statistic Data of Vientiane Water supply

Table B-1 Benefit Monitoring and Evaluation (BME), 2000-2007. Vientiane Capital

Data and Statistics	Unit	2000	2001	2002	2003	2004	2005	2006	2007	2008	Remark
Water Demand											
Population in Vientiane Capital	No	597,800	616,000	633,100	650,600	668,817	698,318	717,871	725,820	746,143	9 Districts
Population in Service Area (7 Districts)	No	539,216	555,632	571,056	586,819	603,250	625,560	643,076	662,369	667,101	7 Districts
Population Served	No	237,042	252,312	258,558	277,884	285,678	286,935	308,347	328,895	343,640	Ref. NSC
Coverage (in Vientiane Capital)	%	40	41	41	43	43	41	43	45	46	
Coverage (in Service Area)	%	44	45	45	47	47	46	48	50	52	
Per Capita Consumption	l.p.d.	182	174	176	178	169	186	174	182	175	
Total Area (in Vientiane Capital)	Km^2	3,920	3,920	3,920	3,920	3,920	3,920	3,920	3,920	3,920	9 Districts
Service Area (7 Districts)	Km^2	1,521	1,521	1,521	1,521	2652*	2,652	2,652	2,652	2,652	* Naxaithong
Pipes Network (Size ≥ 40 mm)	Km	386	402	418	438	542	620	675	763	725	
	Km	5	16	16	21	103	78	55	87	19	
Production and Distribution											
Total Water Production	m3	36,273,290	38,378969	41,365415	43,786,885	43,205,699	43,871,789	43,440,196	49,197,540	49,781,245	
Chinaimo Plant	m3	29,975,480	32,345051	33,548692	33,075,199	32,061,006	33,823,285	33,212,527	32,491,689	31,084,110	
Kaoleo Plant	m3	6,297,810	6,033,918	7,816,723	10,593,110	11,038,245	9,584,557	9,223,755	8,347,104	10,376,985	
Dongmakkai Plant	m3	-	-	-	-	-	-	427,738	7,902,381	7,814,850	
Thadeua Plant	m3	-	-	-	118,576	106,448	174,357	258,174	158,991	192,602	
Thangon Plant	m3	-	-	-	-	-	289,590	318,002	297,375	312,698	
Storage (Elevated Reservoir)	m3	9,360	9,360	9,360	9,360	11,360	11,360	11,360	11,360	11,360	
Distribution and Service Connections											
Total Water Sales	m3	24,992,460	27,834267	28,829294	31,350,134	30,484,816	31,509,756	31,679,467	35,562,330	36,177,870	
Domestic (cat 1)	m3	13,698,682	21,193619	22,409366	24,398,746	24,010,768	25,461,574	25,850,730	29,567,867	30,358,130	cat1+cat2
Government (cat 2)	m3	5,408,236	-	-	-	-	-	-	-	-	
Commercial (cat 3)	m3	4,021,539	3,714,380	3,232,286	3,652,169	6,178,043	5,740,238	5,534,359	5,675,024	5,526,418	cat3+cat4
Large Commercial (cat 4)	m3	1,473,463	2,539,150	2,857,251	2,997,065	-	-	-	-	-	
Foreign (cat 5)	m3	390,540	387,118	330,391	302,154	296,005	307,944	294,378	319,439	293,322	
Non Revenue Water (NRW)	m3	11,280,830	10,544702	12,536121	12,436,751	12,720,883	12,362,033	11,760,729	13,635,210	13,603,375	
Non Revenue Water (NRW)	%	31	27	30	28	29	28	27	28	27	

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Lao Water Supply Company.

Corporate Planning & IT Section **Table B-2 Benefit Monitoring and Evaluation (BME), 2001-2006. (Vientiane Capital)**

