Non-residential Urban Water Demand Modelling – a Disaggregation Approach

By

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B.Sc. (Civil Engg.)

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Dedicated
To
My Husband and two beautiful kids
Senoy and Siwan

ABSTRACT

Rapid population growth over the 20th century and changing climate has put many urban water supply systems under pressure around the world. Such pressure also exerted on most of the Australian water supply systems, which has led to the introduction of water use restrictions to ensure environmentally sustainable water supply. To operate cost effective and reliable urban water supply systems, analysing urban water use and forecasting future water demand is an essential task.

Generally, the urban water use classified as residential and non-residential water use based on different activities. In Melbourne (Australia), water authorities have used end-use models to forecast water demand, in which the residential component is extensively modelled. In these end-use models, the total household water use is broken down to the end-use level (e.g. toilets, showers, washing machines, etc.) for forecasting water demand in the residential sector. However, a simple historical trend-based annual water demand is considered for the non-residential sector, as a whole. No temporal (i.e. quarterly or monthly) and spatial disaggregation were considered in the non-residential water demand forecasts in these end-use models. It was also found that the existing work around the world on water demand modelling mainly focused on residential water use modelling. However, a significant portion of urban water usage is non-residential. For example, around 25% of the total water use in Melbourne is used by the non-residential sector. Therefore, the modelling of non-residential urban water use has significant importance for effective water supply system in any urban area. Considering this knowledge gap for effective urban water supply, this project aims to forecast short term (i.e. month to year) non-residential water demand which is useful for system operation as well as budgeting and financial management.

To achieve this aim, the water use billing data for each non-residential customer located in the Yarra Valley Water service area (in Melbourne, Australia) were used for developing non-residential water demand models in this research. All customers were disaggregated into several groups based on the homogenous water activity such as Schools, Sports Grounds, Councils, Restaurants, Hospitals, Hotels, and Laundries. The high water users (>50 ML/year) were also considered as a separate group in this study named as High Water Users. All customers in the homogenous groups were further divided into smaller groups based on the annual water use (>20 ML, >15-20 ML, >10-

15 ML, 5-10 ML, and <5 ML). Data analysis was then carried out for each of these user groups to identify the water use pattern. Data analysis showed that there were some seasonal effects on Schools, Sports Grounds and Councils. Therefore, water use among these groups was modelled using the Multiple Linear Regression (MLR) technique with the available climatic variable and water restrictions data. In the remaining groups no seasonal variations were identified during data analysis. Moreover, most of their water uses are for indoor purposes and therefore, water use modelling was carried out for these remaining groups with the past water use data only due to unavailability of data for other influential factors. All forecasting models developed in this research were validated with the observed data and the model performance was measured with the Nash-Sutcliffe efficiency criteria. Results showed that most of these developed models performed well except for few cases. Some issues and challenges were also identified during models development among the homogenous groups in non-residential sectors. All these issues and challenges are listed in this thesis for future research.

The major innovation of this study was the development of the disaggregation approach for sector based non-residential water demand modelling. This approach is successfully demonstrated in this research by disaggregating customers based on their activity and their annual water use. The development of non-residential water demand models at individual customer level is also the knowledge advancement, as limited work was found in this area.

DECLARATION

I, Suchana Barua, declare that the PhD thesis entitled 'Non-residential Urban Water Demand Modelling – a Disaggregation Approach' is no more than 100,000 words in length including quotes and exclusive of tables, figures, appendices, bibliography, references and footnotes.

This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work.

Signature [redacted]

Suchana Barua

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LIST OF PUBLICATIONS AND AWARDS

Journal Articles:

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Conference Articles:

1. **Barua, S.**, Ng, A.W.M., Muthukumaran, S., Huang, F., Roberts, P. and Perera, B.J.C., 2013. *Modeling water use in schools: a comparative study of quarterly and monthly models*. Proceedings of 20th International Congress on Modelling and Simulation. Adelaide, Australia, December 1-6, 2013, pp. 3141-3147.

2. **Barua, S.**, Ng, A.W.M., Muthukumaran, S., Roberts, P., Athuraliya, A., Diamond, N.T. and Perera, B.J.C., 2012. *Modelling non-residential urban water use: case study on two high water use schools in Melbourne*. Proceedings of 34th Hydrology and Water Resources Symposium, Sydney, Australia, November 19–November 22, 2012, pp. 700 – 707.

Awards:

Winner of Three Minutes PhD Thesis Presentation Heat *2014 held in Victoria University*, *Melbourne*, *Australia*. The presentation title was “Non-residential Water Demand Modelling - A Disaggregation Approach.

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LIST OF ABBREVIATIONS

The following list of abbreviations is used throughout this thesis. The other abbreviations, which are used only in particular sections or chapters are defined in the relevant sections or chapters.

ABM	Agent Based Modelling
ANN	Artificial Neural Network
ANSIC	Australian and New Zealand Standard Industrial Classification
BoM	Bureau of Meteorology
BWPD	Bulk Water Production Data
CWW	City West Water
CMDD	Customer Meter Demand Data
FIS	Fuzzy Inference System
HWU	High Water Users
MF	Membership Functions
MLR	Multiple Linear Regression
MW	Melbourne Water
PCPD	Per Capita Per Day
PWSR	Permanent Water Saving Rules
SEW	South East Water
SIMDEUM	SIMulation of water Demand, an End-Use Model
YVW	Yarra Valley Water

LIST OF SYMBOLS

The following list of symbols is used throughout this thesis. The other symbols, which are used only in particular sections or chapters are defined in the relevant sections or chapters.

E	Nush-Sutcliffe model efficiency
p	p-value or probability value
ML	Megalitre
KL	Kilolitre

Chapter 1. Introduction

1.1. Background

The world's urban population grew very rapidly (from 220 million to 2.8 billion) over the 20th century, and the 21st century marks the first time in history that half of the global human population resides in urban areas (United Nations Population Fund, 2007). The increasing growth in population and changing climate has put many urban water supply systems under immense pressure, often being required to supply a demand which is close to or exceeding its sustainable demand limit to meet the water demands of their residents (House-Peters and Chang, 2011). Such pressures have been exerted on most Australian water supply systems, resulting in record restriction periods and in some cases the introduction of permanent water saving measures (Melbourne Water, 2009). Therefore, although analysing and forecasting urban water demand is a complex task, yet it is essential to operate cost effective and reliable urban water supply systems.

Urban water supply systems provide water for a range of uses from human consumption to fire control, and from garden irrigation to industrial processes. Each urban area has its own economic base, creating its own pattern of water use. The types of activities creating this pattern are categorized into different sectors: residential (e.g. single house, multi-unit apartment, etc.), non-residential (e.g. industrial, commercial, institutional, etc.) and unmetered (non-revenue) (Institute for Sustainable Futures, 2002).

Despite these enormous dissimilar uses of water, a common area of interest for policymakers and hence researchers is the urban water demand forecasting (Worthington, 2010). This is an essential work as it allows water providers often in highly regulated sectors, to better understand and manage the needs of their customers.

More specifically, urban water demand forecasting is useful to the water authorities for effective planning for present and future needs including water rates setting, revenue forecasting and budgeting, water conservation program tracking and evaluation, and system operations management and optimization (Department of Sustainability and Environment, 2011). There are two types of urban water demand forecasting; 1) short term water demand forecasts (i.e. month to year), which are used for system operation as well as budgeting and financial management, and 2) long term water demand forecasts (i.e. years to decades), which are required for planning and infrastructure design (Billings and Jones, 2008).

Urban water demand consists of both residential and non-residential demand. A large amount of work was found in the literature on modelling total urban water demand, mainly focused on water demand modelling in the residential sector, but the existing works were not focused on modelling non-residential water demand both in Australia and overseas. For example, an end-use model is used by water authorities in Melbourne, Australia as the primary tool for its water demand forecasts in which the residential component is extensively modelled (Institute for Sustainable Futures 2005). Total household water use in single-family and multi-residential homes is broken down to the end-use level (e.g. toilets, showers, washing machines, etc.) for forecasting the water demand in the residential sector. However, a simple historical trend-based annual water demand is considered for the non-residential sector, as a whole. No temporal (i.e. quarterly or monthly) and spatial disaggregation are considered in these non-residential water demand forecasts, although they are important for short term sector wise planning and management of urban water system. In addition, the non-residential water demand component is relatively high in many urban areas. For example, in Melbourne, Australia, around 25% of the total water use was used by the non-residential sector in 2014-2015 (Melbourne Water, 2016). Consequently, the non-residential water demand forecasting has great importance for effective urban water demand management. Therefore, to promote research in non-residential water demand sector, this project aims to forecast water demand in non-residential sector. Moreover, this research mainly focused on short term water demand forecasting, more specifically at quarterly time step as this is the usual time interval for billing non-residential water use.

1.2. Problem Statement and Motivation of this Study

Australia is a highly urbanized country (around 89 percent of the population lives in towns and cities), and urban populations are expected to grow rapidly over the next 40 years (Collett and Henry, 2011). Many urban areas have been relied on limited water supplies. To better manage the urban water supply systems with the limited water resources, a large number of studies have been conducted on modelling urban water use in Australia as well as around the world (e.g., Miaou, 1990a; Zhou *et al.*, 2000; Gato *et al.*, 2007b, Perera *et al.*, 2009, Blokker *et al.*, 2010). These studies focused either on the total urban water use or in most cases on modelling the residential water use component. However, as was mentioned in Section 1.1, a significant portion of urban water usage is non-residential (around 25% of total water use in Melbourne). Therefore, modelling non-residential urban water use has significant importance for effective water resources management in any urban area. However, there was not much attention given to model non-residential urban water use. This is an important omission, but has enormous importance to address the emerging water-related challenges including the need for a reliable water supply, rising water prices and seasonal water scarcity (Worthington, 2010). Therefore, reducing the knowledge gap in urban water demand modelling for non-residential sector was the primary motivation of this research.

The possible reason for the abovementioned omission is that the appropriate data required for estimating non-residential water use is difficult to collect and also the heterogeneous nature of this sector. These challenges have been addressed in various ways recently and they are:

1) Billing data at individual customer level is now available in electronic formats (Polebitski and Palmer, 2010). These data can be used to model non-residential water use.

2) The heterogeneous nature of non-residential urban water demands can be handled through considering several homogenous demand groups based on their activities such as schools and colleges, restaurants, hotels and motels,

laundries and hospitals (Turner *et al.*, 2008). Billings and Jones (2008) also suggested that the water users can also be classified based on their volume of water use. Therefore, it is feasible to disaggregate the non-residential water users into different user groups and conduct specific analysis to forecast non-residential water demand for those user groups.

3) The Institute for Sustainable Futures (2002) found that the water use in the non-residential sector exhibit seasonal patterns as in the residential sector. This pattern can be considered for water demand modelling in the non-residential sector.

All above details also motivated this research work on modelling the non-residential water use.

1.3. Aims of the Research

The main aim of this research is to develop a generic methodology for non-residential urban water demand modelling to forecast quarterly water use in a year for short-term planning as outlined in Section 1.1. This aim was achieved through conducting research via the following tasks:

1. Disaggregation of non-residential water use customers based on the homogenous water use activities such as Schools, Hospitals and Restaurants (i.e. water use customer groups), and then further disaggregation of each customer group based on the average annual water use.

2. Identification of quarterly water use patterns of the different customer groups.

3. Development of water demand models for forecasting short term non-residential water demand using the identified water use patterns at disaggregated customer group levels.

The developed methodology is demonstrated via a case study using the non-residential water use within the Yarra Valley Water (YVW) service area which is managed by the YVW retailer in Melbourne, Australia. This approach can be adapted to any other urban water supply system in Australia as well as in other countries around the world to develop own non-residential water demand models using their water use data.

The results of this research project will be useful for short term planning of urban water resources system. This research is also expected to assist water resources managers in decision making related to water conservation program evaluation and water pricing policy assessment for sustainable water resource management.

1.4. Scope of the Study

The scope of the research was to develop non-residential urban water demand models to forecast quarterly water demand at disaggregated levels of homogenous non-residential customers.

Limitations of the study include the followings:

- There were many non-residential customers with different homogenous activities could not be identified and were not included in the study.
- All the data for influential variables were not available for most of the identified homogenous customers groups. Therefore, modelling among these groups is limited in explaining unexpected water use variation.
- All the models performance were measured with the assumption that historical data as the observed data in forecasting period.

1.5. Research Methodology in Brief

The following tasks were conducted in this research project to achieve the above aims:

1. Review of urban water demand modelling approaches
2. Selection of study area, and data collection and processing
3. Water use modelling at disaggregated customer group level

Brief descriptions of each of the above tasks are given below.

1.5.1. Review of Urban Water Demand Modelling Approaches

There are few studies were found on water demand modelling in the non-residential sector. Most of the studies were on modelling the total urban water demand predominantly focused on residential sector. Therefore, a review of existing modelling approaches which were used in both residential and non-residential water demand modelling as well as on the total urban water demand modelling were conducted in this research. This was done to understand the existing modelling approaches and to select a suitable modelling approach for this research. It should be noted that consideration was also given on data requirements during selection of a suitable modelling approach as generally limited data are available in the non-residential sector, as was the case for this study.

1.5.2. Selection of Study Area, Data Sources and Processing

The Yarra Valley Water (YVW) service area which is managed by the YVW retailer was selected as the case study area in this research for modelling non-residential urban water use. The YVW is the largest water retailer in Melbourne which has valuable contribution to water service delivery for a large population. As the YVW provides water service to more people than the two other water retailers in Metropolitan Melbourne (i.e. City West Water (CWW) and South East Water (SEW)), it was considered to have more variation in different types of non-residential customers (e.g. industrial, commercial and institutional) than the two other water retailers in Melbourne. Water use and water restrictions data, and climate data used in this research were collected from the YVW and the Bureau of Meteorology (BoM) respectively. Data processing and analysis were then carried out to obtain the water use patterns which were used for water use modelling at disaggregated customer group levels.

1.5.3. Water Use Modelling at Disaggregated Customer Groups Levels

As was outlined in Section 1.3, based on the different activities, all water use customers were disaggregated into several groups based on homogenous use of water such as Schools, Sports Grounds, Councils, Restaurants, Hospitals, Hotels, and Laundries. The high water users in the study area were also considered as a separate group in this study named as High Water Users. Data analysis for each of these groups was then carried out individually to explore the water use pattern at the disaggregated levels as well as to identify the variables that affect the water use in these customer groups.

In general, there are outdoor uses in Schools, Sports Grounds and Councils groups, and therefore, water use modelling was performed using the Multiple Linear Regression (MLR) technique considering climate data and water restrictions data. On the other hand, as most of the water use in Restaurants, Hospitals, Hotels, and Laundries groups are for indoor purposes, water use modelling was carried out with the past water use data only due to limitation of data availability of other influential factors.

It should be noted that some customers were not identified with any particular activity and named as Others group. However, due to availability of limited information, water use modelling was not performed for this customer group in this research.

1.6. Research Significance, Outcomes and Innovations

1.6.1. Significance

This research project has made several significant contributions in the field of urban water resources management, specifically in short term water demand modelling within the non-residential sector. They are listed below:

- As was mentioned in Section 1.2, very limited work was found in the literature for modelling urban water demand in the non-residential sector, which uses a considerable amount of water. Therefore, the proposed non-residential water demand modelling using disaggregation approach will be a valuable contribution to the water resources managers and researches for producing an accurate estimation of non-residential water demand.

- Data analysis and modelling non-residential water demand carried out in this research at various disaggregation levels (e.g. activities and water use volumes) helped in better understanding of water use behaviour in various disaggregated demand sectors. The developed individual water demand forecasting models in this study will allow the visualization and evaluation of water demand information at different spatial scale (i.e., water distribution zone, census tract) in combination with the customer's geographic locations. This information is useful to the water authorities to make informed decisions when they consider options for conservation efforts to cope with the limited water resources.

- A list of issues and challenges in modelling water use in different non-residential customers were identified in this research, which will be valuable resources to the researchers in urban water area for considering future research in non-residential urban water demand modelling.

1.6.2. Outcomes

The outcomes of this research are listed below:

- Water use pattern analysis at disaggregated level was useful for identifying the customer groups who are affected by weather. It was found that water use in Schools, Sports Grounds and Councils are affected by weather, and there were not much effects of weather on water use in Restaurants, Hospitals, Hotels and Laundries groups.

- Water use data analysis at disaggregated level showed that water use pattern not only varies from one customer group to another, but also varies from high water user to low water user customers within the same customer types (such as the School group).

- Introduction of disaggregation approach was successful in explaining water use variations for modelling non-residential water demand in this research.

- Unlike the modelling urban water demand in the residential sector, it was found that there are significant issues and challenges in the non-residential sector. These are not limited to the availability of historical water use data in different non-residential sectors and the data on variables that affect non-residential demand, but also they are related to the variability in water uses at the temporal scale. These issues and challenges are listed in various chapters in this thesis.

1.6.3. Innovation

There were few studies discussed about the heterogenous nature of the non-residential water use sector (Section 1.2). However, no study was found in developing sector based non-residential water demand model. Therefore, the major innovation of this study is the development of a disaggregation approach for sector based non-residential water demand modelling. This approach was successfully illustrated in this research through disaggregating the non-residential customers based on homogenous water use activities and also based on the annual water use volume within each customer group, and subsequently, water demand modelling was carried out for each customer group. The development of non-residential water demand model at individual level in this research is also the knowledge advancement in the non-residential water demand forecasting as limited work was found in this area.

1.7. Thesis Layout

The thesis layout is presented in Figure 1.1. This figure shows that the thesis consists of seven chapters. The background of the research project along with the motivation for the study, the aims, a brief methodology, the significance, outcomes and innovations of this project are presented in the first chapter. The second chapter presents a review of existing literature related to the research project. Details of the study area, data used in this research, and their sources and processing are described in the third chapter. The fourth chapter provides details on water use modelling for Schools, Sports Grounds and Councils groups. Water use modelling performed for Restaurants, Hospitals, Hotels and Laundries groups are presented in the fifth chapter. The sixth chapter provides the details on water use modelling for High Water Users group. Finally, a summary of the thesis and the main conclusions, and the recommendations for future work are presented in the seventh chapter.

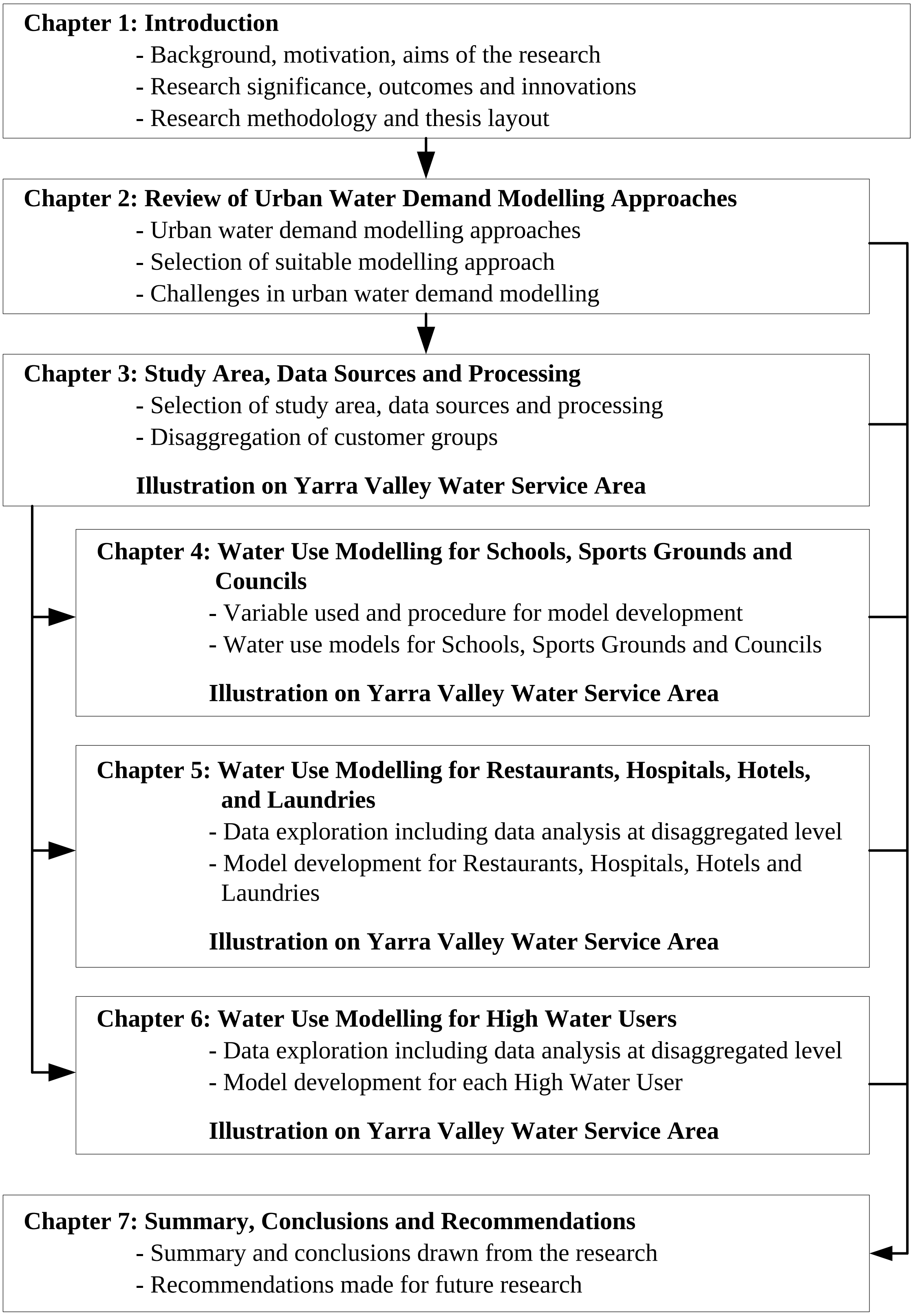


Figure 1.1 Thesis layout

Chapter 2. Review of Urban Water Demand Modelling Approaches

2.1. Overview

Urban water demand modelling is an essential tool for design, operation, and management of urban water supply systems. It supports a number of activities such as: planning new developments or system expansion; estimating the size and operation of reservoirs, pumping stations and pipe capacities; pricing policies setting; and water use restrictions (Bougadis *et al*, 2005; Herrera *et al*, 2010). There are two types of urban water demand modelling: short term and long term demand modelling. Short term water demand modelling helps water managers making better informed water management decisions when balancing the needs of water supply and demand for residential and non-residential sectors (Bougadis *et al*, 2005). It also helps water utilities to plan and manage water demands for near-term events (Jain and Ormsbee, 2002). Long term water demand modelling is required for planning and infrastructure design (Herrera *et al*, 2010; House-Peters and Chang, 2011). Therefore, reliable urban water demand modelling plays a key role in assisting water managers and utilities for optimizing their operational and investment decisions (Cutore *et al*, 2008; Donkor *et al*, 2014).

Urban water demands are highly variable and depends on various factors such as size of city, characteristics of the population, the nature and size of commercial and industrial establishments, climatic conditions, and cost of supply (Zhou *et al*, 2002). Therefore, modelling urban water demand has always been a challenging task. Traditionally, urban water demand modelling has been carried out using a range of modelling approaches varying from simple to complex mathematical formulations. Some are suitable for short term water demand modelling, and they include trend analysis, analysis of base and seasonal use, and end-use modelling approaches (Zhou *et* *al*, 2000; Billings and Jones, 2008; Blokker *et al*, 2010; 2011). Others that are suitable for long-term water demand modelling include regression and artificial intelligence techniques (Miaou, 1990b; Ghiassi *et al*, 2008; Yurdusev and Firat, 2009). A vast amount of literatures are available on these modelling approaches which have been used in the past. Nevertheless, knowledge base of urban water demand modelling has changed progressively to adapt with the changes in coupled human and natural system (House-Peters and Chang, 2011). Therefore, understanding of the current and historical modelling approaches used in urban water demand modelling is crucial for making any future contributions to the field.

The aim of the current chapter is to review the existing urban water demand modelling approaches which have been used for total urban water demand modelling as well as for modelling the residential and the non-residential water demands individually. The outcome of this chapter was used to identify the suitable non-residential water demand modelling techniques in this research. It was outlined in Section 1.1 (Chapter 1) that most of the modelling works in the literature were focused on total urban water demand with special attention to the residential sectors. Therefore, it should be noted that although the focus of this research is the non-residential urban water demand modelling, literature review was extended to the works done in the residential and the total urban water demand modelling, as only few studies were found on water demand modelling in the non-residential sector.

The chapter first reviews the existing modelling approaches applied in urban water demand modelling, followed by selection of suitable modelling approach for this research. The understanding of challenges in urban water demand modelling was then presented. A summary of the review is presented at the end of the chapter.

2.2. Urban Water Demand Modelling Approaches

As stated earlier, there are several urban water demand modelling approaches that have been used around the world to develop urban water demand models for estimating urban water use. Among them, the most commonly used approaches are: historical average or pattern based approach (Snelling *et al*, 2005; Alvisi *et al*, 2007);

climate correction (Maheepala and Roberts, 2006; Perera *et al*, 2009); trend analysis (DEUS, 2002; Billings and Jones, 2008); analysis of base and seasonal use (Maidment *et al*, 1985; Zhou *et al*, 2000; Gato *et al*, 2007b); regression modelling (Froukh, 2001; Berke *et al*, 2002; Babel *et al*, 2007); end-use modelling (Roberts, 2005; Gato *et al*, 2007a; Blokker *et al*, 2010; 2011); agent based modelling (Athanasiadis *et al*, 2005; Galán *et al*, 2009); and artificial intelligence methods (Ghiassi *et al*, 2008; Yurdusev and Firat, 2009). Few other approaches were also found which have limited application for specific purpose or applied in a particular region; list of these approaches can be found in House-Peters and Chang (2011) and Donkor *et al* (2014).

A summary of the abovementioned approaches used in urban water demand modelling is presented in Table 2.1 with some of the important features listed, including explanatory variables considered in these approaches, modelling time steps, sector coverage of model application and location of study conducted. Further details on these modelling approaches are briefly discussed below in several sub-sections. It should be noted that in-depth mathematical details of these modelling approaches are not provided in this section, as all of them were not used in this research. Mathematical details will be provided only for the modelling techniques that were used in this study in the various sections of Chapters 4, 5 and 6. The reader is referred to the original references listed in Table 2.1 for further details of the other approaches.

2.2.1. Historical Average or Pattern Based Approach

The historical average or pattern based approach is used by the water utilities as the primary method for estimating water demand (Institute for Sustainable Futures, 2011). In this approach, the historical average or water use patterns are determined based on different ways, these are:

1) Per capita based: average per capita per day (PCPD) water use is first calculated based on historical bulk water use data. The PCPD water use value is then multiply with the projected population. This approach is applied by Snelling *et al* (2005) in the three water utilities (i.e. City West Water, South East Water and Yarra Valley Water) in Melbourne, Australia to estimate the PCPD residential water demand;

Table 2.1 Summary of urban water demand modelling approaches

Modelling Approach	**Reference**	**Explanatory Variable/ Data Used**	**Time Scale**	**Sector**	**Location of Study**	**Purpose of Study**
Historical Average or Pattern Based (Section 2.2.1)	Snelling *et al* (2005)	Past water use, Population	Daily	Residential	Melbourne, Australia	To estimate the per capita per day residential water demand.
	Snelling *et al* (2005)	Past water use, Population	Annual	Non-residential	Melbourne, Australia	To estimate per property non-residential water demand.
	Alvisi *et al* (2007)	Past water use	Daily, weekly	Total urban area	Castelfranco Emilia, Italy	To estimate total urban water demand.
Climate Correction (Section 2.2.2)	Maheepala and Roberts (2006)	Past water use, Climate variables, Population	Daily	Total urban area	Yarra Valley Water, Melbourne	To estimate total urban water demand.
	Perera *et al* (2009)	Past water use, Climate variables, Population	Daily	Total urban area	Barwon Water, Geelong	To estimate total urban water demand
Trend Analysis (Section 2.2.3)	DEUS (2002)	Past water use	Daily	Total urban area	NSW, Australia	To understand the climate effects in total urban water demands.
	Billings and Jones (2008)	Past water use	Daily	Total urban area	All states, USA	To detect the trend in total urban water demand.
Analysis of Base and Seasonal Use (Section 2.2.4)	Maidment *et al* (1985)	Past water use, Temperature	Daily	Total urban area	Austin at Texas, USA	To model the daily base and seasonal water use.
	Maidment and Miaou (1986)	Past water use, Temperature	Daily	Total urban area	Florida, Pennsylvania and Texas, USA	To model the daily base and seasonal water use.

	Zhou *et al* (2000)	Past water use, Temperature, Evaporation	Daily	Total urban area	Melbourne, Australia	To model the daily base and seasonal water use.
	Gato *et al* (2005)	Rainfall, Temperature	Daily	Total urban area	East Doncaster, Australia	To model the daily base and seasonal water use.
	Gato *et al* (2007b and 2007c)	Rainfall, Temperature, Evaporation, Socioeconomic factors (e.g., Population, Household income and Water price)	Daily	Residential	East Doncaster, Australia	To model the daily base and seasonal water use.
	Miaou (1990a)	Rainfall, Temperature, Evaporation, Socioeconomic factors (e.g., Population, Household income and Water price)	Daily, Monthly	Total urban area	Austin at Texas, USA	To model the daily base and seasonal water use.
Regression Modelling (Section 2.2.5)	Froukh (2001)	Past water use, Household income, Household occupancy rate, Household composition (i.e., number of adults in relation to children), Water price, Climatic conditions (i.e., Rainfall and Temperature)	Daily	Residential	Swindon, UK	To estimate daily household consumptions.
	Babel *et al* (2007)	Population, Ratio of the total population to the university student, household size, Number of households, Income, Water price, Educational level, Temperature, Rainfall	Daily	Residential	Kathmandu Valley, Nepal	To estimate daily household consumptions.

	Polebitski and Palmer (2010)	Population, household size, Lot size, Number of households, Income, Water price, Temperature, Rainfall, Policy	Bi-monthly	Residential	Seattle, Washington, USA	To model single family residential water demands within individual census tracts.
	Williams and Suh (1986), Schneider and Whitlach (1991)	Customer size, Different price measures (e.g., Marginal price, Average revenue, etc.), Average temperature during summer months	Annual	Non-residential	USA	To model annual water demand for commercial and industrial sectors.
	Malla and Gopalakrishnan (1999)	Water Price, Number of Employee	Monthly	Non-residential	Honolulu	To model monthly water demand for commercial and industrial sectors.
	Miaou (1990b)	Water price, Household income and population, Total annual precipitation, Total annual precipitation in the summer months, Average yearly temperature, Average yearly temperature in the summer months	Annual	Residential	Oklahoma City, Tulsa and Tucson area, USA	To modelling annual residential water demand.
	Berke *et al* (2002)	Water Price, Temperature, Rainfall	Monthly	Residential	Washington, USA	To model monthly single-family residential water demand.
End-Use Modelling (Section 2.2.6)	Mayer *et al* (1999)	Census data such as the number of people per household and their ages, The frequency of use, Duration and flow per water-use event, Occurrence over the day for different end-uses such as flushing the toilet, doing the laundry, washing hands, etc.	Daily	Residential	Several states in USA	To analyse water use patterns at end-use level and to estimate daily household water use.

Loh and Coghlan (2003)	Household size, Frequency and duration of occurrence, flow per event.	Daily	Residential	Perth, Australia	To analyse water use patterns at end-use level and to estimate daily household water use.
Roberts (2005)	Household size, Frequency and duration of occurrence, flow per event	Daily	Residential	Melbourne, Australia	To analyse water use patterns at end-use level and to estimate daily household water use.
Heinrich (2007)	Household size, Frequency and duration of occurrence, flow per event	Daily	Residential	Kapiti coast, New Zealand	To analyse water use patterns at end-use level and to estimate daily household water use.
Willis *et al* (2009)	Household size, Frequency and duration of occurrence, flow per event	Daily	Residential	Gold Coast, Australia	To analyse water use patterns at end-use level and to estimate daily household water use.
Jacobs and Haarhoff (2004a; 2004b)	Household size, Frequency and duration of occurrence, flow per event	Monthly	Residential	South Africa	To estimate monthly average water demand for a number of indoor (e.g., bath, dishwasher, shower, etc.) and outdoor (e.g., pool evaporation, garden vegetation, etc.) activities.
Blokker *et al* (2010)	Household size, Frequency and duration of occurrence, flow per event	Second time interval	Residential	Netherlands	To predict water demand pattern at one second time scale.
Gato *et al* (2007a)	Household size, Frequency and duration of occurrence, flow per event	5 Second time interval	Residential	Greater Melbourne, Australia	To model GIS-based end water use.
Blokker *et al* (2011)	Household size, Frequency and duration of occurrence, flow per event	Second time interval	Non-residential	Netherlands	To predict water demand pattern in office buildings, hotels and nursing homes.

	Pieterse-Quirijns *et al*, (2010)	Household size, Frequency and duration of occurrence, flow per event	Second time interval	Non-residential	Netherlands	To drive design rule through end-use demand modelling.
Agent Based Modelling (Section 2.2.7)	Athanasiadis *et al* (2005)	Simulator agent, Meteorological agent, Water supplier agents, Consumer agents	Monthly	Residential	Thessaloniki, Greece	To simulate the residential water demand and supply chain.
	Rixon *et al* (2007)	Artificial data	Quarterly	Total urban area	Australia	To explore the effects of tariff structure depletion on urban water demand.
	Perugini *et al* (2008)	Household type, Price	Yearly	Residential	Australia	To analyse the impact of urban water trading on households.
	Galán *et al* (2009)	Past water use, socioeconomic and geo-referenced data, Urban development plan, Census data	Quarterly	Residential	Valladolide, Spain	To evaluate the impacts of interactions between water consumption, urban dynamics, technological and opinion diffusion.
Artificial Intelligence Methods (Section 2.2.8)	Jain *et al* (2001)	Past water use, Temperature, Rainfall	Weekly	Total urban area	Kanpur, India	To predict weekly urban water demand.
	Bougadis *et al* (2005)	Past water use, Temperature, Rainfall	Weekly	Total urban area	Ottawa, Canada	To predict weekly urban water demand.
	Zhang *et al* (2006)	Past water use, Temperature, Rainfall	Weekly	Total urban area	Louisville, USA	To predict weekly urban water demand.
	Adamowski (2008)	Past water use, Temperature,	Daily	Total urban area	Ottawa, Canada	To forecast peak daily urban

		Rainfall, Population				water demand.
	Firat *et al* (2009; 2010)	Past water use, Temperature, Rainfall, Past water use	Monthly	Total urban area	City of Izmir, Turkey	To forecast monthly urban water demand.
	Herrera *et al* (2010)	Past water use, Temperature, Rainfall, Past water use	Hourly	Total urban area	South-eastern Spain	To forecast hourly urban water demand.
	Ghiassi *et al* (2008)	Past water use, Temperature, Rainfall, Past water use	Monthly, Weekly, Daily, Hourly	Total urban area	San Jose, California, USA	To forecast monthly, weekly, daily and hourly urban water demand.
	Yurdusev and Firat (2009)	Average monthly water bill, Population, Number of households, Gross national product, Monthly average temperature, Monthly total rainfall, Monthly average humidity, Inflation rate	Monthly	Total urban area	Izmir, Turkey	To forecast monthly urban water use.

2) sector based: average water use per sector such as residential (single and multi-residential properties), non-residential (commercial, industrial, institutional, etc. sectors) and non-revenue (real and apparent losses) is first calculated. This is then projected based on population growth or sector-specific base units (e.g. number of properties or utility accounts, employment, floor space, etc.). Snelling *et al* (2005) also used this approach to estimate non-residential water demand per property in the three water retailers (i.e. City West Water, South East Water and Yarra Valley Water) in Melbourne, Australia;

3) pattern-based: average water use is calculated at different time steps such as daily or weekly for the Julian day or specific week of the year to get the water use pattern at different time scale. This approach is used by Alvisi *et al* (2007) in the municipality of Castelfranco Emilia, Italy to estimate the total urban water demand.

The historical average or pattern based approach is a simple water use estimation method and easy to use by water utilities. However, this approach relies on a historical average to estimate future water use and has limited capability to adequately account for changes in demand caused by external factors such as climate, structural (e.g. growth in use of more water efficient appliance such as dual flush toilets and low flow shower heads) and other changes to the urban water system (e.g., increased dependency on water source, such as rainwater and major reuse) (Institute for Sustainable Futures, 2011). Hence, it is necessary to complement this primary forecasting method with other analytical techniques that adequately account for the impacts of the above factors.

2.2.2. Climate Correction

The process that uses for identifying and quantifying the influence of weather on urban water use is called climate-correction (Maheepala and Roberts, 2006). Specifically, climate correction is a process in which observed water use values are adjusted by either increasing or decreasing it to a level that it would have been under normal climatic conditions in the absence of water restrictions. The normal climatic condition represents the typical climate of the area of interest and it is usually defined as the 30-year average of climatic parameters (Maheepala and Roberts, 2006; Perera *et al*, 2009). In more recent years, the climate correction process is occasionally applied to the estimated water demand obtained by using the abovementioned historical average or pattern based approach to get the climate corrected PCPD water demand (Institute for Sustainable Futures, 2011). Application of climate correction process allows accounting the influence of climate and weather in calculation of PCPD water demand.

Primarily, the climate correction method first establish an appropriate starting point for demand projections, ensuring that the starting point for a forecast is based upon a figure for demand that is representative of typical seasonal demand and not influenced by a typical weather (Beatty *et al*, 2007). Water demand is then extrapolated from this starting point based on population (or other base unit) growth using historical average or pattern based approach. In recent years, the climate correction approach is applied by Maheepala and Roberts (2006) in the Yarra Valley Water (YVW) service area in Melbourne, Australia and by Perera *et al* (2009) in the Barwon Water service area in Geelong, Australia for estimating daily total urban water use. There are some other applications of this approach were also found in the literature, a list of these works can be found in Institute for Sustainable Futures (2011).

The formulation of a climate correction model typically involves performing a multiple regression on water demand/use in a selected ‘baseline’ period. Outside of this baseline period, there is no certainty that the derived relationships will hold (Institute for Sustainable Futures, 2011). Therefore, the climate correction models are not used to generate demand forecasts directly; rather it has been used as a part of the other water demand modelling approaches such as trend analysis, and base and seasonal uses analysis.

2.2.3. Trend Analysis

Analysis of trends in urban water demand is a simple and essential part that has been most commonly used to provide an indication of long-term changes in water demand on an aggregated or PCPD or per sector (e.g. household, building, production unit) basis (Institute for Sustainable Futures, 2011). The most straightforward means of identifying longer term trends in demand is to apply a moving (or running) average to time series of customer meter demand data (CMDD) or bulk water production data (BWPD), thereby smoothing the 'noise' in the data to reveal the more general direction of demand over the period of interest (Billings and Jones, 2008). The identified trend is then adjusted for weather effects using the climate correction approach discussed earlier. This is to avoid the influence of any extreme climate events or climate variability.

The trend analysis approach was used by DEUS (2002) in developing Water Demand Trend Tracking and Climate Correction software (Version 10, May 2002) to be used by New South Wales (NSW) water utilities in Australia to get a better understanding of climate effects in determining total urban water demands. This approach was also used by Billings and Jones (2008) across all states in USA for detecting trend in total urban water use. The application of the trend analysis approach is useful at a broad strategic level of planning. Moreover, the trend analysis at sector based is also useful in developing projections of demand for PCPD or sector-based forecasts. While the trend analysis approach can provide some insight into the presence of trends in water demand, the approach is unable to explain causes of the trends that are occurred. Nevertheless, identifying the trends in water use with the trend analysis approach helps to further investigate different analytical techniques such as fitting a regression model.

2.2.4. Analysis of Base and Seasonal Use

Analysis of base and seasonal use approach has been widely used in total urban water demand modelling (Maidment *et al*, 1985; Zhou *et al*, 2000; Gato *et al*, 2007b). Total urban water use is considered as the sum of base and seasonal use. In general, base use is defined as the average low period (i.e. winter) use, and seasonal use is defined as the water use obtained by subtracting base use from the total use (Danielson, 1979; Billings and Jones, 2008). Further, the seasonal use has been analyzed in three separate components: seasonal cycle, potential or climate dependent, short memory or persistent water use. Methods used for modelling the base and seasonal use are discussed below.

Base Use:

Typically, the base use is considered as the monthly (or daily) average water use identified from the lowest monthly (or daily) water use and assume that it is weather insensitive. This technique was used by Maidment *et al* (1985) in Austin at Texas, USA to model the daily base water use. The same technique was also applied in nine cities from Florida, Pennsylvania and Texas, USA by Maidment and Miaou (1986) and in Melbourne, Australia by Zhou *et al* (2000). However, studies conducted by Gibbs (1978), Miaou (1987) and Gato *et al* (2003) found that the base water use can also be quite weather sensitive in some areas. Therefore, in recent times, researchers modelled the base water use (mainly indoor water use) as function of climatic variables such as rainfall and temperature, and socioeconomic factors such as population, household income and water price. Some examples of the application of this technique are: Gato *et al* (2005) modelled daily base water use at East Doncaster water supply distribution zone level in Australia as a function of daily air temperature and total rainfall; later, Gato *et al* (2007b and 2007c) also included the socioeconomic factors with these two climatic variables where they have modelled the daily base water use for the same study area. This approach was also applied by Miaou (1990a) in Austin at Texas, USA to model the monthly base water use.

Seasonal Use:

Seasonal water use is the remaining water use (mainly outdoor water use) component after the expected base water use is subtracted from the total water use. This component of the total water use is weather sensitive and generally varies with climate conditions such as temperature, evaporation and rainfall (Gato *et al*, 2005). Miaou (1990a) modelled the monthly seasonal water use separately in two different components: potential and short memory water use. Potential water use was modelled as a function of monthly maximum air temperature. The short memory water use was obtained by subtracting the potential water use from the total seasonal water use, and modelled as a function of monthly total rainfall. A different approach was used by Maidment *et al* (1985), Maidment and Miaou (1986), and Gato *et al* (2005) to model these two components at daily time scale. They modelled the potential water use as a function of normal or average air temperature which was calculated from the long term records. The short memory water use was modelled as a function of residual air temperature which was obtained after deducting the normal air temperature from the daily maximum record. In different studies, Zhou *et al* (2000) and Gato *et al* (2007b and 2007c) modelled the seasonal water use at daily time scale separately in three different components: seasonal cycle, climate dependent and persistent water use. The seasonal cycle component represents the periodic pattern of water use in a calendar year and modelled as the daily means in yearly records. The climate dependent seasonal water use represents the dependence of water use on weather and modelled as function of daily maximum air temperature, and total rainfall and evaporation. The persistent water use represents the dependence of water use on its own past value which is the remaining portion of seasonal water use after subtracting the seasonal cycle and climate dependent water use. An autoregressive procedure was fitted to this residual time series.

The analysis of base and seasonal use approach is relatively easy and simple to use. However, its application is often specific to a region and depends on reliable data available at small time scale such as daily or monthly time scale. Moreover, the base water use identified using the above techniques does not necessarily correspond to indoor water use as garden watering may be occurred even during the periods of minimum demand (Institute for Sustainable Futures, 2011). Nonetheless, despite peak seasonal use generally being associated with discretionary uses, such as watering and evaporative cooling, the assumption that base use directly reflects non-discretionary use is also confounded by winter watering. Thus, close attention is required to the distinction between base and non-discretionary, and between seasonal and discretionary water demand when interpreting the seasonality of water use in a specific region.

2.2.5. Regression Modelling

Application of several types of regression modelling approaches was found in residential and non-residential water demands modelling. The commonly used regression models are: simple linear regression (Froukh, 2001), multiple linear regression (MLR) (Froukh, 2001; Babel *et al*, 2007; Williams and Suh, 1986; Malla and Gopalakrishnan, 1999) and stepwise MLR (Miaou, 1990b; Berke *et al*, 2002) models. Unlike the base and seasonal water use approach, the regression modelling approach models the total water use without splitting into several components. The total water use was modelled as a function of a set of explanatory variables such as household income, household occupancy rate, water price and climatic variables (e.g. rainfall and temperature).

The simple linear regression modelling approach was used by Froukh (2001) for the Swindon area located in the Wiltshire municipality of Thames basin, UK to project the future daily household consumptions based on the available historical records. Froukh (2001) also used the MLR modelling approach to estimate daily household consumptions for the same area with a set of independent variables such as household income, household occupancy rate, household composition (i.e. number of adults in relation to children), water price and climatic conditions (i.e. rainfall and temperature), and incorporated this approach in their decision support system as an alternative approach to be used depending on data availability. The MLR modelling approach was also used by Babel *et al* (2007) to model daily total residential water use in Kathmandu Valley, Nepal where nine independent variables (i.e. population, ratio of the total population to the university student, household size, number of households, income, water price, educational level, temperature and rainfall) were used. Polebitski and Palmer (2010) also used a similar approach for modelling single family residential water demands within individual census tracts in Seattle, Washington, USA at bimonthly time-step.

Few studies were also found on application of the regression modelling approach for estimating non-residential water demand, mostly the MLR modelling approach. It was used by Williams and Suh (1986), and Schneider and Whitlach (1991) for developing annual water demand models for commercial and industrial sectors in USA. Several explanatory variables including customer size, different price measures (e.g., marginal price, average revenue, etc.) and average temperature during summer months were used in their studies. A similar approach was also used by Malla and Gopalakrishnan (1999) where the monthly non-residential demand models were developed for the abovementioned sectors in USA.

It can be seen from the above discussion that the MLR modelling approach was the regression approach that was used mostly for both residential and non-residential water demand modelling. However, Miaou (1990b) noted that the MLR modelling approach has four associated issues: 1) it require long records of time series data; 2) need to consider a large set of candidate explanatory variables; 3) input variables can be highly correlated with each other (i.e. multi-collinearity issue); and 4) model error series are often highly auto-correlated or even non-stationary. To overcome these issues, a stepwise MLR modelling approach was proposed in that study where they tested the proposed approach for Oklahoma City, Tulsa and Tucson area in USA by developing annual residential water demand model. Dependent variables were used in that study: water price, household income, household population, total annual precipitation, total annual precipitation in the summer months, average yearly temperature and average yearly temperature in the summer months. The proposed procedure adopted the sequential input variable selection concept of stepwise regression. The stepwise selection procedure begins with a univariate time series demand model with no input variables. Subsequently, input variables are selected and inserted into the equation one at a time until the last entered variable is found to be statistically insignificant. The order of insertion is determined by a statistical measure called between-variable partial correlation. This correlation measure is free from the contamination of serial autocorrelation. The stepwise MLR modelling approach was also found to be quite successful by Berke *et al* (2002), where this approach was used to develop monthly single-family residential water demand model for Lakehaven Utility District in Washington, USA.

2.2.6. End-Use Modelling

The “end-use” of water is a breakdown of the total water usage at the user end levels such as toilet, shower, taps, lawn watering, etc (Gato, 2006). The end-use water demand modelling approach has been used to estimate urban water demand and simulate the water demand patterns by considering humans behavioral parameters (e.g. frequency of use, duration and flow per use-event, etc.) (Roberts, 2005; Gato *et al*, 2007a; Blokker *et al*, 2010; 2011). This approach was developed based on large amount of statistical information of users and end-uses. They are: census data such as the number of people per household and their ages; the frequency of various end uses; duration and flow per water-use event; and occurrence over the day for different end-uses such as flushing the toilet, doing the laundry, washing hands, etc (Blokker *et al*, 2010). Therefore, to apply this approach an extensive field survey is required to collect these micro scale water use data. Once these data are available, water use patterns are analysed and subsequently water demand models are developed using simple water demand modelling approaches mentioned earlier such as pattern based, trend analysis and regression modelling approaches.