Data and Statistics	Unit	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	Remark
Production and Distribution												
Total Water Production	m3	26,176,945	30,590,258	31,526,073	36,273,290	38,378,969	41,365,415	43,786,885	43,205,699	43,871,789	43,440,196	
Increase(Decrease) Over previous year	%		16.86	3.06	15.06	5.81	7.78	5.85	(1.33)	1.54	(0.98)	
Chinaimo Plant	m3	20,045,218	24,305,398	25,430,008	29,975,480	32,345,051	33,548,692	33,075,199	32,061,006	33,823,285	33,212,527	
Increase(Decrease) Over previous year	%		21.25	4.63	17.87	7.91	3.72	(1.41)	(3.07)	5.50	(1.81)	
Kaoleo Plant	m3	6,131,727	6,284,860	6,096,065	6,297,810	6,033,918	7,816,723	10,593,110	11,038,245	9,584,557	9,223,755	
Increase(Decrease) Over previous year	%		2.50	(3.00)	3.31	(4.19)	29.55	35.52	4.20	(13.17)	(3.76)	
Dongmakkai Plant	m3					-	-	-	-	-	427,738	
Increase(Decrease) Over previous year	%					-	-	-	-	-	-	
Thadeua Plant	m3				67,484	-	-	118,576	106,448	174,357	258,174	
Increase(Decrease) Over previous year	%				#DIV/0!	-	-	-	(10.23)	63.80	48.07	
Thangon Plant	m3					-	-	-	-	289,590	318,002	
Increase(Decrease) Over previous year	%					-	-	-	-	-	9.81	
Storage (Elevated Reservoir)	m3	5,000	9,000	9,000	9,360	9,360	9,360	9,360	11,360	11,360	11,360	
Distribution and Service Connections												
Total Water Sales	m3	18,386,534	20,861,567	21,943,494	24,992,460	27,834,267	28,829,294	31,350,134	30,484,816	31,509,756	31,679,467	
Increase(Decrease) Over previous year	%		13.46	5.19	13.89	11.37	3.57	8.74	(2.76)	3.36	0.54	
Domestic Meters (cat 1)	m3	8,988,146	10,550,617	11,581,201	13,698,682	21,193,619	22,409,366	24,398,746	24,010,768	25,461,574	25,850,730	
Increase(Decrease) Over previous year	%		17.38	9.77	18.28	54.71	5.74	8.88	(1.59)	6.04	1.53	
Commercial (cat 2)	m3	2,788,049	3,061,173	3,344,039	4,021,539	3,714,380	3,232,286	3,652,169	6,178,043	5,740,238	5,534,359	cat2+cat3
Increase(Decrease) Over previous year	%		9.80	9.24	20.26	(7.64)	(12.98)	12.99	69.16	(7.09)	(3.59)	
Large Commercial (cat 3)	m3	998,884	1,143,176	1,180,411	1,473,463	2,539,150	2,857,251	2,997,065	-	-	-	
Increase(Decrease) Over previous year	%		14.45	3.26	24.83	72.33	12.53	4.89	-	-	-	
Foreign (cat 4)	m3	510,396	499,610	384,983	390,540	387,118	330,391	302,154	296,005	307,944	294,378	
Increase(Decrease) Over previous year	%		(2.11)	(22.94)	1.44	(0.88)	(14.65)	(8.55)	(2.04)	4.03	(4.41)	

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Appendix C. Statistic data of population

Table C-1 Statistic data of population 1997

No	District	Number of Village	Number of House	Number of population	Number of Female	Size of family	Area	Population density
		Ban	Rung	capita/yearly	capital	capita/ family/year	Km^2	capita/Km^2
1	Chanthabury	37	10,083	55,315	29,909	5	29	1,907
2	Sikhottabong	59	13,361	72,677	38,403	5	140	519
3	Xaisettha	51	13,368	72,594	39,274	5	147	494
4	Sisattanak	40	9,225	55,429	28,696	6	31	1,788
5	Naxaythong	56	8,419	45,206	24,005	5	1,131	40
6	Xaythany	104	19,729	107,069	56,196	5	916	117
7	Hatxayfong	58	12,944	66,847	33,649	5	258	259
8	Sangthong	36	3,591	19,148	9,715	5	622	31
9	Paknguem	53	6,713	36,133	18,535	5	646	56
10	Other		-	26,013	12,233			
Total		494	97,433	556,432	290,615	6	3,920	142

Table C-2 Statistic data of population 1998

No	District	Number of Village	Number of House	Number of population	Number of Female	Size of family	Area	Population density
		Ban	Rung	capita/yearly	capital	capita/ family/year	Km^2	capita/Km^2
1	Chanthabury	37	10,289	57,362	30,211	6	29	1,978
2	Sikhottabong	59	13,634	75,366	38,791	6	140	538
3	Xaisettha	51	13,641	75,280	39,671	6	147	512
4	Sisattanak	40	9,413	57,480	28,986	6	31	1,854
5	Naxaythong	56	8,591	46,879	24,248	5	1,131	41
6	Xaythany	104	20,131	111,030	56,763	6	916	121
7	Hatxayfong	58	13,208	69,321	33,989	5	258	269
8	Sangthong	36	3,664	19,856	9,814	5	622	32
9	Paknguem	53	6,850	37,470	18,722	5	646	58
10	Other		-	26,975	12,357			
Total		494	99,421	577,019	293,550	6	3,920	147