There are number of end-use studies that were found on residential water use around the world. Mayer *et al* (1999) conducted an extensive end-use study on residential water use across several states in USA where they conducted mail surveys over 5,000 households and details end-use data collected from around 1,200 households. Loh and Coghlan (2003) conducted an end-use study in Perth, Australia where water end-use data were collected from around 1,000 households. A similar study was also performed by Roberts (2005) in Melbourne, Australia where the end-use data were collected for 100 selected households from 840 appliance stock and usages pattern survey participants. Heinrich (2007) conducted an end-use study in Kapiti coast, New Zealand on 12 households. Willis *et al* (2009) conducted detailed end-use analysis in Gold Coast, Australia on two highly variable water end-uses namely shower and irrigation. Water use patterns were analysed at end-use level in most of these studies using pattern based and trend analysis approaches. In some of these studies, simple water demand models were also developed to estimate daily household water use in a multiplicative form where co-efficient for each of the components were determined using the regression modelling approach.

Residential end-use water demand modelling was also found at different temporal scale using the household end-use data. Jacobs and Haarhoff (2004a; 2004b) developed an end-use model in South Africa to estimate monthly average water demand for a number of indoor (e.g. bath, dishwasher, shower, etc.) and outdoor (e.g. pool evaporation, garden vegetation, etc.) activities. Blokker *et al* (2010) developed an end-use simulation models in Netherlands to predict water demand pattern at one second time scale. Gato *et al* (2007a) developed a GIS-based end-use demand model in Greater Melbourne, Australia using end-use data at 5 seconds interval. Rathnayaka et al (2017) developed end-use based models for predicting residential water use at different time-scale in Melbourne, Australia.

Limited studies were found on end-use modelling in non-residential sector. This is due to lack of end-use data which is not readily available for the non-residential sector and they are also difficult to collect. Blokker *et al* (2011) developed end-use based non-residential water demand simulation model in Netherlands to predict water demand pattern in office buildings, hotels and nursing homes at one second time scale. They used a modular approach where assumption was made that each type of building is composed of functional rooms such as lodging, restaurant and conference rooms. A functional room is characterised by its typical users and water using appliances. With this work, they have extended the end-use modelling capability to non-residential water demand in SIMDEUM (SIMulation of water Demand, an End-Use Model) model. Pieterse-Quirijns *et al*, (2010) used the simulated data from SIMDEUM model to drive design rule through end-use demand modelling in Netherlands for the peak demand values of both cold and hot water for various types of non-residential buildings such as offices, hotels and nursing homes.

Although human behavioural parameters were considered in the end-use modelling approach, but it is limited to simulate the consumer behaviour and responses to urban water planning policy and initiatives (Institute for Sustainable Futures, 2011). Moreover, this approach require a significant amount of disaggregated data that are usually not available and difficult to collect, thus the end-use modelling approach is expensive and often impractical (Galan *et al*, 2009).

2.2.7. Agent Based Modelling

The agent based modelling (ABM) approach has been used for residential water management because of its ability to address the complexity in the system (House-Peters and Chang, 2011). This approach can simulate complex social interactions between consumers and demand management policy instruments such as water pricing, public awareness campaigns and urban water trading. The ABM approach typically includes agents to represent water utilities, water regulators and other stakeholders in the water industry (Institute for Sustainable Futures, 2011). The means of defining agents vary with the purpose of the study and with data availability. However, the only agreed feature for an agent is that it can act autonomously, thus it can take decisions and adapt (Rathnayaka, 2015). Agent behaviours such as learning are defined using sets of rules, which can be adaptive or fixed, stochastic or deterministic, and complex or simple (Billari *et al*, 2006).

There are only few applications of ABM that were found in the literature on total urban water demand and residential water demand modelling as this is a fairly new water demand modelling approach. No ABM application was found on non-residential water demand modelling. Athanasiadis *et al* (2005) used the ABM approach in Thessaloniki, Greece to simulate the residential water demand and supply chain using the simulator agent, meteorological agent, water supplier agents and consumer agents. In similar applications in Australia, Rixon *et al* (2007) explored the effects of tariff structure depletion on urban water demand using artificial data, and Perugini *et al* (2008) analysed the impact of urban water trading on households. In a separate application of the ABM approach in Valladolide metropolitan area in Spain, Galán *et al* (2009) evaluated the impacts of interactions between water consumption, urban dynamics, technological and opinion diffusion. Chu *et al* (2009) used the ABM approach in Beijing City, China to evaluate the heterogeneous consumer responses on residential water use.

The ABM modelling approach often requires the input of other models such as end-use models and may form part of a broader modelling framework or a decision support system. The main advantage of the ABM approach is that it has capacity to incorporate behavioural information in water demand modelling, which was the limitation in the end-use modelling approach. However, its success depends on the collection of accurate behavioural data which are not readily available, requiring potentially expensive market research studies (Institute for Sustainable Futures, 2011). In the absence of these data, a range of assumptions require to be made leading to potentially large uncertainties in the model outputs. As a result, the ABM modelling approach has been mainly used to explore the implication of various water conservation scenarios (Institute for Sustainable Futures, 2011), rather than for generating accurate estimation of water demand.

2.2.8. Artificial Intelligence Methods

Artificial intelligence methods such as artificial neural network (ANN) and fuzzy inference system (FIS) have become popular in recent years for forecasting total urban water demand (Bougadis *et al*, 2005; Adamowski, 2008; Ghiassi *et al*, 2008; Yurdusev and Firat, 2009; Firat *et al*, 2009). An ANN is an information processing system that resembles the structure and operation of the brain (ASCE Task Committee on Application of Artificial Neural Networks in Hydrology, 2000; Maier and Dandy, 2000). Given sufficient data and complexity, ANN can be designed to model any relationship between a series of independent and dependent variables. FIS is a rule based system consisting of three components, these are: 1) a rule-base, containing fuzzy if-then rules, 2) a data-base, defining the membership functions (MF), and 3) an inference system that combines the fuzzy rules and produces the system results (Yurdusev and Firat, 2009). In contrast to binary logic, fuzzy logic defines the degree to which a given element belongs to a set and has demonstrated improved forecasting performance over the traditional regression methods by minimizing the deviations of the estimates (Bárdossy *et al*, 2009; House-Peters and Chang, 2011). The ANN and FIS approaches have been used in urban water demand modelling as effective alternatives to traditional linear modelling approaches because of their ability to explicitly analyse nonlinear time series events.

A number of ANN and FIS applications were found around the world on total urban water demand modelling. Jain *et al* (2001), Bougadis *et al* (2005) and Zhang *et* *al* (2006) used the ANN to predict weekly urban water demand in Kanpur (India), Ottawa (Canada) and Louisville (USA) respectively. They used the climate variables such as temperature and rainfall along with past water use as the independent variables in their models. In addition to these variables, population data was also used by Adamowski (2008) to forecast peak daily urban water demand in Ottawa, Canada. A similar approach was also used by Firat *et al* (2009; 2010) to forecast monthly urban water demand for the City of Izmir, Turkey, and Herrera *et al* (2010) to forecast hourly urban water demand in an urban area of a city in south-eastern Spain. In a separate study, Ghiassi *et al* (2008) used an ANN modelling approach to forecast monthly, weekly, daily and hourly urban water demand for the city of San Jose, California (USA). Very few applications of the FIS approach were found in the literature; Yurdusev and Firat (2009) used this approach to forecast monthly urban water use in Izmir, Turkey. They have used several socio-economic and climatic variables including average monthly water bill, population, number of households, gross national product, monthly average temperature observed, monthly total rainfall, monthly average humidity observed and inflation rate.

All above studies in the literature which had used the artificial intelligence modelling approach had shown that it had performed better than the traditional modelling approaches in urban water demand modelling. However, this approach is significantly more time intensive to apply compared to more basic techniques such as the regression approach, requiring trial and error optimization of important network parameters and topology. Moreover, the artificial intelligence modelling approach requires extensive and reliable data dependency which is very hard to get at discrete level. It could be the reason, no work was found to use the ANN modelling approach for modelling residential and non-residential water use separately.

2.3. Selection of Suitable Modelling Approaches for this Project

As can be seen in Section 2.2, only few studies were found on water demand modelling in the non-residential sector mainly due to limited data availability and also large number of challenges involved in this sector compared to the residential sector.

Therefore, the literature review was conducted on modelling of both residential and non-residential demands as well as on total urban water demand (Section 2.2). Suitable modelling approaches were selected based on this review work and also data availability for this study (which will be presented in Chapter 3).

In the review, it was found that the ABM modelling approach is suitable for scenario analysis and it was mainly used to explore the implications of various urban water conservation scenarios (Section 2.2.7). Therefore, the application of this approach was out of scope in this research where the main focus of the study was to estimate water use in non-residential sector (Chapter 1). The analysis of base use and seasonal use, end-use modelling approaches and artificial intelligence methods have shown good capability in water demand modelling (Section 2.2.4, 2.2.6 and 2.2.8 respectively). However, the application of the base use and seasonal use approach, and the artificial intelligence methods require discrete level or shorter time scale (e.g. hourly and daily) data which is not often available in the non-residential sector. On the other hand, the end-use modelling approach requires data at end-use level which is also difficult to collect in the non-residential sector. In case of this study, data were available mostly in quarterly time scale, and only for few customers data were available in monthly time scale (Chapter 3). Also, no data were available at end-use level. Therefore, the adoption of any of these three approaches was not possible in this research. Moreover, as was outlined in Section 2.2.2, the climate correction approach is generally used as part of other modelling approaches such as trend analysis, rather than directly forecasting water demand. Therefore, after considering all the above water demand modelling approaches, regression and historical pattern based modelling approaches were adapted in this research.

As outlined in Section 1.4.3, all non-residential customers were disaggregated into several groups such as Schools, Sports Grounds, Councils, Restaurants, Hospitals, Hotels and Laundries based on their homogenous nature of water use. The above selected modelling approaches were used to model water demand individually for each of these groups based on the data availability of their influential factors. In Schools, Sports Grounds and Councils groups, there are some outdoor water uses and therefore, climate data and water restrictions data were considered for modelling water use among these groups. As discussed in Section 2.2, several regression modelling approaches were found in water demand modelling, and in most cases the MLR modelling approach were used. Therefore, water use modelling was performed using the MLR technique considering climate data and water restrictions data among these customer groups as data related to the other influential factors were not available. However, multiple studies were showed that the MLR approach has some limitation (Miaou, 1990b, Berke *et al,* 2002) and to overcome these limitations a stepwise MLR modelling approach used in this study and presented in Chapter 4. Water use in Restaurants, Hospitals, Hotels and Laundries are mostly for indoor purposes and water use modelling was carried out with the past water use data only due to limitation of data availability of other influential factors. Therefore, historical pattern based approach was used for modelling water use among these groups and presented in Chapter 5. This approach was also used for modelling water use in High Water Users group as limited data was available for this group, and presented in Chapter 6.

2.4. Challenges in Urban Water Demand Modelling

Urban water demands are highly variable and modelling urban water demand is always been a challenging task as outlined in Section 2.1. There are more challenges in modelling water use in non-residential sectors due to large diversity in the customer classes as well as variability in water use. A literature review was also performed to understand the challenges that have been identified in the past studies. A list of challenges noted in the literature is listed below which include both residential and non-residential urban water demand modelling:

- The complex relationship between human and natural systems in urban areas makes urban water demand modelling a complicated process. This relationship results from multiple interactions between micro-scale (i.e. individual, household or parcel level) and macro-scale (i.e. municipal or regional level) processes and patterns (House-Peters and Chang, 2011). This embedded nature of social and ecological systems in natural resource management poses a significant challenge to water managers in urban water demand modelling.

- Urban dynamics put a significant challenge in urban water demand modelling. For instance, people moving from more compact housing (with predominately indoor water use) in the city centre to more disbursed houses in the suburbs (with significant outdoor water use) can significantly increase city-wide water use (Galan *et al*, 2009).

- Incorporating impact of climate change in urban water demand modelling is a challenging task. For this reason, water managers generally produce water demand estimates using long term trends and assume that the natural systems fluctuate within an unchanging envelope of variability (Milly *et al*, 2008). Therefore, uncertainties associated with the impact of climate change limits the accuracy of reliable urban water demand forecasts.

- The outdoor water use is generally poorly characterized as it is dominated by user behaviour rather than the technical efficiency of equipment (White *et al*, 2004). Changes in lawn and garden watering are often driven by land use changes, such as the tendency for new developments to have larger houses on smaller lots, and a trend towards urban consolidation which increases the proportion of multi-family dwellings.

- There is a large number of urban water demand models found in the literature. However, models that contain many variables and those utilize derivatives such as “days since 2 mm of rainfall” pose the greatest challenge to practice in terms of collecting and keeping track of the data (Donkor *et al*, 2014). Operationalising such models will be practically difficult.

- Non-residential sectors (e.g. commercial, industrial, etc.) have large heterogeneity than the residential sector, which poses more difficulty in characterizing the customer class. The commercial sector in particular, is dependent on employment and economic activity, and the industrial sector to long terms structural changes in the economy of a city.

- Water use patterns in non-residential sector are quite specific to the particular customer classes (e.g. schools, hotels, nursing homes, etc.) and therefore, it is difficult to get any generic water use patterns across the customer classes

(Blokker *et al*, 2011). Therefore, success of non-residential water demand model depends on extensive field survey to collect a diverse range of field data.

- Water use in non-residential sectors is a “drive demand” that depends on production of goods and services (Kiefer, 2015). In many cases, sale of products depend on the demand in foreign country leading to greater challenges in accounting for the accurate market information in water demand modelling, and subsequently model outputs accrue large uncertainties.

- Industrial water demands are sensitive to economic factors such as input prices and the level of output, and the accurate relationship between these two factors varies across the different industries and their production capacity. Thus, the knowledge of industrial water demand is quite limited (Reynaud, 2003).

- Data on explanatory variables are generally not available for non-residential sector and also difficult to collect (Reynaud, 2003). Because of that very few works on non-residential water demand modelling exist in the literature.

- Significant variability in water use between and within the customer classes exists in the non-residential sectors. Some customers have the flexibility to vary techniques in usage (e.g. recycle used water) and some customers do not (Reynaud, 2003). Therefore, it is difficult to define a representative water demand function to estimate industrial water demand.

- Water demand in non-residential sectors is plan dependent such as hospital expansion, increase in industry size, etc. Therefore, any model developed based on the past water use data will give an under estimate of future water use when expansions happen.

- Small customers in non-residential sectors often will not exist over time or change to a different type of water use class (e.g. restaurant may change to a small business). Therefore, there is a greater challenge in modelling water use in small customers in the non-residential sectors.

In general, there are large number of challenges exists in urban water demand modelling as listed above. There are even more challenges in the case of water demand modelling for the non-residential sector compared to the residential sector. These challenges in the non-residential sector led to very limited studies on water demand modelling of non-residential sector. In this research, attempts were made to overcome some of these challenges which will be further elaborated in Chapters 4, 5 and 6.

2.5. Summary

Urban water demand modelling is an important component in the successful operation of any water supply system. However, accurate estimation of urban water use through developing a good water demand model always been a challenging task. To deal with this immense challenge, researchers and professionals have used a range of modelling approaches for urban water demand modelling. Some approaches are suitable for short term modelling, while others are suitable for long term modelling. Moreover, some approaches require extensive data at micro scale as well as in shorter time scale. To understand these existing modelling approaches, a literature review was conducted in this research which lad to selection of suitable modelling approaches for this study.

Various urban water demand modelling approaches were found in the literatures which were used to estimate urban water use. Some are widely used around the globe and some are used in a particular region for a specific purpose. In general, it was found that there are eight general modelling approaches which were widely used for urban water demand modelling. They are; historical average or pattern based approach; climate correction; trend analysis; analysis of base and seasonal use; regression modelling; end-use modelling; agent based modelling; and artificial intelligence methods. Among them, the agent based modelling approach was used for scenario analysis rather than for actual estimation of water use, and the analysis of base use and seasonal use, artificial intelligence methods and end-use modelling approaches require an extensive micro scale data in shorter time scale. The application of climate correction and trend analysis approaches were found to be limited to certain extends. Moreover, these approaches are often used as part of other modelling approaches such as regression modelling approach where some of their limitations are overcome. Based on the data available in this research (presented in Chapter 3), it was found that the regression modelling approach; particularly the stepwise multiple linear regressions (MLR) and the historical pattern based modelling approaches were suitable for this research. Therefore, these modelling approaches were used for developing water demand models for several customer groups in the non-residential sector in this research.

A literature review was also conducted on various challenges in urban water demand modelling listed in the past studies to understand the difficulty in non-residential urban water demand modelling and presented in this chapter. This helped to focus on some of the challenges in this research and will be presented in Chapters 4, 5 and 6.

Chapter 3. Study Area, Data Sources and Processing

3.1. Overview

As stated in Chapter 1, the Yarra Valley Water (YVW) service area located in the Melbourne metropolitan water service region in Victoria (one of the States in Australia) was used as the study area in this research. The YVW retailer is one of the important water retailers in Melbourne which has valuable contribution to water service delivery for a large population. It is one of the most efficient water retailers in Australia (National Water Commission and Water Services Association of Australia, 2008).

Water use billing data for non-residential customers located in the YVW service area were used in this research for developing the water use model for non-residential customers. Historical water restrictions and climate data such as rainfall and temperature were also used in the research work as independent variables during model development.

To have consistent time interval, data across the variables used in this study were processed which were important before the model development. Then all non-residential customers were disaggregated into groups to capture the best hidden nature of water use behaviour. Homogeneous nature of water use customers and their water use patterns were used to disaggregate the non-residential customers into different groups. Based on these groups, non-residential water use models were developed in this research which is presented in Chapters 4 to 6.

This chapter first provides the background of Melbourne water supply system including a brief overview of the sources of water, description of Melbourne metropolitan water retailers and their distribution system. Then, the selection of study area and its importance are described, followed by sources of water use billing data, and water restrictions and climate data which were used in this research. Data processing is then presented, followed by disaggregation of customer groups which were used to develop the water use models separately for different customer groups. Finally, a summary is presented.

3.2. Background of Melbourne Water Supply System

Melbourne Water (MW) manage water supply catchments, treat and supply drinking and recycled water, remove and treat most of Melbourne’s sewage, and manage waterways and major drainage systems in Melbourne (Melbourne Water, 2014). Most of Melbourne’s drinking water comes from the protected catchments with limited public access. Rainfalls are captured in the catchment area and directed into 10 major storage reservoirs. These reservoirs are interconnected, making the Melbourne water supply system very flexible. While the water supply catchments are the Melbourne’s primary source of drinking water, in times of critical need they also have other supply options like the desalination plant and north-south pipeline where water gets from outside the catchments (Melbourne Water, 2014).

Stored water is then passed through water treatment plants, so it meets the water quality requirements and is safe to drink. Most of Melbourne’s water needs very little treatment since it comes from the protected catchments, but water from open catchments is fully treated to make sure it also meets water quality guidelines. After treatment, water flows through large pipes to 38 service reservoirs located around suburban Melbourne, which range in capacity from 2 to 250 million litters (Melbourne Water, 2014). These service reservoirs are often in elevated areas so water can be transferred via gravity, which is less costly and power-intensive than pumping water.

From the service reservoirs, water flows through smaller pipes to the water retailers who operate the water distribution and sewerage systems. There are three water retailers in Melbourne metropolitan area (Victorian Water, 2014). They are Yarra Valley Water (YVW), City West Water (CWW) and South East Water (SEW). They own thousands of kilometres of pipes that carry the water through an intensive pipe network to individual water users. Each retail company provides water supply and sewerage services within their specified geographic region of the metropolitan zone/service areas as shown in Figure 3.1. It should be noted that within the individual service area, retailers have their own distribution zones where they supply water accordingly. Further details of these three water retailers are given below briefly.

3.2.1. Yarra Valley Water (YVW)

YVW provides essential water and sanitation services to more than 1.76 million people in the northern and eastern suburbs in Melbourne – from as far north as Wallan to as far east as Warburton in the Yarra Valley area (Yarra Valley Water, 2014). It manages more than $3.5 billion of infrastructure across a service area of approximately 4,000 square kilometres. The YVW deliver its services through over 9,908 kilometres of water supply mains and 9,345 kilometres of sewer mains with the support of 79 water pumps and 95 sewage pump stations. The key stakeholders include residential and non-residential customers.

3.2.2. City West Water (CWW)

CWW provides water, sewerage, trade waste and recycled water services to over 0.9 million people in the Melbourne's Central Business District, and inner and western suburbs in Melbourne – from Melbourne (north of Yarra River) to Wyndham, and parts of Melton and Hume (City West Water, 2012). The CWW manages a significant asset base including 4,561 km of water mains, which supply more than 80 GL of water each year, 4,043 km of sewer pipes and an increasing dual supply network. Around 380,000 residential and non-residential customers are the key stakeholders of CWW.

3.2.3. South East Water (SEW)

SEW provides water, sewerage and recycled water services to more than 1.65 million people in Melbourne’s south east region (South East Water, 2014). Its service region spreads across 3,640 square kilometres from Port Melbourne to Portsea to Pakenham. The SEW is responsible for $3.5 billion of assets and manages over 23,500 kilometres of pipeline to deliver its services with the support of 80 water pump stations and 255 sewage pump stations. The key stakeholders include residential, industrial and commercial customers. In addition, SEW provides reticulated Class A and C recycled water to customers in Melbourne’s southeast and on the Mornington Peninsula areas.

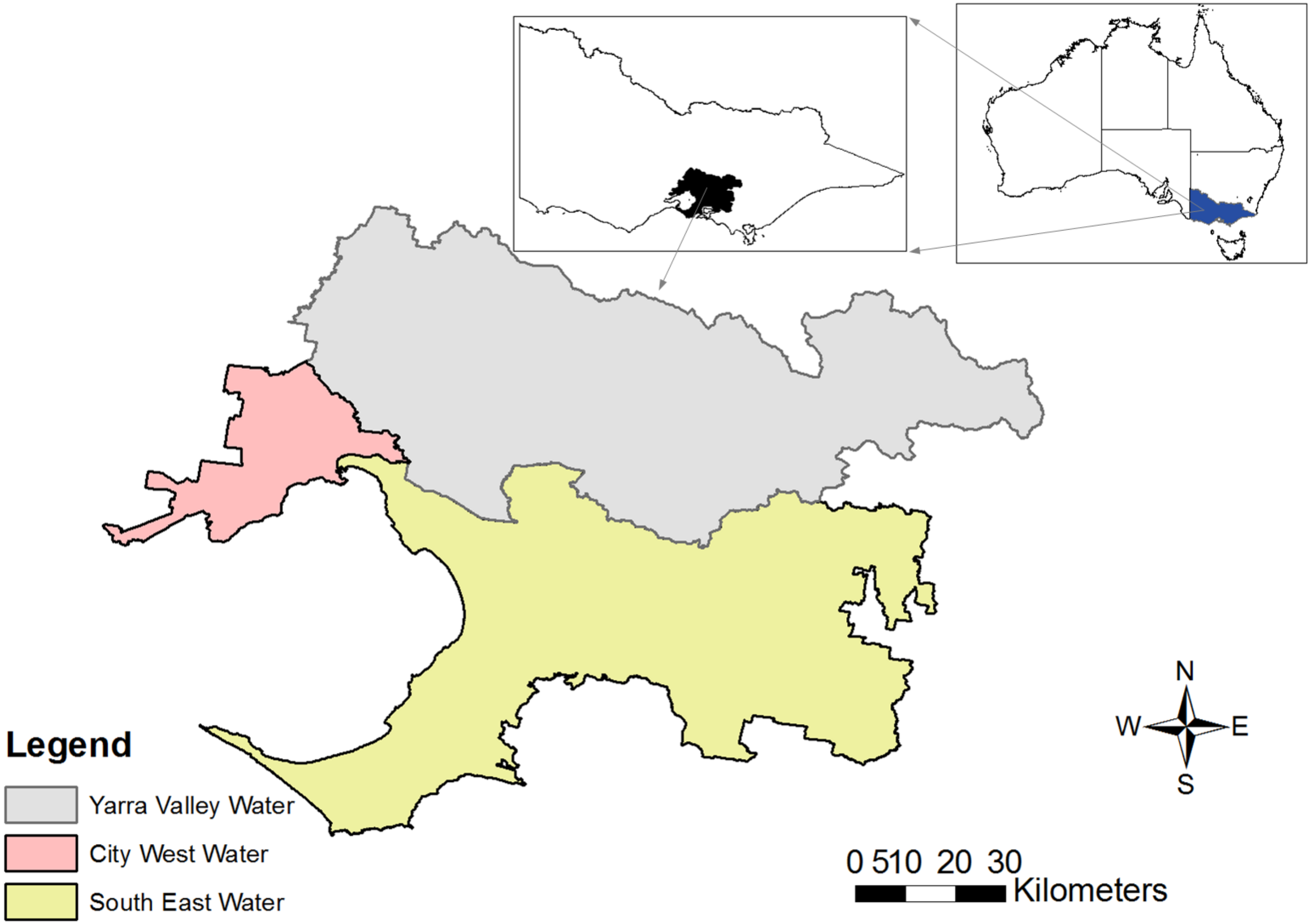


Figure 3.1 Melbourne metropolitan three water retailers geographic regions

3.3. Selection of Study Area

Among the three water retailers, YVW is the largest water utility, delivering sustainable, innovative and forward-thinking urban water solutions to more than 1.7 million people in the northern and eastern suburbs in Melbourne covering 16 municipalities as shown in Figure 3.2 (Yarra Valley Water, 2011). It is owned by the Victorian Government and governed by an independent Board of Directors.

The YVW has been the lead global water industry in serving both the customer and the environment, by maintaining a high-performing culture and by continuously improving service efficiency. Their service efficiency was assessed independently and found as one of the most efficient water utilities in Australia (National Water Commission and Water Services Association of Australia, 2008).

As the YVW provides water service to more people than the two other water retailers (i.e. CWW and SEW), it was considered to have more variation in different types of non-residential customers (e.g. industrial, commercial and institutional) than other water retailers in Melbourne. Therefore, considering the valuable contributions to Melbourne's community in water service delivery and large number of non-residential customers, YVW's service area was selected as the study area in this research.

3.4. Data Sources

The available data required for this research project to develop the non-residential water demand models were water use billing data, water restrictions levels history and climate (i.e. rainfall and temperature) variables data. Water use billing and water restrictions level data were collected from the YVW retailer. Rainfall and temperature data were collected from the Bureau of Meteorology (BoM). Moreover, water use customer's locations and distribution zone level map were also obtained from the YVW. Locations of water use customers and climate data measurement station are shown in Figure 3.3. Water use data were available for around 36,000 customers. However, customers with missing data were not used in this study. Climate data (i.e. rainfall and temperature) record at Melbourne Regional Office (Station #86071; Bureau of Meteorology, 2013) station was used in this study as most of the water use customers are located nearby this station.

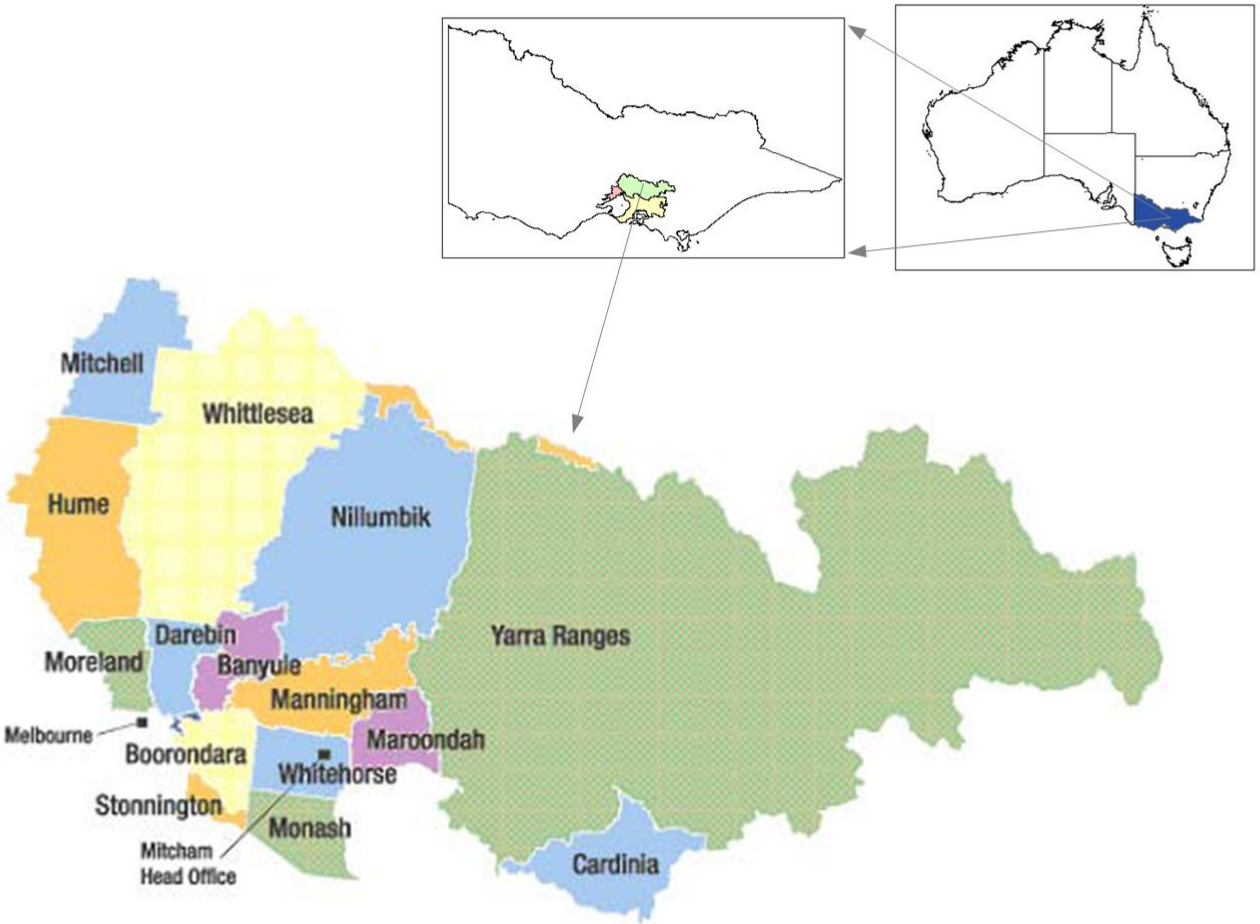


Figure 3.2 Yarra Valley Water (YVW) service area by municipality (adapted from Yarra Valley Water 2008)

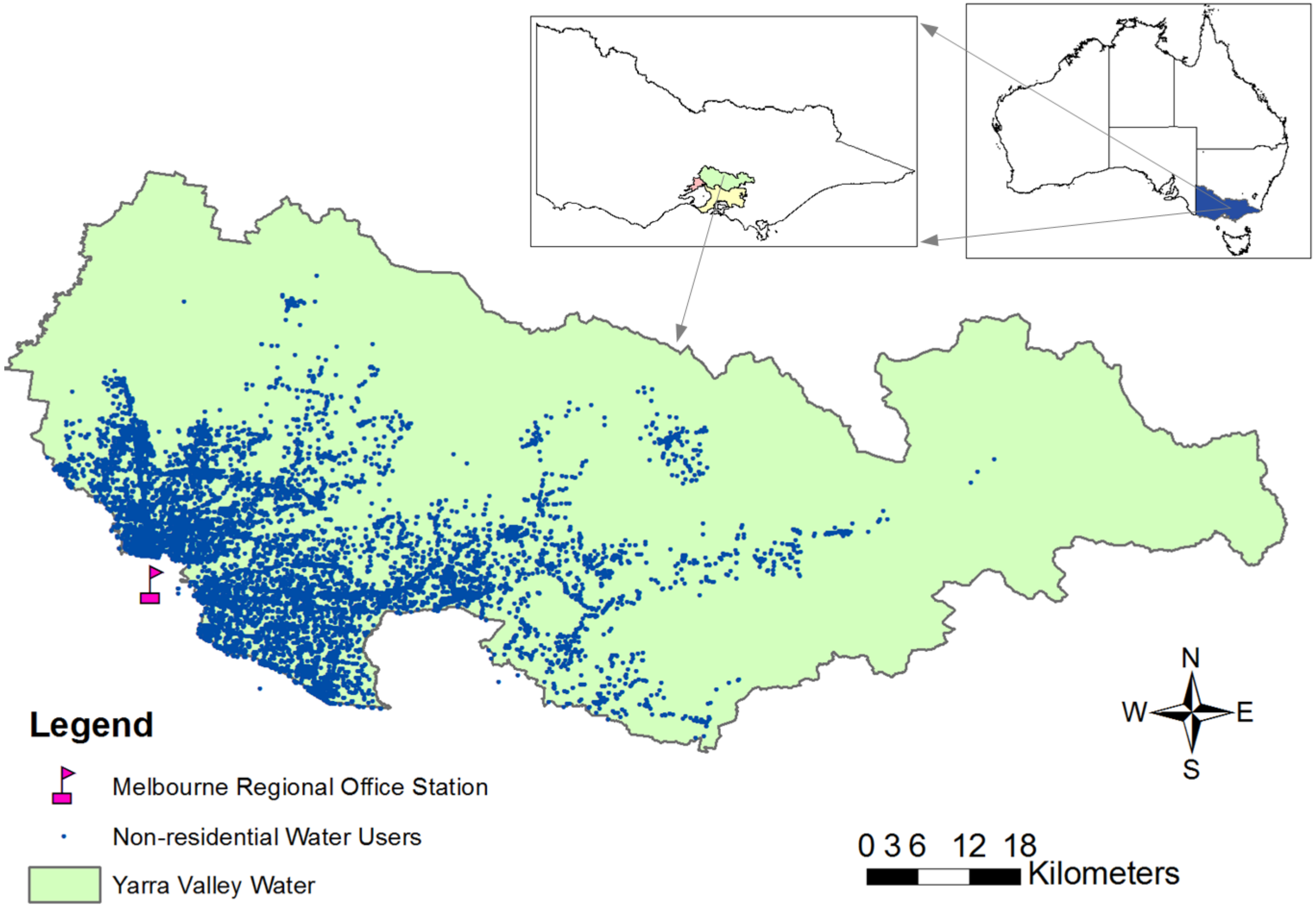


Figure 3.3 Locations of water use customers and climate data measurement station

Data ranged from 2000 to 2011 (12 years) were available for this study for all variables (i.e. water use billing data, water restrictions level, rainfall and temperature). However, water usage patterns significantly different in pre and post 2005 due in part to permanent water saving rules which were introduced in 2005. Other reasons for the reduced water use patterns after 2005 could be due to alternate sources of water use and use of water efficient appliances etc. (Yarra Valley Water, 2008). As there were no information available for the changed water use pattern, it was considered that the current reduced water use pattern will continue into the future and consequently data from 2005 to 2011 (7 years) were used in this study for model development and validation. It should be noted that disaggregation of customer groups were performed at the beginning of the study and models development were done for the disaggregated customer groups progressively. Therefore, to keep the consistency in models development among the different customers groups, same data period (2005-2011) were used for all disaggregated customers groups.

It is worth to mention here that the data were available for the abovementioned variables were in different time scales (i.e. water use data mainly in quarterly, restrictions level data in monthly, and climate data in daily). However, water use data in monthly time scale were available for very few customers (only around 100 out of 36,000 customers). Therefore, the model development was performed in this study mainly using the quarterly time step and data processing was carried out at this scale. The procedures that were used in data processing are described in the following section.

3.5. Data Processing

3.5.1. Water Use Data

Water use billing data for about 36,000 customers within the YVW service area were provided by YVW along with the billing start and end dates for this research project, as was mentioned in Section 3.4. Data were provided in two different stages for this project. First, data were obtained for the period from 2000 to 2009. Later on, data from 2010 to 2011 were also obtained. Other information such as postal address of each customer, geographic location of the customers, and Australian and New Zealand Standard Industrial Classification (ANSIC) code were also provided by YVW. ANSIC code provides the information about the industry type. This information was useful in this study to identify the customer types.

As mentioned in Section 3.4, although water use billing data were available from 2000 to 2011, but data from 2005 to 2011 were used in this study. After careful observation at billing start and end dates, it was found that there was inconsistency in billing record (i.e. billing start and end date were not the same for all customers). Therefore, data processing was done to make the data consistent and obtain the quarterly water use time series. The approach followed in this data processing is shown in Figure 3.4 using two successive quarterly billing data, as an example. First, quarterly metered consumption for two successive quarters were taken with the billing start and end dates. Thereafter, average daily consumption was obtained by dividing the quarterly metered consumption data with the number of days between the billing start and end dates (i.e. number of billings days). Therefore, the daily average water use for a month lying fully within the quarter is the same as the daily average water use for that quarter. However, for the month spanning end of one quarter and beginning of the next quarter, daily average water use is the weighted average of these two quarters based on the how many days of the month lies in each quarter. Thereafter, monthly data was produced by multiplying the daily average with the number of days in that month. Finally, monthly data was transformed into quarterly data by summing three months water use and named as Quarter 1 (January – March), Quarter 2 (April – June), Quarter 3 (July – September), and Quarter 4 (October – December). An MS Excel macro was written and used in this project to perform this data processing for all the 36,000 customers in this research project.

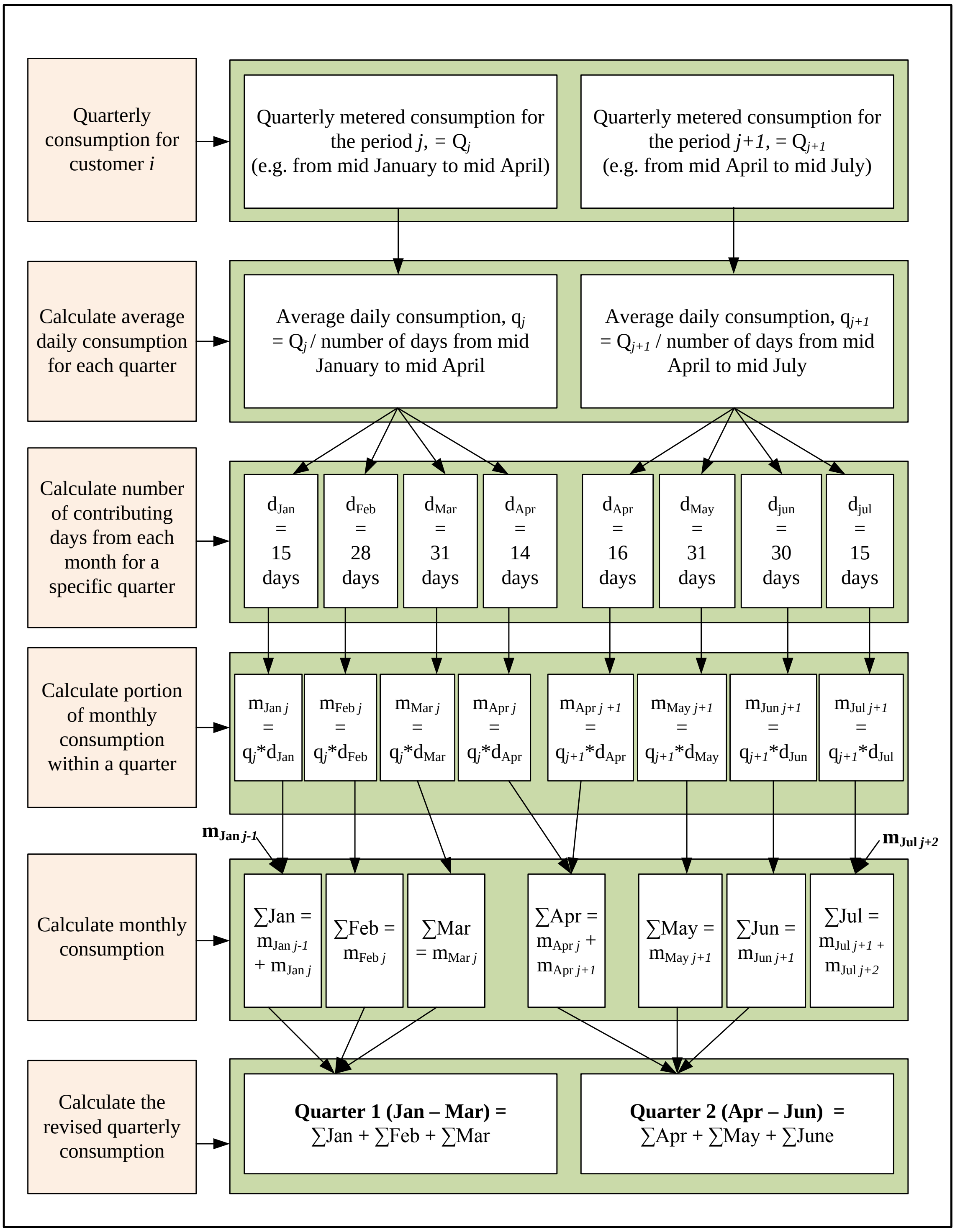


Figure 3.4 Flow chart of water use billing data processing procedure

3.5.2. Water Restrictions Data

Historical water restrictions records were obtained from YVW are shown in Table 3.1. It should be noted that the start date of each restrictions level was the first day of the indicated month in this table, and when one level of restrictions starts, the previous level becomes ineffective. The details of each water restrictions level shown in Table 3.1 can be found in Yarra Valley Water (2010).

Table 3.1 Historical water restrictions record

Water Restrictions Stage	**Start Date**
Stage 1	November 2002
Stage 2	August 2003
PWSR	March 2005
Stage 1	September 2006
Stage 2	November 2006
Stage 3	January 2007
Stage 3a	April 2007
Stage 3a + T 155	December 2008
Stage 3 + T 155	April 2010
Stage 2	September 2010
Stage 1	December 2011
PWSR	December 2012

From the above Table, it can be seen that various levels of water restrictions – Stage 1 (mild) to Stage 3a (severe) have been in place over the last decade. Following Stage 1 and Stage 2 restrictions from November 2002 to February 2003, Permanent Water Saving Rules (PWSR) were introduced in March 2005. PWSR is a set of common sense water use rule that apply at all times, whether or not any stage of water restrictions are in force. In 2006, restrictions were imposed again transitioning rapidly into Stage 3a restriction level over the following seven months. From December 2008 to March 2010, an additional voluntary water conservation program Target 155 (155 L/person/day) was in place.

It can be seen from Table 3.1 that Stage 1 and Stage 2 restrictions levels were for very short period of time after 2005 compared to Stage 3 and Stage 3a restrictions levels. It was also found that restrictions Stage 3 and Stage3a has very little difference in severity and therefore, was considered as same restrictions level as far the YVW suggestion. It was outlined in Section 3.4, that water use data from 2005 to 2011 were used in this research for developing quarterly time step model and Stage 1 and Stage 2 restrictions levels were for very short period of time. Therefore, to make the restrictions variable simple, all the restrictions levels were considered as same level of restrictions and PWSR as for no water restrictions in place.

3.5.3. Climate Data

Total rainfall amount and maximum temperature are the two climate variables that were considered in this study. Daily records of these two variables data were obtained at the Melbourne Regional Office (Station #86071) station from January 2005 to December 2011 as was mentioned in Section 3.4. Daily data were converted to the quarterly time scale (i.e. total rainfall in mm and mean daily maximum temperature in °C) to be similar with the water use data.

3.6. Disaggregation of Customer Groups

As outlined in Section 3.1, water demand modelling was performed with different levels of customer groups based on their homogenous character. First, different types of non-residential customers were identified by matching the ANZIC code with the name and address obtained with the water use billing data.

It was found that only 8,000 customers out of 36,000 were identified as homogeneous user types falling into seven different groups such as Schools, Sports Grounds, Councils, Restaurants, Hospitals, Hotels, and Laundries. Additionally customers with very high water use (>50 ML/year) were considered as separate group and named as High Water Users in this study. The remaining customers were named as Others in this study as they were not able to be identified into homogeneous categories.

Percent water uses by the abovementioned homogeneous user groups based on 2011 water use is shown in Figure 3.5. From the figure, it can be seen that the highest percentage of (52%) non-residential water is used by the "Others" group which has a large number of customers (around 28,000). The next highest percentage of non-residential water is used by the High Water Users group, which was expected, as customers in this group are the highest water users among the non-residential customers. Figure 3.5, also shows that total percentage of water used by the abovementioned eight identified groups is 48% of the total non-residential water uses in 2011, although only 22% of the total non-residential customers are falls within these groups.

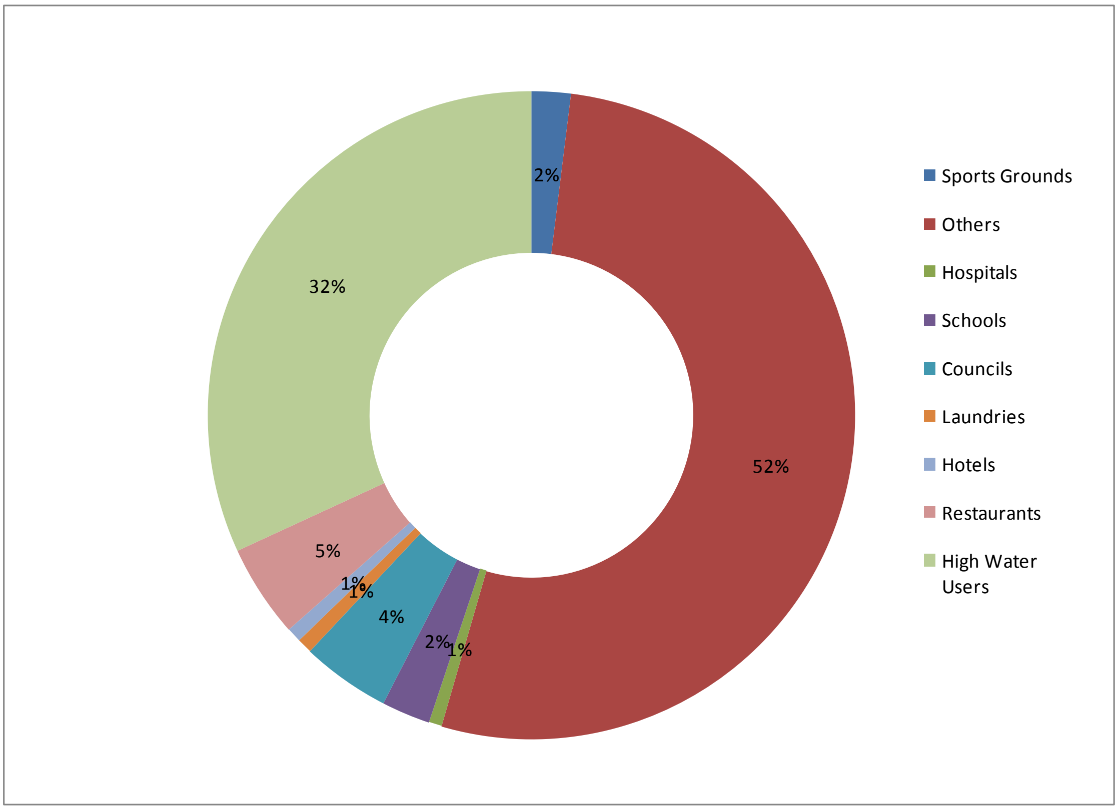


Figure 3.5 Water uses by different homogeneous user groups in 2011

Water use distribution among the customers in the non-residential sector is shown in Figure 3.6. It can be seen that only around 3,000 customers use on average 1 ML and more water in a year and about 25,000 customers use less than 1 ML. It indicates that most of the non-residential water use is concentrated within relatively small number of customers, as discussed earlier.

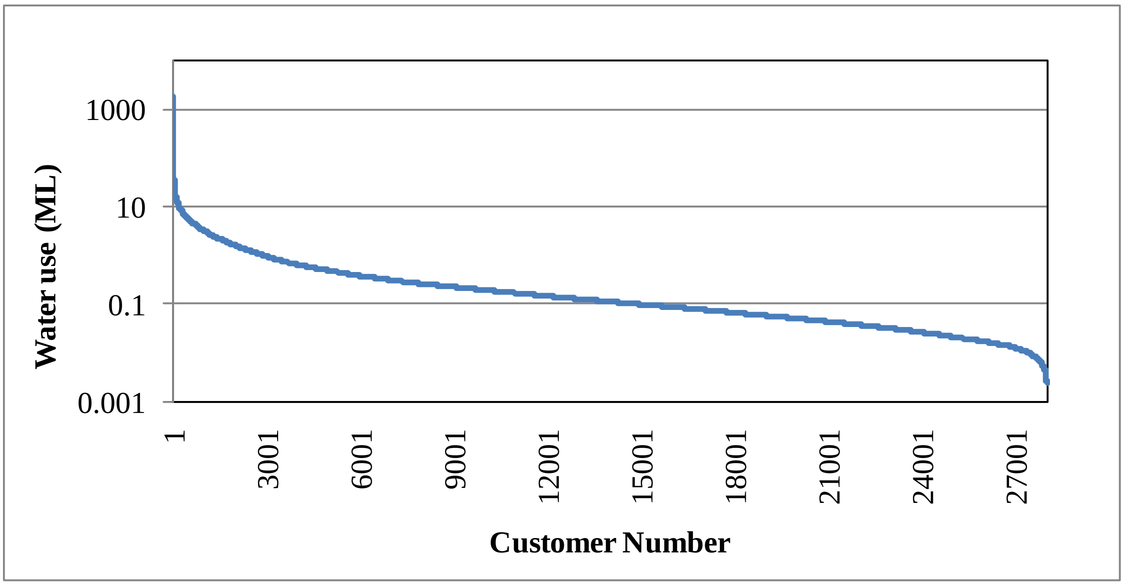


Figure 3.6 Customer ranking based on average yearly water use

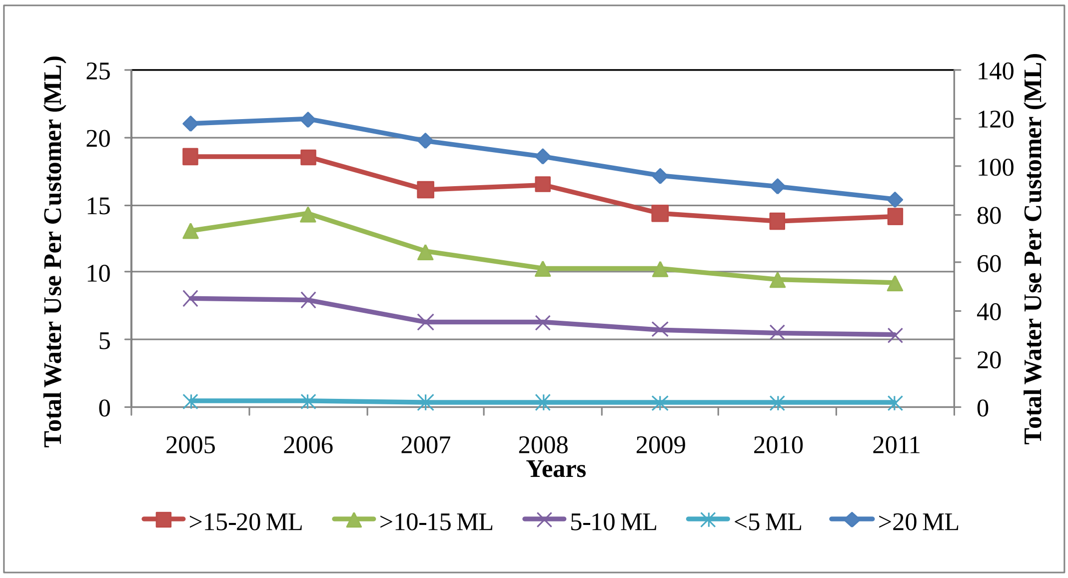
As a part of data analysis, all non-residential customers were further disaggregated into different groups based on the average yearly water uses (based on 2005-2009 data) such as >20 ML, >15-20 ML, >10-15 ML, 5-10 ML and <5 ML. the average water use percentage among these groups is presented in Table 3.2. It can be seen from Table 3.2 that the customers in >20 ML group uses over 40% of the total non-residential water, although only 0.3% of total non-residential customers are falls in this group. Also, Table 3.2 shows that almost 60% of the total non-residential water used by only 2.11% of the total non-residential customers (>5 ML).

Table 3.2 Water use by different sub-groups based average on annual water use in 2005-2009

Group	Total number of customers	% of total customers	Average Water use per customer (ML/year)	% Contribution to the total water use
> 20 ML	84	0.30	109.92	40.2
>15-20 ML	43	0.15	16.85	3.2
>10-15 ML	90	0.32	11.90	4.7
5-10 ML	377	1.34	6.86	11.3
<5 ML	27482	97.89	0.34	40.6
Total	28076	100	-	100

Note: customers with missing data are not used in this table.

Water use pattern per customer by the above mentioned groups over the years from 2005 to 2011 is shown in Figure 3.7. From this figure, it can be seen that water use per customer in <5 ML group is almost same over the years from 2007. On the other hand, there is a decreasing trend among the remaining groups.



Note: Water use in >20 ML group is presented in secondary axis.

Figure 3.7 Non-residential water uses per customer in different groups

Based on the aforementioned homogeneity and different amounts of water use, the non-residential water use modelling was performed individually for each group (i.e. >20 ML, >15-20 ML, >10-15 ML, 5-10 ML and <5 ML) within the different homogeneous customer groups (i.e. Schools, Sports Grounds, Councils, Restaurants, Hospitals, Hotels and Laundries) to capture the best hidden nature of water use behaviour.

Before performing the water use modelling, data analysis was done to check the water use pattern over the different quarters in a year for each homogenous customer group. Average percentages of quarterly water use was calculated using all seven years of available water use data where quarterly water use volume was divided by the total yearly water use volume, and then average them separately for each quarter. This analysis was done individually for all seven homogeneous customer groups (i.e. Schools, Sports Grounds, Councils, Restaurants, Hospitals, Hotels and Laundries).

Average percentages of quarterly water use for Schools, Sports Grounds and Councils are shown in Figure 3.8, whereas they shown in Figure 3.9 for Hospitals, Hotels, Laundries and Restaurants. From Figure 3.8, it can be seen that Schools, Sports Grounds and Councils uses less water in quarter 2 and quarter 3, which are usually cooler months than the months in quarter 1 and quarter 4. Moreover, there is more rainfall during the cooler months in Melbourne than the warmer months. Therefore, it might be less outdoor water use in gardens, sports fields and pools among these groups in quarter 2 and 3 than in quarter 1 and 4. It shows that there are some seasonal effects on water use in these groups. Therefore, climate data and water restrictions data were used in case of modelling water use in Schools, Sports Grounds and Councils and presented in Chapter 4.

On the other hand, Figure 3.9 shows that the average percentage of quarterly water use is almost the same in all four quarters in Hospitals, Hotels, Laundries and Restaurants groups. There is less variation in water use over the year indicating no seasonal effect. Moreover, due to most of the water uses are indoor purposes among these groups, models was developed considering only water use for Restaurants, Hospitals, Hotels and Laundries groups, which are presented in Chapter 5.

Total water use by the High Water Users group is 32% of total non-residential water use in YVW's service area in 2011 as were shown in Fig 3.5. There are different types of industry, manufacturer, and company falls in this group and their water uses are quite different over the study years. The water use data analysis and model development for these customers are discussed in Chapter 6.

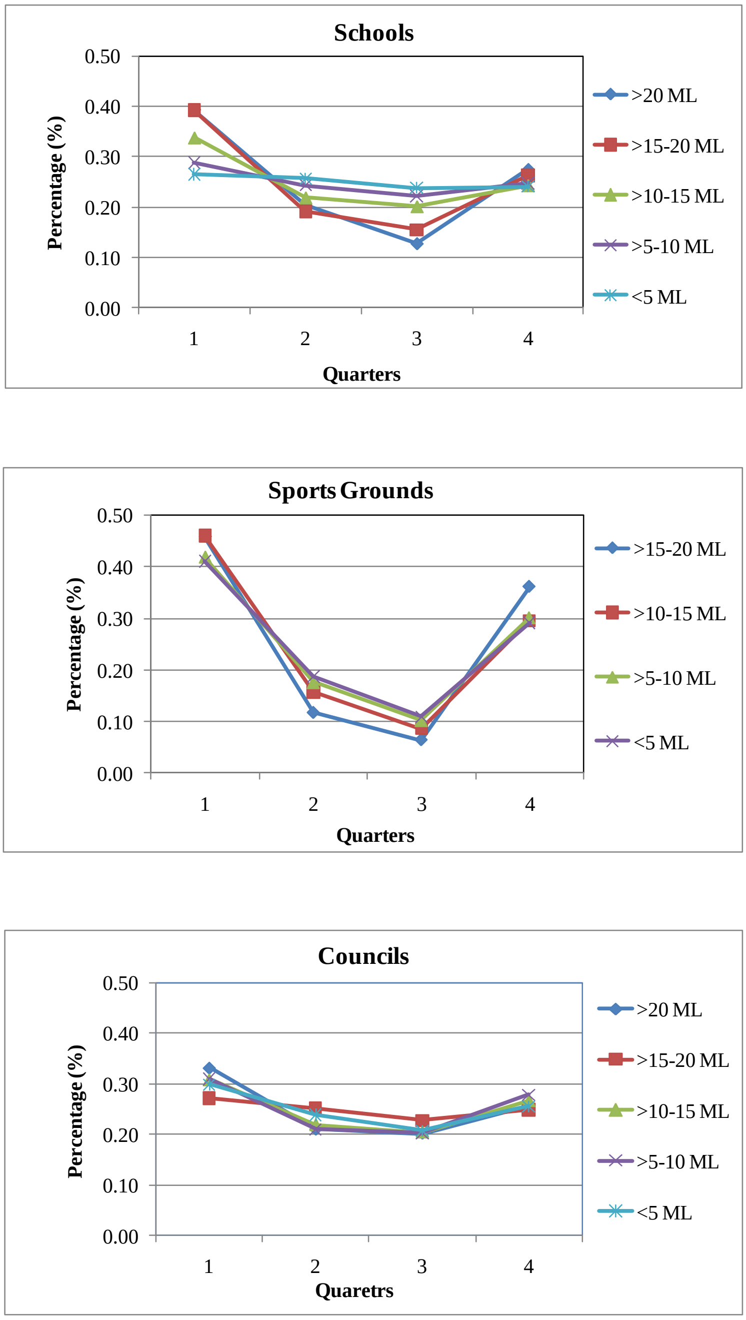


Figure 3.8 Average percentages of quarterly water uses in Schools, Sports Grounds and Councils

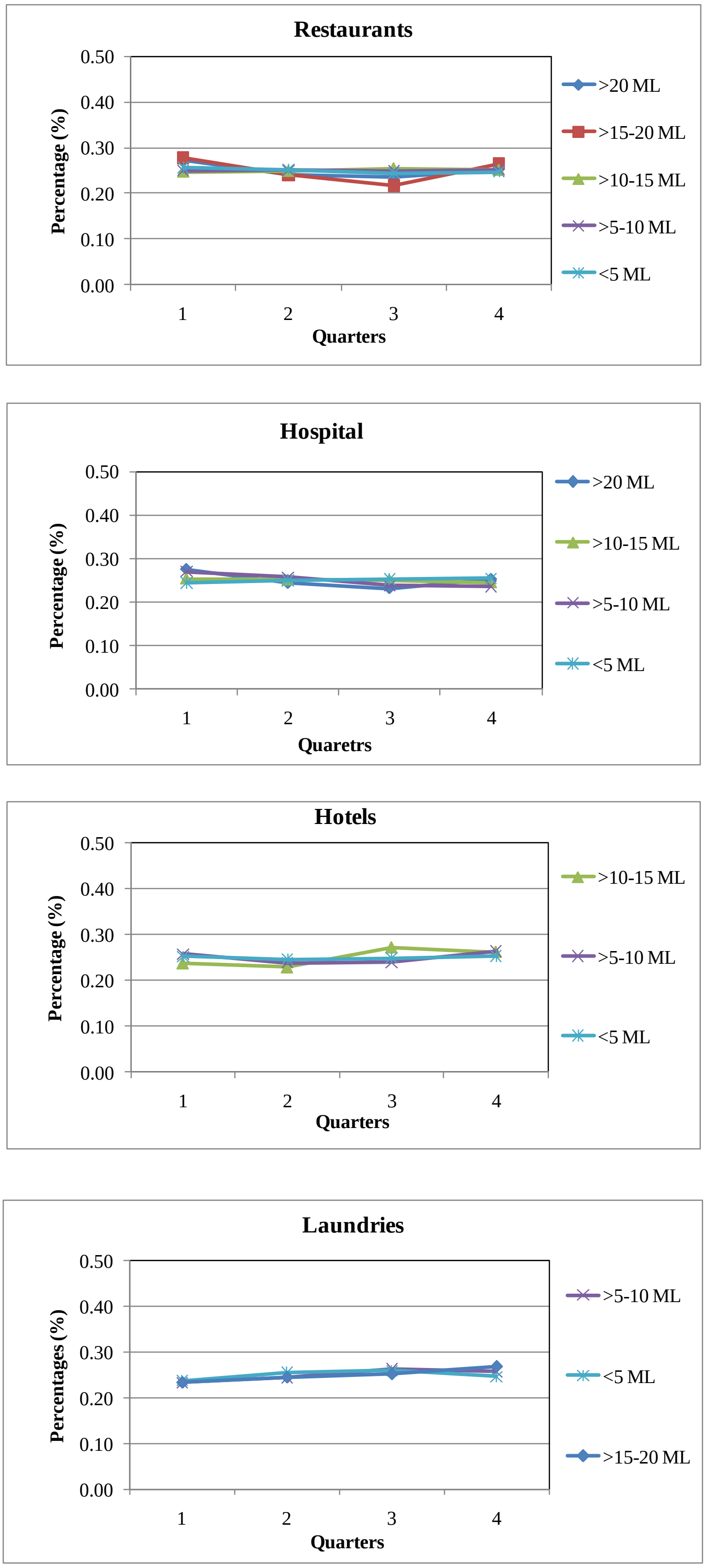


Figure 3.9 Average percentages of quarterly water uses in Restaurants, Hospital, Hotels and Laundries

3.7. Summary

There are three water retailers in Melbourne metropolitan area (Victorian Water, 2014). They are Yarra Valley Water (YVW), City West Water (CWW) and South East Water (SEW). Among them YVW is the largest retailer provides essential water and sanitation services to more than 1.76 million people in the northern and eastern suburbs in Melbourne. The YVW has been the lead global water industry in serving both the customer and the environment, and found as one of the most efficient water utilities in Australia. Therefore, considering the valuable water services to Melbourne's community YVW's service area was selected as the study area in this study.

Water use billing data and historical water restrictions data were collected for the YVW service area from YVW. Moreover, climate data such as rainfall and temperature were obtained from Bureau of Meteorology. These data were used in this study to develop non-residential water use models. However, as there was inconsistency in water use billing period (i.e. number of billing days were not same) among various non-residential water customers, data processing were required to make a consistent time series data across all customers.

Data for different variables were obtained for different time scales. However, most water use data were in quarterly time scale and only few customers' water use data were in monthly time scale. Therefore, data for all variables were transformed into the quarterly time scale, and the quarterly time scale was used in non-residential water use models development (Chapters 4). Water use billing data were obtained from 2000 to 2011. However, it was found that water use pattern significantly different before and after 2005, when Permanent Water Savings Rule (PWSR) was introduced. It was considered that this water use pattern will continue in future and therefore, data record from 2005 to 2011 was used for model development and validation.

Disaggregation of non-residential customer was performed to capture the best hidden nature of water use behaviour during model development in this study. This was done based on the homogeneous nature of water use customers and their annual average water use patterns. It was found that there were seven homogeneous customer groups: Schools, Sports Grounds, Councils, Restaurants, Hospitals, Hotels and Laundries. Each of these homogenous groups was further disaggregated into five groups: >20 ML, >15-20 ML, >10-15 ML, 5-10 ML and <5 ML. The data analysis and models development for the above listed homogenous groups and High Water Users customers are presented in Chapters 4, 5 and 6 progressively.

Chapter 4. Water use Modelling for Schools, Sports Grounds and Councils

4.1. Overview

As discussed in Chapter 3, there are some seasonal effects on water use in Schools, Sports Grounds and Councils groups. Similar quarterly water use pattern was observed in these three groups. Therefore, water use modelling was done for these three groups in a similar way considering the seasonal effects and presented in this Chapter.

Multiple Linear Regression (MLR) technique was used in this research to develop the water use models for the abovementioned three groups as mentioned in Chapter 2 (Section 2.3). Several independent variables such as past water use, different levels of water restrictions, climate variables (i.e. rainfall and temperature) and fixed quarterly effects were tested during model development and the best combination of these variables was used in the final model. Five years of quarterly water use data (2006-2010) were used for model calibration, whereas data for one year (2011) was used for model validation. Model performance was measured using the Nash-Sutcliffe efficiency. Based on the water use analysis, it was found that different customers use different amounts of water volume ranging from >20 ML to <1 ML per year. It was also found that only few customers use large volumes of water per year (e.g. >20 ML and >15-20 ML), whereas more customers use smaller volume of water per year (e.g. <5 ML). Therefore, higher water use customers were modelled at an individual level, whereas smaller water use customers were modelled at a group level in this study.

This chapter first describes the variable used for model development followed by the stepwise procedure used for model development in this research. Water use models developed for Schools, Sports Grounds and Councils groups are then presented separately. Finally, a summary of water use model development for these three groups is presented.

4.2. Variables Used for Model Development

As discussed in Chapter 3 (Section 3.5.1) quarterly water use billing data were available for this study. Therefore, quarterly water use modelling was carried out for forecasting quarterly water use over next year in this study for Schools, Sports Grounds and Councils. The variables used for modelling water use among these groups were also transformed into quarterly time step. It should be noted that the quarters are named as Quarter 1 (January – March), Quarter 2 (April – June), Quarter 3 (July – September) and Quarter 4 (October – December) in this study. More details about those variables are stated below.

4.2.1. Past Water Use

As discussed in Chapter 2, previous work revealed that there was strong influence of past water use on the current water use (House-Peters and Chang, 2011). Moreover, there are seasonal cycle of water use in Schools, Sports Grounds and Councils over a year due to school holidays, festival and cultural things. Therefore, the past water use in terms of (t-1) and (t-4) time-lagged (i.e. the previous quarter and the same quarter in the preceding year) was considered as important independent variables to model quarterly water use for Schools, Sports Grounds and Councils in this research. These variables also useful in explaining the nature of adaptive seasonal variations in water use behaviour.

4.2.2. Levels of Water Restrictions

The water use in Sports Grounds is mostly for outdoor use, and in case of Schools and Councils there might be some significant outdoor water uses. Therefore, the levels of water restrictions were considered as an independent variable for modelling water use in these groups. As discusses in Chapter 3, there were five levels of water restrictions: Permanent Water Saving Rules (PWSRs), stage 1, stage 2, stage 3 and stage 3a in Melbourne over the period of 2005-2011. The PWSRs is a set of water use rules that apply at all times, whereas other different levels of water restrictions were in force to reduce some water use. However, due to insufficient length of some restriction levels during this period, PWSRs were considered as 'no restrictions', and all other four levels of water restrictions were considered as a single restriction level in this study. Dummy variables were used to handle the water restrictions for water use modelling, as shown in Table 4.1.

Table 4.1 Dummy variables used for water restrictions

Water restriction information	**R**
No restrictions	0
Imposed water restrictions	1

4.2.3. Climate Variables

Water use in Sports Grounds mainly depends on climatic factors such as rainfall and temperature as most water use in this group is for outdoor purposes. Schools usually have gardens, play grounds and sometimes pools where water use also depends on climatic factors. In Councils, there are different types of organizations (i.e. library, council office, aquatic centre, police station, youth club, community centre, community garden) where water use might also be affected by climatic factors both for indoor and outdoor purposes. Therefore, total rainfall and mean maximum daily temperature were considered as likely independent variables for modelling water use in these three customer groups.

4.2.4. Fixed Quarterly Effects

There are some fixed time periods over the year when some activities among the schools and councils are run. Some sports also take place in certain time of the year. Therefore, to account these fixed effects in the quarterly water use model (Section 4.2) development, four quarters were considered as one of the important variables through dummy variables as shown in Table 4.2 where, D_2, D_3 and D_4 are the dummy variables.

Table 4.2 Dummy variables used for four quarters

Quarter	**D_2**	**D_3**	**D_4**
Quarter 1 (January – March)	0	0	0
Quarter 2 (April – June)	1	0	0
Quarter 3 (July – September)	0	1	0
Quarter 4 (October –December)	0	0	1

4.3. Procedure for Model Development

Quarterly water use data from 2005-2011 (Chapter 3, Section 3.4) were used in this study for developing MLR model along with the other variables discussed in Section 4.2. As discussed in section 4.1 model developments were performed in different disaggregated levels based on average annual water use in 2005-2009. It should be noted that data arrangement also performed in case of water use modelling at group level. Data set for one customer were arranged after the data set of another customer to make a longer data set and than a general model was developed for the group. Therefore, developed model for all group in this study are able to forecast at individual customer level. As part of modelling process, data for both dependent and independent variables were transformed and tested for correlation between them. More details of these procedures are stated below.

4.3.1. Data Transformation

It was discussed in Section 4.1 that, water use in previous quarters in terms of (t-1) and (t-4) time-lagged, mean maximum daily temperature, total rainfall, and dummy variables to represent water restrictions and four quarters are used as the independent variables to model the current water use (which is the dependent variable) in this study. In order to make the data normally distributed for both independent and dependent variables (which is a requirement for multiple linear regressions method

(Lewis-Beck 1980)), data transformation was performed before model development. Data were transformed using a log function because of its more interpretability as changes in a log value are relative (percent) changes on the original scale (Makridakis *et al.*, 1998).

4.3.2. Correlation Test

A correlation analysis was carried out separately for each water user groups before the model development to investigate the degree of correlation among the dependent and independent variables, and also between independent variables. This has given an early indication of independent variables that may play a significant role for development of the best model, and also to check the multicollinearity between the independent variables. The Pearson correlation coefficient r was used in this study, which indicates the strength of the linear relationship between two variables X and Y:

$$r = \sum_{i=1}^{n} (X_i - \overline{\mathrm{X}})\ (Y_i - \overline{\mathrm{Y}}) / (n-1) S_X S_Y \tag{4.1}$$

where, n is the number of data points, $\bar{X}$ and $\bar{Y}$ are the mean values of data of variables X and Y, S_X and S_Y are the standard deviations of data of variables X and Y .

Generally, high and low relationships are considered to have values of the correlation coefficient between (0.68-1) and (0-0.35) respectively. The values between 0.35 and 0.68 are considered to have moderate relationships (Taylor, 1990).

4.3.3. Mathematical Structure

Mathematical details of the multiple linear regression (MLR) model used in this study using the above mentioned independent variables are as follows:

$$\mathrm{Log}_{10}\,(WU_t) = \mathrm{b}_0 + \mathrm{b}_1\log_{10}\,(WU_{t\text{-}1}) + \mathrm{b}_2\log_{10}\,(WU_{t\text{-}4}) + \mathrm{b}_3\log_{10}\,(T)$$

$$+ \mathrm{b}_4\log_{10}\,(R_n) + \mathrm{b}_5 R + \mathrm{b}_6 D_2 + \mathrm{b}_7 D_3 + \mathrm{b}_8 D_4 \tag{4.2}$$

$$\mathrm{WU_t} = 10^{(\log_{10} (\mathrm{WU_t}))} \tag{4.3}$$

where,

WU_t, WU_{t-1} and WU_{t-4}	= Quarterly water use at time t, (t-1) and (t-4) respectively (KL)
T	= Quarterly mean maximum daily temperature (^oC)
R_n	= Total quarterly rainfall (mm)
R	= Dummy variable to represent water restrictions as shown in Table 4.1
D_2, D_3 and D_4	= Dummy variables to represent four quarters as shown in Table 4.2
b_0, b_1… b_8	= Regression constant and coefficients

It should be noted that the quarterly water use, mean maximum daily temperature and total rainfall are continuous variables, while dummy variables used for water restrictions and quarters are nominal variables. The nominal variables are handled in MLR through matrices as shown in Tables 4.1 and 4.2.

4.3.4. Measurement of Model Performance

The model performance was measured using the Nash-Sutcliffe model efficiency (*E*) which is commonly used for such performance evaluation. This measure is as follows:

$$E = 1 - \sum_{i=1}^{n}(O_i - P_i)^2 / \sum_{i=1}^{n}(O_i - \bar{O})^2 \tag{4.4}$$

where, n is the number of data points; O_i and P_i are the observed and predicted water use values respectively for the time step i; and $\bar{O}$ is the average observed water use.

E is a normalized statistic that determines the relative magnitude of the residual variance compared to the observed data variance (Nash and Sutcliffe 1970). It indicates how well the plot of observed vs. modelled data fits the 1:1 line. *E* varies from $-\infty$ to 1 (perfect fit). An efficiency of lower than zero indicates that the mean value of the observed time series would have been a better predictor than that predicted by the model. Large *E* values (e.g. close to 1) were considered in selecting the best model in this study.

4.3.5. Significance Test for Model Parameters

All parameters considered in this study are tested for statistical level of significance by its *p* value. The *p* value is the smallest level of significance at which the parameter is significant (called the significance level of the test). Conventionally (and arbitrarily), *p* value of 0.05 (5%) is generally regarded as sufficiently small (Gato *et al*, 2007b).

4.3.6. Steps for Model Development

The overall steps followed during the model development are shown in Figure 4.1. The brief descriptions of each of these steps are given below:

Step 1: Consider the influential variables to perform MLR.

Step 2: Perform MLR with all variables considered and obtain the regression coefficients.

Step 3: Check the regression coefficient sign of each influential variable considered in MLR. Remove the variable with contrary sign to the expected sign of the coefficient (i.e. +ve coefficient for rainfall) and the highest insignificant level, and follow Step 2. This step is repeated for all such variables until all the coefficients are as were expected sign to be.

Step 4: Once there are no regression coefficients with signs contrary to the expected signs, check whether coefficients are significant at 5% level. If all coefficients are significant at 5% level, then proceed to Step 5. Otherwise, remove the variables with highest insignificant level and perform MLR again (Step 2). This step is repeated until all remaining variables become significant.

Step 5: Calculate *E* value for the validation period with the final model in step 4.

Step 6: If *E* value is satisfactory (e.g. above 0.5) then select the model in Step 4 as the best model. Otherwise, include the last removed variables with expected sign one at a time and re-construct the MLR model and subsequently re-perform Steps 5 and 6. This step is repeated until the *E* value for the validation period is above the threshold value (e.g. above 0.5).

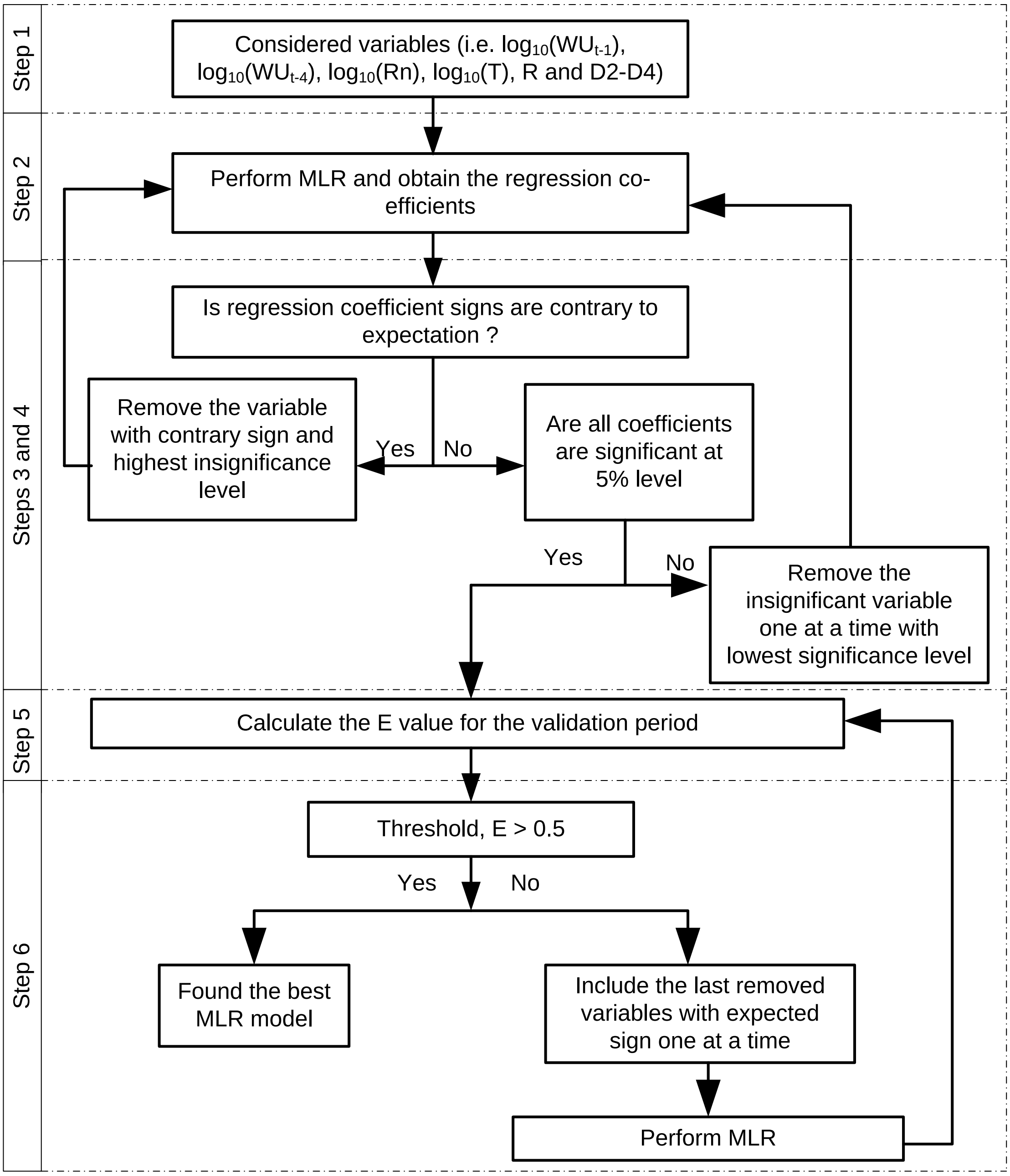


Figure 4.1 MLR model development procedure

4.4. Water Use Models for Schools

4.4.1. Data Analysis and Disaggregation

Analysis of water use in schools shows that the Schools sector accounts for 2.4% of the total non-residential water use in 2011 in the Yarra Valley Water (YVW) service area. Quarterly billing data for 500 schools located within the YVW service area were received. However, only 375 schools were used in this research work due to the unavailability of data for the remaining schools over the period of 2005-2011. As discussed in Chapter 3, all 375 schools were categorized into several smaller groups based on the annual average water use in 2005-2009. These groups are shown in Table 4.3 with the contributing percentage to the total Schools sector's water use in 2011.

Table 4.3 Disaggregated annual water use of Schools in the YVW service area

Water user groups	**>20 ML**	**>15-20 ML**	**>10-15 ML**	**5-10 ML**	**<5 ML**	**Total**
Number of schools	1	2	3	19	350	375
Water use (%)	6.0	5.0	4.5	14.5	70.0	100

From Table 4.3, it can be seen that almost 16% of the total School sector's water usage is by 6 schools (>10 ML per year), which is a large percentage of water use consumed by these individual schools. Therefore, water use in >20 ML, >15-20 ML and >10-15 ML School groups was modelled at an individual school level. However, there are a large number of schools in 5-10 ML and <5 ML user groups compared to the other groups. Therefore, these two groups were divided into smaller subgroups based on their annual average water use, as shown in Tables 4.4 and 4.5 respectively.

Table 4.4 Subgroups in 5-10 ML Schools group

Water user group	**>9-10 ML**	**>8-9 ML**	**>7-8 ML**	**>6-7 ML**	**5-6 ML**	**Total**
Number of schools	1	1	4	7	6	19
Water use (%)	0.5	0.5	4.0	6.0	3.5	14.5

Table 4.5 Subgroups in <5 ML Schools group

Water user group	**>4-<5 ML**	**>3-4 ML**	**>2-3 ML**	**1-2 ML**	**<1 ML**	**Total**
Number of schools	11	28	70	145	96	350
Water use (%)	6.5	13.0	20.0	26.0	4.5	70

Quarterly percentages of total annual water use (Section 3.6) were calculated for all five groups mentioned in Table 4.3 are shown in Figure 4.2. From the figure, it can be seen that the water use pattern over the year is different from one schools group to the other. It can also be seen from Figure 4.2 that there are high percentages of water use during quarters 1 and 4 and low percentages of water use during quarters 2 and 3 among the high water user groups as well as low water users group. This difference in quarterly water use percentages over the year reflects more outdoor activity during summer period. Moreover, from figure it also can be seen that the difference in quarterly water use percentages in warmer and cooler quarters are very high in the high water user Schools groups than in the low water user Schools groups. Therefore, it is apparent that high water user schools have more play grounds and gardens than those with low water user schools.

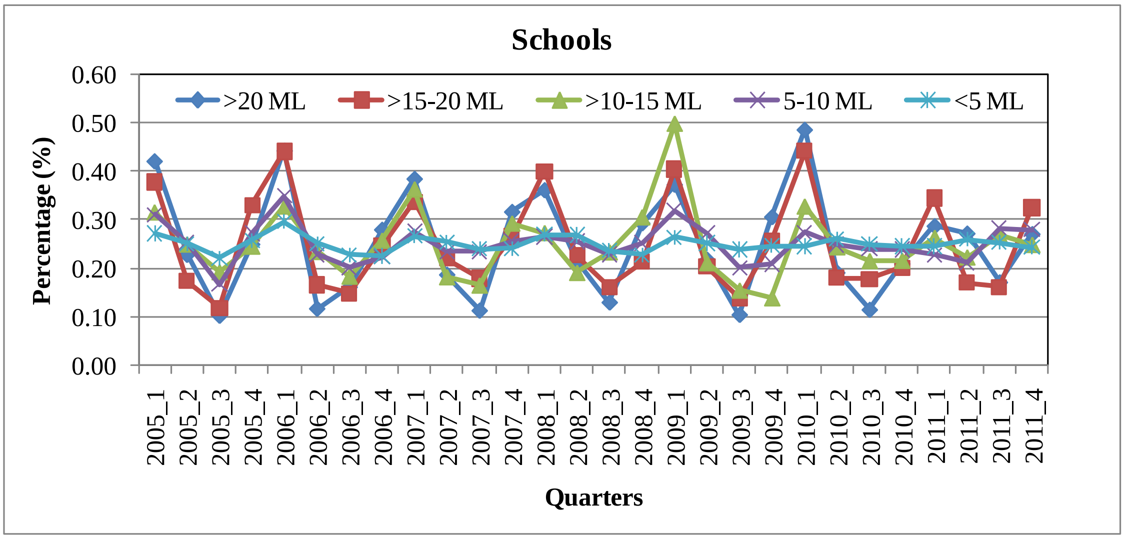


Figure 4.2 Time series of quarterly percentage to annual water use among the different user groups in Schools

4.4.2. Model Calibration and Validation

Model calibration and validation were performed using two independent data sets by splitting the total data period into two sets. Initially, the calibration period was considered as 2006-2009 (66.67% of total data) and the validation period as 2010-2011 (33.33% of total data). However, to see whether increasing calibration period produce better results, the model was then calibrated using 2006-2010 data (83.33% of total data) and validated with 2011 data (16.67% of total data).

4.4.3. Results and Discussions

Results of the correlation test performed among the dependent and the independent variables for all subgroups in the Schools group are shown in Table 4.6. Correlation between the independent variables for all School subgroups is presented in Appendix A.

Table 4.6 Correlation coefficient between the dependent and independent variables used in all subgroups in the Schools group

Group	**Modelled by**	**$Log_{10}(WU_t)$**	**$Log_{10}(WU_{t-1})$**	**$Log_{10}(WU_{t-4})$**	**$Log_{10}(T)$**	**$Log_{10}(R_n)$**	**R**	**D_2**	**D_3**	**D_4**
>20 ML	Individual	1	0.06	***0.77***[a]	***0.89***[a]	-0.17	-0.06	-0.21	***-0.71***[a]	0.24
>15-20 ML	Individual (School 1)	1	0.19	***0.82***[a]	***0.87***[a]	-0.14	-0.11	-0.20	*-0.67*[b]	0.07
	Individual (School 2)	1	*0.48*[b]	***0.76***[a]	*0.46*[b]	-0.20	*-0.48*[b]	-0.24	-0.22	-0.09
>10-15 ML	Individual (School 1)	1	-0.02	*0.40*[b]	*0.59*[b]	-0.15	-0.26	-0.30	*-0.38*[b]	0.05
	Individual (School 2)	1	***0.92***[a]	***0.70***[a]	0.04	*-0.44*[b]	***-0.71***[a]	0.04	-0.08	-0.07
	Individual (School 3)	1	*0.42*[b]	0.31	0.29	*-0.43*[b]	*-0.47*[b]	-0.08	-0.21	-0.02
>9-10 ML	Individual	1	***0.78***[a]	*0.44*[b]	0.26	0.01	***-0.72***[a]	0.06	-0.34	-0.08
>8-9 ML	Individual	1	***0.80***[a]	*0.62*[b]	-0.08	-0.17	*-0.64*[b]	0.13	-0.02	-0.16
>7-8 ML	Group	1	*0.58*[b]	*0.43*[b]	-0.16	0.21	-0.25	0.03	-0.25	0.03
>6-7 ML	Group	1	***0.82***[a]	*0.46*[b]	0.05	-0.14	-0.30	0.01	-0.05	-0.05
5-6 ML	Group	1	***0.75***[a]	*0.49*[b]	0.13	-0.28	*-0.40*[b]	-0.03	-0.11	-0.03
>4-<5 ML	Group	1	***0.85***[a]	*0.62*[b]	0.06	-0.14	*-0.36*[b]	0.02	-0.06	-0.09
>3-4 ML	Group	1	***0.73***[a]	*0.38*[b]	0.07	-0.16	-0.32	0.00	-0.07	-0.04
>2-3 ML	Group	1	***0.75***[a]	*0.37*[b]	0.03	-0.11	-0.34	0.04	-0.06	-0.06
1-2 ML	Group	1	***0.78***[a]	*0.44*[b]	-0.01	-0.09	-0.21	0.03	-0.01	-0.04
<1 ML	Group	1	***0.88***[a]	***0.76***[a]	-0.01	-0.04	-0.16	0.02	-0.01	-0.02

Note: *a* – variables are highly correlated, *b* – variables are moderately correlated.

It can be seen from Table 4.6 that there are moderate to high correlations between the current water use and the water use of previous quarters (in terms of WU_{t-1} and WU_{t-4}) for most of the subgroups, particularly previous quarter's water use (WU_{t-1}). Similar correlations can also be seen with the mean maximum daily temperature for high water use subgroups. There are moderate correlations with restrictions for some subgroups (Table 4.6). Remaining variables were found to have low correlation with the current water use.

From correlation analysis between the independent variables (Appendix A), it was found that the correlation coefficient ranged from -0.70 to 0.70 for most of the groups except for >20 ML, School 1 in >15-20 ML, School 2 in >10-15 ML and sub-group 9 ML. Babel *et al.*, 2007 noted that the correlation coefficients within this range should not be considered as a significant correlation to cause the multicollinearity effect in the MLR model development. Therefore, it can be considered that there are no significant correlations between all independent variables for most of the groups. Only few variables were found to be inter-correlated for above subgroups. However, it was found that one of those inter-correlated variables was not included in the best model considered in this study (refer to Appendix A and Table 4.7).

The *E* values of the best models for the two different calibration (i.e. 2006-2009 and 2006-2010) and validation (i.e. 2010-2011 and 2011) periods are presented in Table 4.7. The variables used in these models are given within the parenthesis. It can be seen in Table 4.7 that the independent variables used in the best models of each subgroup are found to be the same for both calibration periods (i.e. 2006-2009 and 2006-2010). Also, the *E* values obtained are quite similar in the calibration results for both calibration periods, as expected. However, the *E* values of the 2011 validation period are either greater or same to the values of the 2010-2011 validation period in 11 models out of 16 models. Therefore, it was concluded that the models with a longer calibration period yielded better results in validation, and the best models developed with the 2006-2010 calibration period are discussed in Section 4.4.3.1 to 4.4.3.5. It should be noted that for the same reason, model calibration was only performed using the 2006-2010 data period for the Sports Grounds and Councils groups, which are discussed later in this Chapter. The regression coefficients obtained for the best models (developed with the 2006-2010 calibration period) of different School subgroups are presented in Table 4.8. Further discussions on individual model performance are presented in the following sub-sections.

Table 4.7 *E* values for the best models in Schools group

School Group	School subgroups	Number of Schools	Modelled by	Calibration period: 2006-2009 Validation Period: 2010-2011		Calibration Period: 2006-2010 Validation Period: 2011	
				Calibration	**Validation**	**Calibration**	**Validation**
>20 ML		1	Individual	0.86 (T,Rn,R)	0.71	0.89 (T,Rn,R)	0.18
>15-20 ML		2	Individual (School 1)	0.86 (WU_{t-1},T,Rn,R)	0.92	0.88 (WU_{t-1},T,Rn,R)	**0.92**
			Individual (School 2)	0.68 (WU_{t-4},T,R)	0.67	0.65 (WU_{t-4},T,R)	**0.67**
>10-15 ML		3	Individual (School 1)	0.48 (T,R)	0.38	0.47 (T,R)	**0.56**
			Individual (School 2)	0.80 (T,Rn,R)	0.79	0.78 (T,Rn,R)	0.68
			Individual (School 3)	0.62 (T,Rn,R)	0.60	0.59 (T,Rn,R)	**0.76**
5-10 ML	>9 -10 ML	1	Individual	0.77 (WU_{t-1},T)	0.81	0.77 (WU_{t-1},T)	**0.86**
	>8-9 ML	1	Individual	0.73 (WU_{t-1},Rn,R)	0.80	0.70 (WU_{t-1},Rn,R)	**0.86**
	>7-8 ML	4	Group	0.32 (WU_{t-1}, WU_{t-4},T)	0.69	0.44 (WU_{t-1}, WU_{t-4},T)	**0.76**
	>6-7 ML	7	Group	0.68 (WU_{t-1}, WU_{t-4},T,Rn,R)	0.75	0.69 (WU_{t-1}, WU_{t-4},T,Rn,R)	**0.75**
	5-6 ML	6	Group	0.52 (WU_{t-1}, WU_{t-4},T,Rn,R)	0.78	0.62 (WU_{t-1}, WU_{t-4},T,Rn,R)	0.57
<5 ML	>4-<5 ML	11	Group	0.71 (WU_{t-1},T)	0.78	0.73 (WU_{t-1},T)	0.75
	>3-4 ML	28	Group	0.46 (WU_{t-1}, WU_{t-4},T,R)	0.70	0.55 (WU_{t-1}, WU_{t-4},T,R)	**0.80**
	>2-3 ML	70	Group	0.35 (WU_{t-1}, WU_{t-4},R)	0.41	0.58 (WU_{t-1}, WU_{t-4},R)	**0.62**
	1-2 ML	145	Group	0.61 (WU_{t-1}, WU_{t-4},R)	0.60	0.62 (WU_{t-1}, WU_{t-4},R)	0.57
	<1 ML	96	Group	0.81 (WU_{t-1}, WU_{t-4})	0.73	0.79 (WU_{t-1}, WU_{t-4})	**0.75**

Note: *E* values with bold number in the 2011 validation period are either greater or same to the values of the 2010-2011 validation period

Table 4.8 Estimated regression coefficients for different Schools group models (calibration period: 2006-2010, validation period: 2011)

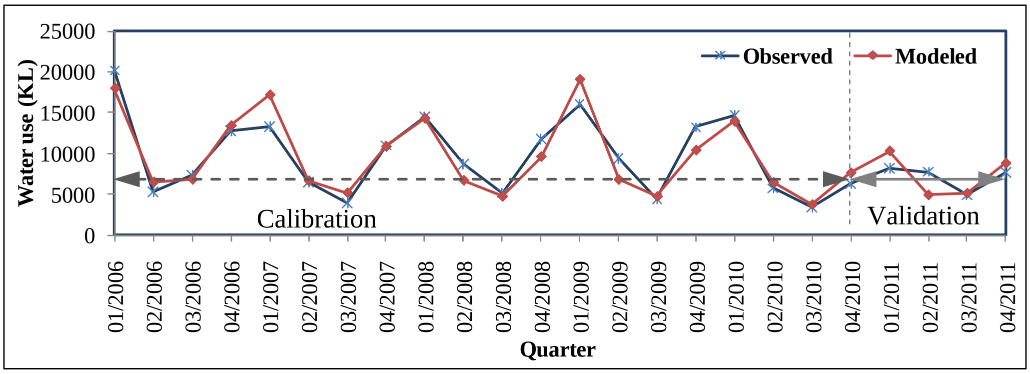
School Group	**School subgroups**	**Modelled by**	**Constant**	**$\log_{10}(WU_{t-1})$**	**$\log_{10}(WU_{t-4})$**	**$\log_{10}(T)$**	**$\log_{10}(Rn)$**	**R**	**D_2**	**D_3**	**D_4**
			(b_0)	**(b_1)**	**(b_2)**	**(b_3)**	**(b_4)**	**(b_5)**	**(b_6)**	**(b_7)**	**(b_8)**
>20 ML		Individual	1.54	-	-	**2.33 (0.00)**	**-0.28 (0.01)**	**-0.12 (0.03)**	-	-	-
>15-20 ML		Individual (School 1)	0.44	0.19 (0.07)	-	**2.17 (0.00)**	-0.15 (0.18)	-0.08 (0.18)	-	-	-
		Individual (School 2)	1.20	-	**0.48 (0.01)**	0.53 (0.19)	-	-0.16 (0.09)	-	-	-
>10-15 ML		Individual (School 1)	1.86	-	-	**1.29 (0.00)**	-	-0.17 (0.07)			
		Individual (School 2)	4.12	-	-	0.29 (0.18)	**-0.42 (0.00)**	**-0.33 (0.00)**	-	-	-
		Individual (School 3)	3.59	-	-	**1.79 (0.02)**	**-1.08 (0.01)**	**-0.64 (0.00)**	-	-	-
5-10 ML	>9 -10 ML	Individual	-1.30	**0.74 (0.00)**	-	**1.55 (0.00)**	-	-	-	-	-
	>8-9 ML	Individual	1.71	**0.60 (0.00)**	-	-	-0.18 (0.09)	-0.12 (0.20)	-	-	-
	>7-8 ML	Group	0.13	**0.53 (0.00)**	**0.21 (0.05)**	**0.49 (0.05)**	-	-	-	-	-
	>6-7 ML	Group	0.52	**0.81 (0.00)**	-0.02 (0.79)	0.26 (0.15)	-0.09 (0.32)	-0.08 (0. 11)	-	-	-
	5-6 ML	Group	0.68	**0.60 (0.00)**	0.13 (0.08)	**0.34 (0.05)**	-0.14 (0.09)	**-0.10 (0.03)**	-	-	-
<5 ML	>4-<5 ML	Group	0.10	**0.85 (0.00)**	-	**0.23 (0.00)**	-	-	-	-	-
	>3-4 ML	Group	0.37	**0.69 (0.00)**	**0.11 (0.01)**	**0.21 (0.04)**	-	**-0.06 (0.02)**	-	-	-
	>2-3 ML	Group	0.68	**0.69 (0.00)**	**0.06 (0.00)**	-	-	**-0.6 (0.00)**	-	-	-
	1-2ML	Group	0.44	**0.73 (0.00)**	**0.09 (0.00)**	-	-	**-0.04 (0.00)**	-	-	-
	< 1ML	Group	0.09	**0.73 (0.00)**	**0.19 (0.00)**	-	-	-	-	-	-

Note: *p*-value is presented in the parenthesis; bold coefficients are statistically significant at 5% level

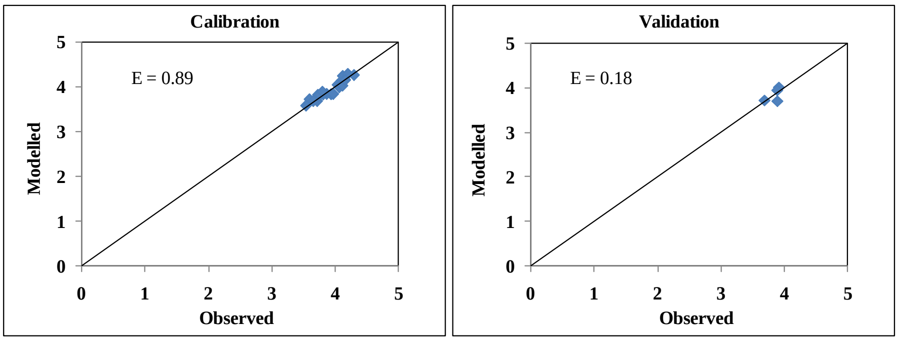
4.4.3.1. Group: >20 ML

There is only one school in this group, and therefore, it was modelled as an individual school. Table 4.8 shows that the mean maximum daily temperature, total rainfall and water restrictions have statistically significant contributions on the current water use in this school. This might be due to the more outdoor water use (i.e. large playground and swimming pools), where water use is affected by the climate and also by the water restrictions.