Table C-3 Statistic data of population 1999

No	District	Number of Village	Number of House	Number of population	Number of Female	Size of family	Area	Population density
		Ban	Rung	capita/yearly	capital	capita/ family/year	Km^2	capita/Km^2
1	Chanthabury	37	10,499	57,764	30,516	6	29	1,992
2	Sikhottabong	59	13,912	75,894	39,182	5	140	542
3	Xaisettha	51	13,919	75,807	40,071	5	147	516
4	Sisattanak	40	9,605	57,883	29,279	6	31	1,867
5	Naxaythong	56	8,767	47,208	24,493	5	1,131	42
6	Xaythany	104	20,542	111,809	57,337	5	916	122
7	Hatxayfong	58	13,477	69,807	34,332	5	258	271
8	Sangthong	36	3,739	19,995	9,913	5	622	32
9	Paknguem	53	6,990	37,733	18,911	5	646	58
10	Other		-	27,164	12,482			
Total		494	101,450	581,063	296,516	6	3,920	148

Table C-4 Statistic data of population 2000

No	District	Number of Village	Number of House	Number of population	Number of Female	Size of family	Area	Population density
		Ban	Rung	capita/yearly	capital	capita/ family/year	Km^2	capita/Km^2
1	Chanthabury	37	10,713	59,418	30,825	6	29	2,049
2	Sikhottabong	59	14,196	78,068	39,578	5	140	558
3	Xaisettha	51	14,203	77,978	40,476	5	147	530
4	Sisattanak	40	9,801	59,541	29,574	6	31	1,921
5	Naxaythong	56	8,945	48,560	24,740	5	1,131	43
6	Xaythany	104	20,961	115,011	57,916	5	916	126
7	Hatxayfong	58	13,752	71,806	34,679	5	258	278
8	Sangthong	36	3,815	20,568	10,013	5	622	33
9	Paknguem	53	7,132	38,814	19,102	5	646	60
10	Other			27,942	12,608			
Total		494	103,520	597,800	299,511	6	3,920	152

Table C-5 Statistic data of population 2001

No	District	Number of Village	Number of House	Number of population	Number of Female	Size of family	Area	Population density
		Ban	Rung	capita/yearly	capital	capita/ family/year	Km^2	capita/Km^2
1	Chanthabury	37	10,932	61,253	31,136	6	29	2,112
2	Sikhottabong	59	14,486	80,478	39,978	6	140	575
3	Xaisettha	51	14,493	80,386	40,885	6	147	547
4	Sisattanak	40	10,001	61,379	29,873	6	31	1,980
5	Naxaythong	56	9,128	50,059	24,990	5	1,131	44
6	Xaythany	104	21,389	118,562	58,501	6	916	129
7	Hatxayfong	58	14,033	74,023	35,029	5	258	287
8	Sangthong	36	3,893	21,203	10,114	5	622	34
9	Paknguem	53	7,278	40,012	19,295	5	646	62
10	Other			28,805	12,735			
Total		494	105,633	616,000	302,536	6	3,920	157

Table C-6 Statistic data of population 2002

No	District	Number of Village	Number of House	Number of population	Number of Female	Size of family	Area	Population density
		Ban	Rung	capita/yearly	capital	capita/ family/year	Km^2	capita/Km^2
1	Chanthabury	37	12,060	62,782	31,973	5	29	2,165
2	Sikhottabong	60	15,044	82,096	40,275	5	140	586
3	Xaisettha	51	15,155	80,724	39,632	5	147	549
4	Sisattanak	40	9,840	60,911	32,416	6	31	1,965
5	Naxaythong	56	9,447	51,862	25,711	5	1,131	46
6	Xaythany	104	20,866	119,089	59,752	6	916	130
7	Hatxayfong	58	14,120	71,302	35,925	5	258	276
8	Sangthong	37	4,317	22,507	11,166	5	622	36
9	Paknguem	53	7,234	39,967	20,069	6	646	62
10	Other			44,515	18,367			
Total		496	108,083	633,100	315,286	6	3,920	162

Table C-7 Statistic data of population 2003

No	District	Number of Village	Number of House	Number of population	Number of Female	Size of family	Area	Population density
		Ban	Rung	capita/yearl y	capital	capita/ family/year	Km^2	capita/Km^2
1	Chanthabury	37	11,781	65,307	32,307	6	29	2,252
2	Sikhottabong	60	17,089	93,761	46,884	5	140	670
3	Xaisettha	51	15,842	87,661	44,500	6	147	596
4	Sisattanak	40	10,316	62,550	33,761	6	31	2,018
5	Naxaythong	56	9,868	54,978	27,777	6	1,131	49
6	Xaythany	104	23,304	135,529	65,804	6	916	148
7	Hatxayfong	58	14,825	73,233	36,817	5	258	284
8	Sangthong	37	4,386	22,764	11,168	5	622	37
9	Paknguem	53	8,098	43,460	21,547	5	646	67
10	Other							
Total		496	115,509	650,600	320,565	6	3,920	163