Comparison of observed against modelled water use for this school is shown in Figure 4.3, with scatter plots for both calibration and validation periods. Figure 4.3 shows that the modelled water uses time series is well matched with the observed data in both calibration and validation periods. Also, it can be seen from the scatter plots in Figure 4.3 that the data points lie close to the 1:1 line. The *E* value for calibration is high, but for validation it is low (Table 4.7). Low *E* value in validation might be because of the sudden change in water use of the school in 2011. From the time series plot, it can be seen that there was a big drop in water use in 2011.



Time series plot



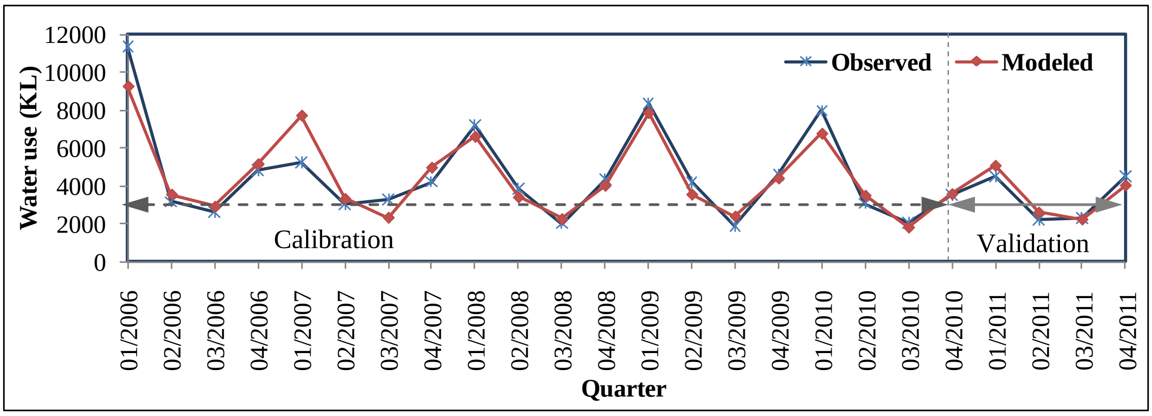
Note: values are in $\log(WU_t)$

Scatter plot

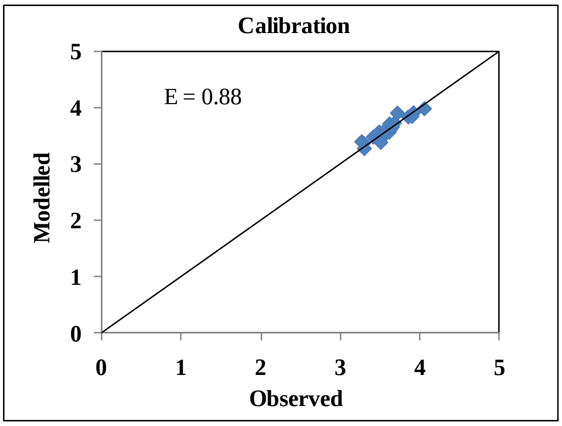
Figure 4.3 Observed vs modelled water use for >20 ML Schools group

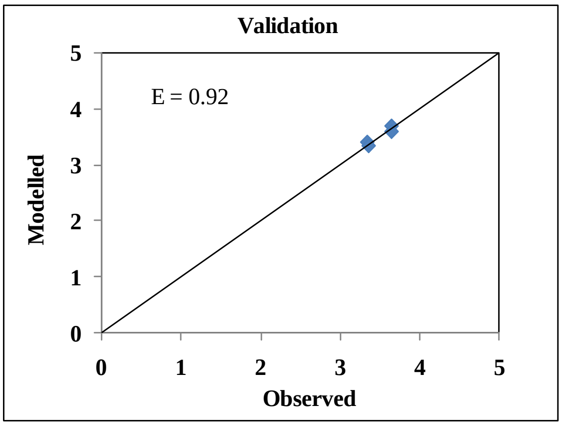
4.4.3.2. Group: >15-20 ML

There are two schools in this group and modelling water use was performed individually for each of these schools. From Table 4.8, it can be seen that the mean maximum temperature is the only statistically significant independent variable for School 1 in this group. However, it should be noted that the previous quarter's water use WU_{t-1}, rainfall and restrictions variables were also included in this model although they were not statistically significant as including these variables improved the model performance (see Figure 4.1 for model development procedure). Comparison of observed against modelled water use time series and scatter plots are shown in Figure 4.4 for both calibration and validation periods. It shows that the modelled water use time series is well matched with the observed data in both calibration and validation periods. From Figure 4.4, it can also be seen that the data points in the scatter plots lie close to the 1:1 line.



Time series plot



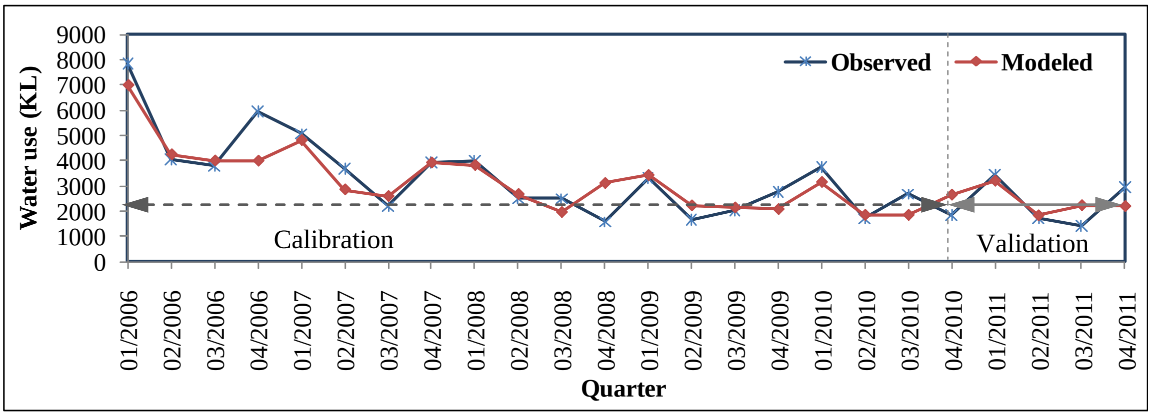


Note: values are in $\log(WU_t)$

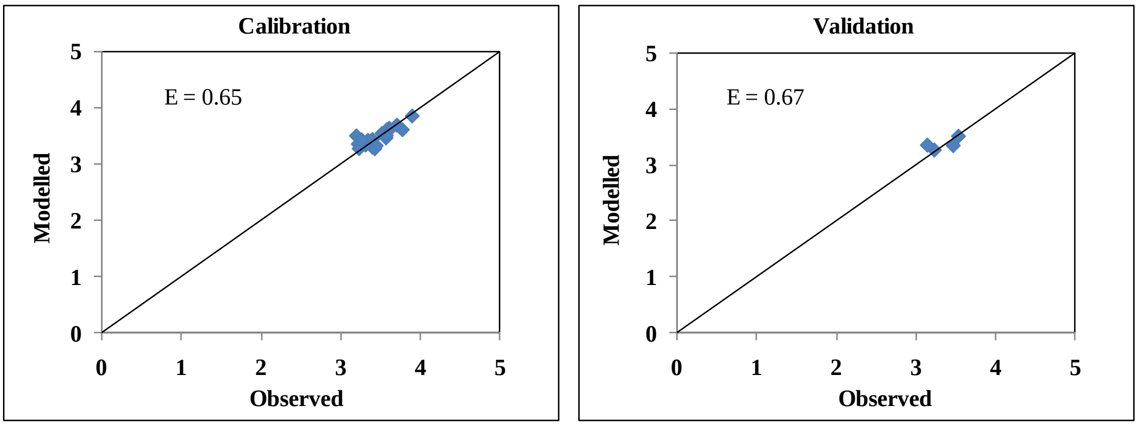
Scatter plot

Figure 4.4 Observed vs modelled water use for School 1 in >15-20 ML Schools group

For School 2, it was found that the previous quarter's water use in terms of WU_{t-4} was the only the statistically significant independent variable. However, the mean maximum daily temperature and water restrictions were also included in this model. Although, they were not statistically significant, including these variables improved the model performance (see Figure 4.1 for model development procedure). Comparison of observed against modelled water use time series for School 2 is shown in Figure 4.5 with scatter plots for both calibration and validation periods. Figure 4.5 shows that the modelled water use time series is well matched with the observed data in both calibration and validation periods. Moreover, *E* values presented in Table 4.7 for both calibration and validation periods indicate that the model performed well, which can also be seen from the scatter plots (Figure 4.5).



Time series plot



Note: values are in $\log(WU_t)$

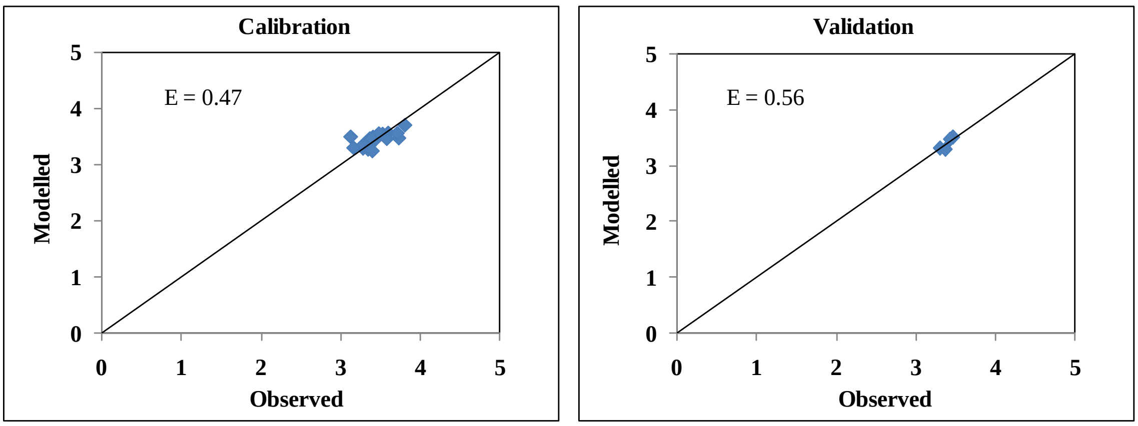
Scatter plot

Figure 4.5 Observed vs modelled water use for School 2 in >15-20 ML Schools group

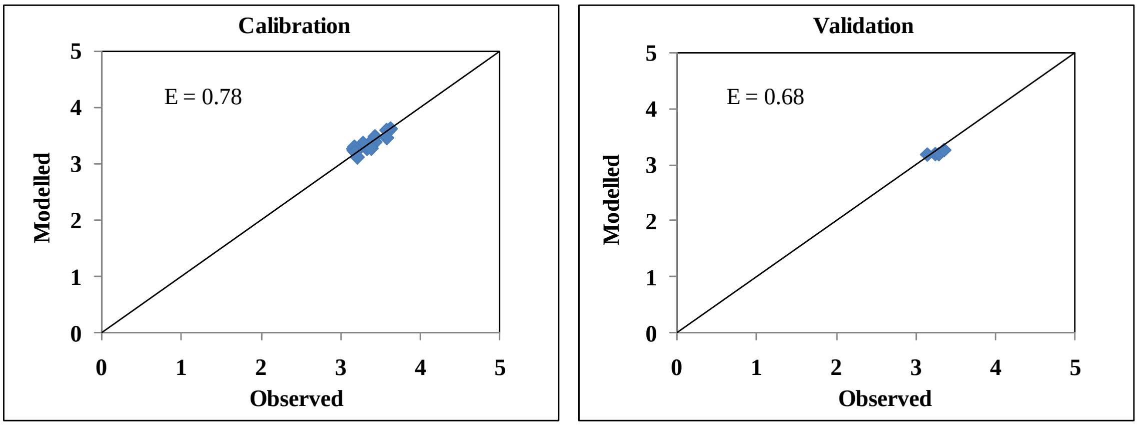
From the above discussion, it can be seen that climatic variables and restrictions are the common independent variables in modelling the current water use in both of the schools in this group. Therefore, it is apparent that there are significant outdoor water uses in the two schools of this group.

4.4.3.3. Group: >10-15 ML

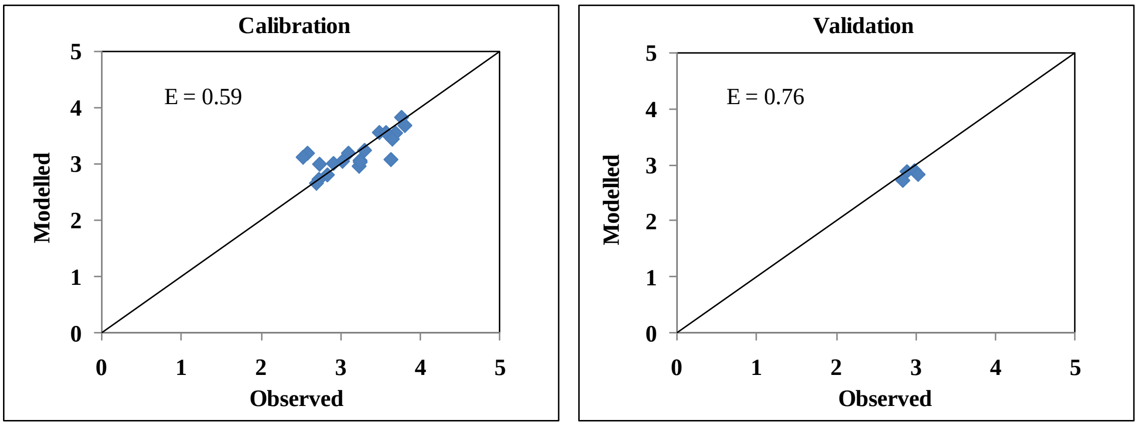
There are three schools in this group and they were individually modelled because of high average annual water use as discussed in Section 4.4.1. It can be seen from Table 4.8 that the mean maximum daily temperature and water restrictions were found as important independent variables in all three schools. Although these variables were not statistically significant in all cases, including these variables improves the model performance (see Figure 4.1 for model development procedure). The total rainfall variable was also found to have significant contribution on current water use in Schools 2 and 3 in this group. Therefore, it implies that there are some outdoor water uses in this Schools group. Comparison of observed against modelled water use is shown in scatter plots in Figure 4.6 for both calibration and validation periods for all three schools. It can be seen from the figure that the modelled water use in all three schools is well matched with the observed water use, which is also reflected with the *E* values (Table 4.7).



a) School 1



b) School 2



Note: values are in $\log(WU_t)$

c) School 3

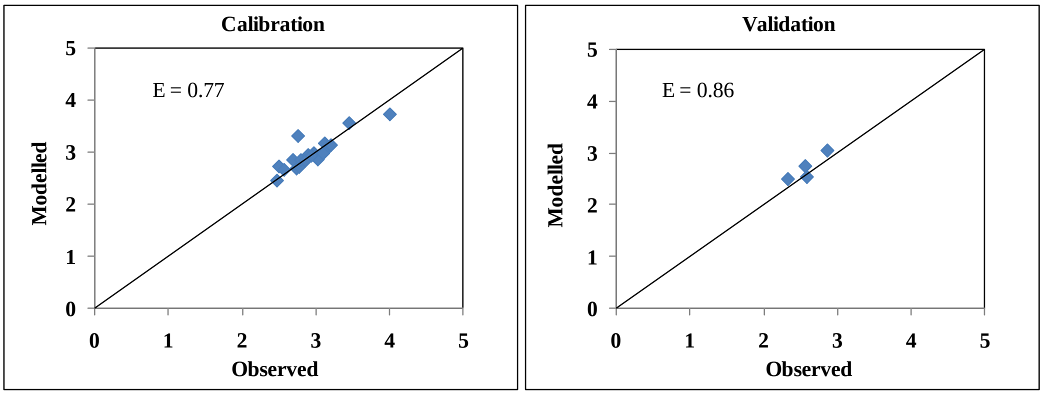
Figure 4.6 Scatter plots of observed vs modelled water use for the three schools in >10-15 ML Schools group

4.4.3.4. Group: 5-10 ML

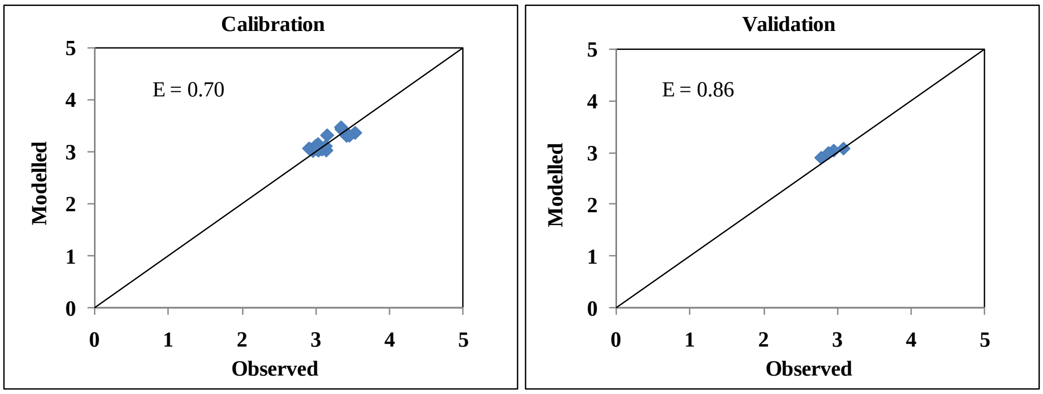
There are five subgroups in this group as shown in Table 4.4 (Section 4.4.1). Among these subgroups, >8-9 ML and >9-10 ML subgroups have only one school, but there are multiple schools in the remaining subgroups (i.e. >7-8 ML, >6-7 ML and 5-6 ML). Therefore, as outlined in Section 4.4.1, >8-9 ML and >9-10 ML subgroups were modelled as individual schools and the other subgroups were modelled as individual groups with multiple schools.

From Table 4.8, it can be seen that previous quarter's water use WU_{t-1} has statistically significant contribution on the current water use of the school in all subgroups of this group. Although the other variables such as total rainfall and mean maximum daily temperature (Table 4.8) were included as important variables in this group (see Figure 4.1 for model development procedure), it can be seen from Table 4.8 that the coefficient of these variables were small. Therefore, these results indicate that there are less outdoor activities among the schools in this group.

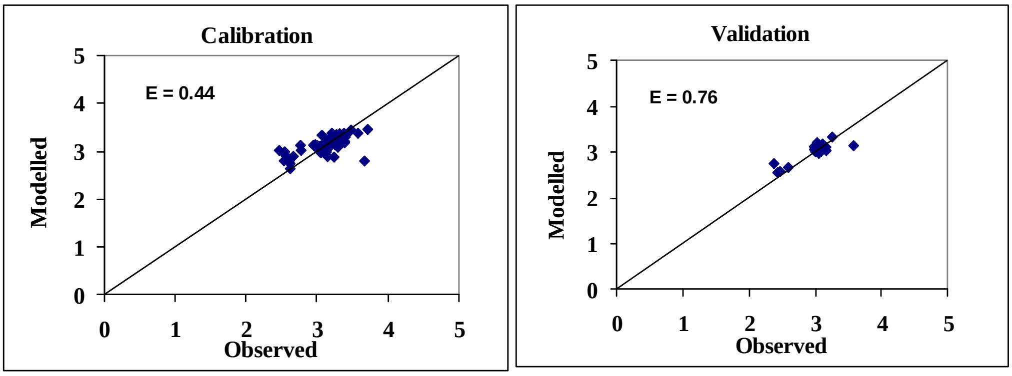
Comparison of observed against modelled water use is shown in scatter plots in Figure 4.7 for both calibration and validation periods for all five subgroups. It can be seen from this figure that the modelled water use in these subgroups are well matched with the observed water use, which is also reflected with the *E* values (Table 4.7).



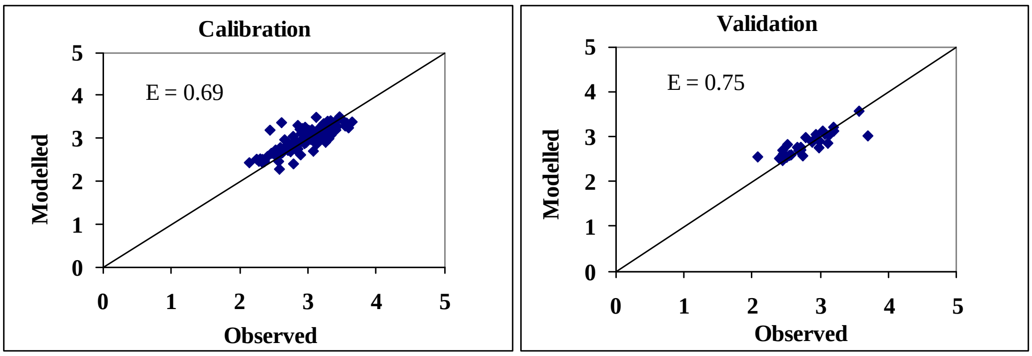
a) Subgroup >9-10 ML



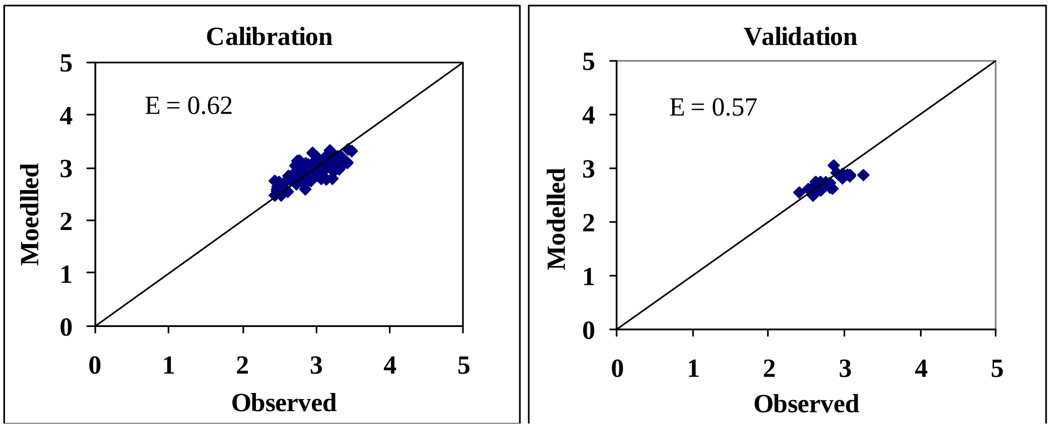
b) Subgroup >8-9 ML



c) Subgroup >7-8 ML



d) Subgroup >6-7 ML



Note: values are in log(WU_t)

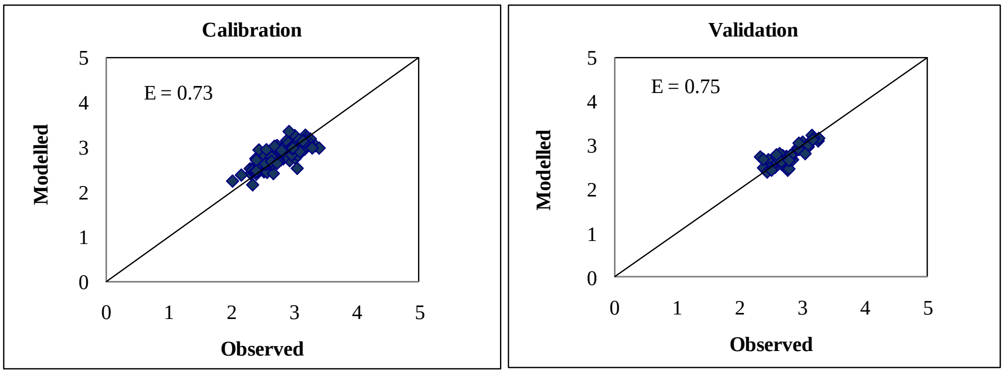
e) Subgroup 5-6 ML

Figure 4.7 Scatter plots of observed vs modelled water use for the five school subgroups in 5-10 ML Schools group

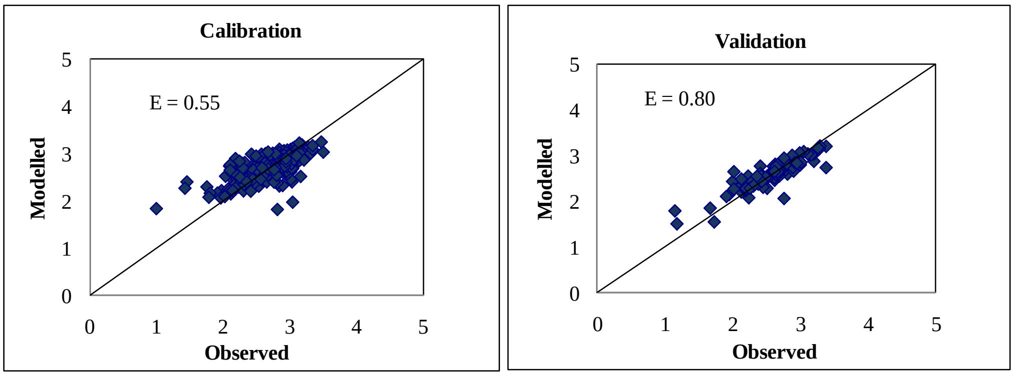
4.4.3.5. Group: <5 ML

Models for >4-<5 ML, >3-4 ML, >2-3 ML, 1-2 ML and <1 ML subgroups were developed as for 5-6 ML, >6-7 ML and >7-8 ML subgroups as there are more than one school within these subgroups. From Table 4.8, it can be seen that the WU_{t-1} and WU_{t-4} water use are the statistically significant independent variables in all of these school subgroups except the >4-5 ML subgroup. However, restrictions was also included as an important variable in >3-4 ML, >2-3 ML and 1-2 ML subgroups as including this variable improved the model performance (see Figure 4.1 for model development procedure). It can also be seen that climate variables do not contribute to the water use in these subgroups in the <5 ML group. This could be due to less outdoor activities among the schools in these low annual water use subgroups.

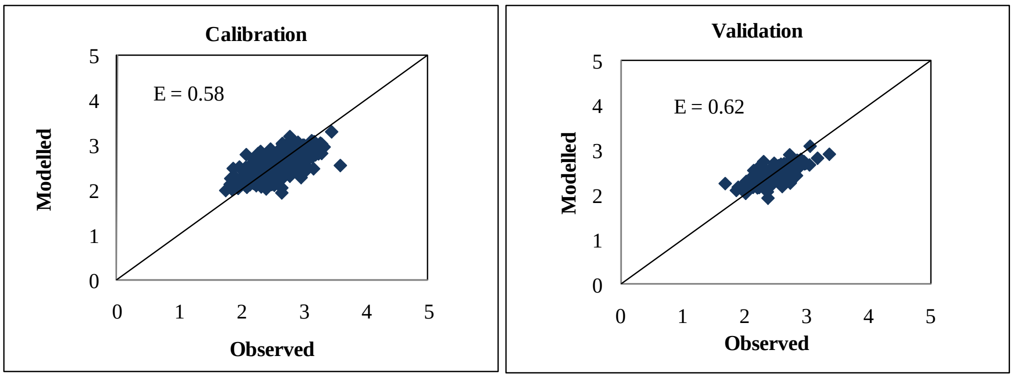
Similar to the 5-10 ML group, comparison of observed against modelled water use is shown in scatter plots in Figure 4.8 for both calibration and validation periods for all five subgroups. The modelled water uses in these subgroups are well matched with the observed water use as can be seen from Figure 4.8, which is also reflected with the *E* values (Table 4.7).



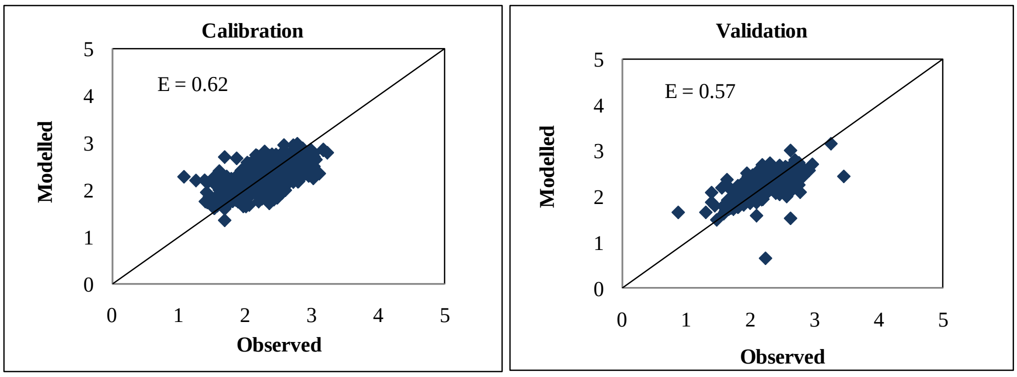
a) Subgroup >4-5 ML



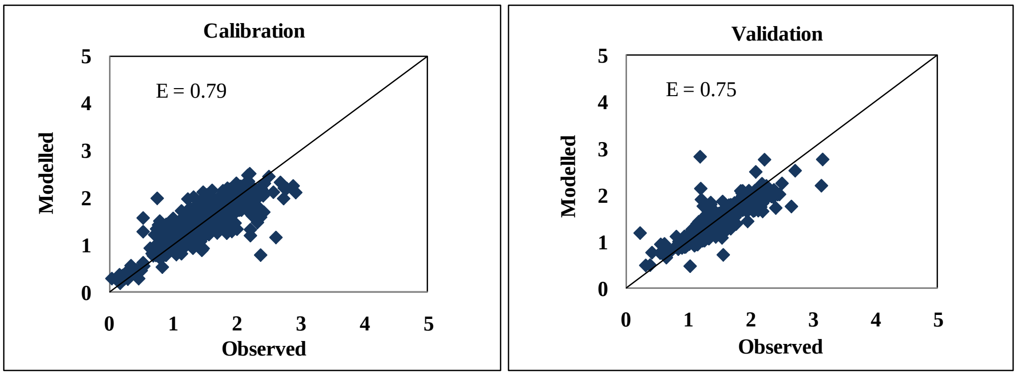
b) Subgroup >3-4 ML



c) Subgroup >2-3 ML



d) Subgroup 1-2 ML



Note: values are in $\log(WU_t)$

e) Subgroup <1 ML

Figure 4.8 Scatter plots of observed vs modelled water use for the five school subgroups in <5 ML Schools group

4.5. Water Use Models for Sports Grounds

4.5.1. Data Analysis and Disaggregation

Analysis of water use in sports Grounds shows that the Sports Grounds sector accounts for 2.0% of the total non-residential water use in 2011 in the YVW service area. Although, quarterly billing data for 277 sports grounds located within the YVW service area were received, only 154 sports grounds were used in this research work due to the missing data record for the remaining sports grounds over the period of 2005-2011. As discussed in Chapter 3 (Section 3.6), all 154 sports grounds were categorized into several smaller groups based on the average annual water use in 2005-2009. These groups are shown in Table 4.9 with the contributing percentages to the total Sports Grounds group's water use in 2011.

Table 4.9 Disaggregated annual water use of Sports Grounds in the YVW service area

Water user groups	**>20 ML**	**>15-20 ML**	**>10-15 ML**	**5-10 ML**	**<5 ML**	**Total**
Number of sports grounds	1	1	5	36	111	154
Water use (%)	1.0	2.5	6.5	33.5	56.5	100

From Table 4.9, it can be seen that 10% of the total sports ground's water usage is by 7 sports grounds with more than 10 ML water use, which is a large percentage of water use consumed by these individual sports grounds. Therefore, they were modelled at an individual level. However, the water use by the sports ground in >20 ML was not modelled in this research due to its changing water use behaviour and discussed in Section 4.5.2.1. There are large number of sports grounds in 5-10 ML and <5 ML user groups compared to the other groups. These two groups were divided into smaller subgroups based on their annual average water use, as shown in Tables 4.10 and 4.11 respectively. They were modelled at individual subgroup level with multiple sports grounds.

Table 4.10 Subgroups in 5-10 ML Sports Grounds group

Water user group	**>9-10 ML**	**>8-9 ML**	**>7-8 ML**	**>6-7 ML**	**5-6 ML**	**Total**
Number of sports grounds	5	2	6	4	19	36
Water use (%)	4.0	6.0	5.0	5.5	13.0	33.5

Table 4.11 Subgroups in <5 ML Sports Grounds group

Water user group	**>4 -<5 ML**	**>3-4 ML**	**>2-3 ML**	**1-2 ML**	**<1 ML**	**Total**
Number of sports grounds	18	20	29	32	12	111
Water use (%)	13.0	15.0	14.0	13.5	1	56.5

Quarterly percentages of total annual water use (Section 3.6) were calculated for all groups in Table 4.9 and are shown in Figure 4.9 except for >20 ML group. It can be seen from the figure that the water use pattern over the year is quite similar in all Sports grounds subgroups. However, with careful observation it is clear that high user group use more percentage of annual water use in quarter 1 and 4 and less percentage in quarter 2 and 3 than the low user groups.

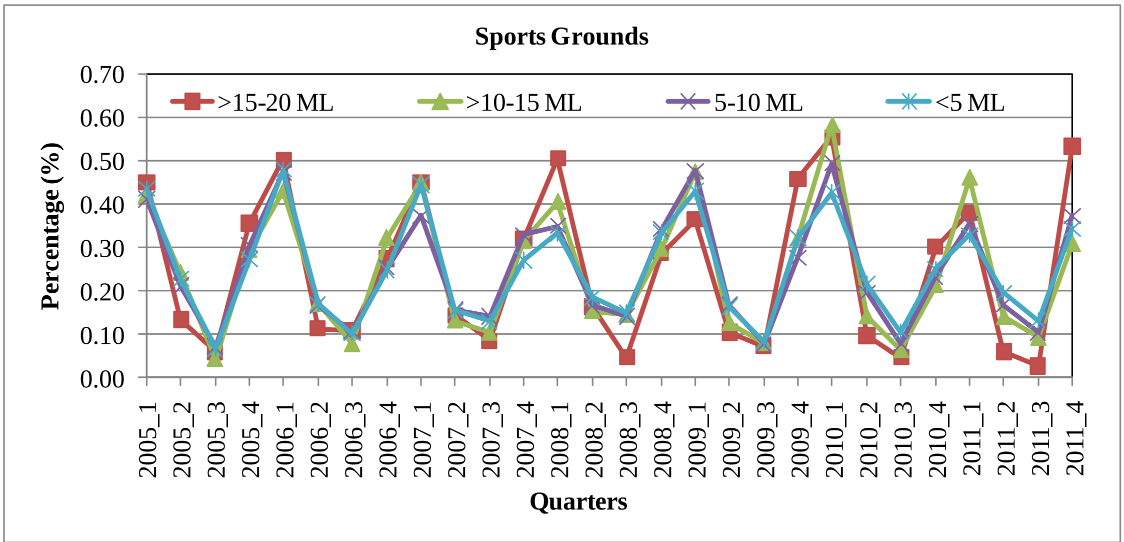


Figure 4.9 Time series of quarterly percentage to annual water use among the different user groups in Sports Grounds

4.5.2. Results and Discussions

Results of the correlation analysis performed among the dependent and the independent variables for all subgroups in the Sports Grounds group are shown in Table 4.12. Correlation between the independent variables for all Sports Grounds subgroups is presented in Appendix B.

It can be seen from Table 4.12 that there are moderate to high correlations between the current water use and the temperature for all subgroups except for lowest four water use subgroups. Similar correlations can also be seen with the previous quarter's water use (in terms of WU_{t-4}) for most of the high water use subgroups. There are moderate correlations with the previous quarter's water use (in terms of WU_{t-1}) for the subgroups 8 ML or less (Table 4.12). Remaining variables were found to have low correlation with the current water use in most cases.

From correlation analysis between the independent variables (Appendix B), it was found that the correlation coefficients ranged from -0.70 to 0.70 for most of the groups except for Sports Grounds 1, 2, 3 and 5 in >10-15 ML, and <1 ML subgroups. However, one of the inter-correlated variables in these subgroups was not found to be significant variable in the best model as was in the Schools group.

As mentioned in Section 4.4.3, model calibration and validation were performed for the Sports Grounds group using 2006-2010 and 2011 period data respectively. The *E* values found for the best models in this research are presented in Table 4.13. The regression coefficients obtained for the best models of different Sports Grounds subgroups are also presented in Table 4.13.

Table 4.12 Correlation coefficient between the dependent and independent variables used in all subgroups in the Sports Grounds group

Group	**Modelled by**	**Log$_{10}$(WU$_t$)**	**Log$_{10}$(WU$_{t-1}$)**	**Log$_{10}$(WU$_{t-4}$)**	**Log$_{10}$(T)**	**Log$_{10}$(R$_n$)**	**R**	**D$_2$**	**D$_3$**	**D$_4$**
>20 ML	Individual	-	-	-	-	-	-	-	-	-
>15-20 ML	Individual	1	0.34	***0.90***[a]	***0.82***[a]	0.02	*-0.36*[b]	-0.27	*-0.63*[b]	0.33
>10-15 ML	Individual (Sports G.1)	1	*0.37*[b]	0.47[b]	*0.56*[b]	-0.01	-0.31	*-0.38*[b]	-0.33	0.34
	Individual (Sports G.2)	1	*0.36*[b]	***0.70***[a]	*0.69*[b]	-0.29	-0.27	-0.12	*-0.57*[b]	0.12
	Individual (Sports G.3)	1	0.19	***0.70***[a]	***0.80***[a]	-0.13	-0.06	-0.32	*-0.58*[b]	0.30
	Individual (Sports G.4)	1	*0.36*[b]	***0.79***[a]	***0.80***[a]	-0.25	-0.18	-0.29	*-0.56*[b]	0.20
	Individual (Sports G.5)	1	0.32	***0.75***[a]	***0.78***[a]	-0.27	-0.12	-0.19	*-0.63*[b]	0.20
>9-10 ML	Individual	1	0.32	*0.65*[b]	*0.54*[b]	-0.09	-0.26	-0.08	*-0.48*[b]	0.16
>8-9 ML	Individual	1	0.23	0.24	*0.60*[b]	0.07	-0.20	-0.15	*-0.52*[b]	0.23
>7-8 ML	Group	1	*0.44*[b]	*0.65*[b]	*0.54*[b]	-0.21	-0.32	-0.06	*-0.51*[b]	0.11
>6-7 ML	Group	1	*0.67*[b]	*0.63*[b]	*0.45*[b]	-0.19	-0.30	-0.11	*-0.36*[b]	0.09
5-6 ML	Group	1	*0.55*[b]	*0.46*[b]	*0.39*[b]	-0.06	-0.26	-0.13	-0.30	0.11
>4-<5 ML	Group	1	*0.53*[b]	*0.46*[b]	*0.43v*	0.03	-0.26	-0.14	-0.35	0.17
>3-4 ML	Group	1	*0.57*[b]	0.34	0.33	-0.01	-0.28	-0.08	-0.29	0.11
>2-3 ML	Group	1	*0.65*[b]	*0.43*[b]	0.25	-0.09	*-0.39*	-0.06	-0.22	0.04
1-2 ML	Group	1	*0.65*[b]	*0.40*[b]	0.20	0.04	*-0.39*[b]	-0.09	-0.17	0.08
<1ML	Group	1	***0.78***[a]	*0.67*[b]	0.05	-0.14	-0.30	0.01	-0.06	-0.03

Note: *a* – variables are highly correlated, *b* – variables are moderately correlated.

4.5.2.1. Group: >20 ML

There is one sports ground in this group. The time series of water use data of this sports ground is shown in Figure 4.10. It can be seen from the figure that water uses was started to decrease from 4th quarter in 2006 and has become very low from 2nd quarter of 2009 onward. After discussion with the YVW, it was found that this customer had invested in stormwater collection and reuse from 4th quarter of 2006 and also has licence to extract water from a nearby Creek. All of these alternate sources of water make this customer less dependent on using water from YVW. Therefore, water use for this sports ground was not modelled in this research.

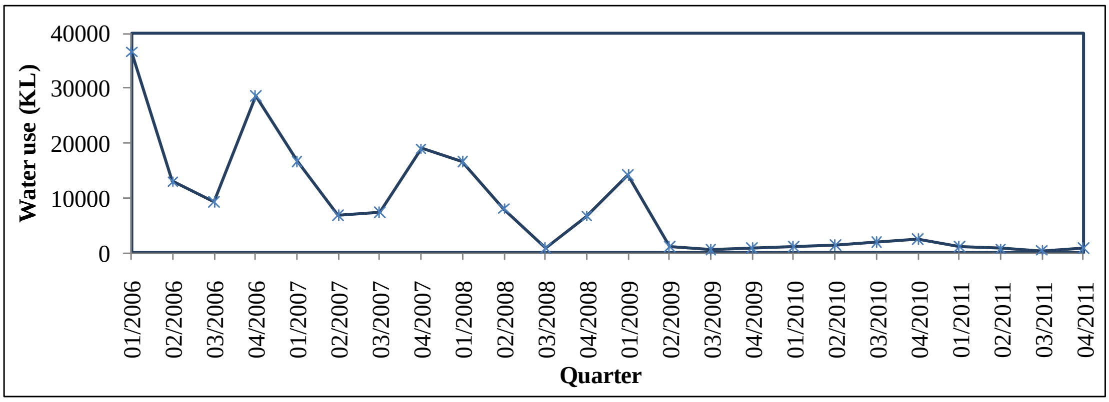


Figure 4.10 Time series of water use data for >20 ML Sports Grounds group

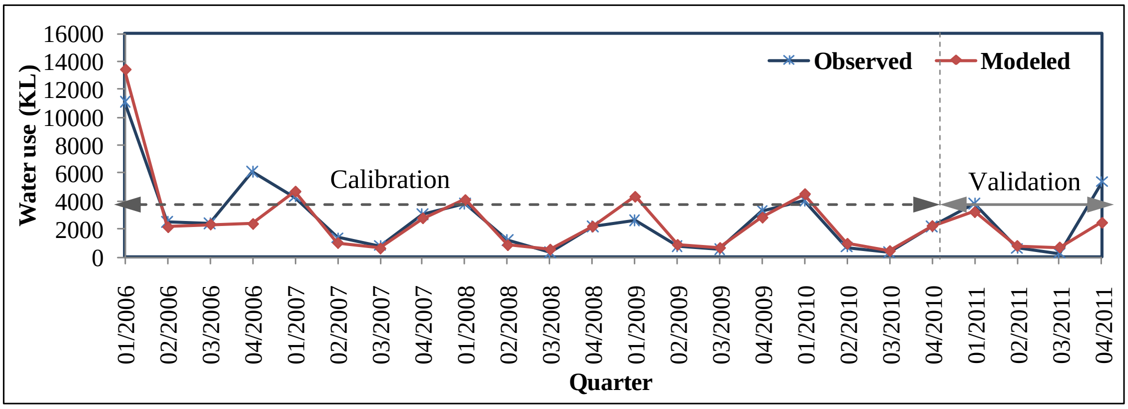
Table 4.13 *E* values for the best models and estimated regression coefficients for different Sports Grounds group models

Sports Grounds Group	**Sports Grounds subgroups**	**Number of Sports Grounds**	**Modelled by**	***E* values**		**Constant**	**$\log_{10}(WU_{t-1})$**	**$\log_{10}(WU_{t-4})$**	**$\log_{10}(T)$**	**$\log_{10}(Rn)$**	**R**	**D_2**	**D_3**	**D_4**
				Calibration	**Validation**	**(b_0)**	**(b_1)**	**(b_2)**	**(b_3)**	**(b_4)**	**(b_5)**	**(b_6)**	**(b_7)**	**(b_8)**
>20 ML	-	1	Not modelled	-	-	-	-	-	-	-	-	-	-	-
>15-20 ML	-	1	Individual	0.89	0.76	-1.59	-	-	**4.02 (0.00)**	-	**-.53 (0.00)**	-	-	-
>10-15 ML	-	5	Individual (S.G. 1)	0.46	0.64	0.35	-	-	**2.47 (0.00)**	-	**-0.39 (0.05)**			
			Individual (S.G. 2)	0.60	0.40	-4.66	-	-	**6.31 (0.00)**	-	**-0.78 (0.03)**	-	-	-
			Individual (S.G.3)	0.67	0.38	-1.45	-	-	**3.65(0.00)**	-	-0.18 (.26)	-	-	-
			Individual (S.G.4)	0.83	0.90	-0.03	-	-	**3.68 (0.00)**	**-0.65 (0.01)**	**-0.33 (0.01)**	-	-	-
			Individual (S.G.5)	0.77	0.42	1.31	-	-	**2.30 (0.00)**	**-0.43 (0.01)**	**-0.17 (0.05)**	-	-	-
5-10 ML	>9 -10 ML	5	Group	0.54	0.62	-0.73	**0.19 (0.01)**	**0.42 (0.00)**	**1.54 (0.00)**	-	-0.15 (0.10)	-	-	-
	>8-9 ML	2	Group	0.50	0.68	-1.09	0.17 (0.19)	-0.26 (0.10)	**3.61 (0.00)**	-	-0.31 (0.06)	-	-	-
	>7-8 ML	6	Group	0.58	0.43	-2.50	**0.40 (0.00)**	-	**3.42 (0.00)**	-	**-0.31 (0.00)**	-	-	-
	>6-7 ML	4	Group	0.63	0.33	-2.63	**0.62 (0.00)**	-	**2.90 (0.00)**	-	-0.18 (0.11)	-	-	-
	5-6 ML	19	Group	0.47	0.42	-2.46	**0.50 (0.00)**	-	**3.06 (0.00)**	-	**-0.25 (0.00)**	-	-	-
<5 ML	>4-<5 ML	18	Group	0.56	0.52	1.51	**0.59 (0.00)**	-	-	-	**-0.29 (0.00)**	**-0.57 (0.00)**	**-0.50 (0.00)**	**0.29 (0.00)**
	>3-4 ML	20	Group	0.51	0.53	1.42	**0.60 (0.00)**	-	-	-	**-0.27 (0.00)**	**-0.47 (0.00)**	**-0.48 (0.00)**	**0.21(0.00)**
	>2-3 ML	29	Group	0.54	0.33	1.28	**0.62 (0.00)**	-	-	-	**-0.34 (0.00)**	**-0.49 (0.00)**	**-0.45 (0.00)**	0.12 (0.08)
	1-2 ML	32	Group	0.51	0.36	1.13	**0.60 (0.00)**	-	-	-	**-0.29 (0.00)**	**-0.32 (0.00)**	**-0.22 (0.00)**	**0.18 (0.00)**
	<1 ML	12	Group	0.61	0.51	0.35	**0.77 (0.00)**	-	-	-	-	-	-	-

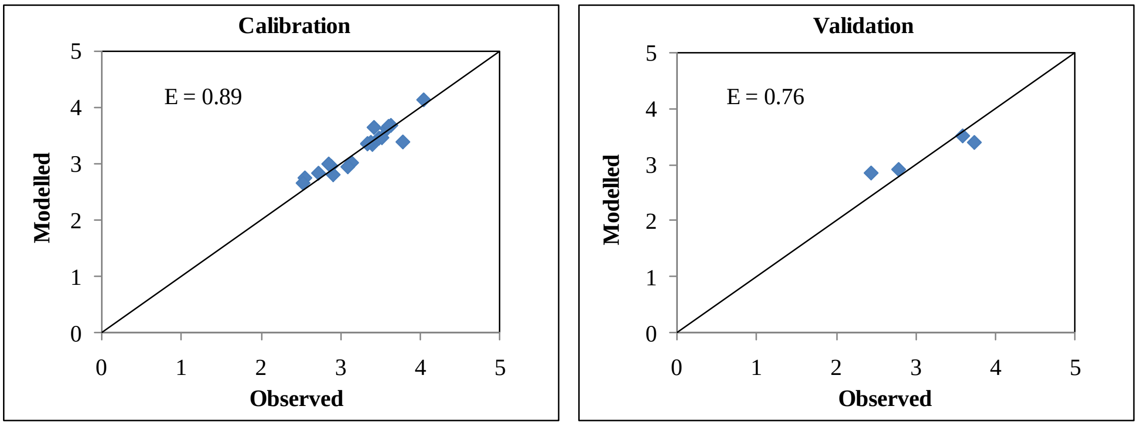
Note: *p*-value is presented in the parenthesis; S.G. is Sports Grounds; bold coefficients are statistically significant at 5% level

4.5.2.2. Group: >15-20 ML

Water use modelling for this group was performed as an individual sports ground as there is only one sport ground in this group. It was found that the mean maximum daily temperature and water restrictions have statistically significant contributions on current water use in this sports ground (Table 4.13). Comparison of observed and modelled water use time series for this sports ground is shown in Figure 4.11 with scatter plots for both calibration and validation periods. It shows that the modelled and observed water use is well matched. Higher *E* values for both calibration and validation shown in Table 4.13 also indicate that the model performed well.



Time series plot



Note: values are in log(WU_t)

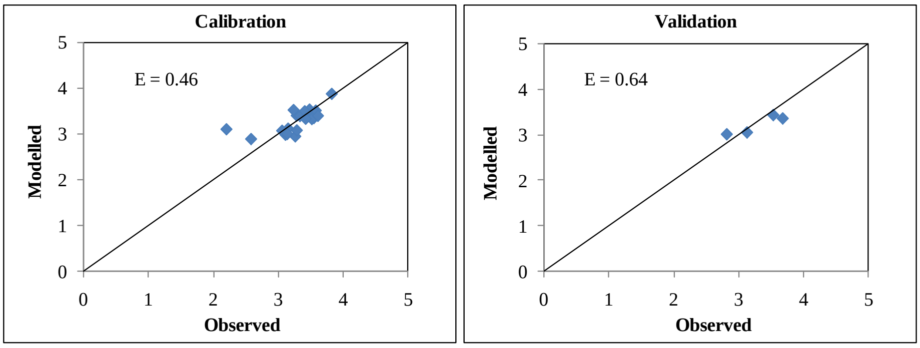
Scatter plot

Figure 4.11 Observed vs modelled water use in >15-20 ML Sports Grounds group

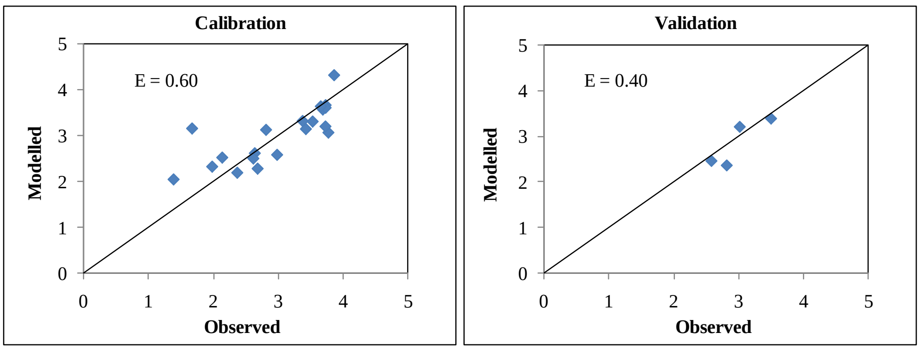
4.5.2.3. Group: >10-15 ML

There are five sports grounds in this group and are modelled separately (Section 4.5.1). From Table 4.13, it can be seen that the mean maximum daily temperature has statistically significant contribution on current water use for all sports grounds. Similar contribution was also found for the water restrictions in all cases except for Sports Grounds 3, having insignificant contribution. It can be also seen from Table 4.13 that total rainfall has statistically significant contribution on current water use in Sports Grounds 4 and 5. However, for these two sports grounds, it is clear that the mean maximum daily temperature has more contribution than the total rainfall and water restrictions as coefficient obtained for this variable is higher than the coefficients of rainfall and water restrictions variables (Table 4.13).

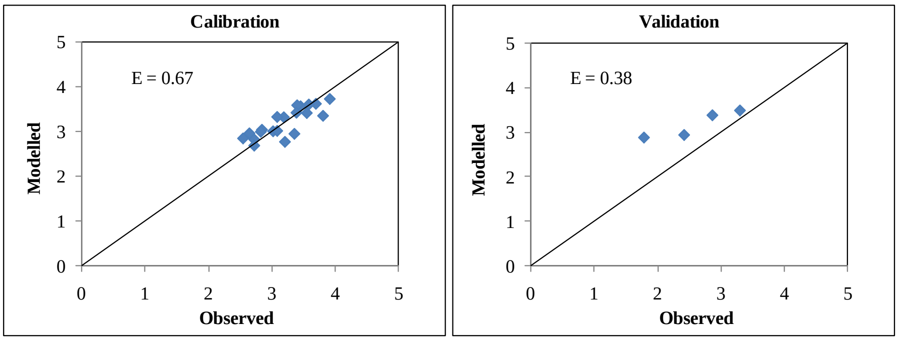
Comparison of observed and modelled water use scatter plots for both calibration and validation periods are shown in Figure 4.12. It shows that the modelled and observed water use is well matched for all sports grounds in this group as most of the data points are closed to 1:1 line. *E* values for both calibration and validation (Table 4.13) also indicate that the models performed well in all cases in this group.



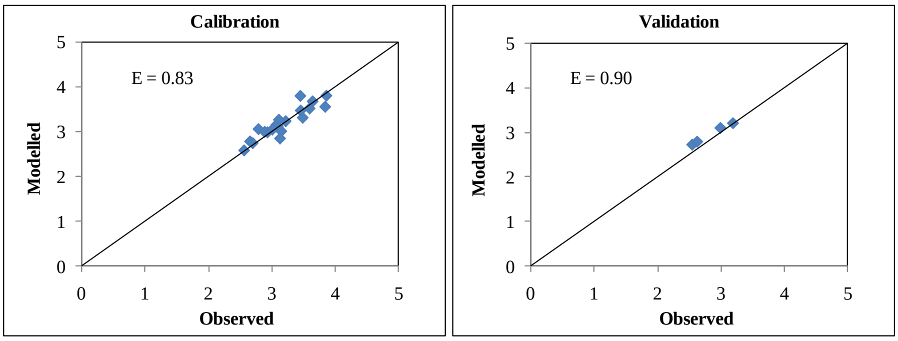
a) Sports Ground 1



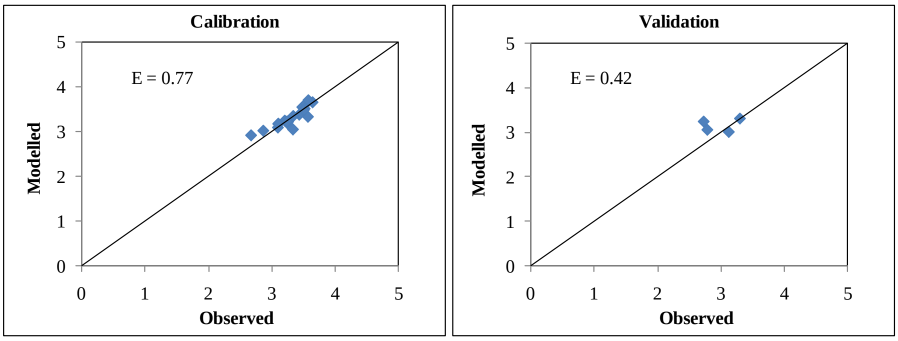
b) Sports Ground 2



c) Sports Ground 3



d) Sports Ground 4



Note: values are in log(WU_t)

e) Sports Ground 5

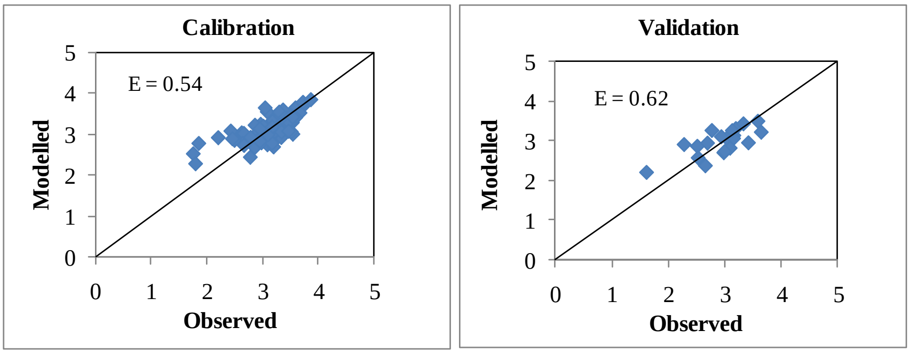
Figure 4.12 Scatter plots of observed vs modelled water use for the five sports grounds in >10-15 ML Sports Grounds group

4.5.2.4. *Group: 5-10 ML*

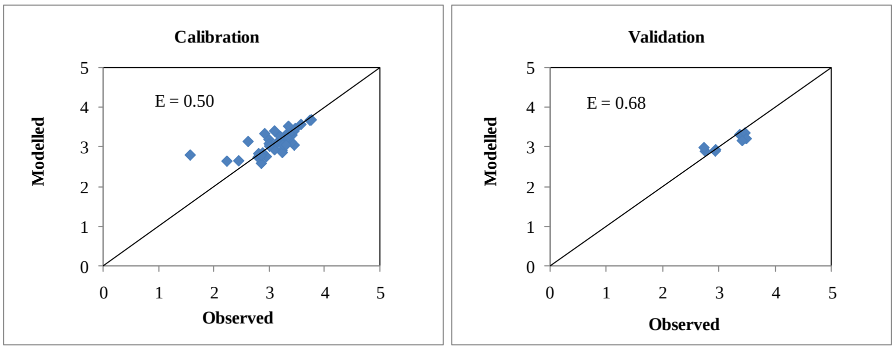
There are 36 sports grounds in this group. As outlined in Section 4.5.1, based on annual average water use (in 2005-2009) all 36 sports grounds were divided into five subgroups, these are: >9-10 ML, >8-9 ML, >7-8 ML, >6-7 ML, and 5-6 ML. It can be seen from Table 4.13 that there are more than one sports ground in each of these subgroups and therefore, water use for these subgroups were modelled at individual group level with multiple sports grounds, as discussed in Section 4.5.1.

From Table 4.13, it can be seen that previous quarter's water use in terms of WU_{t-1}, mean maximum daily temperature and water restrictions have statistically significant effect on current water use in case of all subgroups in this group. Moreover, previous quarter's water use in terms of WU_{t-4} was also found to have effect on current water use in subgroups >9-10 ML and >8-9 ML. From Table 4.13, it can also be seen that the coefficient for the mean maximum daily temperature is higher than the coefficients of other variables used in the models. Therefore, it is clear that the current water use in this group is adjusted based on the previous quarter's water use along with the temperature and the water restrictions levels.

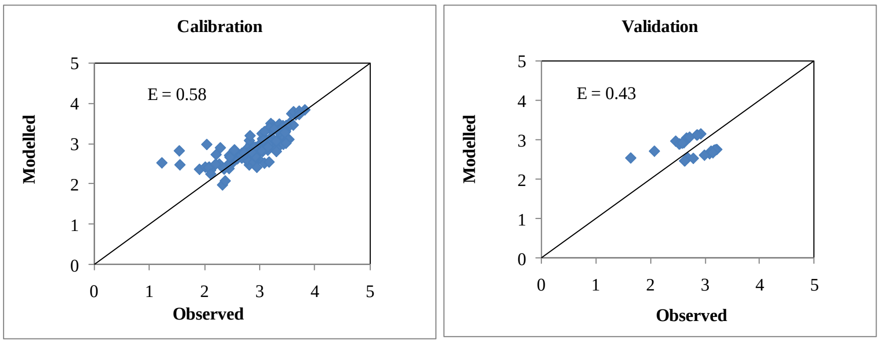
Scatter plots for both calibration and validation periods are presented for all subgroups in Figure 4.13. *E* values for both calibration and validation in Table 4.13 also indicates that the models performed well in most of the subgroups.



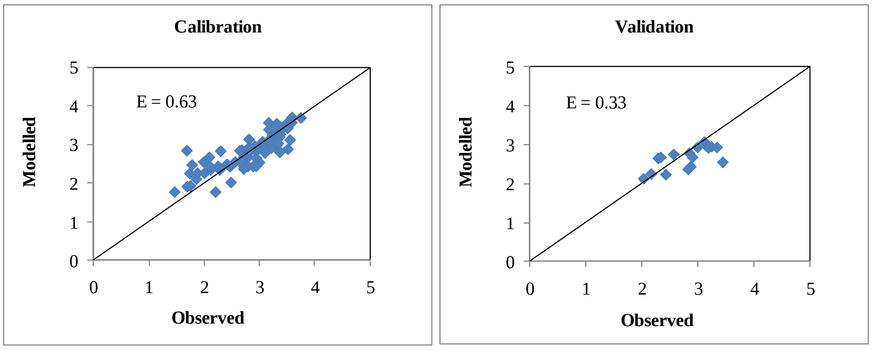
a) Subgroup >9-10 ML



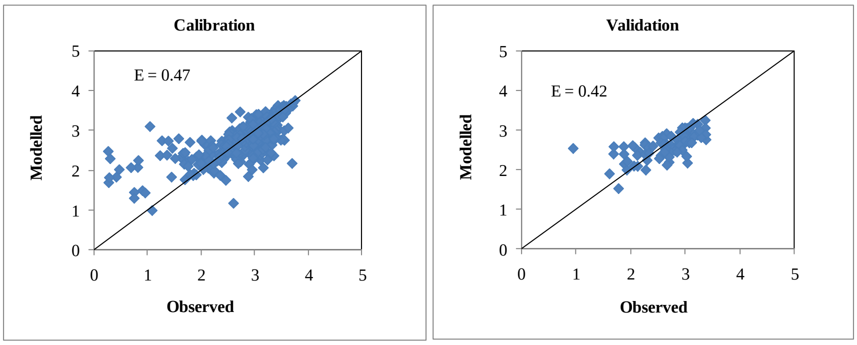
b) Subgroup >8-9 ML



c) Subgroup >7-8 ML



d) Subgroup >6-7 ML



Note: values are in log(WU_t)

e) Subgroup 5-6 ML

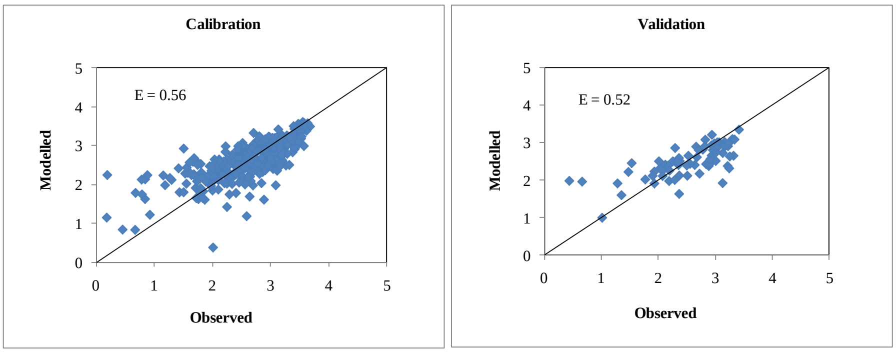
Figure 4.13 Scatter plots of observed vs modelled water use for the five subgroups in 5-10 ML Sports Grounds group

4.5.2.5. Group: < 5 ML

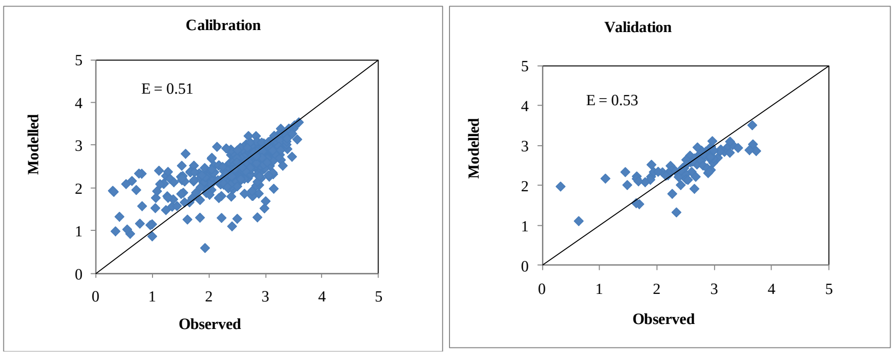
There are 111 sports grounds customers in this group and all these customers were classified into five subgroups based on the average annual water use (in 2005-2009), and model development was performed at individual group level.

From Table 4.13, it can be observed that previous quarter's water uses in terms of WU_{t-1} have statistically significant contribution on the current water use in all subgroups. Similar contribution was also found for water restrictions and fixed quarterly effects for all subgroups except the <1 ML subgroup. It is also apparent that the coefficient for WU_{t-1} is higher than the coefficient for the water restrictions and the dummy variables representing the fixed quarterly effects. Therefore, it is clear that water use in these less user sports grounds are almost same for each quarter from year to year, and current water use are also depends on previous quarter's water uses in terms of WU_{t-1} and imposed water restrictions levels.

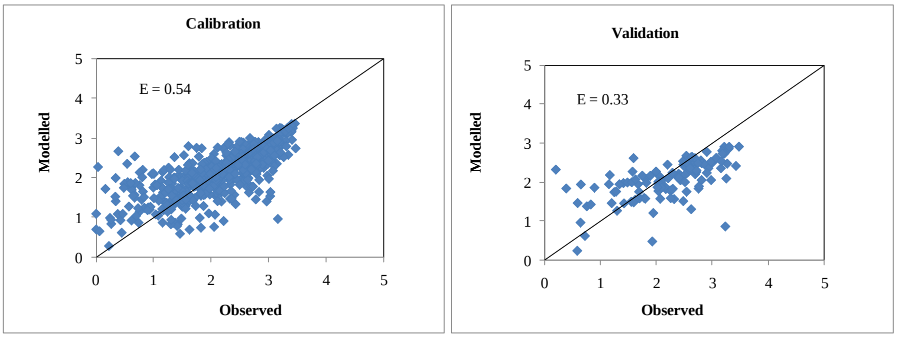
Scatter plots for both calibration and validation periods are presented for all subgroups in Figure 4.14. They show that most of the data points are close to 1:1 line. *E* values for both calibration and validation in Table 4.13 also indicate that the models performed well in all subgroups.



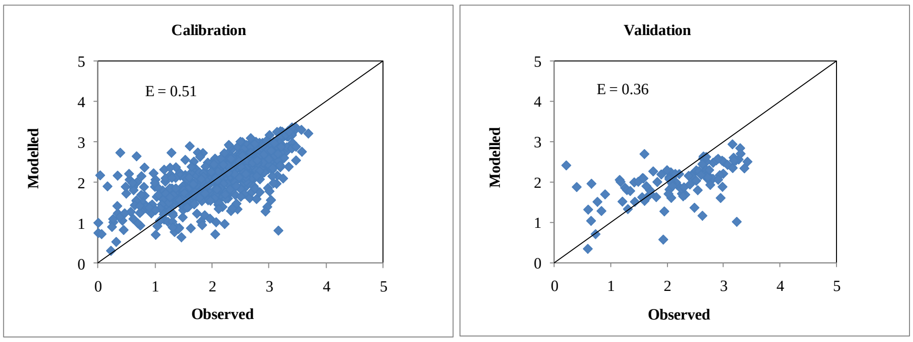
a) Subgroup >4-<5 ML



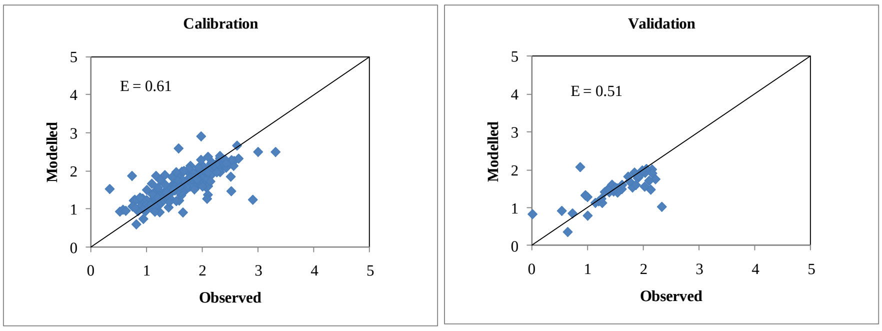
b) Subgroup >3-4 ML



c) Subgroup >2-3 ML



d) Subgroup 1-2 ML



Note: values are in $\log(WU_t)$

e) Subgroup <1 ML

Figure 4.14 Scatter plots of observed vs modelled water use for the five subgroups in <5 ML Sports Grounds group

4.6. Water Use Models for Councils

4.6.1. Data Analysis and Disaggregation

There are 1429 customers listed as Councils in the data provided by YVW, having all quarter's data for the period of 2005-2011. Different types of organisations lie in the Councils list such as Library, Community Garden, Club and Office in various types, Police station, and Aquatic facility. However, the identification of the specific type of customers was not carried out in this research. From data analysis, it was found that, the total water use by these 1429 councils is about 4.5% of the total non-residential water use in YVW in 2011. As outlined in Chapter 3, all these councils were categorized into several smaller groups based on the average annual water use in 2005-2009. These groups are shown in Table 4.14 along with their contributing percentages to the total Council's water use in 2011.

Table 4.14 Disaggregated annual water use of Councils in the YVW service area

Water user groups	**>20 ML**	**>15-20 ML**	**>10-15 ML**	**5-10 ML**	**<5 ML**	**Total**
Number of councils	4	4	5	27	1269	1429
Water use (%)	10	6	7	16	61	100

From Table 4.14, it is clear that there are 13 councils using more than 10 ML and contributing 23% to the total Council's water use in 2011. Therefore, water use in these 13 councils was modelled at an individual council level.

Similar to the School and Sports Grounds groups, as there are large number of councils in the 5-10 ML and <5 ML user groups, these two groups were divided into smaller subgroups based on their average annual water use and shown in Table 4.15 and Table 4.16 respectively. All subgroups in these two groups were modelled at individual subgroup level with multiple councils.

Table 4.15 Subgroups in 5-10 ML Councils group

Water user group	**>9-10 ML**	**>8-9 ML**	**>7-8 ML**	**>6-7 ML**	**5-6 ML**	**Total**
Number of councils	2	1	5	11	8	27
Water use (%)	1.5	1.0	3.0	6.5	4.0	16

Table 4.16 Subgroups in <5 ML Councils group

Water user group	**>4 -<5 ML**	**>3-4 ML**	**>2-3 ML**	**1-2 ML**	**<1 ML**	**Total**
Number of councils	14	20	42	84	1269	1429
Water use (%)	6.0	5.0	8.5	9.5	32.0	61

Quarterly percentages of annual water uses (Section 3.6) for the Councils groups shown in Table 4.14 were calculated and are shown in Figure 4.15. It is apparent from the figure that there is a high percentage of annual water use in quarters 1 and 4, and less percentage in quarters 2 and 3. Therefore, it is apparent that there are outdoor water uses in Councils similar to Schools and Sports Grounds. From the figure it also can be seen that there is less similarity in >15-20 ML group with the other Sports Grounds groups. However, it should be noted that there are no specific data about each council available for this study.

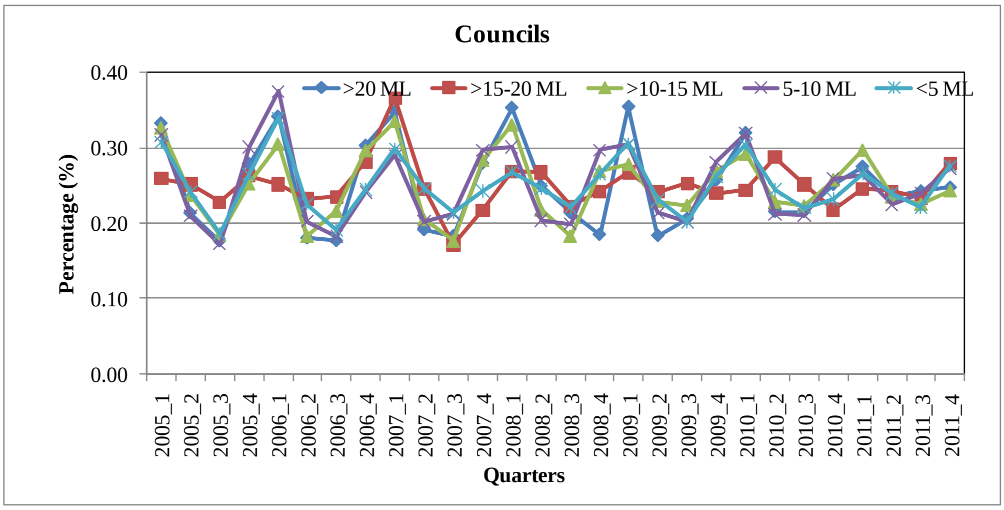


Figure 4.15 Time series of quarterly percentage to annual water use among the different user groups in Councils

4.6.2. Results and Discussions

Table 4.17 presents the correlation coefficients among the dependent and the independent variables for all subgroups in the Councils group. Correlation results between the independent variables for all groups are presented in Appendix C.

From Table 4.17, it is noticeable that there are moderate to high correlations between the current water use and the previous quarter's water use in terms of WU_{t-1} for all subgroups except for Council 4 in >15-20 ML and Council 5 in >10-15 ML subgroups. Similar correlation was also found with the previous quarter's water use in terms of WU_{t-4} for most of the subgroups. Although, the mean maximum daily temperature has moderate correlation with the current water use in some subgroups, in most subgroups this variable has low correlation with the current water use. Remaining variables used in this study have very low correlations with the current water use in almost all cases.

From the correlation analysis between the independent variables (Appendix C), it was found that the correlation coefficients ranged from -0.70 to 0.70 for most of the groups except for Councils 1 and 3 in >20 ML, Council 4 in 15-20 ML, Council 3 in >10-15 ML, >8-9 ML and <1 ML subgroups. However, one of the inter-correlated variables in these councils and subgroups was not found to be significant variable in the best model as was in the Schools and Sports Grounds groups.

As mentioned in Section 4.4.3, model calibration and validation were performed for the Councils group using 2006-2010 and 2011 data respectively. The *E* values found for the best models in this research are presented in Table 4.18. The regression coefficients obtained for the best models of different councils subgroups are also presented in Table 4.18.

Table 4.17 Correlation coefficient between the dependent and independent variables used in all subgroups in the Councils group

Group	**Modelled by**	**$Log_{10}(WU_t)$**	**$Log_{10}(WU_{t-1})$**	**$Log_{10}(WU_{t-4})$**	**$Log_{10}(T)$**	**$Log_{10}(R_n)$**	**R**	**D_2**	**D_3**	**D_4**
>20 ML	Individual (Council 1)	1	***0.78***[a]	*0.51*[b]	0.31	0.12	***-0.81***[a]	-0.08	-0.28	0.06
	Individual (Council 2)	1	*0.63*[b]	0.15	*0.38*[b]	0.02	-0.23	-0.21	-0.24	0.13
	Individual (Council 3)	1	*0.40*[b]	*0.49*[b]	*0.63*[b]	*-0.42*[b]	-0.22	-0.20	*-0.44*[b]	0.03
	Individual (Council 4)	1	*0.59*[b]	0.14	0.34	0.17	0.08	-0.18	-0.22	0.19
>15-20 ML	Individual (Council 1)	1	*0.62*[b]	0.28	*0.43*[b]	-0.01	-0.34	-0.17	-0.30	0.11
	Individual (Council 2)	1	***0.68***[a]	-0.27	-0.20	*-0.46*[b]	*-0.38*[b]	0.24	0.10	-0.29
	Individual (Council 3)	1	*0.60*[b]	-0.35	-0.22	0.19	0.04	0.02	0.14	0.05
	Individual (Council 4)	1	0.13	***0.73***[a]	***0.70***[a]	-0.29	*0.42*[b]	-0.01	*-0.65*[b]	0.07
>10-15 ML	Individual (Council 1)	1	*0.59*[b]	*0.66*[b]	0.03	-0.08	***-0.69***[a]	-0.29	0.20	-0.09
	Individual (Council 2)	1	***0.85***[a]	*0.46*[b]	0.08	*0.36*[b]	*0.47*[b]	0.04	-0.12	0.06
	Individual (Council 3)	1	*0.50*[b]	*0.60v*	*0.53*[b]	*-0.52*[b]	-0.19	0.08	*-0.51*[b]	-0.04
	Individual (Council 4)	1	*0.54*[b]	0.24	-0.01	-0.26	-0.20	-0.01	0.01	0.09
	Individual (Council 5)	1	0.13	*0.53*[b]	***0.78***[a]	0.13	0.20	*-0.60*[b]	*-0.38*[b]	*0.48*[b]
>9-10 ML	Group	1	*0.43*[b]	***0.72***[a]	*0.47*[b]	-0.14	-0.34	-0.15	*-0.40*[b]	0.17
>8-9 ML	Individual	1	*0.51*[b]	0.14	0.05	0.30	*-0.63*[b]	-0.31	0.08	0.15
>7-8 ML	Group	1	***0.89***[a]	*0.53*[b]	0.14	-0.09	-0.25	-0.04	-0.09	0.02
>6-7 ML	Group	1	*0.52*[b]	*0.39*[b]	0.27	-0.01	-0.12	-0.13	-0.19	0.12
5-6 ML	Group	1	*0.64*[b]	0.35	0.32	-0.06	-0.12	-0.11	-0.24	0.11
>4-<5 ML	Group	1	*0.64*[b]	*0.45*[b]	0.25	-0.02	-0.20	-0.05	-0.23	0.07
>3-4 ML	Group	1	***0.73***[a]	*0.47*[b]	0.20	-0.16	-0.21	-0.05	-0.16	0.02
>2-3 ML	Group	1	*0.63*[b]	*0.37*[b]	0.22	-0.08	-0.19	-0.04	-0.20	0.02
1-2 ML	Group	1	***0.72***[a]	*0.55*[b]	0.21	-0.11	-0.20	-0.06	-0.16	0.05
<1ML	Group	1	***0.88***[a]	***0.78***[a]	0.00	-0.03	-0.09	0.02	-0.01	-0.02

Table 4.18 *E* values for the best models and estimated regression coefficients for different Councils group models

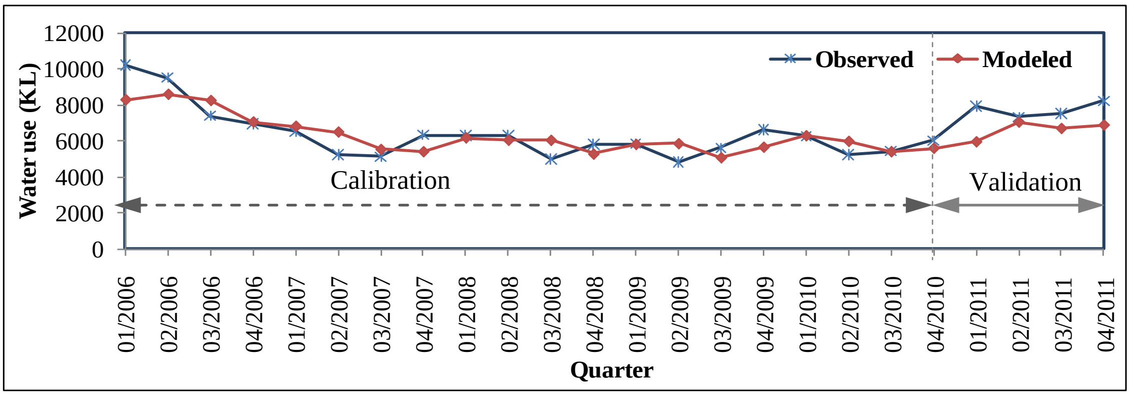
Councils Group	Councils Group subgroups	Number of Councils	Modelled by	*E* values		Constant	$\log_{10}(WU_{t-1})$	$\log_{10}(WU_{t-4})$	$\log_{10}(T)$	$\log_{10}(Rn)$	R	D_2	D_3	D_4
				Calibration	Validation	(b_0)	(b_1)	(b_2)	(b_3)	(b_4)	(b_5)	(b_6)	(b_7)	(b_8)
>20 ML	-	4	Individual (Council 1)	0.61	0.36	1.01	**0.65 (0.00)**	0.08 (0.59)	-	-	-	-	-	-
			Individual (Council 2)	0.40	0.22	1.55	**0.60 (0.01)**	-	-	-	-0.04 (0.58)	-	-	-
			Individual (Council 3)	0.73	0.75	0.04	-	-	**6.08 (0.00)**	**-2.00 (0.00)**	**-0.74 (0.02)**	-	-	-
			Individual (Council 4)	0.43	0.68	1.46	**0.56 (0.01)**	-	0.16 (0.15)	-	-	-	-	-
>15-20 ML	-	4	Individual (Council 1)	0.39	0.22	1.24	**0.57 (0.01)**	0.09 (0.62)	-	-	-	-	-	-
			Individual (Council 2)	0.64	0.99	2.35	**0.60 (0.00)**	-	-	**-0.39 (0.04)**	-0.18 (0.06)	-	-	-
			Individual (Council 3)	0.36	0.25	1.44	**0.61 (0.01)**	-	-	-	-	-	-	-
			Individual (Council 4)	0.59	0.18	0.57	**0.33 (0.04)**	-	**1.39 (0.00)**	-	-	-	-	-
>10-15 ML	-	5	Individual (Council 1)	0.43	0.27	1.18	-	**0.66 (0.00)**	-	-	-	-	-	-
			Individual (Council 2)	0.80	0.97	0.37	**0.81 (0.00)**	-	-	-	**0.38 (0.03)**	-	-	-
			Individual (Council 3)	0.68	0.56	2.01	-	-	**3.98 (0.00)**	-1.79 (0.30)	**-0.51 (0.04)**	-	-	-
			Individual (Council 4)	0.29	0.81	1.57	**0.54 (0.01)**	-	-	-	-	-	-	-
			Individual (Council 5)	0.62	0.34	0.39	-	-	**2.23 (0.00)**	-	-	-	-	-
5-10 ML	>9 -10 ML	2	Group	0.58	0.74	0.89	-	**0.76 (0.00)**	-	-	**-0.19 (0.03)**	-	-	-
	>8-9 ML	1	Individual	0.34	0.81	1.13	**0.50 (0.02)**	-	-	0.24 (0.17)	-	-	-	-
	>7-8 ML	5	Group	0.80	0.49	-0.32	**0.93 (0.00)**	-	**0.43 (0.02)**	-	-0.06 (0.22)	-	-	-
	>6-7 ML	11	Group	0.37	0.52	0.08	**0.45 (0.00)**	**0.24 (0.00)**	**0.67 (0.00)**	-	-	-	-	-
	5-6 ML	8	Group	0.49	0.54	-0.88	**0.64 (0.00)**	-	**1.47 (0.00)**	-	-	-	-	-
<5 ML	>4-<5 ML	14	Group	0.53	0.67	-0.65	**0.58 (0.000**	**0.21 (0.00)**	**0.93 (0.00)**	-	-	-	-	-
	>3-4 ML	20	Group	0.60	0.71	-1.11	**0.68 (0.00)**	**0.19 (0.00)**	**1.06 (0.00)**	-	-	-	-	-
	>2-3 ML	42	Group	0.47	0.52	-1.09	**0.61 (0.00)**	**0.12 (0.00)**	**1.35 (0.00)**	-	-	-	-	-
	1-2 ML	84	Group	0.60	0.62	-0.68	**0.62 (0.00)**	**0.24 (0.00)**	**0.74 (0.00)**					
	<1 ML	1269	Group	0.78	0.77	0.16	**0.88 (0.00)**	-	-	-	-	-	-	-

Note: *p*-value is presented in the parenthesis; bold coefficients are statistically significant at 5% level

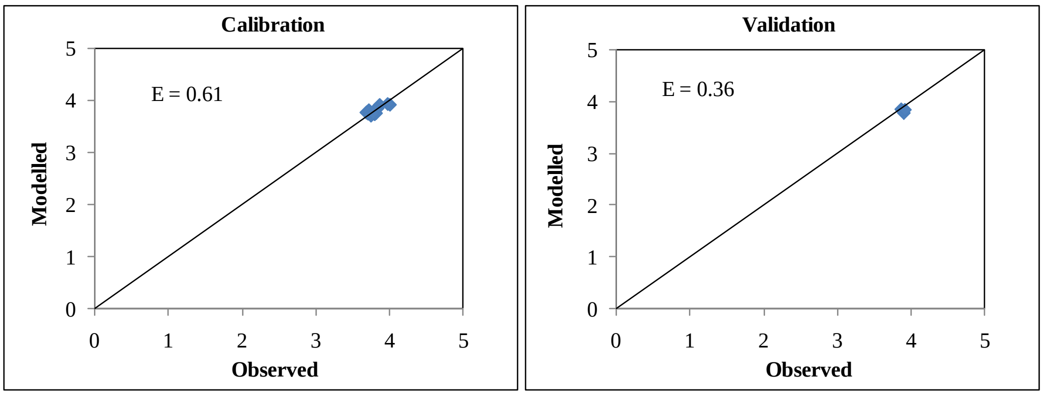
4.6.2.1. Group: >20 ML

There are four councils in this group. These councils use 11% of total water use of the Councils group. Water use was modelled individually for these four councils (Section 4.6.1).

From Table 4.18, it can be seen that in case of Council 1, *E* value for calibration was 0.61, although for validation it was 0.36. The low *E* value could be due to changed water use in the validation period. Moreover, it should be noted that as there are many other factors affects the council's water use are not available in this study. Table 4.18 indicates that previous quarter's water use in terms of WU_{t-1} and WU_{t-4} have important contributions to the current water use of these councils. Although, WU_{t-4} was not statistically significant, including this variable improved the model performance. The scatter plots and the time series plot in Figure 4.16 show that the modelled water use agrees with the observed water use.



Time series plot

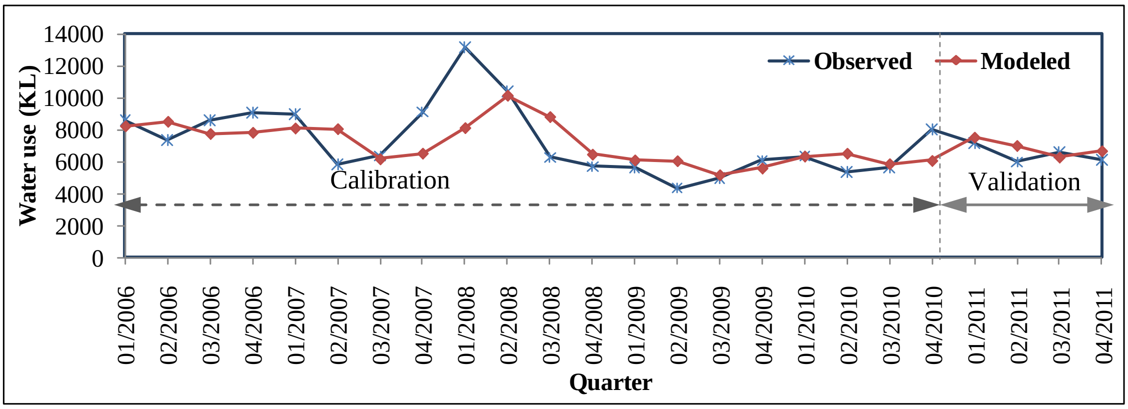


Note: values are in $\log(WU_t)$

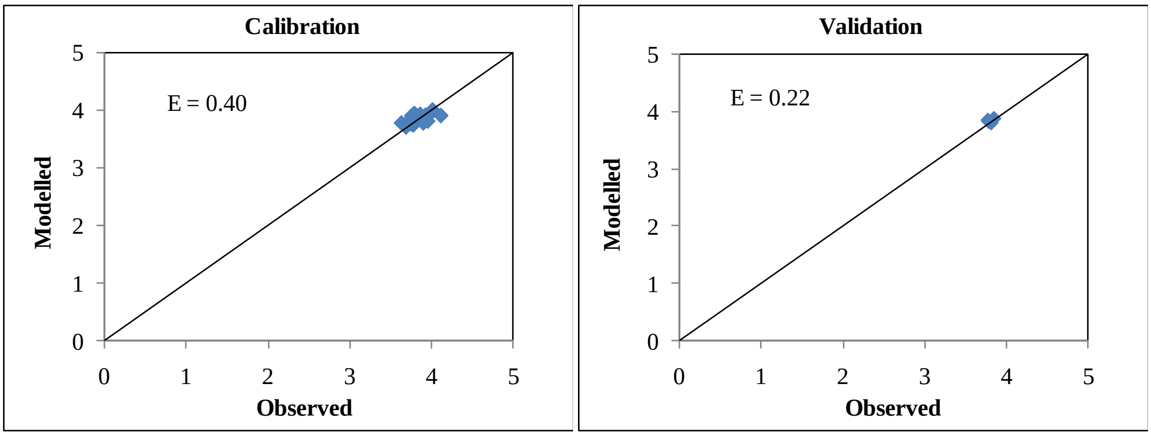
Scatter plot

Figure 4.16 Observed vs modelled water use for Council 1 in >20 ML Councils group

For Council 2, it can be seen from Table 4.18 that the previous quarter's water use in terms of WU_{t-1} and water restrictions have important contributions in modelling the current water use although water restrictions are not statistically significant. Scatter plots and the time series plot for Council 2 are shown in Figure 4.17. From the time series plot, it can be seen that modelled and observed water use are matched well.



Time series plot

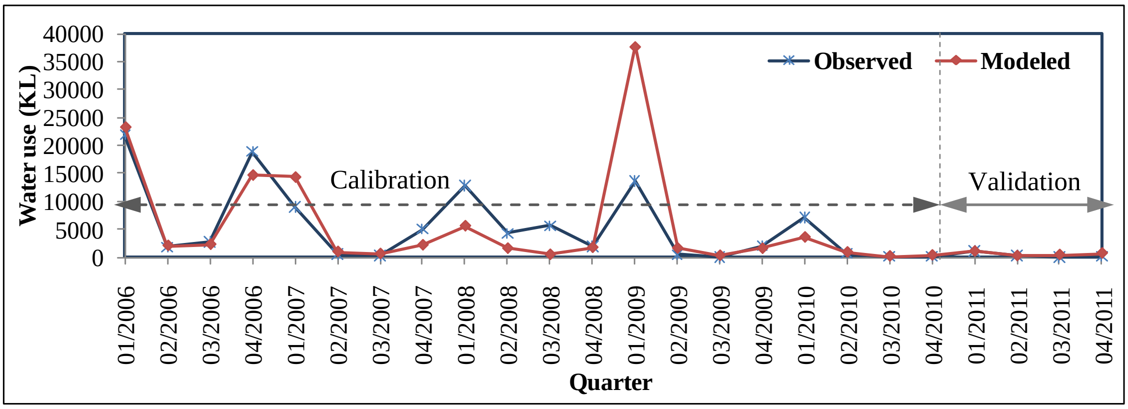


Note: values are in $\log(WU_t)$

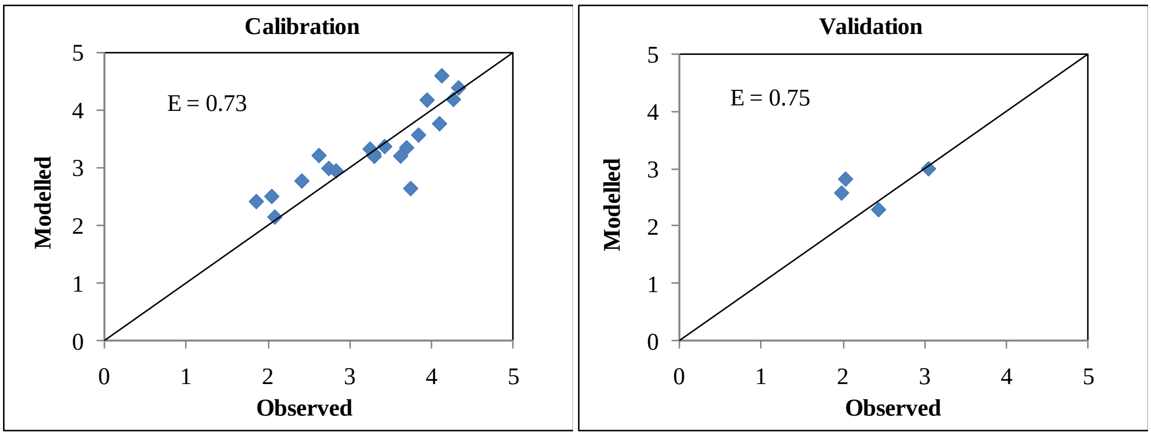
Scatter plot

Figure 4.17 Observed vs modelled water use for Council 2 in >20 ML Councils group

In case of Council 3, it can be seen from Table 4.18 that the mean maximum daily temperature, the total rainfall and the water restrictions have significant effects on current water use. The *E* values in Table 4.18 indicate that the modelled and observed water use are well matched, which can also be seen from the time series plot and the scatter plots of calibration and validation, shown in Figure 4.18.



Time series plot

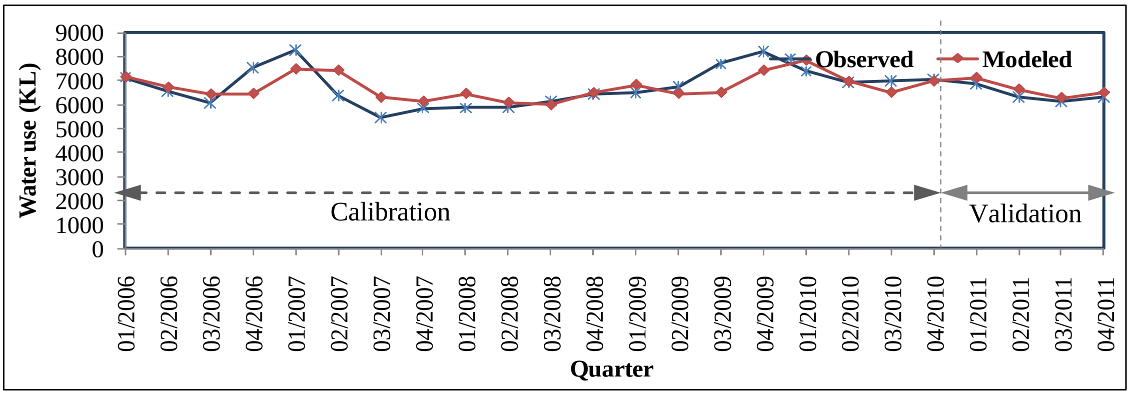


Note: values are in log(WU_t)

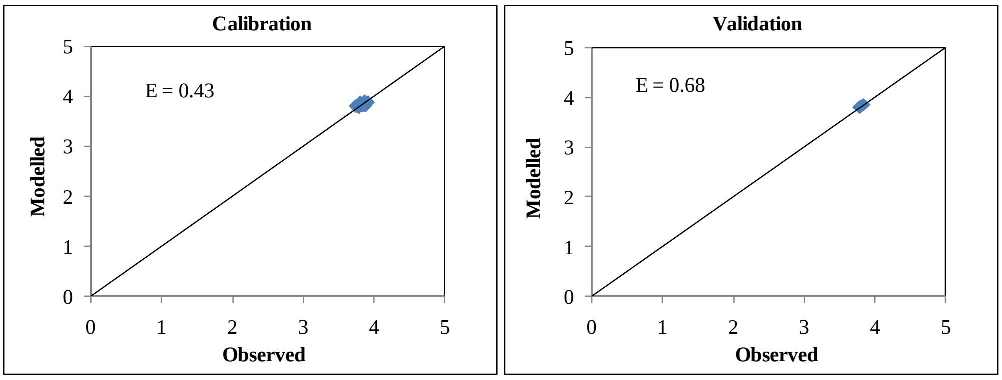
Scatter plot

Figure 4.18 Observed vs modelled water use for Council 3 in >20 ML Councils group

For Council 4, it is clear that the previous quarter's water use in terms of WU_{t-4} and the mean maximum daily temperature are the important variables affecting the current water use. Although, the *E* value for calibration was little less (0.43) than 0.5, for validation it was 0.68. The time series plot of observed and modelled water use is shown in Figure 4.19 along with the scatter plots for both calibration and validation. It can be seen from the figure that observed and modelled water uses agree well with each other.