Table C-8 Statistic data of population 2004

No	District	Number of Village	Number of House	Number of population	Number of Female	Size of family	Area	Population density
		Ban	Rung	capita/yearly	capital	capita/ family/year	Km^2	capita/Km^2
1	Chanthabury	37	11,622	59,668	30,303	5	29	2,058
2	Sikhottabong	60	18,225	94,894	47,742	5	140	678
3	Xaisettha	52	16,593	87,577	44,373	5	147	596
4	Sisattanak	40	10,655	62,486	34,185	6	31	2,016
5	Naxaythong	56	10,289	53,935	27,086	5	1,131	48
6	Xaythany	104	23,763	132,021	66,001	6	916	144
7	Hatxayfong	60	15,180	76,572	37,578	5	258	297
8	Sangthong	37	4,833	23,896	11,781	5	622	38
9	Paknguem	53	8,072	44,219	21,872	5	646	68
10	Other			21,874	8,619	#DIV/0!		
Total		499	119,232	668,817	329,540	6	3,920	168

Table C-9 Statistic data of population 2005

No	District	Number of Village	Number of House	Number of population	Number of Female	Size of family	Area	Population density
		Ban	Rung	capita/yearly	capital	capita/ family/year	Km^2	capita/Km^2
1	Chanthabury	37	12,246	73,595	38,433	6	29	2,538
2	Sikhottabong	61	17,959	100,738	49,696	6	140	720
3	Xaisettha	52	17,785	96,589	48,242	5	147	657
4	Sisattanak	40	11,322	68,195	36,113	6	31	2,200
5	Naxaythong	56	10,899	58,551	29,150	5	1,131	52
6	Xaythany	104	26,820	149,507	73,687	6	916	163
7	Hatxayfong	60	15,859	78,385	39,542	5	258	304
8	Sangthong	37	4,947	24,687	12,057	5	622	40
9	Paknguem	53	8,348	45,226	22,274	5	646	70
10	Other							
Total		500	126,185	698,318	349,194	6	3,920	177

Table C-10 Statistic data of population 2006

No	District	Number of Village	Number of House	Number of population	Number of Female	Size of family	Area	Population density
		Ban	Rung	capita/yearly	capital	capita/ family/year	Km^2	capita/Km^2
1	Chanthabury	37	11,900	64,737	33,498	5	29	2,232
2	Sikhottabong	61	17,720	96,794	49,273	5	140	691
3	Xaisettha	52	17,021	92,621	46,829	5	147	630
4	Sisattanak	40	10,502	56,654	26,962	5	31	1,828
5	Naxaythong	56	11,060	58,551	29,150	5	1,131	52
6	Xaythany	104	26,523	150,151	73,356	6	916	164
7	Hatxayfong	60	15,170	75,763	37,868	5	258	294
8	Sangthong	37	5,004	24,856	12,455	5	622	40
9	Paknguem	53	8,274	45,923	22,804	6	646	71
10	Other			35,934	18,095			
Total		500	123,174	717,871	350,290	6	3,920	179

Table C-11 Statistic data of population 2007

No	District	Number of Village	Number of House	Number of population	Number of Female	Size of family	Area	Population density
		Ban	Rung	capita/yearly	capital	Capita /family/year	Km^2	capita/Km^2
1	Chanthabury	37	12,136	73,478	38,135	6	29	2,534
2	Sikhottabong	61	18,159	106,611	53,305	6	140	762
3	Xaisettha	52	17,093	104,056	52,028	6	147	708
4	Sisattanak	40	10,491	73,294	38,773	7	31	2,364
5	Naxaythong	56	11,184	62,284	31,204	6	1,131	55
6	Xaythany	104	25,188	160,910	78,202	6	916	176
7	Hatxayfong	60	15,955	83,594	42,298	5	258	324
8	Sangthong	37	5,083	25,840	12,713	5	622	42
9	Paknguem	53	8,369	48,063	23,791	6	646	74
10	Other			7,040	2,534			
Total		500	123,658	725,820	372,983	6	3,920	190

Table C-12 Statistic data of population 2008

No	District	Number of Village	Number of House	Number of population	Number of Female	Number of family	Area	Population density
		Ban	Rung	capita/yearly	capital	Capita /family/year	Km^2	capita/Km^2
1	Chanthabury	37	11,778	75,902	39,393	6	29	2,617
2	Sikhottabong	61	19,313	110,129	55,064	6	140	787
3	Xaisettha	52	17,093	107,489	53,745	6	147	731
4	Sisattanak	40	10,491	75,713	40,052	7	31	2,442
5	Naxaythong	56	11,472	64,339	32,234	6	1,131	57
6	Xaythany	104	26,511	166,220	80,783	6	916	181
7	Hatxayfong	60	16,801	86,352	43,694	5	258	335
8	Sangthong	37	5,413	26,692	13,133	5	622	43
9	Paknguem	53	8,129	49,649	24,576	6	646	77
10	Other			7,272	2,618			
Total		500	127,001	746,143	385,292	6	3,920	196

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