Time series plot



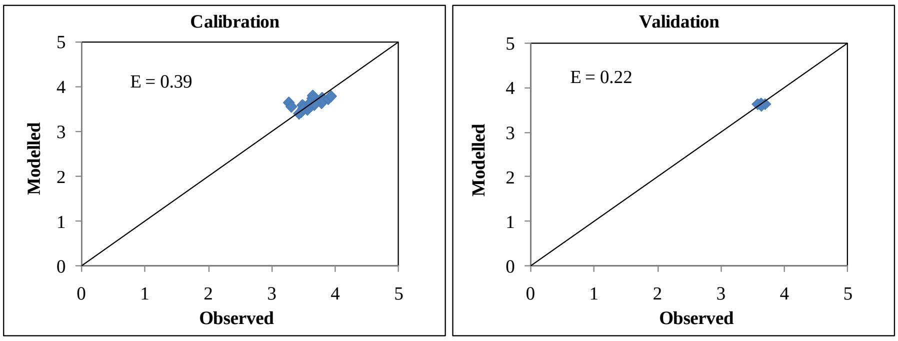
Note: values are in log(WU_t)

Scatter plot

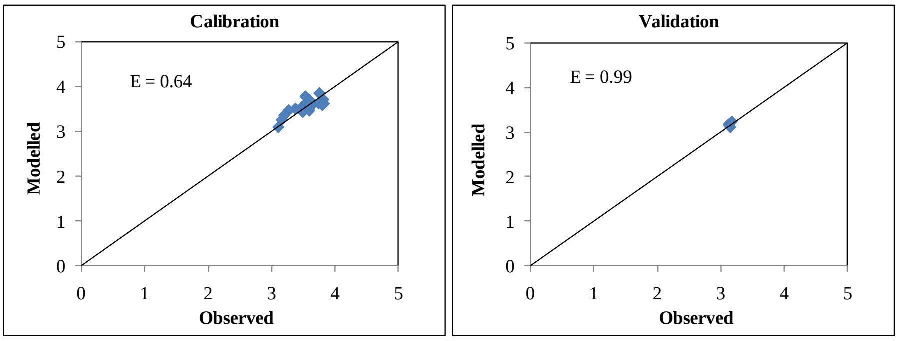
Figure 4.19 Observed vs modelled water use for Council 4 in >20 ML Councils group

4.6.2.2. Group: >15-20 ML

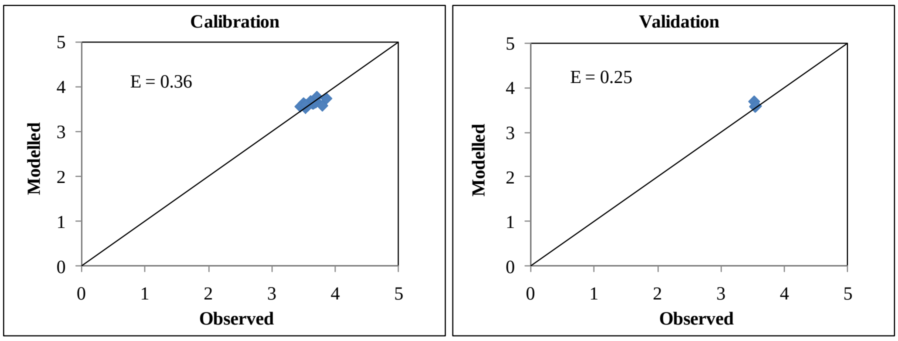
There are four councils in this group contributing 6% of the total Council's water use and these councils were modelled separately. From Table 4.18, it is observable that the previous quarter's water use (WU_{t-1}) is the common statistically significant variable in case of all four councils. However, the other variables such as the mean maximum daily temperature in Council 4, the total rainfall and the water restrictions in Council 2 and the previous quarter's water use (WU_{t-1}) in Council 1 were also included (see Figure 4.1 for model development procedure). The *E* value for calibration in Councils 1 and 3 were below 0.5, which could be attributable to the omission of other influential variables that was not considered in this study due to unavailability of data. Therefore, a field survey to collect these data and consider them as additional variables is recommended as a future study to improve the model performance. Scatter plots for both calibration and validation are shown in Figure 4.20; shows that observed and modelled water use are well matched as most of the data points are close to 1:1 line.



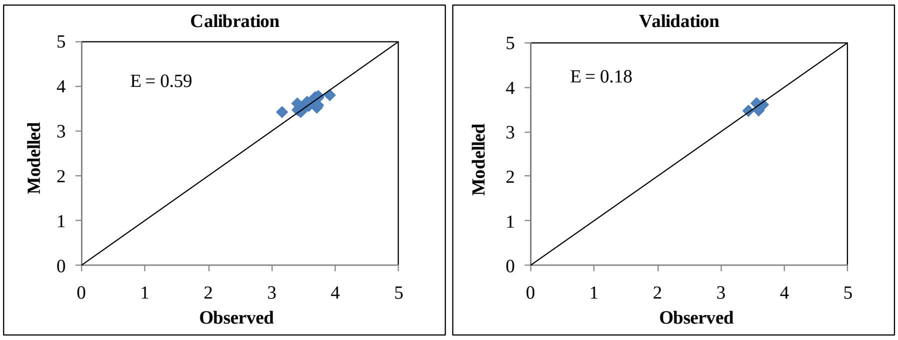
a) Council 1



b) Council 2



c) Council 3



Note: values are in log(WU_t)

d) Council 4

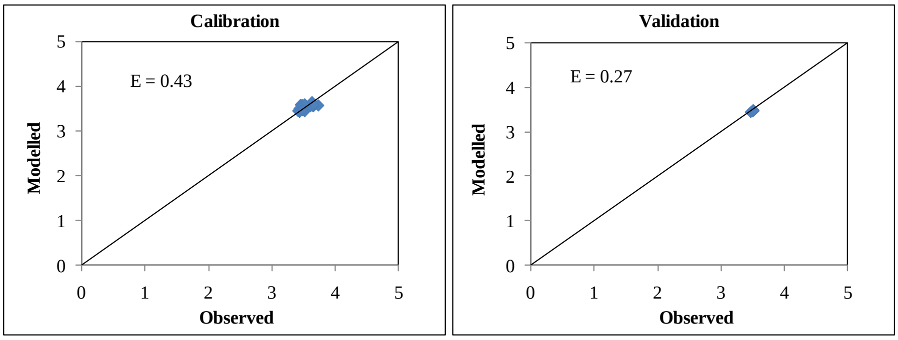
Figure 4.20 Scatter plots of observed vs modelled water use for the four councils in >15-20 ML Councils group

4.6.2.3. Group: >10-15 ML

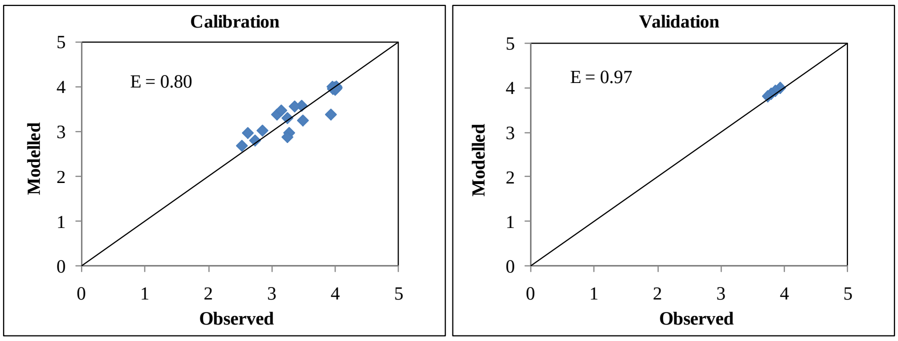
There are five councils in this group and they were modelled individually. From Table 4.18, it is apparent that the previous quarter's water uses (WU_{t-1} and WU_{t-4}) have statistically significant effect on current water use in Councils 1, 2 and 4. In case of Council 2, the water restrictions found to be statistically significant.

In case of Council 3, it was found that the mean maximum daily temperature, the total rainfall and the water restrictions have significant contributions on the current water use. In case of Council 5, the mean maximum daily temperature was found to have statistically significant contribution on the current water use. Based on these results, it can be concluded that these two councils might have outdoor water use.

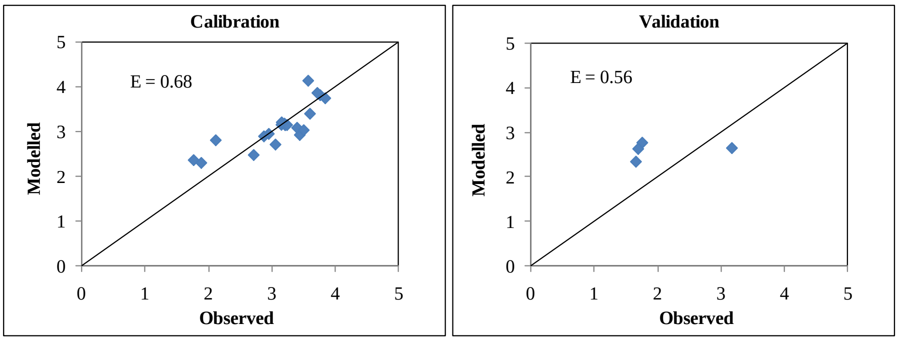
Scatter plots of calibration and validation for all five councils are shown in Figure 4.21. It can be seen that data points are close to the 1:1 line, which show that that the modelled water use is matched well with the observed water use.



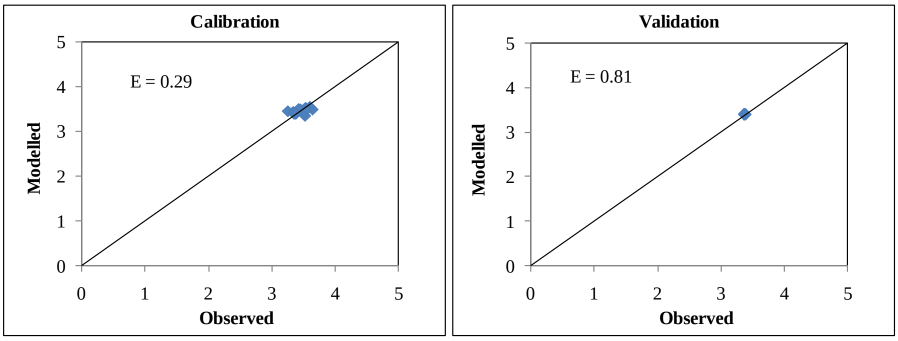
a) Council 1



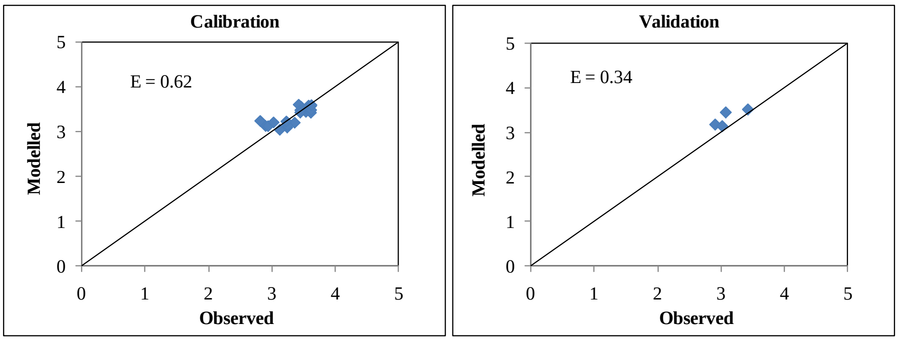
b) Council 2



c) Council 3



d) Council 4



Note: values are in log(WU_t)

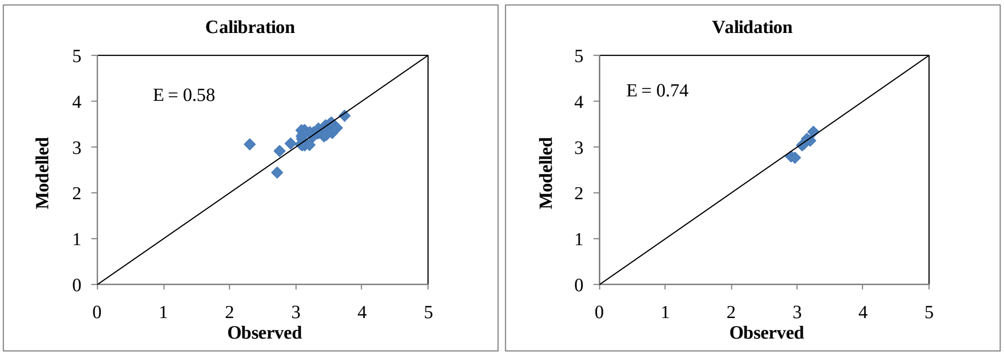
e) Council 5

Figure 4.21 Scatter plots of observed vs modelled water use for the five councils in >10-15 ML Councils group

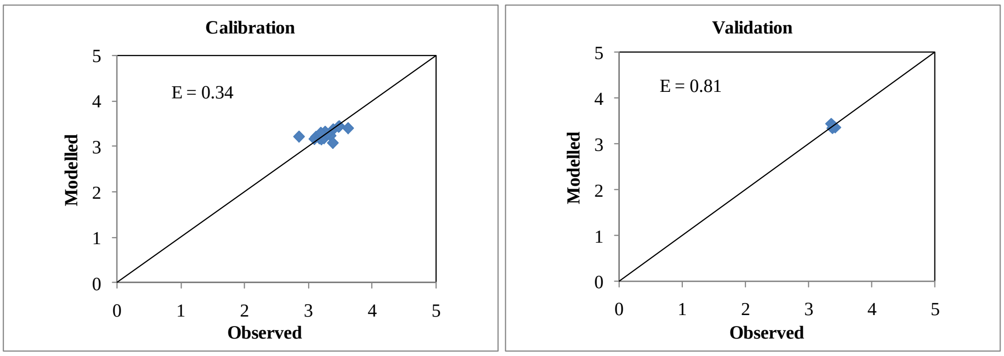
4.6.2.4. Group: 5-10ML

There are five subgroups in this Councils group. From Table 4.18, it can be seen that within each subgroup there are multiple councils except in case of >8-9 ML subgroup. From the table, it can also be seen that previous quarter's water use in terms of WU_{t-1} and, WU_{t-4} have statistically significant impact on the current water use in all subgroups. The mean maximum daily temperature also found to have statistically significant contribution on the current water use in case of >7-8 ML, >6-7 ML and 5-6 ML subgroups. Although, the total rainfall in >8-9 ML subgroup and water restrictions in >9-10 ML and >7-8 ML subgroups are found to have some effect, the coefficients of these variable are very small.

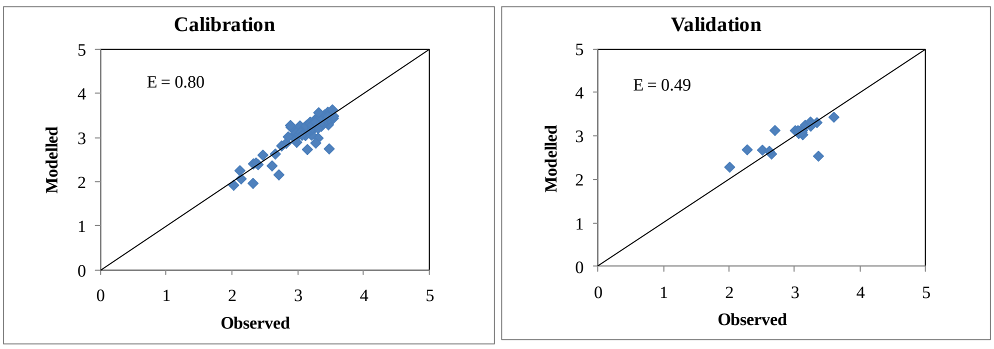
Scatter plots of calibration and validation for all five subgroups are shown in Figure 4.22. This figure shows that the modelled water use is well matched with the observed water use as data points lie close to the 1:1 line and *E* values was also found to have more than 0.5 in most cases (Table 4.18).



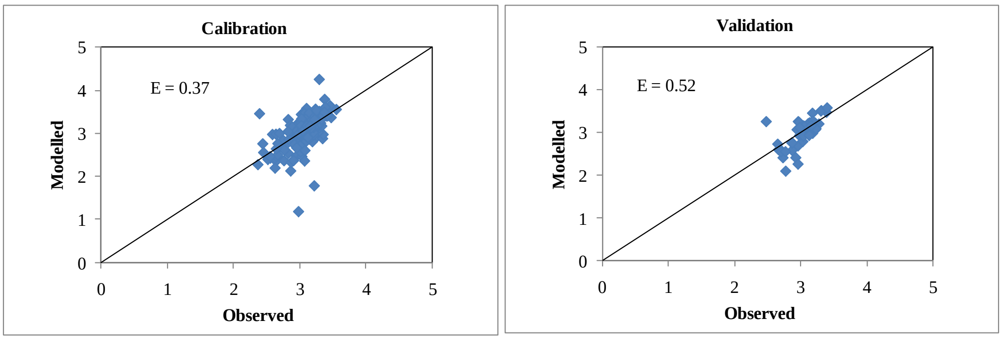
a) Subgroup >9-10 ML



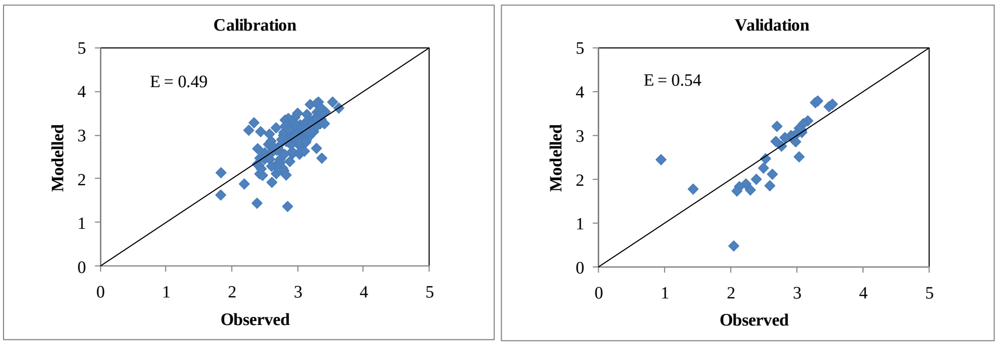
b) Subgroup >8-9 ML



c) Subgroup >7-8 ML



d) Subgroup >6-7 ML



Note: values are in log(WU_t)

e) Subgroup 5-6 ML

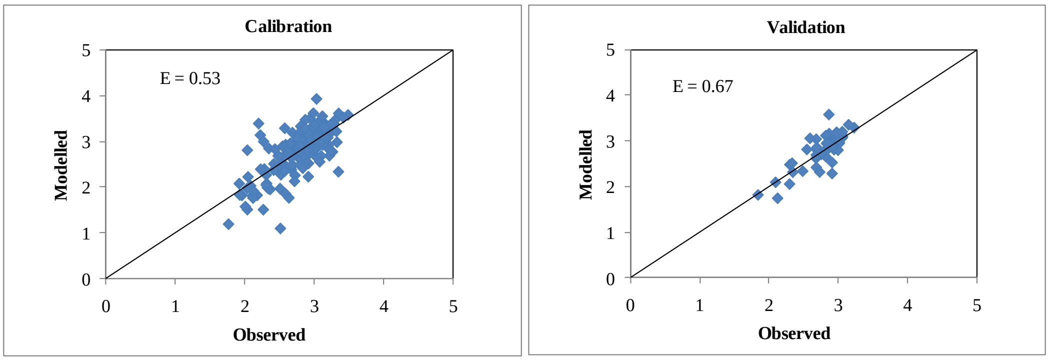
Figure 4.22 Scatter plots of observed vs modelled water use for the five subgroups in 5-10 ML Councils group

4.6.2.5. Group: <5 ML

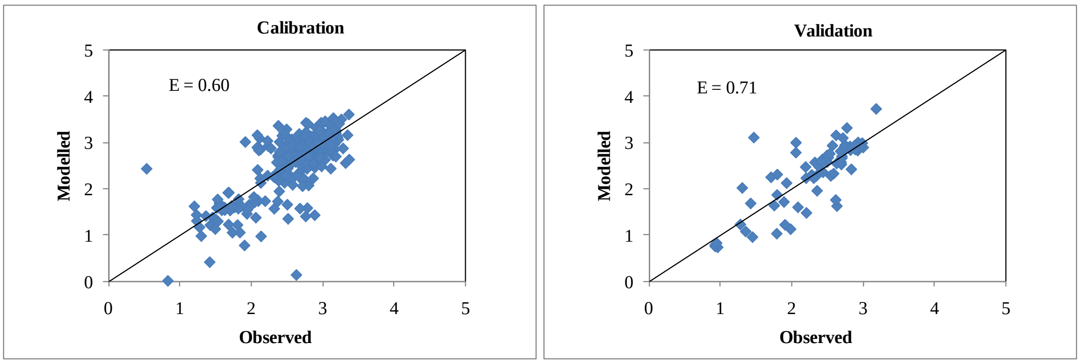
There are 1269 customers in this Councils group and all customers were classified into five subgroups based on the average annual water use (in 2005-2009), and models were developed at individual group level.

From Table 4.18, it can be observed that the previous quarter's water uses in terms of both WU_{t-1} and WU_{t-4} and the mean maximum daily temperature have statistically significant contributions on the current water use in all subgroups except in <1 ML subgroup. In case of <1 ML subgroup, the previous quarter's water uses in terms of WU_{t-1} was found to have significant effect on the current water use. Therefore, it can be said that in this less water user subgroups, current water use are adjusted based on previous quarter's water use and temperature.

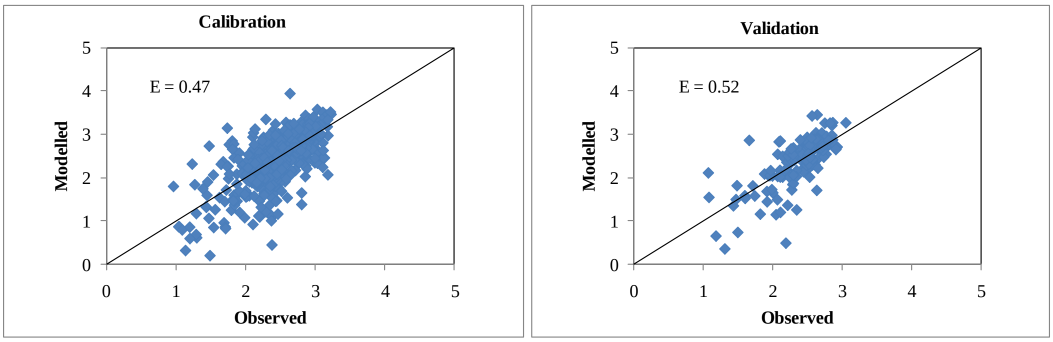
Scatter plots for both calibration and validation periods presented for all subgroups in Figure 4.23 show that most of the data points are close to 1:1 line. Moreover, *E* values for both calibration and validation in Table 4.18 also indicate that models performed well in all subgroups.



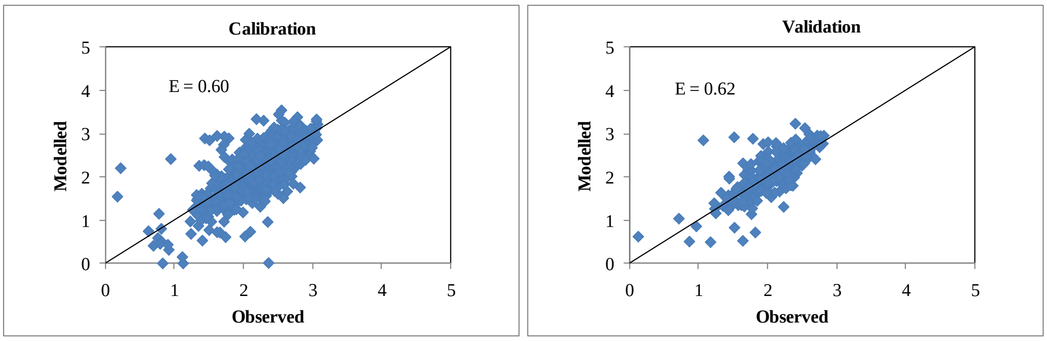
a) Subgroup >4-<5 ML



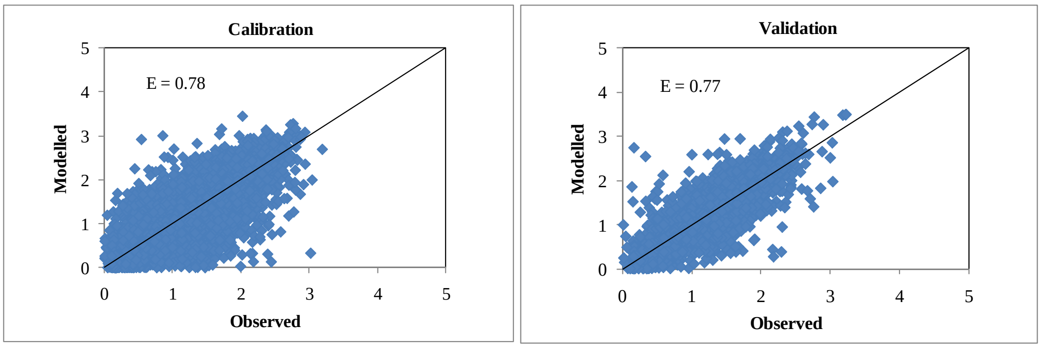
b) Subgroup >3-4 ML



c) Subgroup >2-3 ML



d) Subgroup 1-2 ML



Note: values are in log(WU_t)

e) Subgroup <1 ML

Figure 4.23 Scatter plots of observed vs modelled water use for the five subgroups in <5 ML Councils group

4.7. Models Applications, Limitations and Challenges

Modelling performed for Schools, Sports Grounds and Councils groups using a single approach are able to provide individual water demand forecasting for the customers are presented in this chapter. This individual forecasting will be useful for considering different conservation efforts for different customer group and for different geographic area. The modelling approach used are also useful in case of water demand estimation at distribution zone level as models are able to forecast individual customer’s water use.

All the models in this chapter were developed with the available data (i.e. rainfall, mean maximum temperature and water restrictions level. However, there are many other factors affect the water use among the customers, such as:

- Factors affecting water use at Schools

1) number of students, teachers and staff, 2) size and layout of school grounds swimming pool, 3) availability of alternate water source, 4) garden watering time/irrigation practices, 5) gardening practices (e.g. mulching, soil preparation, soil-wetting agents), 6) water wise garden design (using native plants), 7) presence of evaporative air conditioners, 8) water-efficient appliances (e.g. dual-flush toilets, flow regulators in taps and showers), 9) behavioural practices (e.g. reporting and fixing leaking taps), 10) type of specialised classes (e.g. gymnasium, home economics, hairdressing, bricklaying), 11) cleaning practices, and 12) use of school facilities after hours (community group meetings/weekend sports).

- Factors affecting water use at Sports Grounds

1) size of the sports ground, 2) availability of alternate water source, 3) watering time/irrigation practices, 4) type of grass, and 5) Activity taking places in the sports ground (e.g. golf, football, cricket)

- Factors affecting water use at Councils

1) number of employee, customers or participants, 2) Presence of garden and swimming pool, 3) availability of alternate water source, 4) efficiency of water use appliances 5) garden watering time/irrigation practices, 6) gardening practices (e.g. mulching, soil preparation), and 7) occurrence of community and other festival.

Difficulty in accessing these information, limits the water use modelling in this research to explain the water use variation precisely. Moreover, some of these factors, such as the level of awareness of users are difficult to quantify. Therefore, water demand forecasting among these groups can be improved by conducting field survey.

4.8. Summary

Modelling water use was performed for Schools, Sports Grounds and Councils groups using a single approach as similar water use pattern was observed in these three groups.

Past modelling work on total urban water use has shown that a number of independent variables such as previous water use, different levels of water restrictions, and climate variables such as rainfall and temperature have some effects on the water use pattern. In addition, data analysis in the current study revealed that water uses in these groups are affected by seasonal cycle over the year. Therefore, the past water use in terms of (t-1) and (t-4) time-lagged, level of water restrictions, climate variables such as total rainfall and mean maximum daily temperature, and fixed quarterly effects were used as the independent variables during model development in this research.

The Multiple Linear Regressions (MLR) technique was used in this research for model development of water use in Schools, Sports Grounds and Councils groups. At first all customers in these groups are disaggregated into subgroups based on the average annual water use. Then, before the model development, data transformation was done in order to make the data normally distributed for both independent and dependent variables using a log function. A correlation analysis was also carried out separately for each water users groups to investigate the degree of correlation among the dependent and independent variables, which has given an early indication of which variables may play significant role in model development. Moreover, the correlation analysis between the independent variables was performed to check whether there is any multi co-linearity effect between the independent variables. It was found that the independent variables are not correlated each other for most of the cases. In those exceptional cases where variables found to be inter-correlated, one of the variables was not used in best model.

Model calibration for Schools was performed using two different periods: 2005-2009 and 2005-2010 to see whether increasing calibration periods produce better results. At the same time models were also validated with the data of 2010-2011 and 2011 respectively. The Model performance was measured by the Nash-Sutcliffe efficiency (E) and the significance test for model parameters was done using the p value. It was found that increasing data period during calibration results better E values in most of the Schools subgroups. Therefore, models developed with the calibration period of 2005-2010 were discussed and followed for models development in case of other two groups (Sports Grounds and Councils) in this Chapter.

Based on the water use analysis, it was found that different customers use different amount of water ranging from >20 ML to <1 ML. It was also found that only few customers use large amount of water (e.g. >20 ML and >15-20 ML), whereas a large number of customers use smaller volume of water (e.g. 5-10 ML and <5 ML). Therefore, higher water use customers are modelled as an individual customer, whereas the smaller water use customers are modelled at group level in this study.

Among the independent variables considered in this study, it was found that mean maximum daily temperature, total rainfall and water use restrictions have significant effect on current water use of high water users Schools (e.g. >10 ML), where as in low water users Schools, past water use in terms of (t-1) and (t-4) has significant effect on current water use. Therefore, it implies that high water user Schools have more outdoor activities than the low water user Schools, could be due to more play grounds and gardens.

In case of Sports Grounds, water use restrictions was found to have significant effect on current water use of both high water users (e.g. >10 ML) and low water users (e.g. <10 ML) as was expected due to outdoor water use. Moreover, it was found that mean maximum daily temperature has significant effects on current water use of high water users Sports Grounds and past water use in terms of (t-1) has significant effects on current water use of low water users Sports Grounds.

The past water use in terms of (t-1) in Councils has significant effects on current water use. Moreover, unlike Schools and Sports Grounds, different variables were found to have significant effect on current water use of Councils regardless of high and low users, which were also expected as there are different types of organization exist in the Councils group.

In general, comparison of observed against modelled water use shown in time series and scatter plots are well matched, and also high E values were found in most models, implies that the developed model are performed well. It was found that few cases E values were poor for validation with compare to the calibration although observed and modelled data lies close to 1:1 line in the scatter plot. This poor model performance might be due to omission of some important independent variables due to lack of data availability.

Chapter 5. Water Use Modelling for Restaurants, Hospitals, Hotels and Laundries

5.1. Overview

Generally, water use in restaurants, hospitals, hotels and laundries has no seasonal variation as most of the water uses among these groups are for indoor purposes (Chapter 3, Section 3.6). There are many factors affect the water use in these groups (i.e. opening hours for restaurants, number of beds in hospitals, number of rooms in hotels, and number of customers and frequency of use in laundries), data for these factors are not readily available as was the case in this study. Therefore, as mentioned in Chapter 3, water use modelling was done for these four groups differently from the Schools, Sports Grounds and Councils groups and only historical water use data were used for analysis and forecasting. The details of this work is presented in this Chapter.

As mentioned in Chapter 1, short term water demand forecasting (1 year) was carried out using quarterly time steps in this research. Disaggregation of water users for each customer group was done first based on the average historical water use volume. Thereafter, data analysis was performed at disaggregated level for all four customer groups.

Historical quarterly water use data from 2005 to 2010 were used for analysing purpose and then quarterly water use in 2011 were forecasted in this study. From data analysis, there were three different patterns were identified in historical annual water use and those are:

1) The annual water uses were variable over the period (2005-2010).

2) The annual water uses were constant over the very recent period (2008-2010) or over the period (2005-2010). and

3) The annual water use followed an increasing or decreasing trend.

Based on the historical annual water use pattern, forecast annual water uses in 2011 were forecast differently. In type 1, annual water use in 2010; in type 2, average annual water use in 2008-2010; and in type 3, a linear regression model were considered to forecast annual water use in 2011.

Thereafter, forecast annual water uses were disaggregated into quarterly water uses in 2011 based on the quarterly water use disaggregating factors obtained from data analysis. From the data analysis, it was found that most of the customers among Restaurants, Hospitals, Hotels and Laundries groups follow consistent quarterly percentages of annual water use over years (2005-2010). However, there were very few years when quarterly water use percentages were different from the other years. Therefore, the average quarterly water use percentages were considered as the quarterly disaggregating factors excluding those exceptional years in this study. As outlined in Chapter 3 (Section 3.5.1) the quarters are named as Quarter 1 (January – March), Quarter 2 (April – June), Quarter 3 (July – September) and Quarter 4 (October – December).

This chapter first describes the data exploration includes analysis of historical water use and disaggregation of water user. The water use models developed at disaggregated level for Restaurants, Hospitals, Hotels and Laundries groups is then presented followed by issues and limitations of the modelling work performed for these water user groups. Finally, a summary of the chapter is presented.

5.2. Data Exploration

5.2.1. Historical Water Use

Annual water use variation in Restaurants, Hospitals, Hotels and Laundries customer groups over the study period (2005-2011) is shown in Figure 5.1. From Figure 5.1, it can be seen that the annual water use in 2005 and 2006 was almost the same in each of all four customer groups. In general, since 2006, water use in Restaurants and Hospitals has decreased, and water use in Hotels and Laundries was less variable.

There are many factors that could be attributable to the abovementioned changes in water use among all four customer groups. For example, the presence, diversity and efficiency of various types of appliances in hotels, restaurants, hospitals and laundries that affect the quantity of water used (Dziegielewski, *et al,* 2000). Furthermore, the activity in one customer group could affect the water use in another customer group. For example, the number of guests in hotels and restaurants, and the number of patients in hospitals could affect the water use in laundries, and the number of guests in hotels can affect the water use in restaurants. However, it should be noted that these are general comments and have not been validated for the current study due to limited data.

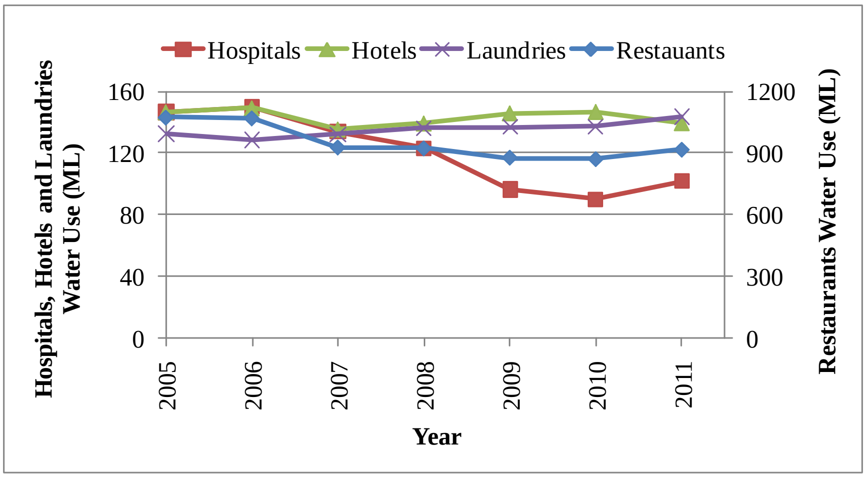


Figure 5.1 Annual water uses of Restaurants, Hospitals, Hotels, and Laundries over the study period

5.2.2. Disaggregation of Water User Groups

Water uses in Restaurants, Hospitals, Hotels and Laundries accounts for 4.6%, 0.5%, 0.7%, and 0.8% of total non-residential water use in 2011 respectively in the Yarra Valley Water (YVW) service area (Chapter 3, Section 3.6). As discussed in Section 3.6, all customers within Restaurants, Hospitals, Hotels and Laundries were classified into five groups based on the average annual water use in 2005-2009 as shown in Table 5.1. Water use models were then developed at these disaggregated levels in this research. It should be noted that some pathologies were also classified as hospitals in the YVW customer list. All the pathologies were considered as a separate group within the Hospitals in this study as their water use pattern could be different from hospitals although they are in the same list.

From Table 5.1, it is apparent that there is no hotel and laundry using average annual water use more than 20 ML. It can also be seen that most of the customers among all these water customer groups are low water users (<5 ML group), and they use higher percentages of the total water except in Hospitals. However, the >20 ML Hospitals group's water use was high which was around 32% of total Hospital water use.

Table 5.1 Disaggregation of water users of Restaurants, Hospitals, Hotels and Laundries in the YVW service area

Water user groups	Restaurants		Hospitals		Hotels		Laundries	
	Number of restaurants	Water use (%)	Number of hospitals	Water use (%)	Number of hotels	Water use (%)	Number of laundries	Water use (%)
>20 ML	1	3.0	1	26.5	-	-	-	-
>15-20 ML	1	1.9	-	-	-	-	1	22.8
>10-15 ML	4	4.0	2	21.4	2	15.6	-	-
5-10 ML	26	17.4	2	12.1	4	21.6	2	9.2
<5 ML	1031	73.7	4	5.3	38	62.8	124	68
Healthscope	-	-	5	34.7	-	-	-	-
Total	1063	100	14	100	44	100	127	100

5.3. Model Development

There are many factors that affect the water use in Restaurants, Hospitals, Hotels and Laundries groups such as the number of meals served by restaurants, the number of rooms in a hotel, the number of bed in hospitals and the number of customers for a laundry. However, these details data are not available for this research as mentioned in Section 5.1. Moreover, water uses among these groups are mostly for indoor purposes. Therefore, weather and water restrictions data that were used for water use model development for Schools, Sport Grounds and Councils groups were not considered in modelling water use for the Restaurants, Hospitals, Hotels and Laundries groups. Model development for these groups in this chapter was performed with only historical water use data.

Data period used is 2005 -2011 for model development in this part of the study. As outlined in Chapter 4 (in Section 4.4.3), the water use data in 2005-2010 were used to determine the quarterly water use pattern and also for model development to forecast quarterly water use in 2011. The water use data in 2011 were used for the comparison of the forecast and observed water use. All the model performance was measured using the Nash-Sutcliffe model efficiency (*E*). The details of this efficiency criterion can be found in Chapter 4 (Section 4.3.4). Further details on the water use data analysis and model development for each customer group are discussed in the following sections.

5.3.1. Data Analysis and Model Development for Restaurants

5.3.1.1. Data Analysis

Total water use of the Restaurants group is about 4.6% of the total non-residential water use in 2011 in the study area. There are 1,063 restaurants within the study area. All these restaurants are grouped into different groups based on the annual water use, as discussed in Section 5.2.2 and data analysis were then performed separately for these groups.

a. Group: >20 ML

There is one restaurant in this group with 3% of water use of the total Restaurants water use in 2011. The time series of annual water use data of this restaurant is shown in Figure 5.2 along with the quarterly percentages of water use in each year. It can be seen from this figure that the annual water use in this restaurant is highly variable. From Figure 5.2, it can also be seen that the percentage of quarterly water use pattern was quite similar in most of the years except in 2005 and 2007.

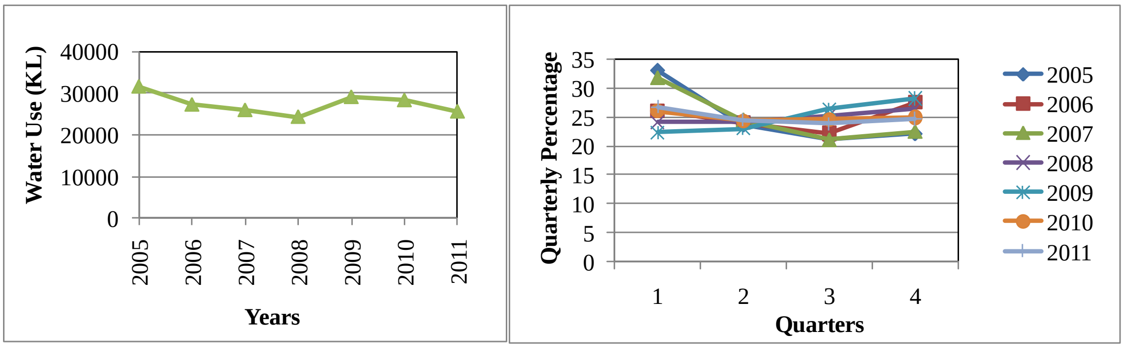


Figure 5.2 Water use pattern of >20 ML Restaurants group

b. Group: >15-20 ML

There is one restaurant in this group with 1.9% of water use of the total Restaurants water use in 2011. The time series of annual water use data and quarterly percentages of water use in each year for this restaurant is shown in Figure 5.3. It can be seen from the figure that although there is decreasing trend in water use from 2005 to 2009, water use in 2008-2010 were fairly constant and close to 15 ML. From Figure 5.3, it can also be seen that the quarterly water use pattern was different in 2009 but it was fairly consistent in the remaining years.

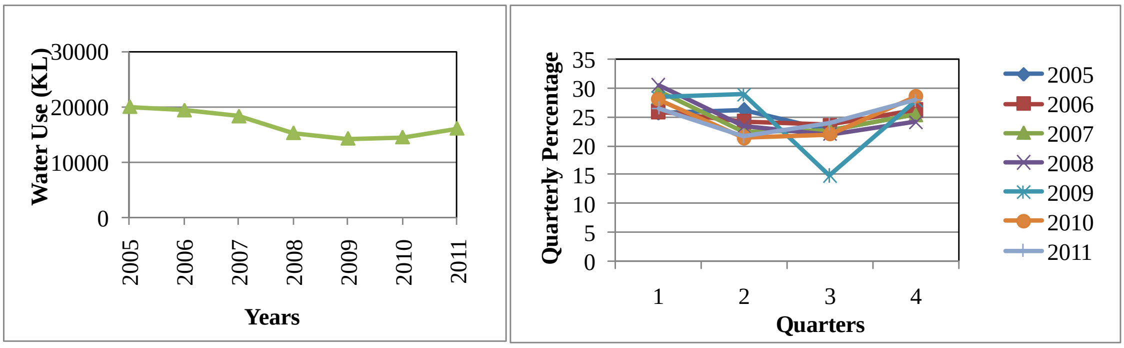


Figure 5.3 Water use pattern of >15-20 ML Restaurants group

c. Group: >10-15 ML

There are four restaurants in this group with 4% of water use of the total Restaurants water use in 2011. As this is a high percentage of water use within this group, all four restaurants were analysed separately. The time series of the annual water use data and the percentage of quarterly water use in each year for all these four restaurants are shown in Figure 5.4. From the figure, it can be seen that there was a huge reduction in Restaurant 1 water use since 2006. In case of Restaurant 2, the annual water use decreased from 2006-2009 and it was constant in 2009-2010. In case of Restaurant 3, the annual water use was fairly constant over the years. The annual water use in Restaurant 4 was moderately varied and in 2006-2009, it was fairly constant before an increase in 2010. From Figure 5.4, it can also be seen that the quarterly water use patterns for Restaurants 2, 3 and 4 are reasonably consistent over the years except the percentages for Restaurant 4 in 2007. It was also found that the quarterly water use pattern of the Restaurant 1 was not consistent over the years.

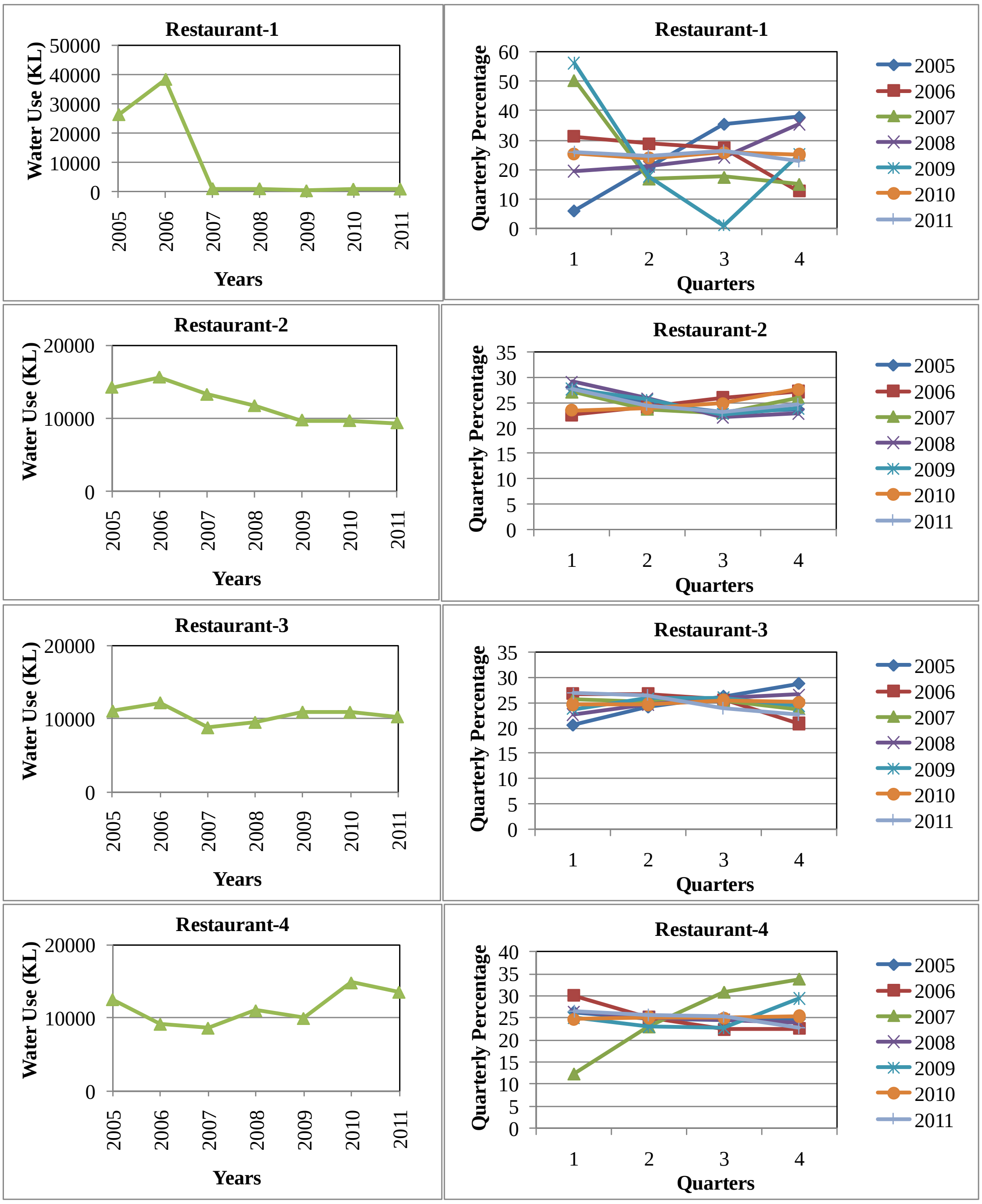


Figure 5.4 Water use pattern of >10-15 ML Restaurants group

d. Group: 5-10 ML

There are 26 restaurants in this group using 17.4% of the total Restaurants water use in 2011. All these 26 restaurants were divided into five smaller subgroups based on the average annual water use from 2005 to 2009. These subgroups with their water use percentages within the Restaurant group and the numbers of restaurants in each subgroup are shown in Table 5.2. The annual water use by each restaurant subgroup is presented in the left hand charts in Figure 5.5. It should be noted that the average annual water use by the subgroup was calculated and shown with the bold black line in the same chart. The average quarterly percentages of water use by each subgroup were calculated for each year and are also shown in Figure 5.5. From Figure 5.5, it can be seen that in the subgroups 5-6 ML and >6-7 ML, the water use of one restaurant is quite different from the other restaurants. Therefore, the specific restaurants were not included in calculating the average water use in these two subgroups.

From Figure 5.5, it is apparent that although there was water use reduction over the years in all subgroups, the average annual water uses in 2008-2010 were fairly constant. From the figure it is also can be seen that quarterly percentages of the annual water use in subgroups >8-9 ML, >6-7 ML and 5-6 ML were consistent over the years. However, in subgroup >7-8 ML, the quarterly percentages of 2006 and 2010 were different from the percentages of other years and in subgroup >9-10 ML the quarterly percentages of 2010 were different from the percentages in other years.

Table 5.2 Water use percentage among Restaurants subgroups in 5-10 ML group

Subgroup	**Number of Restaurants**	**Water use (%) in Restaurants group**
>9-10 ML	6	5.2
>8-9 ML	3	2.5
>7-8 ML	3	2.2
>6-7 ML	5	2.7
5-6 ML	9	4.8
Total	26	17.4

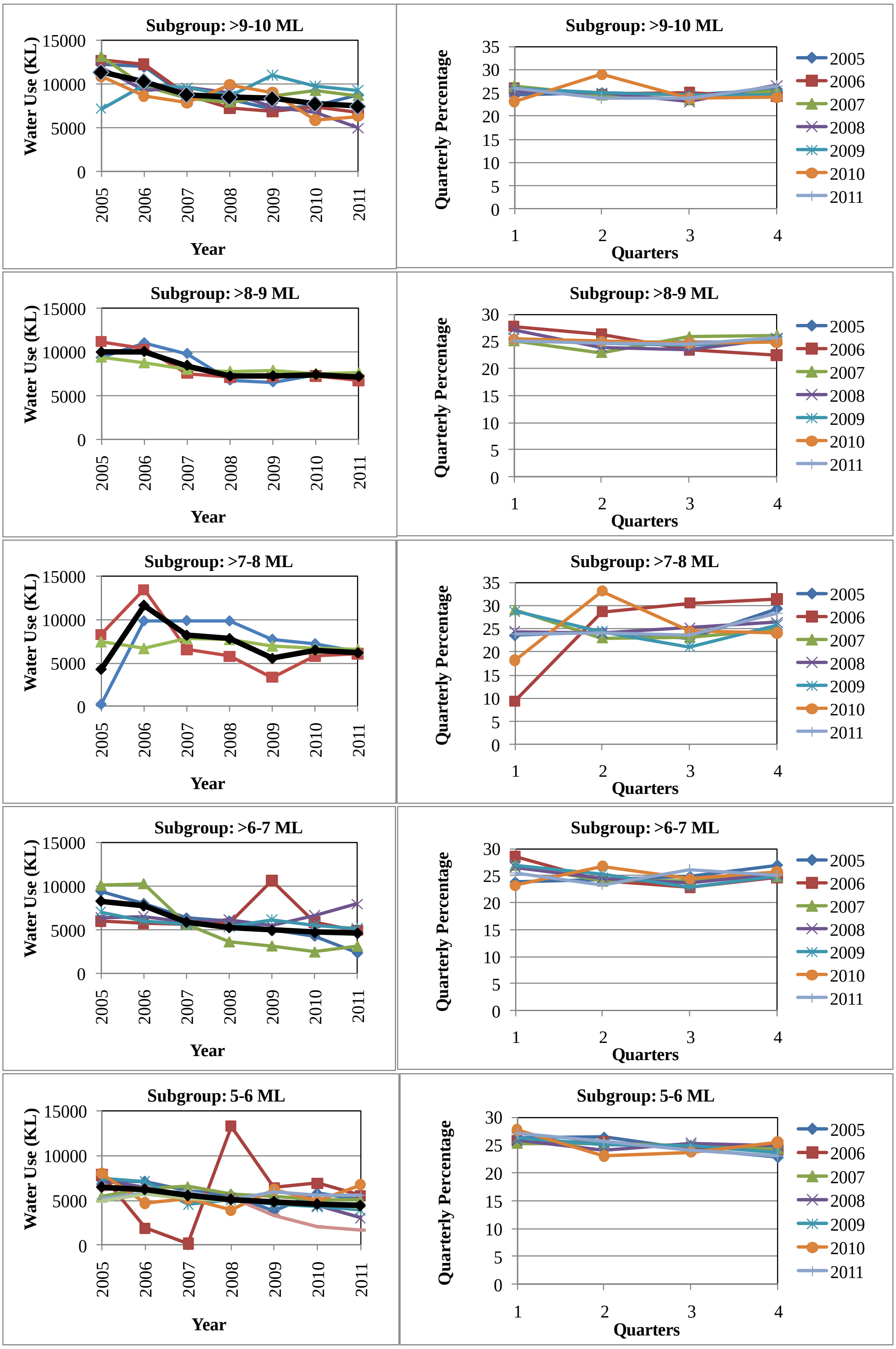


Figure 5.5 Water use pattern of 5-10 ML Restaurants group

e. Group: <5 ML

There are 1,031 restaurants in this group using 73.7% of the total Restaurants water use in 2011. All these 1031 restaurants were divided into five smaller subgroups based on the average annual water use from 2005 to 2009. These subgroups with their water use percentages and the numbers of restaurants in each subgroup are shown in Table 5.3. Similar to Figure 5.5, the annual water use by each restaurant is presented in Figure 5.6. It should be noted that the average yearly water use by the subgroup was calculated and shown with the bold black line in the same chart. The average quarterly percentages of water use by each subgroup were calculated for each year and also shown in Figure 5.6 as well. It should be noted that there is a restaurant having very high water use in 2010 and 2011 in the subgroup >4-<5 ML and this particular restaurant was not included in calculating the average annual water use. From Figure 5.6, it can also be seen that the average annual water use by each subgroups are constant over the years and the quarterly percentages of the average annual water use by each subgroup are consistent over the years.

Table 5.3 Water use percentage among Restaurants subgroups in <5 ML group

Subgroup	**Number of Restaurants**	**Water use (%) in Restaurants group**
>4-<5 ML	13	6.8
>3-4 ML	21	7.5
>2-3 ML	47	11.0
1-2 ML	132	19.4
<1 ML	818	29.0
Total	1,031	73.7

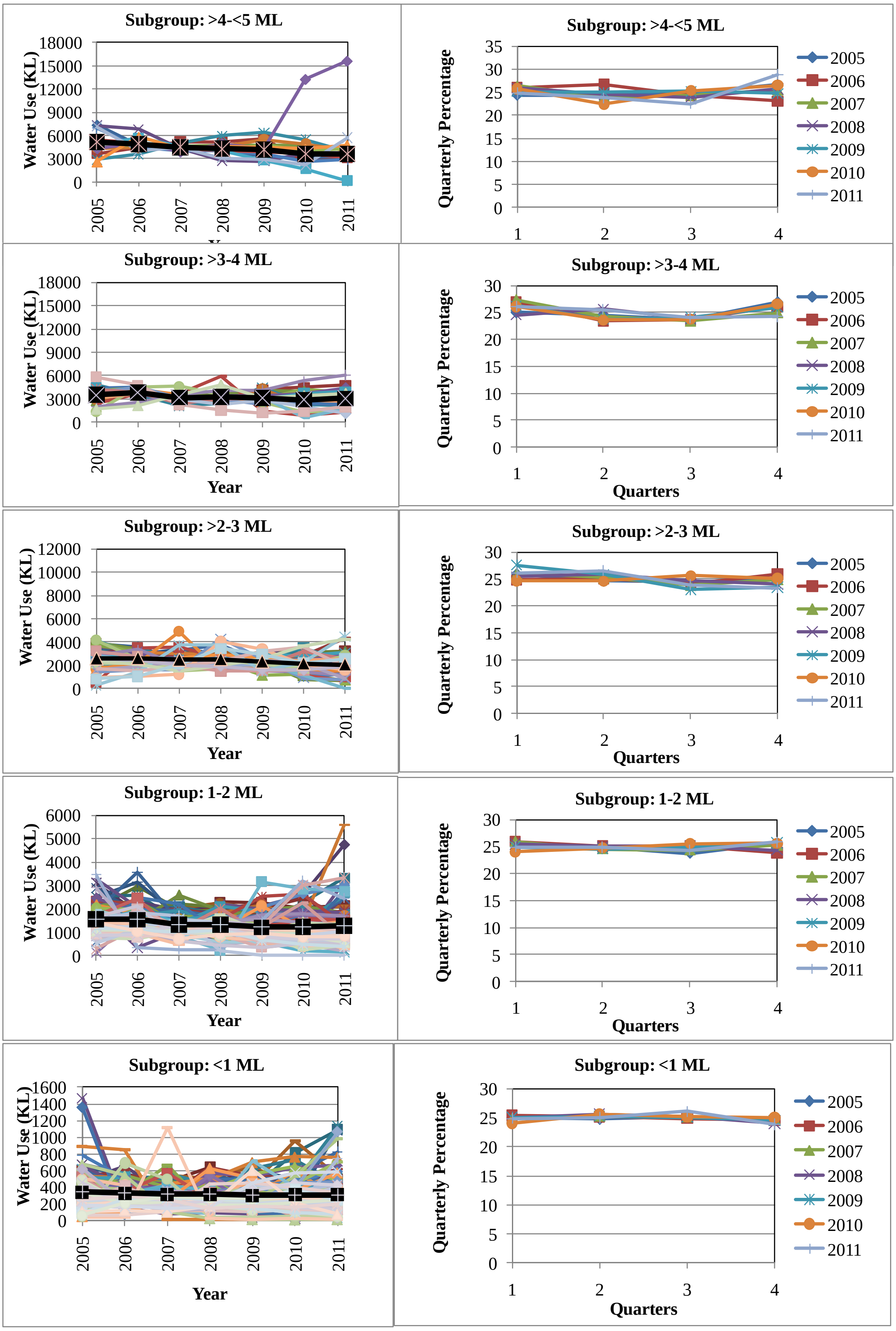


Figure 5.6 Water use pattern of <5 ML Restaurants group

f. Summary of Data Analysis

A summary of the findings of the above water use data analysis is presented in Table 5.4. Based on this analysis, the approach used for modelling (or forecasting) the annual water use in 2011 and the disaggregating factors to disaggregate the annual water use into quarterly water use, were also identified and presented in the Table 5.4. From the table, it can be seen that the most of the Restaurants groups follow the similar annual water use pattern over the different years, and therefore, the average annual water use over the 2008-2010 periods was considered to forecast annual water use in the following year (i.e. 2011) for these groups. There are few water user groups where the annual water use is highly variable, and for these water user groups, the annual water use in the latest year (i.e. 2010) was considered as the next year's (i.e. 2011) forecast annual water use. However, it was found that the quarterly water use percentages that in most of the subgroups were consistent over the years. Therefore, the disaggregating factors were considered as the average over the period of 2005-2010 excluding the exception years.

Table 5.4 Summary of water use data analysis and selection of modelling approach for Restaurants group

Group	Subgroups	Number of restaurants	Modelled by	Variation of annual water use	Variation of quarterly water use percentages	Approach used for annual water use forecast in 2011	Approach used for disaggregating factors (quarterly percentages)
>20 ML	-	1	Individual	Highly variable	Similar over the years except in 2005 and 2007	Annual water use in 2010	Average of 2006 and 2008-2010
>15-20 ML	-	1	Individual	Moderately varied and fairly constant in 2008-2010	Similar over the years except in 2009	Average annual water use in 2008-2010	Average of 2005-2008 and 2010
>10-15 ML	-	4	Individual (Restaurant 1)	Significant reduction since 2006	Highly variable over the years	Not modelled	Not modelled
			Individual (Restaurant 2)	Moderately varied	Similar over the years	Annual water use in 2010	Average of 2005-2010
			Individual (Restaurant 3)	Fairly constant	Similar over the years	Average annual water use in 2008-2010	Average of 2005-2010
			Individual (Restaurant 4)	Moderately varied with an increase in 2010	Similar over the years except in 2007	Annual water use in 2010	Average of 2005-2010 excluding 2007
5-10 ML	>9 -10 ML	5	Group	Fairly constant	Similar over the years except in 2010	Average annual water use in 2008-2010	Average of 2005-2010 excluding 2010

	>8-9 ML	2	Group	Fairly constant	Similar over the years	Average annual water use in 2008-2010	Average of 2005-2010
	>7-8 ML	6	Group	Fairly constant	Similar over the years except in 2006 and 2010	Average annual water use in 2008-2010	Average of 2005-2010 excluding 2006 and 2010
	>6-7 ML	4	Group	Fairly constant	Similar over the years	Average annual water use in 2008-2010	Average of 2005-2010
	5-6 ML	19	Group	Fairly constant	Similar over the years	Average annual water use in 2008-2010	Average of 2005-2010
<5 ML	>4-<5 ML	18	Group	Fairly constant	Similar over the years	Average annual water use in 2008-2010	Average of 2005-2010
	>3-4 ML	20	Group	Fairly constant	Similar over the years	Average annual water use in 2008-2010	Average of 2005-2010
	>2-3 ML	29	Group	Fairly constant	Similar over the years	Average annual water use in 2008-2010	Average of 2005-2010
	1-2 ML	32	Group	Fairly constant	Similar over the years	Average annual water use in 2008-2010	Average of 2005-2010
	<1 ML	12	Group	Fairly constant	Similar over the years	Average annual water use in 2008-2010	Average of 2005-2010

5.3.1.2. Forecasting Water Use Model Development

Based on the data analysis two different modelling approaches (i.e. average of 2008-2010 water use and 2010 water use) were considered to forecast the annual water use in 2011 for different Restaurants groups and was outlined in Table 5.4. This forecast annual water use was then disaggregated into quarterly water use using the quarterly disaggregating factors. For most of the water user groups, the quarterly disaggregating factors were obtained from the average percentages over 2005-2010 periods as similar quarterly percentages of total annual water use were observed during this period. Further details on water use modelling for individual groups are discussed below.

a. Group: >20 ML

As outlined in Table 5.4, it was found that the annual water use in this restaurant was highly variable. Therefore, the total water use (as it is the recent year's water use) in 2010 was considered as the forecast total water use in 2011. The disaggregating factors also obtained using the outlined procedure in Table 5.4 and presented in Table 5.5.

Table 5.5 Disaggregating factors for >20 ML Restaurants group

Restaurant Group	**Disaggregating factors for quarters**			
	Quarter 1	**Quarter 2**	**Quarter 3**	**Quarter 4**
>20 ML	24.5	24	24.5	27

The forecast annual water use in 2011 was then disaggregated into quarterly water use with the factor outlined in Table 5.5. The comparison of the observed and the modelled water use in 2011 are presented in Table 5.6 in both quarterly and annual time steps. The resulted *E* value from the comparison of the quarterly observed and forecast water use is also presented in the table. The negative *E* value indicates that the average values would be better predictions than the forecast quarterly water uses.

Table 5.6 Comparison of observed and forecast water use of >20 ML Restaurants group in 2011

Restaurant Group		**Annual water use in 2011 (KL)**	**Water use in each quarter in 2011 (KL)**				***E* value**
			1	**2**	**3**	**4**	
>20 ML	Observed	25,617	6,871	6,296	6,117	6,333	-0.23
	Forecasted	28,375	6,952	6,810	6,952	7,661	

It can be also seen from Figure 5.2, the forecast water use in 2011 was very different from the past annual water use for this restaurant. As this is very high water using restaurant and there is no particular trend can be identified without more information, a future field survey should be considered for predicting the quarterly water use of this restaurant.

b. Group: >15-20 ML

From the data analysis, it can be seen that the total water use in 2008, 2009 and 2010 for this restaurant is close to 15 ML. As the annual water use is almost same in these three consecutive years, the average annual water use of 2008-2010 was consider as the forecast annual water use in 2011 as outlined in Table 5.4. In Table 5.4, it is also outlined that the quarterly percentages of 2005-2010 are similar except those in the year 2009. Therefore, the average quarterly percentages in 2005-2008 and 2010 were considered as the quarterly water use disaggregating factors for this restaurant which is shown in Table 5.7. Finally, the quarterly water use by this restaurant in 2011 was then forecasted using these disaggregating factors and the forecast annual water use in 2011. The observed and forecast water use in 2011 for this restaurant in both quarterly and annual time steps are presented in Table 5.8. The *E* value from the comparison of the forecast quarterly water uses with the observed quarterly water use in 2011 also presented in the table.

Table 5.7 Quarterly disaggregating factors in >15-20 ML Restaurants group

Restaurant Group	Disaggregating factors for quarters			
	Quarter 1	Quarter 2	Quarter 3	Quarter 4
>15-20 ML	28	24	22	26

Table 5.8 Comparison of observed and forecast water use of >15-20 ML Restaurants group in 2011

Restaurants Group		Annual water use in 2011 (KL)	Water use in each quarter in 2011 (KL)				*E* value
			1	2	3	4	
>15-20 ML	Observed	16,159	4,296	3,500	3,859	4,505	0.22
	Forecasted	14,738	4,127	3,537	3,242	3,832	

c. Group: >10-15 ML

There are four restaurants in this group. Water use in Restaurant 1 has significantly changed in 2007. Therefore, water use modelling for this restaurant was not performed in this research. Future field survey is recommended to model the water use of this restaurant. As mentioned in Table 5.4, the total water use in 2010 was considered as the forecast annual water use in 2011 for Restaurants 2 and 4. In case of Restaurant 3, from data analysis it was found that the water use was fairly constant over the years. Therefore, the average annual water use in 2008-2010 was considered as the forecast annual water use in 2011 for Restaurant 3.

From data analysis, all these three restaurants were found to have similar quarterly water use percentages for different years except in 2007 in Restaurant 4. Therefore, the average quarterly percentages in 2005-2010 (excluding 2007 in Restaurant 4) were considered as the quarterly water use disaggregating factors individually for all three restaurants as shown in Table 5.9. Thereafter, using the forecast annual water use and these disaggregating factors, quarterly water use in 2011 were forecasted for Restaurants 2, 3 and 4. The *E* values were also obtained from the comparison of observed and forecast quarterly water use in 2011 for all three restaurants. The *E* values along with the observed and forecast water use in 2011 for annual and quarterly time steps are presented in Table 5.10. From the table it can be seen that models performed well for Restaurants 2 and 4. However, in case of Restaurants 3, negative *E* value indicates that the average of previous quarterly water use would be better prediction than the forecast water use in this research.

Table 5.9 Quarterly disaggregating factors in >10-15 ML Restaurants group

>10-15 ML Restaurants Group	Quarter 1	Quarter 2	Quarter 3	Quarter 4
Restaurant 2	26	25	24	25
Restaurant 3	24	25	26	25
Restaurant 4	26.5	24.5	24	25

Table 5.10 Comparison of observed and forecast water use of >10-15 ML Restaurants group in 2011

>10-15 ML Restaurants Group		Annual water use in 2011 (KL)	Water use in each quarter in 2011 (KL)				*E* value
			1	2	3	4	
Restaurant 2	Observed	9,337	2,583	2,289	2,157	2,309	0.97
	Forecasted	9,643	2,507	2,411	2,314	2,411	
Restaurant 3	Observed	10,299	2,773	2,739	2,462	2,325	-0.58
	Forecast	10,472	2,513	2,618	2,723	2,618	
Restaurant 4	Observed	13,592	3,602	3,488	3,428	3,074	0.52
	Forecast	14,874	3,942	3,644	3,570	3,718	

d. Group: 5-10 ML

There is more than one restaurant in each subgroup in this group (Section 5.3.1.1) and the annual water uses among the restaurants are similar over the years. Therefore, average water use for each subgroup was considered for modelling and forecasting. From data analysis, it was also found that the average water use by the subgroups are similar from 2008-2010. Therefore, average annual water use by each subgroups from 2008 – 2010 are considered as the forecast average annual water use in 2011 for all subgroups.

The quarterly water use disaggregating factors were obtained for each subgroup from the average quarterly percentages excluding for the years mentioned in Table 5.4. These factors are shown in Table 5.11. Finally, the forecast average annual water uses were disaggregated into quarterly water use in each subgroup. The observed and the forecast average quarterly water uses in 2011 for each subgroup are presented in Table 5.12. The *E* values obtained from the comparison of the forecast quarterly average water uses with the observed quarterly average water uses in 2011 among the subgroups are also presented in Table 5.12. It can be seen from this table that high *E* values were obtained among all the subgroups.

Table 5.11 Quarterly disaggregating factors in 5-10 ML Restaurants group

5-10 ML Restaurants Group	**Disaggregating factors for quarters**			
	Quarter 1	**Quarter 2**	**Quarter 3**	**Quarter 4**
Subgroup: >9-10 ML	26	25	24	25
Subgroup: >8-9 ML	26	25	24	25
Subgroup: >7-8 ML	26	24	23	27
Subgroup: >6-7 ML	26	24.6	24	25.4
Subgroup: 5-6 ML	26	25	25	24

Table 5.12 Comparison of observed and forecast water use of 5-10 ML Restaurants group in 2011

5-10 ML Restaurants Subgroups		**Annual water use in 2011 (KL)**	**Water use in each quarter in 2011 (KL)**				***E* value**
			1	**2**	**3**	**4**	
>9-10 ML	Observed	7,472	1,934	1,780	1,780	1,978	0.84
	Forecasted	8,224	2,138	2,056	1,974	2,056	
>8-9 ML	Observed	7,186	1,808	1,780	1,753	1,846	0.94
	Forecasted	7,300	1,898	1,789	1,789	1,825	
>7-8 ML	Observed	6,342	1,520	1,527	1,498	1,798	0.91
	Forecasted	6,642	1,760	1,594	1,528	1,760	
>6-7 ML	Observed	4,720	1,185	1,100	1,227	1,208	0.72
	Forecasted	4,731	1,230	1,159	1,135	1,206	
5-6 ML	Observed	4,446	1,205	1,139	1,073	1,029	0.82
	Forecasted	4,866	1,265	1,216	1,216	1,168	

e. Group: <5 ML

As listed in Table 5.4, the average annual water use by the each subgroup from 2008-2010 were considered as the average annual forecast water use in 2011. The quarterly water use disaggregating factors were obtained for each subgroup from the average quarterly percentages excluding for the years mentioned in Table 5.4. These factors are shown in Table 5.13. Thereafter, quarterly average water uses in 2011 were forecasted using the average annual forecast water use in 2011 and the disaggregating factors.

The forecast average quarterly water uses were than compared with the observed average quarterly water use in 2011. The *E* values obtained from this comparison are shown in Table 5.14 along with the observed and the forecast average quarterly and annual water use in 2011. From this table, it can be seen that models for all subgroups are performed well with good *E* values.

Table 5.13 Quarterly disaggregating factors in <5 ML Restaurants group

Group: <5 ML	**Disaggregating factors for quarters**			
	Quarter 1	**Quarter 2**	**Quarter 3**	**Quarter 4**
Subgroup: >4-<5 ML	26	24.4	24.6	25
Subgroup: >3-4 ML	26	24	24	26
Subgroup: >2-3 ML	26	25	24	25
Subgroup: 1-2 ML	25	25	25	25
Subgroup: <1 ML	25	25	25	25

Table 5.14 Comparison of observed and forecast water use of <5 ML Restaurants group in 2011

<5 ML Restaurants Subgroups		**Annual water use in 2011 (KL)**	**Water use in each quarter in 2011 (KL)**				***E* value**
			1	**2**	**3**	**4**	
>4-<5 ML	Observed	3,586	890	853	807	1,036	0.65
	Forecasted	4,010	1,043	978	986	1,003	
>3-4 ML	Observed	3,057	799	781	737	739	0.66
	Forecasted	3,095	805	743	743	805	
>2-3 ML	Observed	2,074	543	551	496	484	0.50
	Forecasted	2,331	606	583	559	583	
1-2 ML	Observed	1,263	315	314	308	326	0.93
	Forecasted	1,251	313	313	313	313	
<1 ML	Observed	305	76	76	80	73	0.62
	Forecasted	308	77	77	77	77	

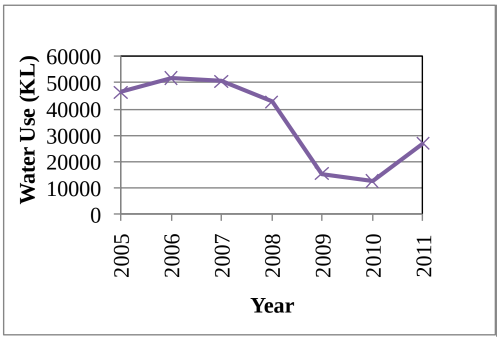
5.3.2. Data Analysis and Model Development for Hospitals

5.3.2.1. Data Analysis

The total water use of the Hospitals group is about 0.5% of the total non-residential water use in 2011 in the study area. There are nine hospitals within the study area. Water use in all these hospitals was analysed separately. As outlined in Section 5.2, pathologies in the YVW service area were also analysed in the Hospitals customer group. All hospitals except pathologies were grouped into different water user groups based on the average yearly water use from 2005 to 2009. All the pathologies were considered as a separate group.

a. Group: >20 ML

There is one hospital in this group with 26.5% water use of the total Hospitals water use in 2011. The annual water use time series of this hospital is shown in Figure 5.7 with its quarterly percentages for each year. From Figure 5.7, it can be seen that the total water use has decreased since 2008 to 2009 and then it was similar in 2011. From the same figure, it can also be seen that the quarterly percentages of water use of each year have similar patterns except in 2011, which is quite different.



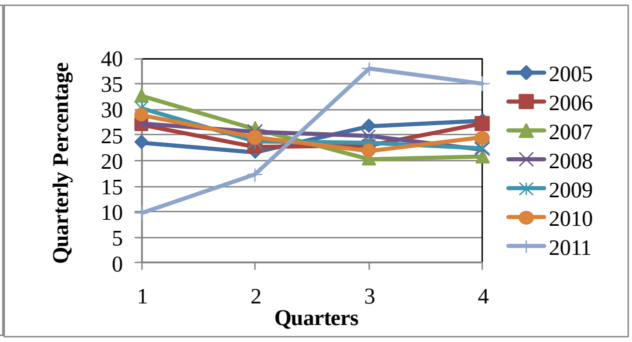


Figure 5.7 Water use pattern of >20 ML Hospitals group

b. Group: >10-15 ML

There are two hospitals in this group with 21.4% of the total Hospitals water use in 2011. The water use of these two hospitals was analysed separately. The annual water use of these two hospitals is presented in Figure 5.8 along with their quarterly percentages for each year. In Hospital 1, it can be seen that the annual water use is fairly variable although it has stabilized after 2009. The quarterly percentages for this hospital are similar in all years. In case of Hospital 2, the annual water uses is highly variable over the years, although the quarterly water use percentages were similar in all years.

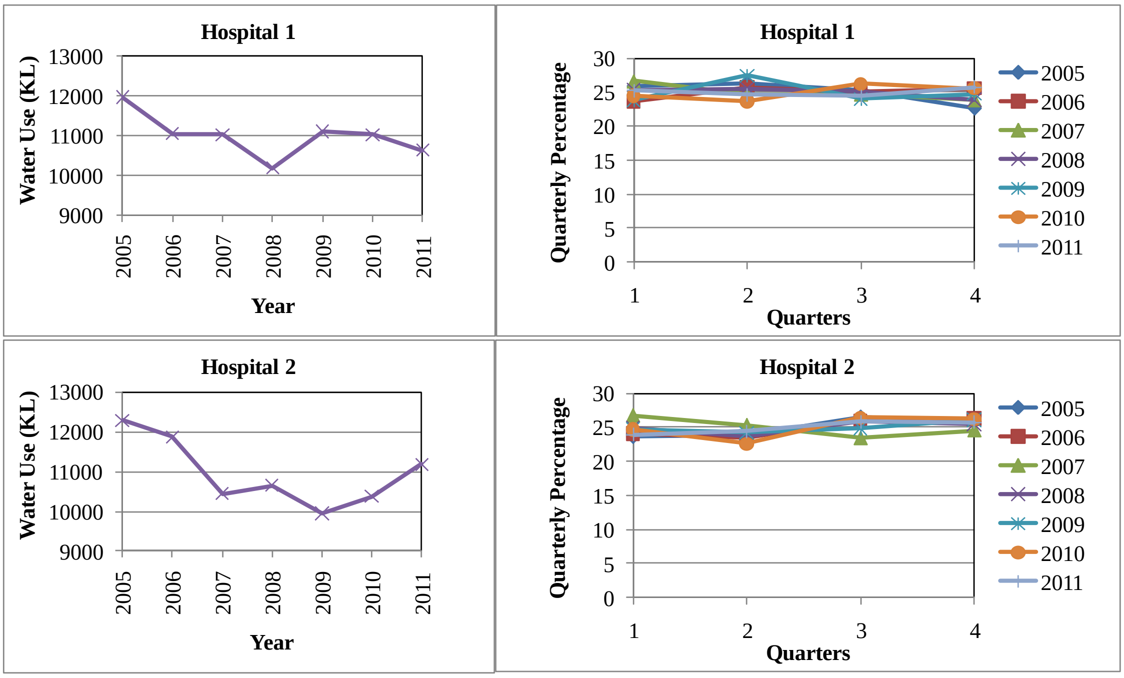


Figure 5.8 Water use pattern of >10-15 ML Hospitals group

c. Group: 5-10 ML

There are two hospitals in this group using 12.1% of the total Hospitals water use in 2011. The annual water use of these two hospitals is presented in Figure 5.9 along with their quarterly percentages for each year. In Hospital 1, it can be seen that water use decreased from 2005 to 2008, and after 2008 it was fairly constant. The

Hospital 2 has a similar pattern to Hospital 1 but more variable. Quarterly percentages for both of the hospital were similar in all years (Figure 5.9).

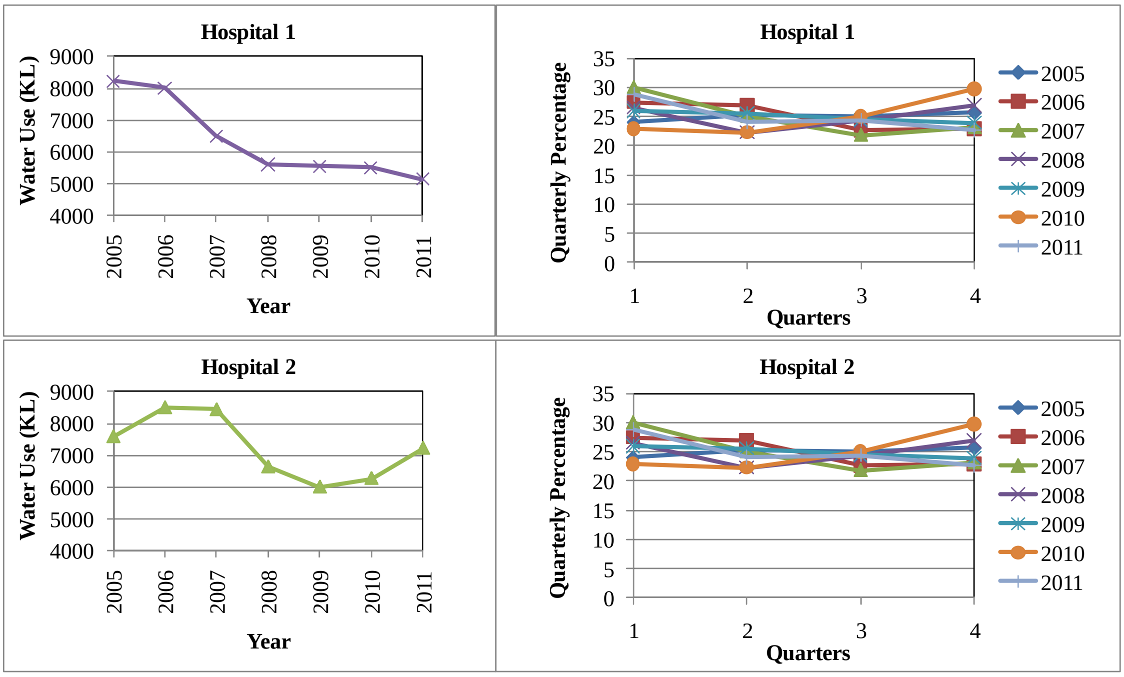


Figure 5.9 Water use pattern of 5-10 ML Hospitals group

d. Group: <5 ML

There are four hospitals in this group and these were analysed separately. The annual water use time series for these hospitals is shown in Figure 5.10. From Figure 5.10, it is apparent that the annual water use in each hospital was similar over the years for except the water use of Hospital 2 in 2008. Quarterly water use percentages for all four hospitals are shown in Figure 5.11. It can be seen that in Figure 5.11, the quarterly water use percentages were consistent across the years in Hospitals 3 and 4. In case of Hospital 2, the quarterly percentages of 2008 and 2009 were similar but different those from the other years. From Figure 5.11, it is also apparent that there was not much consistency in the quarterly water use percentages in Hospital 1.

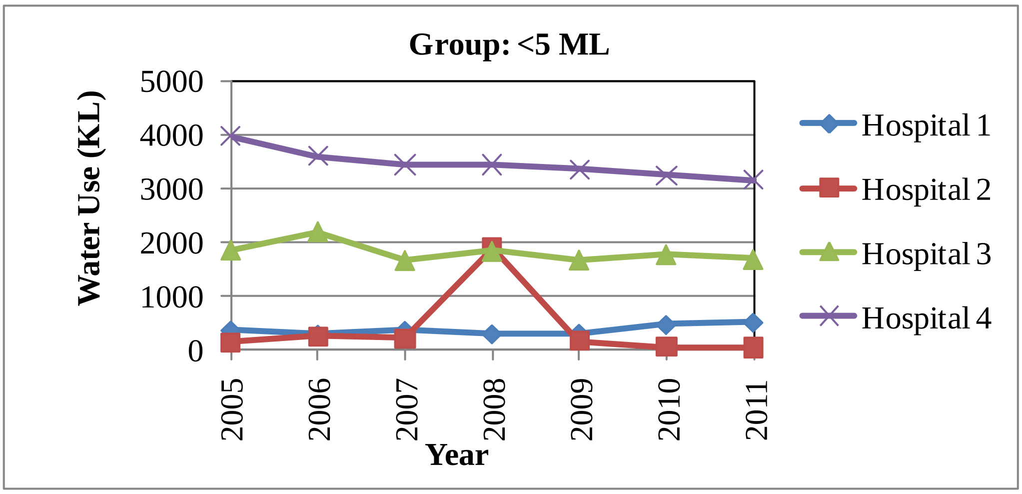


Figure 5.10 Annual water use time series of <5 ML Hospitals group

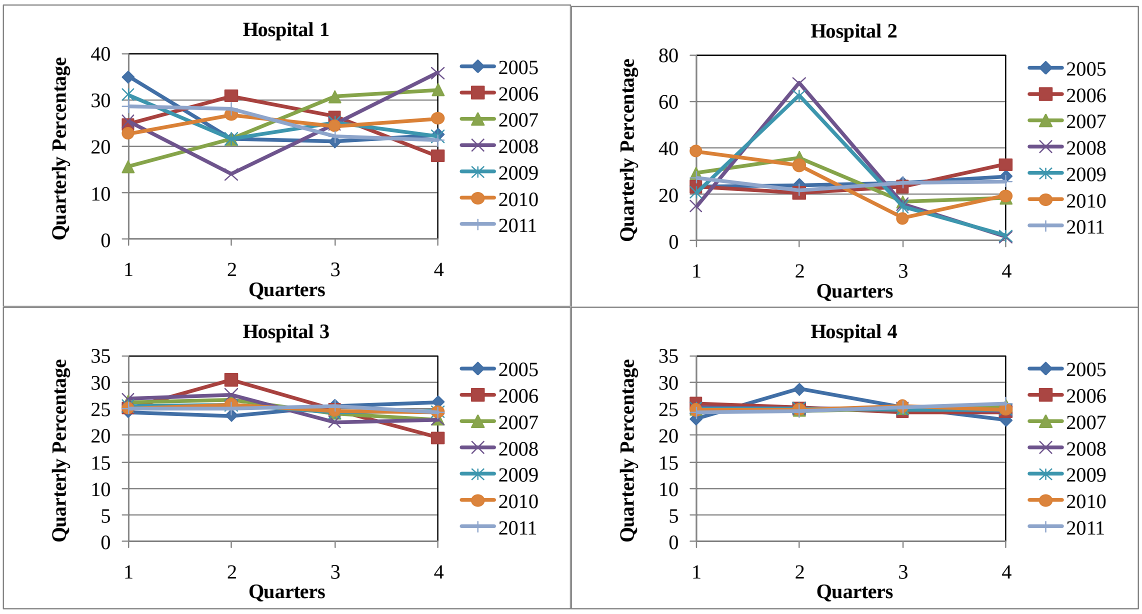


Figure 5.11 Quarterly percentages of individual hospital in <5 ML Hospitals group

e. Pathologies

There are five pathologies that were listed in the Hospitals group using 34.7% of total water use by the Hospitals group in 2011. The water use of all these five pathologies were analysed separately as their average annual water use (based on 2005-2009) is highly variable from each other and using a high percentages of total water use by Hospitals. The annual water use time series and quarterly percentages for different years are shown in Figure 5.12 for each of the pathologies.

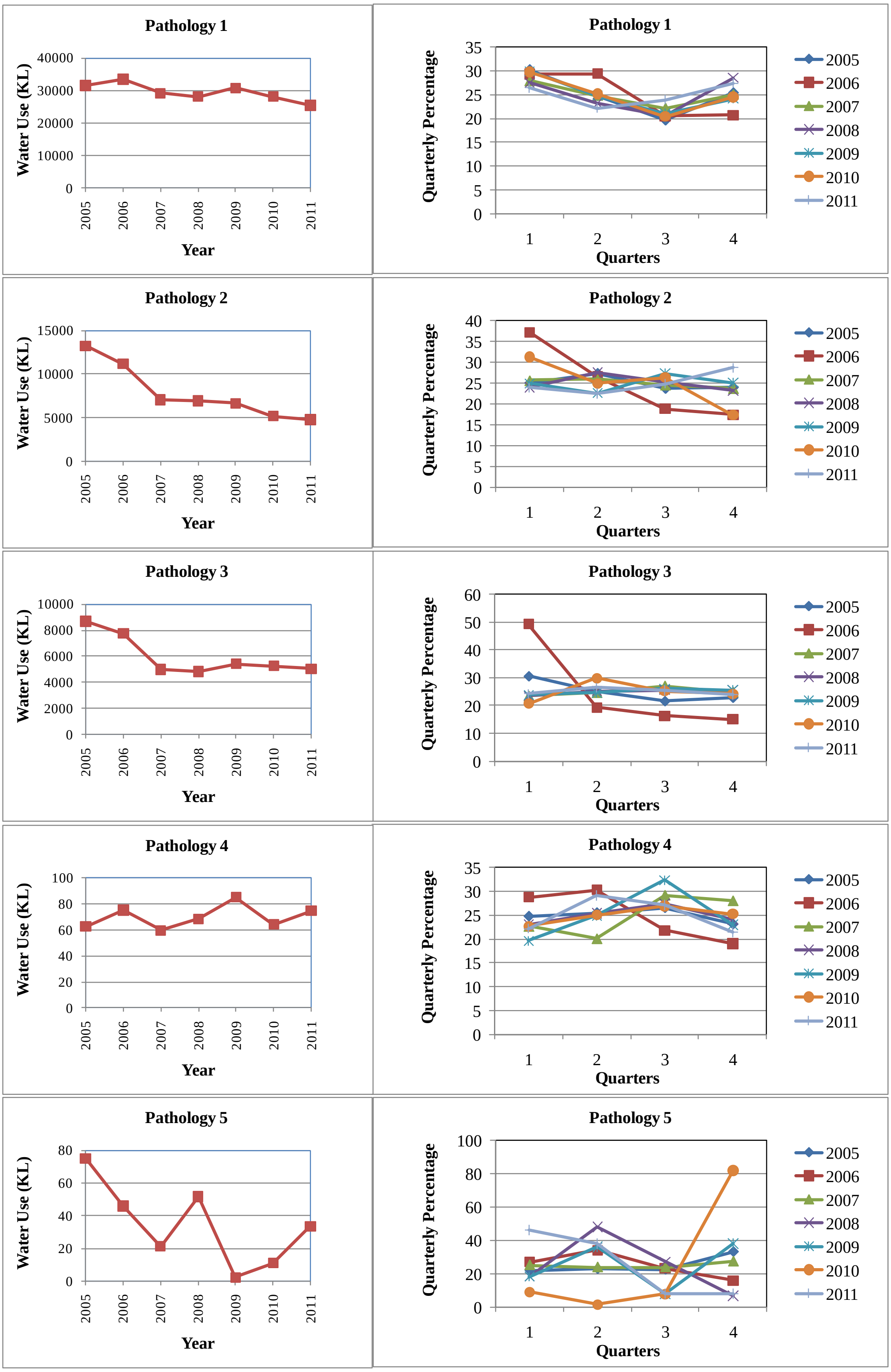


Figure 5.12 Water use pattern of Pathologies in Hospitals group

From the Figure 5.12, it can be seen that the annual water use were almost constant in 2008-2010 for Pathologies 1, 2, and 3. In case of Pathology 4, the annual water use was variable over years, but the variability was very high in Pathology 5. From the Figure 5.12, it is apparent that the quarterly percentages of the Pathologies 1, 2, and 3 were fairly consistent over the years and those for Pathologies 4 and 5 were highly variable over years. It should be noted that in Pathology 5, quarterly water use percentages in 2010 were highly variable than those of other years as it shows that most of the water used in 4^{th} quarter (82%).

f. Summary of Data Analysis

A summary of above water use data analysis is presented in Table 5.10; based on this analysis, different modelling approaches were considered for forecasting annual water use for the different groups which are also presented in this table. From the table, it can be seen that the most of the Hospitals groups follow the similar annual water use pattern over the different years. Therefore, average annual water use over the 2008-2010 periods were considered for the forecast annual water use in 2011 for these groups. There were few groups with variable annual water use over the years and for them the annual water use in 2010 was considered as the forecast annual water use in 2011. However, it was found that the quarterly water use percentages in most of the subgroups were consistent over the years. Therefore, the disaggregating factors were considered as the average over the period of 2005-2010 excluding the exception years.

Table 5.15 Summary of water use data analysis and selection of modelling approach for Hospitals group

Group	**Number of hospitals**	**Modelled by**	**Variation of annual water use**	**Variation of quarterly water use percentages**	**Approach used for annual water use forecast in 2011**	**Approach used for disaggregating factors (quarterly percentages)**
>20 ML	1	Individual	Highly variable	Similar over the years	Annual water use in 2010	Average of 2005-2010
>15-20 ML	-	-	-	-		
>10-15 ML	2	Individual (Hospital 1)	Fairly variable	Similar over the years	Annual water use in 2010	Average of 2005-2010
		Individual (Hospital 2)	Highly variable	Similar over the years	Annual water use in 2010	Average of 2005-2010
5-10 ML	2	Individual (Hospital 1)	Decreased until 2008 and then almost constant	Similar over the years	Average annual water use in 2008-2010	Average of 2005-2010
		Individual (Hospital 2)	Decreased until 2008 and then fairly constant	Similar over the years	Average annual water use in 2008-2010	Average of 2005-2010
<5 ML	4	Individual (Hospital 1)	Similar over the years	Not consistent over the years	Average annual water use in 2008-2010	Same as in 2010

		Individual (Hospital 2)	Similar over the years except 2008	Similar over the years except in 2008 and 2009	Average annual water use in 2009-2010	Average of 2005-2010 excluding 2008 and 2009
		Individual (Hospital 3)	Similar over the years	Similar over the years	Average annual water use in 2008-2010	Average of 2005-2010
		Individual (Hospital 4)	Similar over the years	Similar over the years	Average annual water use in 2008-2010	Average of 2005-2010
Pathologies	5	Individual (Pathology 1)	Fairly constant in 2008-2010	Similar over the years except in 2006 and 2010	Average annual water use in 2008-2010	Average of 2005-2010 excluding 2006 and 2010
		Individual (Pathology 2)	Fairly constant in 2008-2010	Similar over the years except in 2006	Average annual water use in 2008-2010	Average of 2005-2010 excluding 2006
		Individual (Pathology 3)	Fairly constant in 2008-2010	Similar over the years except in 2006	Average annual water use in 2008-2010	Average of 2005-2010 excluding 2006
		Individual (Pathology 4)	Highly variable	Not consistent over the years	Annual water use in 2010	Same as in 2010
		Individual (Pathology 5)	Highly variable	Not consistent over the years	Annual water use in 2010	Same as in 2010

5.3.2.2. Forecasting Water Use Model Development

Since the findings from the data analysis for the Hospitals group (Section 5.3.2.1) was similar to those of the Restaurants group (Section 5.3.1.1), model development procedure for Hospitals group is also the same as that of the Restaurants group (Section 5.3.1.2).

a. Group: >20 ML

The annual water use in this hospital was highly variable over the years as was outlined in Table 5.15. Therefore, the total water use in 2010 is considered as the forecast annual water use for 2011. From data analysis it was also found that the quarterly water use percentages over the different years were consistent and therefore, the quarterly disaggregating factors (shown in Table 5.16) were obtained from the average of quarterly water use percentages over years (2005-2010). The forecast annual water use in 2011 was then disaggregated into quarterly water use with the disaggregating factors. The observed and forecast water uses in 2011 are presented in Table 5.17 for both annual and quarterly time step. The *E* value obtained from the comparison of quarterly observed and forecast water use in 2011 is -0.49, which indicates poor model performance. From Table 5.17, it is clear that the forecast annual water use were very different from the observed water use, especially in 3rd quarter of 2011. However, there was no detail information available except water use data to further investigate for possible reasons. Therefore, it is recommended that a field survey should be considered for collecting more information on factors affecting the water use for better forecast.

Table 5.16 Quarterly disaggregating factors in >20 ML Hospitals group

Group	**Disaggregating factors for quarters**			
	Quarter 1	**Quarter 2**	**Quarter 3**	**Quarter 4**
>20 ML	28	24	23.5	24.5

Table 5.17 Comparison of observed and forecast water use of >20 ML Hospitals group in 2011

Hospitals Group		Annual water use in 2011 (KL)	Water use in each quarter in 2011 (KL)				*E* value
			1	2	3	4	
>20 ML	Observed	26,873	2,619	4,624	10,198	9,432	-0.49
	Forecasted	12,591	3,526	3,022	2,959	3,085	

b. Group: >10-15 ML

From Table 5.15, it was seen that the annual water use in both of these hospitals in this group were not consistent over the years. However, the quarterly percentages of annual water uses were consistent over the different years. Therefore, the quarterly disaggregating factors obtained from the average quarterly percentages over the last years (2005-2010) which are also shown in Table 5.18. The annual water use in 2010 was considered as the forecast annual water use in 2011 for these two hospitals. The forecast annual water use was then disaggregated into the quarterly water use using the disaggregating factors shown in Table 5.18. These observed and forecast water use in 2011 for both quarterly and annual time step are shown in Table 5.19. The *E* values obtained from the comparison of forecast and observed quarterly water use in 2011 are also presented in Table 5.19. A negative *E* value shows the poor model performance, indicating the average quarterly water use of previous years would be better prediction for 2011 than the forecast quarterly water use in this research.

Table 5.18 Quarterly disaggregating factors in >10-15 ML Hospitals group

Group	Disaggregating factors for quarters			
	Quarter 1	Quarter 2	Quarter 3	Quarter 4
Hospital 1	25	25.6	25	24.4
Hospital 2	24.5	24	25.5	26

Table 5.19 Comparison of observed and forecast water use of >10-15 ML Hospitals group in 2011

>10-15 ML Hospitals Group		**Annual water use in 2011 (KL)**	**Water use in each quarter in 2011 (KL)**				***E* value**
			1	**2**	**3**	**4**	
Hospital 1	Observed	10,637	2,686	2,618	2,595	2,739	-0.30
	Forecasted	11,027	2,757	2,823	2,757	2,691	
Hospital 2	Observed	11,181	2,678	2,733	2,887	2,883	-2.60
	Forecasted	10,379	2,595	2,491	2,647	2,647	

c. Group: 5-10 ML

As outlined in Table 5.15, the annual water uses in the two hospitals in this group were similar from 2008 to 2010. Therefore, the average annual water use by each hospital in 2008-2010 was considered as the forecast annual water use in 2011. From data analysis, it was also found that the quarterly water use percentages over different years (2005-2010) were similar. Therefore, the disaggregating factors were obtained from the average of the quarterly water use percentages over years (2005-2010). These disaggregating factors for each of the hospitals are shown in the Table 5.20.

Thereafter, the forecast annual water uses in 2011 were disaggregated into the quarterly water uses using the disaggregating factors. The forecast and observed water use for both quarterly and annual water use in 2011 are presented in Table 5.21. The *E* value obtained from the comparison of forecast and observed quarterly water use in 2011 are also presented in Table 5.21 show that models were performed well for this Hospitals group.

Table 5.20 Quarterly disaggregating factors in 5-10 ML Hospitals group

Group	Disaggregating factors for quarters			
	Quarter 1	Quarter 2	Quarter 3	Quarter 4
Hospital 1	26	24.5	24	25.5
Hospital 2	28.5	27	23	21.5

Table 5.21 Comparison of observed and forecast water use of 5-10 ML Hospitals group in 2011

5-10 ML Hospitals Group		Annual water use in 2011 (KL)	Water use in each quarter in 2011 (KL)				*E* value
			1	2	3	4	
Hospital 1	Observed	5,134	1,479	1,237	1,254	1,165	0.98
	Forecasted	5,542	1,441	1,358	1,330	1,413	
Hospital 2	Observed	7,218	2,000	1,779	1,682	1,758	0.01
	Forecasted	6,298	1,795	1,700	1,449	1,354	

d. Group: <5 ML

As mentioned in Table 5.15, the annual water uses by each hospital are similar over the years (2005-2010). Therefore, the average annual water use of the last three years (2008-2010) was considered as the forecast annual water use in these hospitals for 2011. As outlined in Table 5.15, the average quarterly percentages over years (2005-2010) were considered as the disaggregating factors for Hospitals 3 and 4, while for Hospitals 1 and 2, the 2010 quarterly percentages were considered. These disaggregating factors are presented in Table 5.22. Finally, the forecast annual water uses were disaggregated into quarterly water use in 2011 by using the quarterly disaggregating factors. The forecast and observed water uses for annual and quarterly time steps in 2011 are presented in Table 5.23. The *E* value obtained from the comparison of forecast and observed water uses are also presented in Table 5.23. The *E* values in Table 5.23 show that models performed well to forecast quarterly water use in 2011 for this Hospitals group.

Table 5.22 Quarterly disaggregating factors in <5 ML Hospitals group

Group <5 ML	**Disaggregating factors for quarters**			
	Quarter 1	**Quarter 2**	**Quarter 3**	**Quarter 4**
Hospital 1	23	27	24	26
Hospital 2	38.5	32.5	9.6	19.4
Hospital 3	25.5	26.5	24.5	23.5
Hospital 4	25	25.5	25	24.5

Table 5.23 Comparison of observed and forecast water use of <5 ML Hospitals group in 2011

<5 ML Hospitals Subgroups		**Annual water use in 2011 (KL)**	**Water use in each quarter in 2011 (KL)**				***E* value**
			1	**2**	**3**	**4**	
Hospital 1	Observed	503	144	141	111	107	0.10
	Forecasted	343	79	93	82	89	
Hospital 2	Observed	23	6	5	6	6	0.55
	Forecasted	98	38	32	9	19	
Hospital 3	Observed	1,678	421	420	430	408	0.53
	Forecasted	1,754	447	465	430	412	
Hospital 4	Observed	3,150	763	774	795	818	0.60
	Forecasted	3,341	835	852	835	819	

e. Group: Pathologies

Based on the analysis of water use data (Table 5.15), it was found that Pathologies 1, 2 and 3 individually had similar annual water use in 2008-2010, but the annual water uses in Pathologies 4 and 5 were highly variable over this period. Therefore, it was considered that the average annual water use in 2008-2010 as the forecast annual water use in 2011 for Pathologies 1, 2 and 3, and the water use in 2010 as the forecast annual water use in 2011 for Pathologies 4 and 5.

The average quarterly percentages were considered as the quarterly disaggregating factors for Pathology 1, 2 and 3 excluding those of the outlined years in Table 5.15. In Pathologies 4 and 5, there were no consistency in quarterly water use percentages and therefore, the percentages of quarterly water use in 2010 and 2009 were considered for the Pathologies 4 and 5 respectively. Finally, the forecast annual water uses were disaggregated into quarterly water uses by using the quarterly disaggregating factors presented in Table 5.24.

The forecast and observed water uses in 2011 are presented in Table 5.25 for both annual and quarterly time steps. The *E* values obtained from the comparison of forecast and observed quarterly water uses for this group are also presented in Table 5.25. It can be seen that for most of the Pathologies, model performed well to forecast water use in 2011.

Table 5.24 Quarterly disaggregating factors in Pathologies in Hospitals group

Group	**Disaggregating factors for quarters**			
	Quarter 1	**Quarter 2**	**Quarter 3**	**Quarter 4**
Pathology 1	29	24.5	21	25.5
Pathology 2	25	26	25	24
Pathology 3	24.5	26	25	24.5
Pathology 4	23	25	27	25
Pathology 5	18	36	8	38

Table 5.25 Comparison of observed and forecast water use of Pathologies in Hospitals group in 2011

Pathologies Hospitals Subgroups		**Annual water use in 2011 (KL)**	**Water use in each quarter in 2011 (KL)**				***E* value**
			1	**2**	**3**	**4**	
Pathology 1	Observed	25,425	6,721	5,637	6,087	6,979	0.23
	Forecasted	28,981	8,405	7,100	6,086	7,390	
Pathology 2	Observed	4,783	1,143	1,077	1,189	1,373	0.80
	Forecasted	6,256	1,564	1,627	1,564	1,501	
Pathology 3	Observed	5,044	1,218	1,336	1,282	1,208	0.98
	Forecasted	5,167	1,266	1,343	1,292	1,266	
Pathology 4	Observed	75	17	22	20	16	0.12
	Forecasted	64	15	16	17	16	
Pathology 5	Observed	34	16	13	3	3	-0.01
	Forecasted	11	2	4	1	4	

5.3.3. Data Analysis and Model Development for Hotels

5.3.3.1. Data Analysis

There are 44 hotels identified within the study area with 0.7% of the total non-residential water use in 2011. All hotels are grouped into different groups based on the average annual water use from 2005 to 2009. Data analysis was carried out similar to the Restaurants and Hospitals groups (Sections 5.3.1.1, and 5.3.2.1).

a. Group: >10-15 ML

There are two hotels in this group using 15.6% of the total water use by Hotels group. Annual water use time series along with their quarterly percentages are shown in Figure 5.13 for these two hotels. From Figure 5.13, it can be seen that there are no particular pattern exist in annual water use over the years for these two hotels.

However, the quarterly water use pattern was similar over the years except in 2009 for both hotels and in 2008 for Hotel 2.

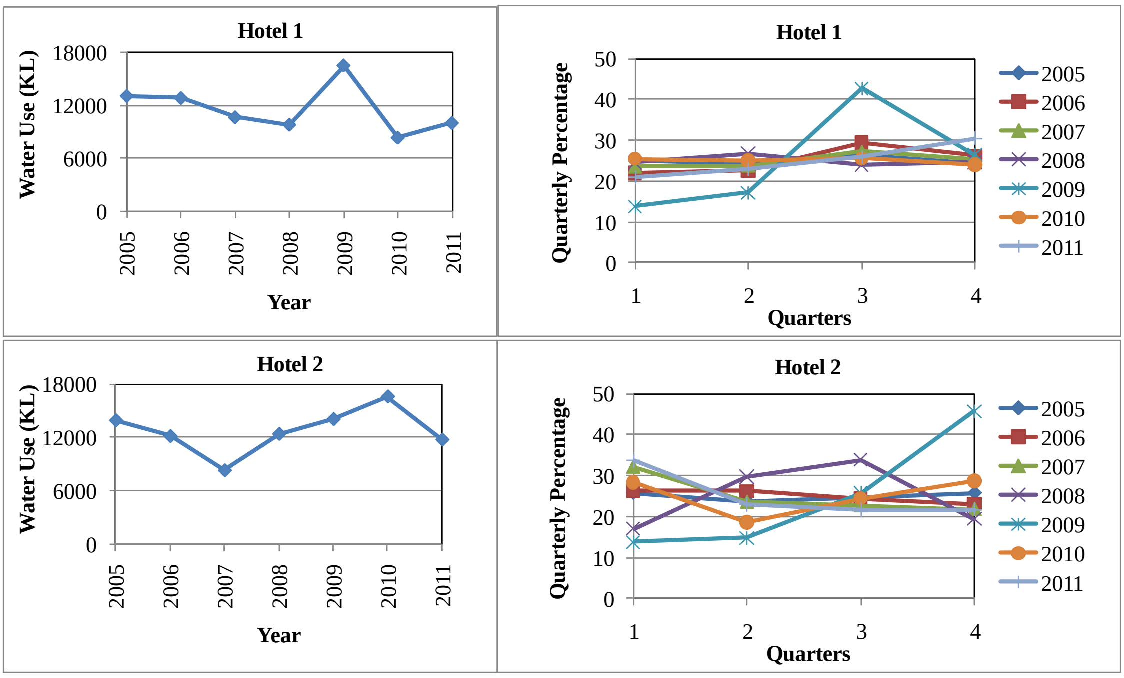


Figure 5.13 Water use pattern of >10-15 ML Hotels group

b. Group: 5-10 ML

There are four hotels in this group with 21.6% of the total water use by Hotels group in 2011. All these four hotels were analysed separately. The time series of annual water use and the percentages of quarterly water use in each year for all four hotels are shown in Figure 5.14. From Figure 5.14, it can be seen that the annual water use in Hotels 1, 2 and 3 were fairly similar over the years. In Hotel 4, the annual water use was fairly similar until 2009 and then in 2010 it has increased. From the same figure, it is also apparent that the quarterly percentages were consistent across the different years among the hotels.

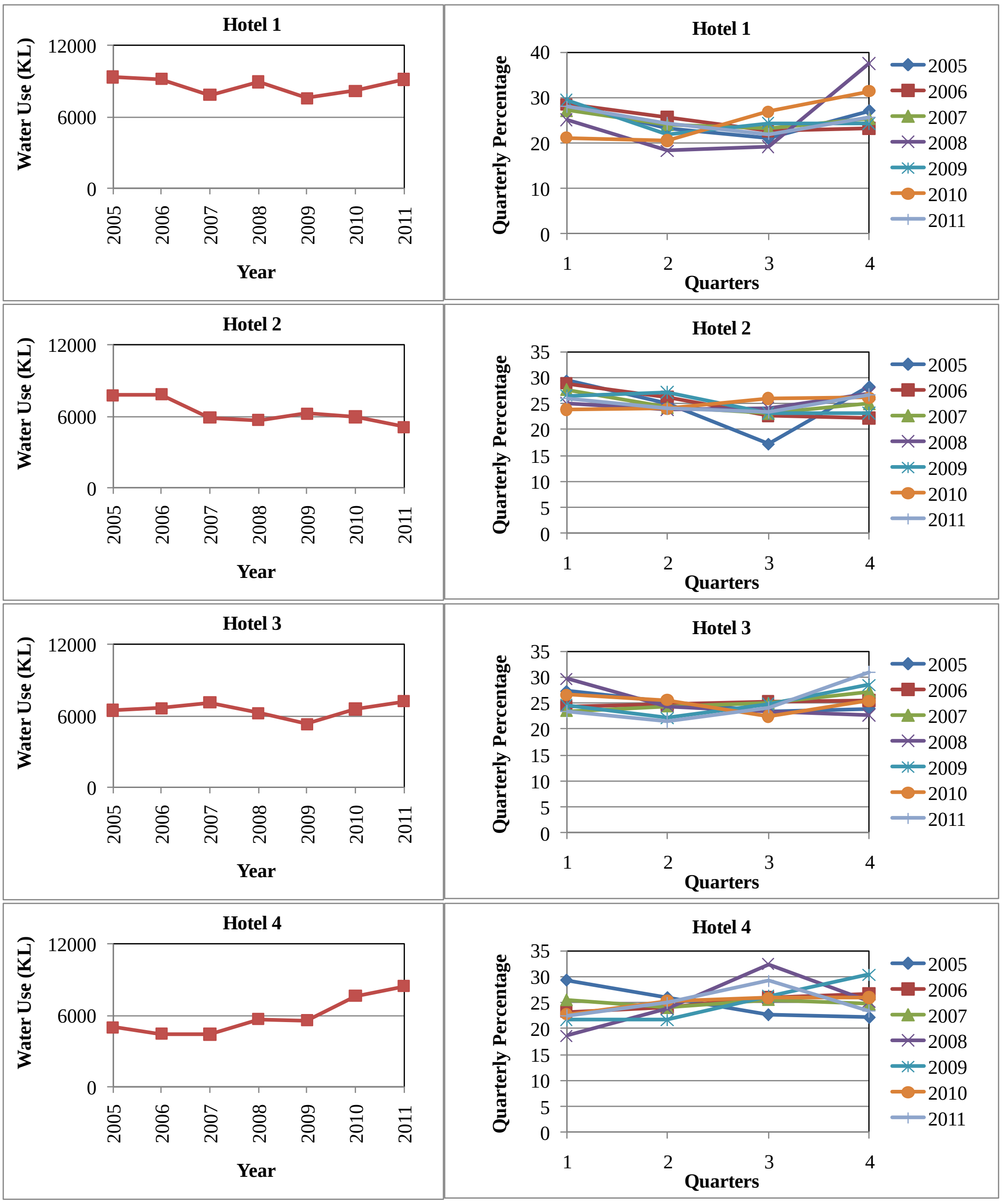


Figure 5.14 Water use pattern of 5-10 ML Hotels group

c. Group: <5 ML

There are 38 hotels in this group with 62.8% of total water use by Hotels group in 2011. All these hotels were divided into five subgroups based on the average annual water use volume in 2005-2009 and then each subgroup analysed separately. These subgroups with their water use percentages within the Hotels group and the numbers of hotels in each subgroup are shown in Table 5.26.

Table 5.26 Water use percentages among Hotels subgroups in <5 ML group

Subgroup	**Number of Hotels**	**Water use (%) in Hotels**
>4-<5 ML	7	22.0
>3-4 ML	7	17.1
>2-3 ML	8	14.1
1-2 ML	9	9.4
<1 ML	7	1.4
Total	38	64

The time series of annual water use and the average percentages of quarterly water use in each year for each subgroup are shown in Figure 5.15. It should be noted that the black bold line in the annual water use time series shows the average water use of the subgroup.

From the annual water use plots in Figure 5.15, it is found that the water uses among the hotels within this group were similar over the years except one hotel in the subgroup >2-3 ML. This hotel was not included in calculating the average water use for this subgroup. A constant average quarterly percentages over different years can also be seen from this figure except the average quarterly percentage in 2009 in the <1 ML subgroup.

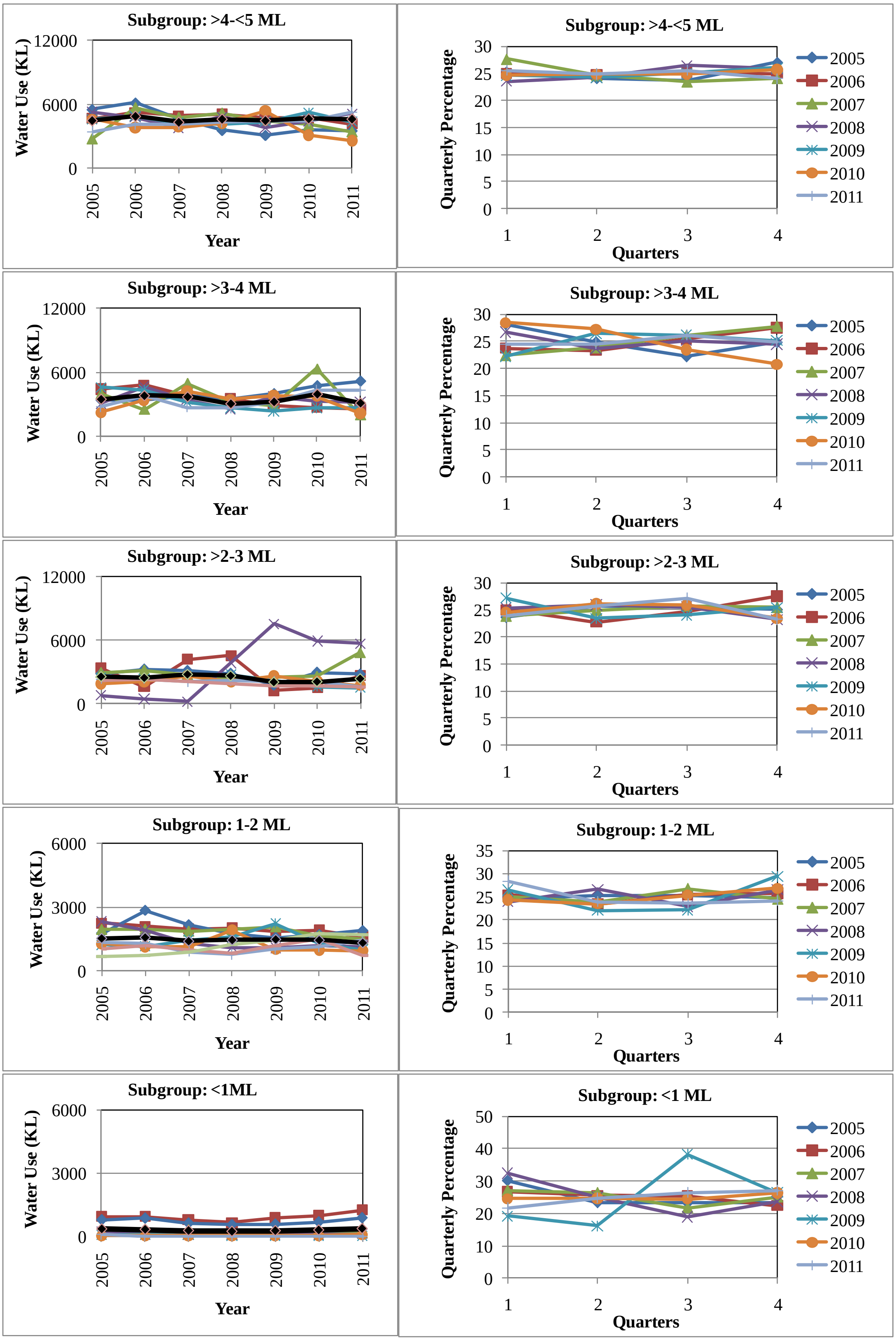


Figure 5.15 Water use pattern of <5 ML Hotels group

d. Summary of Data Analysis

A summary of the above water use data analysis is presented in Table 5.27; Based on this analysis, the approaches that was used to forecast annual water use for the different groups and in some cases for the individual hotels within the group, is also presented in this table. Furthermore, this table also shows how the quarterly water use disaggregating factors were obtained to disaggregate the forecast annual water use into forecast quarterly water use. From the table, it can be seen that the most of the Hotels groups follow the similar annual water use pattern over the different years except for >10-15 ML group and Hotel 4 in 5-10 ML group. Therefore, average annual water use over the 2008-2010 periods were considered to forecast the annual water use in 2011 for these groups. In the case of highly variable water use groups, the annual water use in 2010 was considered as the forecast water use for 2011.

Table 5.27 Summary of water use data analysis and selection of modelling approach for Hotels group

Group	**Subgroups**	**Number of hotels**	**Modelled by**	**Variation of annual water use**	**Variation of quarterly water use percentages**	**Approach used for annual water use forecast in 2011**	**Approach used for disaggregating factors**
>20 ML	-	-	-	-	-	-	
>15-20 ML	-	-	-	-	-	-	
>10-15 ML	-	2	Individual (Hotel 1)	Highly variable	Similar over the years except in 2009	Annual water use in 2010	Average of 2005-2010 excluding 2009
			Individual (Hotel 2)	Highly variable	Similar over the years except in 2008 and 2009	Annual water use in 2010	Average of 2005-2010 excluding 2009
5-10 ML		4	Individual (Hotel 1)	fairly constant over the years	Similar over the years	Average annual water use in 2008-2010	Average of 2005-2010
			Individual (Hotel 2)	fairly constant over the years	Similar over the years	Average annual water use in 2008-2010	Average of 2005-2010
			Individual (Hotel 3)	fairly constant over the years	Similar over the years	Average annual water use in 2008-	Average of 2005-2010
			Individual (Hotel 4)	fairly constant until 2009 and then increased in 2010	Similar over the years	Annual water use in 2010	Average of 2005-2010

	>4-<5 ML	7	Group	Similar over the years	Similar over the years	Average annual water use in 2008-2010	Average of 2005-2010
	>3-4 ML	7	Group	Similar over the years	Similar over the years	Average annual water use in 2008-2010	Average of 2005-2010
<5 ML	>2-3 ML	8	Group	Similar over the years	Similar over the years	Average annual water use in 2008-2010	Average of 2005-2010
	1-2 ML	9	Group	Similar over the years	Similar over the years	Average annual water use in 2008-2010	Average of 2005-2010
	<1 ML	7	Group	Similar over the years	Similar over years except in 2009	Average annual water use in 2008-2010	Average of 2005-2010 excluding 2009

5.3.3.2. Forecasting Water Use Model Development

Since the findings from the data analysis for the Hotels group (Section 5.3.3.1) were similar to those of the Restaurants and Hospitals group (Sections 5.3.1.1 and 5.3.2.1), model development procedure for Hotels group is also the same as those of the Restaurants and Hospitals group (Sections 5.3.1.2 and 5.3.2.2).

a. Group: >10-15 ML

As outlined in Table 5.27, it was found from the data analysis that the water use in these two hotels is highly variable and therefore, the annual water use in 2010 is considered as the forecast annual water use in 2011 for these hotels. However, from Table 5.27, it is apparent that there were consistent quarterly water use pattern exists among these two hotels except in 2009 for Hotel 1, and 2008 and 2009 for Hotel 2. Therefore, the data for these years were excluded when calculating the quarterly water use disaggregating factors. The disaggregating factors are presented in Table 5.28. The forecast annual water use in 2011 was then disaggregated into quarterly water use using the disaggregating factors. The forecast and observed water use in 2011 for these Hotels are presented in Table 5.29 for both of the annual and quarterly time steps.

The E value obtained from the comparison of quarterly forecast and observed water uses in 2011 are also presented in Table 5.29. Low E values in the table show that models are not performing well for these two hotels. This could be due to the different annual water use in 2011 than the annual water use in 2010, which also can be seen from Figure 5.13. As there was not enough information available in this study, it is recommended that a survey should be considered in future for predicting annual water use of this group.

Table 5.28 Quarterly disaggregating factors in >10-15 ML Hotels group

Group	**Disaggregating factors for quarters**			
	Quarter 1	**Quarter 2**	**Quarter 3**	**Quarter 4**
Hotel 1	24	24.5	26.5	25
Hotel 2	28	23	24	25

Table 5.29 Comparison of observed and forecast water use of >10-15 ML Hotels group in 2011

>10-15 ML Hotels Group		**Annual water use in 2011 (KL)**	**Water use in each quarter in 2011 (KL)**				***E* value**
			1	**2**	**3**	**4**	
Hotel 1	Observed	10,028	2,085	2,292	2,592	3,059	0.10
	Forecasted	8,352	2,005	2,046	2,213	2,088	
Hotel 2	Observed	11,757	3,961	2,695	2,547	2,555	-2.1
	Forecasted	16,607	4,650	3,820	3,986	4,152	

b. Group: 5-10 ML

It was found from the data analysis that the annual water uses and the quarterly percentages were fairly consistent over the years for Hotels 1, 2 and 3. Therefore, as outlined in Table 5.17, it was considered that the average annual water use in 2008-2010 as the forecast water use in 2011 for Hotels 1, 2 and 3; and for Hotel 4, the annual water use in 2010 was considered. The disaggregating factors obtained from the average quarterly percentages over years (2005-2010) as similar quarterly pattern were found over that period for all the Hotels in this group. These disaggregating factors for each hotel are presented in Table 5.30.

Thereafter, forecast annual water use in 2011 was disaggregated into quarterly water use by using the disaggregating factors presented in Table 5.30. The observed and the forecast water use in 2011 for all hotels in this group are presented in Table

5.31 in both the annual and the quarterly time step. The *E* values obtained from the comparison of observed quarterly water use with the forecast quarterly water use in 2011 is also presented in Table 5.31. The *E* values in Table 5.31 indicate that the model performed well for Hotels 1, 2 and 4, and in case of Hotels 3 model performance were low.

Table 5.30 Quarterly disaggregating factors in 5-10 ML Hotels group

Group	**Disaggregating factors for quarters**			
	Quarter 1	**Quarter 2**	**Quarter 3**	**Quarter 4**
Hotel 1	28	24	23	25
Hotel 2	27	25	23	25
Hotel 3	26	24.5	24	25.5
Hotel 4	23.5	24	26.5	26

Table 5.31 Comparison of observed and forecast water use of 5-10 ML Hotels group in 2011

5-10 ML Hotels Subgroups		**Annual water use in 2011 (KL)**	**Water use in each quarter in 2011 (KL)**				***E* value**
			1	**2**	**3**	**4**	
Hotel 1	Observed	9,177	2,570	2,228	2,018	2,360	0.38
	Forecasted	8,245	2309	1,979	1,896	2,061	
Hotel 2	Observed	5,119	1,332	1,228	1,194	1,365	0.64
	Forecasted	5,975	1,613	1,494	1,374	1,494	
Hotel 3	Observed	7,264	1,701	1,565	1,754	2,244	0.04
	Forecasted	6,063	1,576	1,486	1,455	1,546	
Hotel 4	Observed	8,498	1,912	2,119	2,479	1,988	0.87
	Forecasted	7,642	1,796	1,834	2,025	1,987	

c. Group: <5 ML

From the data analysis it was seen that there were many hotels in each subgroup and their annual water uses were similar. Therefore, the average water use by the subgroup was considered for modelling purpose in this study. From data analysis it was found that the average annual water use by each subgroup was similar over years (2005-2010) and average quarterly percentages were same over that period for most of the subgroups. Therefore, as listed in Table 5.27, the average annual water use by the each subgroup from 2008-2010 were considered as the average annual forecast water use in 2011 and the disaggregating factors were obtained from the average quarterly percentages excluding for the years mentioned in the table. These factors are presented in Table 5.32. Thereafter, using the average annual forecast water use in 2011 and the disaggregating factors, quarterly average water uses in 2011 were forecasted.

The forecast and the observed average quarterly and annual water use in 2011 are presented in Table 5.33 for each subgroup. The *E* values obtained from the comparison of average quarterly observed and forecast water use are also presented in Table 5.33. From the *E* value in the table, it can be seen that models for most of the subgroups were performed well.

Table 5.32 Quarterly disaggregating factors and *E* values in <5 ML Hotels group

Group	**Disaggregating factors for quarters**			
	Quarter 1	**Quarter 2**	**Quarter 3**	**Quarter 4**
Subgroup: >4-<5 ML	25.5	24.5	24.5	25.5
Subgroup: >3-4 ML	25	25	25	25
Subgroup: >2-3 ML	25	25	25	25
Subgroup: 1-2 ML	25	24	25	26
Subgroup: <1 ML	26.5	24	25	24.5

Table 5.33 Comparison of observed and forecast water use of <5 ML Hotels group in 2011

<5 ML Hotels Subgroups		Annual water use in 2011 (KL)	Water use in each quarter in 2011 (KL)				*E* value
			1	2	3	4	
>4-<5 ML	Observed	4,073	1,078	1,014	996	985	0.44
	Forecasted	4,341	1,107	1,063	1,063	1,107	
>3-4 ML	Observed	3,147	769	772	824	782	0.47
	Forecasted	3,447	862	862	862	862	
>2-3 ML	Observed	2,392	571	615	649	557	-0.38
	Forecasted	2,277	569	569	569	569	
1-2 ML	Observed	1,329	376	318	313	321	0.13
	Forecasted	1,472	368	353	368	383	
<1 ML	Observed	364	79	90	96	99	-0.75
	Forecasted	263	70	63	66	64	

5.3.4. Data Analysis and Model Development for Laundries

5.3.4.1. Data Analysis

There are 127 laundries within the study area using 0.8% of the total non-residential water use in 2011. As discussed in Section 5.2.2, all laundries were grouped into different groups based on the average yearly water use from 2005 to 2009 and then analysed individually for each group. Data analysis in Laundries was carried out similar to the Restaurants, Hospitals and Hotels groups (Sections 5.3.1.1, 5.3.2.1 and 5.3.3.1)

a. *Group: >15-20 ML*

There is only one laundry in this group using 22.8% of the total water use by Laundries in 2011. The time series of annual water use of this laundry is shown in Figure 5.16 along with the quarterly percentages in each year. This figure shows that there is an increasing trend in water use for this laundry. From the figure, it is also apparent that the quarterly percentage of the annual water use is similar over the years.

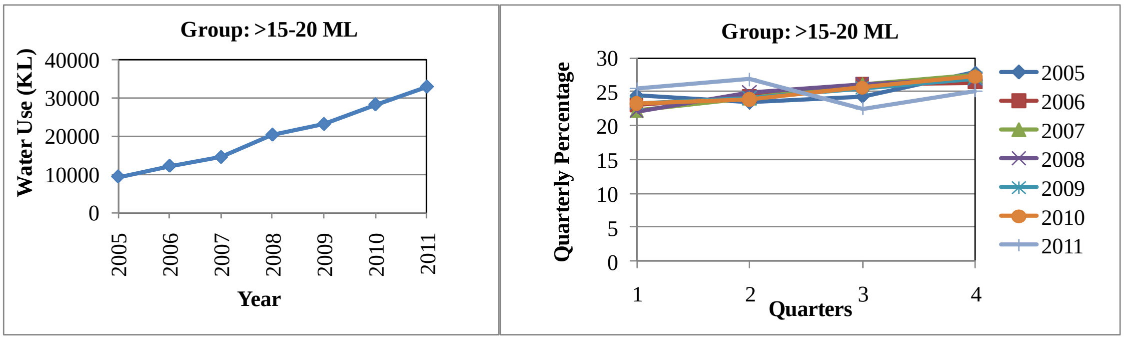


Figure 5.16 Water use pattern of >15-20 ML Laundries group

b. *Group: 5-10 ML*

There are two laundries within this group using 9.2% of the total water use by Laundries in 2011 in the YVW service area. Time series of the annual water use of these two laundries and the quarterly percentages of annual water uses are shown in Figure 5.17. It can be seen from this figure that the annual water use in Laundry 1 since 2007 is almost similar. In case of Laundry 2, it was found that the water use varies over the years. From Figure 5.17, it is also apparent that the quarterly percentages of water use in both laundries were consistent over the years except for 2011 in Laundry 2.

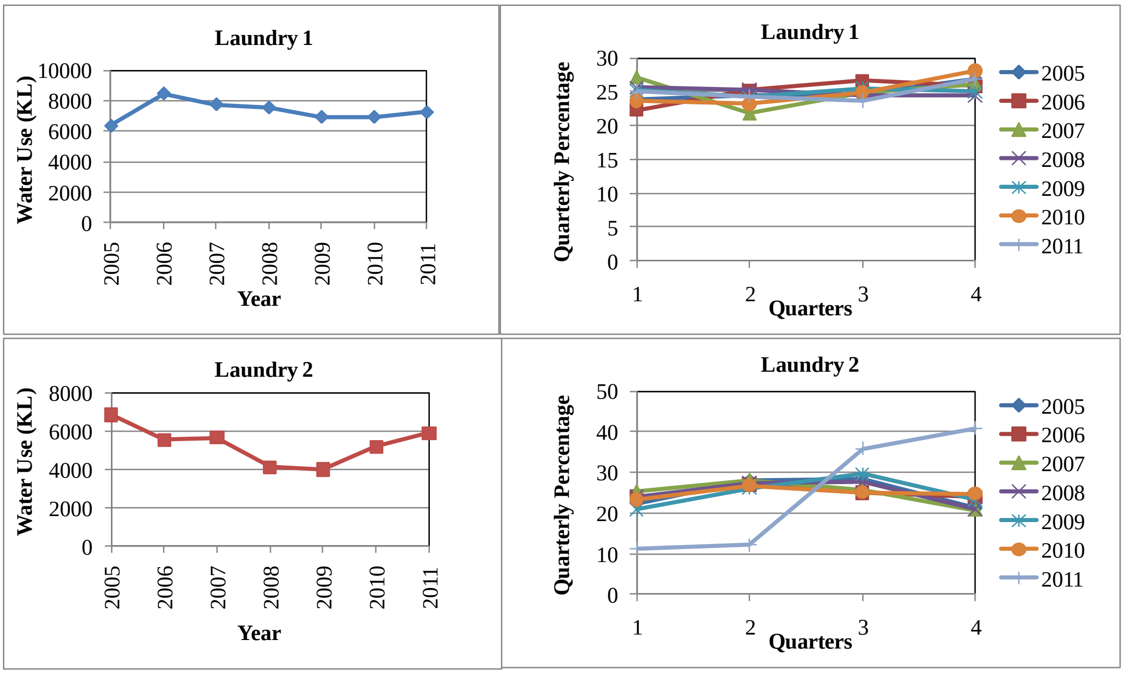


Figure 5.17 Water use pattern of 5-10 ML Laundries group

c. *Group: <5 ML*

Most of the laundries (about 124 out of 127) within study area fall into this group covering 68% of the total water use by the Laundries. Therefore, all these laundries were disaggregated into smaller subgroups based on the annual water use in 2005-2009. These subgroups with their water use percentages and the number of laundries in each subgroup are presented in Table 5.34. The time series of the annual water use and the average percentage of quarterly water use in each year for each subgroup are shown in Figure 5.18. It should be noted that the black bold line in the annual water use time series shows the average water use by the subgroup.

Table 5.34 Water use percentage among Laundries subgroups in group <5 ML

Subgroup	**Number of Laundries**	**Water use (%) in Laundries group**
>4-<5 ML	2	5.0
>3-4 ML	3	8.8
>2-3 ML	6	7.9
1-2 ML	24	21.2
<1 ML	89	25.1
Total	124	68

From the annual water use plot in Figure 5.18, it was found that water use among the laundries within this group are similar over the years except for few laundries in >2-3 ML subgroup. It should be noted that those laundries were not included in average water use data analysis and forecasting. From Figure 5.18, it can be seen that the average annual water use was moderately variable in >4-<5 ML subgroup and in >3-4 ML subgroup, there was an increasing trend until 2009 before decreased in 2010. However, the average annual water use was constant over the years (2005-2010) for rest of the subgroups in this group. The average quarterly percentages over the different years was similar among the subgroups (Figure 5.18) except in 2006 for >4-<5 ML subgroup.

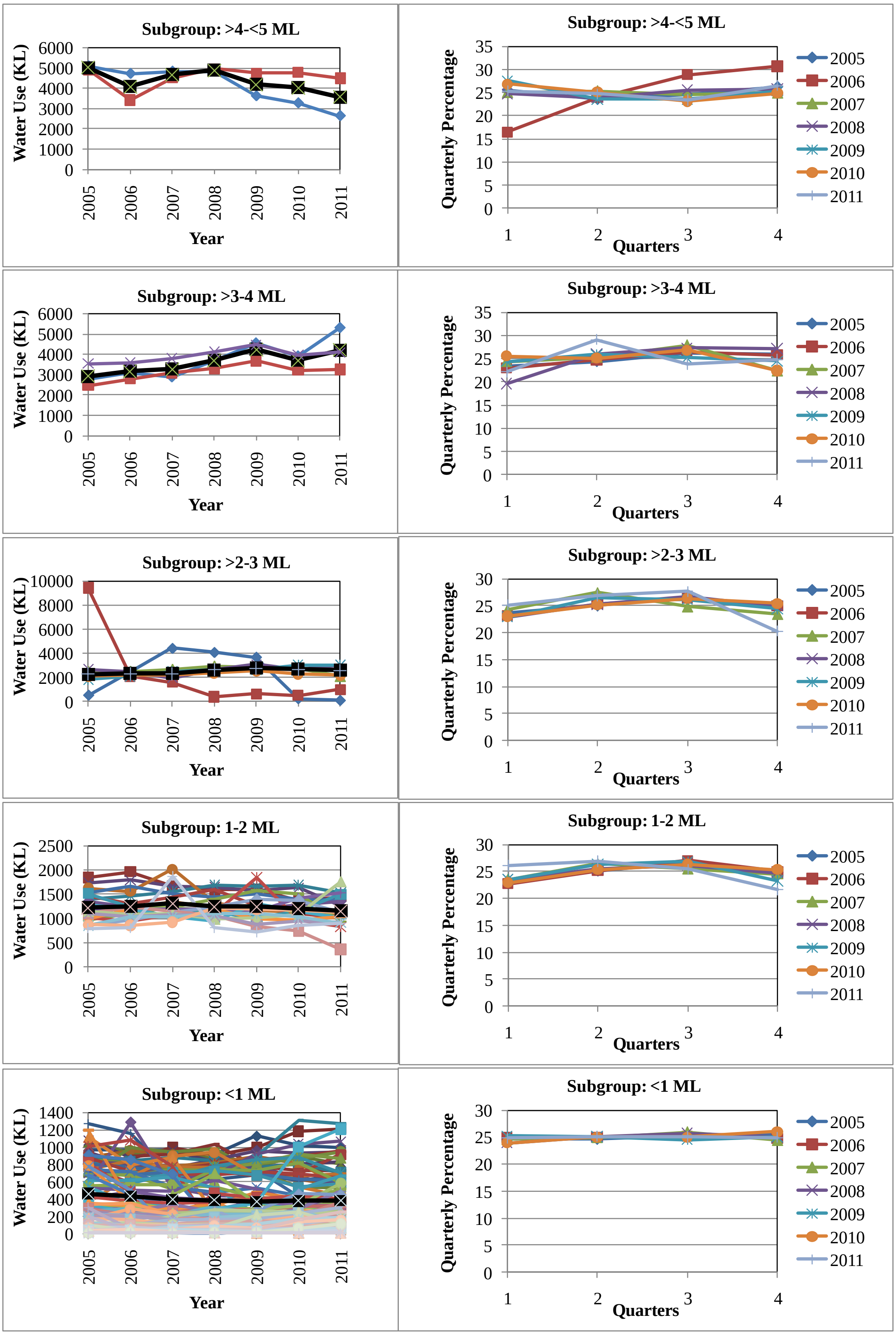


Figure 5.18 Water use pattern of <5 ML Laundries group

d. *Summary of Data Analysis*

A summary of above water use data analysis is presented in Table 5.35; based on this analysis, different modelling approaches were considered for forecasting annual water use for the different groups which are also presented in this table. From the table, it can be seen that the most of the Laundries groups follow the similar annual water use pattern over the different years. Therefore, average annual water use over the 2008-2010 periods were considered to get the forecast annual water use in 2011 in these groups. However, it was found that the quarterly water use percentages in most of the subgroups were consistent over the years. Therefore, the disaggregating factors were considered as the average over the period of 2005-2010 excluding the exception years.

Table 5.35 Summary of water use data analysis and selection of modelling approaches for Laundries group

Group	**Subgroups**	**Number of laundries**	**Modelled by**	**Variation of annual water use**	**Variation of quarterly water use percentages**	**Approach used for annual water use forecast in 2011**	**Approached used for disaggregating factors (quarterly percentages**
>20 ML	-	-	-	-	-	-	
>15-20 ML	-	1	Individual	Increased each year	Similar over the years	A linear regression model developed	Average of 2005-2010
>10-15 ML	-	-	-	-	-	-	
5-10 ML	-	2	Individual (Laundry 1)	Constant after 2007	Similar over the years	Average annual water use in 2008-2010	Average of 2005-2010
			Individual (Laundry 2)	Moderately variable	Similar over the years	Annual water use in 2010	Average of 2005-2010
<5 ML	>4-<5 ML	2	Group	Moderately variable	Similar over the years except in 2006	Average annual water use in 2010	Average of 2005-2010 excluding 2006
	>3-4 ML	3	Group	Moderately variable	Similar over the years	Average annual water use in 2010	Average of 2005-2010
	>2-3 ML	6	Group	Constant over years	Similar over the years	Average annual water use in 2008-2010	Average of 2005-2010
	1-2 ML	24	Group	Constant over years	Similar over the years	Average annual water use in 2008-2010	Average of 2005-2010
	<1 ML	89	Group	Constant over years	Similar over the years	Average annual water use in 2008-2010	Average of 2005-2010

5.3.4.2. Forecasting Water Use Model Development

Since the findings from the data analysis for the Laundries group (Section 5.3.4.1) were similar to those of the Restaurants, Hospitals and Hotels group (Sections 5.3.1.1, 5.3.2.1 and 5.3.3.1), model development procedure for Laundries group is also the same as those of the Restaurants, Hotels and Hospitals group (Sections 5.3.1.2, 5.3.2.2 and 5.3.3.2).

a. Group: >15-20 ML

An analysis of the annual water use over 2005-2010 shows that there is an increasing trend in the annual water use time series, as can be seen from Figure 5.19. Therefore, as listed in Table 5.35, a linear regression model was developed to forecast the annual water use in 2011 considering the past trend. The regression equation is:

$$\text{Annual water use} = 3793x + 4624.5 \qquad (5.1)$$

Where, x = 1, 2, 3, …. (2005=1; 2006= 2; ….. and 2011= 7)

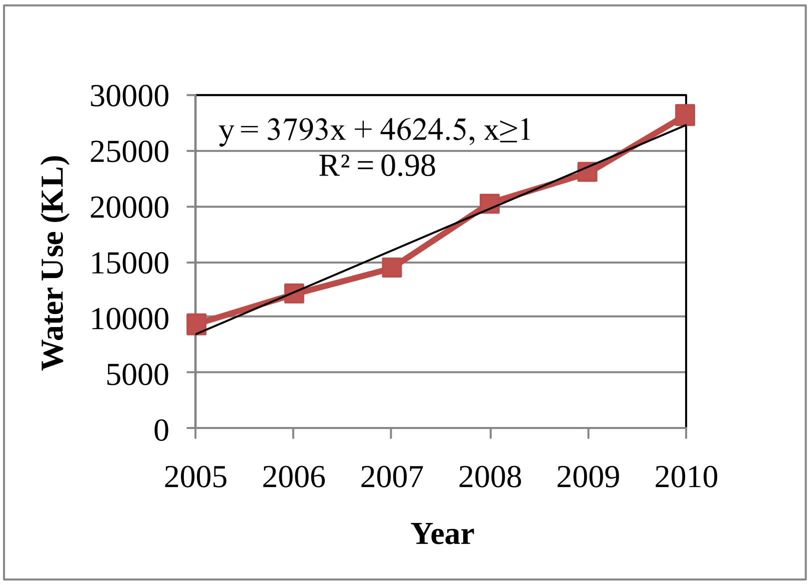


Figure 5.19 Annual water use in >15-20 ML Laundries group

The quarterly water use disaggregating factors were obtained from the average of quarterly percentages over the past years which are presented in Table 5.36. The forecast annual water use obtained for 2011 was then disaggregated into quarterly water use using the disaggregating factors. The annual and quarterly observed and forecast water uses in 2011 are presented in Table 5.37. The *E* value obtained from the comparison of forecast and observed quarterly water use in 2011 is also presented in Table 5.37 shows that model performed well for this Laundry.

Table 5.36 Quarterly disaggregating factors in >15-20 ML Laundries group

Group	**Disaggregating factors for quarters**			
	Quarter 1	**Quarter 2**	**Quarter 3**	**Quarter 4**
Laundry	23	24	26	27

Table 5.37 Comparison of observed and forecast water use of >15-20 ML Laundries group in 2011

Laundries Group		**Annual water use in 2011 (KL)**	**Water use in each quarter in 2011 (KL)**				***E* value**
			1	**2**	**3**	**4**	
>20 ML	Observed	32,813	8,352	8,809	7,404	8,247	0.94
	Forecasted	31,176	7,170	7,482	8,106	8,417	

b. Group: 5-10 ML

As listed in Table 5.35, the forecast annual water use in 2011 for Laundry 1 was considered as the average annual water use in 2008-2010 and for Laundry 2 it was considered as the annual water use in 2010. The disaggregating factors for both these laundries were obtained from the average of quarterly percentages over the years (2005-2010).These disaggregating factors are presented in Table 5.38. Finally, the forecast annual water uses were disaggregated into quarterly water use for these laundries, using the forecast annual water use in 2011 and the disaggregating factors.

These forecast annual and quarterly water use in 2011 are presented in Table 5.39 with the observed value in 2011 for the laundries in this group. The *E* values obtained from the comparison of observed and forecast quarterly water use in 2011 in both laundries are also presented in Table 5.39. It can be seen from the table that model performed well in case of Laundry 1 and poor performance was found in Laundry 2. The negative *E* value could be due to change in quarterly water use in quarter 1 and 2. However, as there are limited information available in this research, future field survey could be useful for better forecast.

Table 5.38 Quarterly disaggregating factors in 5-10 ML Laundries group

Group	**Disaggregating factors for quarters**			
	Quarter 1	**Quarter 2**	**Quarter 3**	**Quarter 4**
Laundry 1	24.5	24.5	25.5	26
Laundry 2	23.5	27	27	22.5

Table 5.39 Comparison of observed and forecast water use of 5-10 ML Laundries in 2011

5-10 ML Laundries Group		**Annual water use in 2011 (KL)**	**Water use in each quarter in 2011 (KL)**				***E* value**
			1	**2**	**3**	**4**	
Laundry 1	Observed	7,241	1,819	1,764	1,715	1,943	0.54
	Forecasted	7,171	1,748	1,748	1,819	1,855	
Laundry 2	Observed	5,930	661	716	2,124	2,428	-0.1
	Forecasted	5,207	1,224	1,406	1,406	1,172	

c. Group: <5 ML

As listed in Table 5.35, the average annual water use by the subgroup from 2008-2010 were considered as the average annual forecast water use in 2011 for >2-3 ML, 1-2 ML and <1ML subgroups. In case of >4-5 ML and >3-4 ML subgroups, average annual water use in 2010 were considered as the forecast average annual water use in 2011. The quarterly water use disaggregating factors were obtained for each subgroup from the average quarterly percentages excluding for the years mentioned in Table 5.35. These factors are presented in Table 5.40. Thereafter, quarterly average water uses in 2011 were forecasted using the average annual forecast water use in 2011 and the disaggregating factors. These observed and forecast average quarterly and annual water use in 2011 for all the subgroups are presented in Table 5.41. The *E* value obtained from the comparison of observed and forecast quarterly water use in 2011 is also presented in the Table 5.41. From this table, it can be seen that models for all subgroups are performed well with good *E* values.

Table 5.40 Quarterly disaggregating factors of subgroups in <5 ML Laundries

Group	**Disaggregating factors for quarters**			
	Quarter 1	**Quarter 2**	**Quarter 3**	**Quarter 4**
Subgroup: >4-<5 ML	26	24	24.5	25.5
Subgroup: >3-4 ML	23.5	25	26.5	25
Subgroup: >2-3 ML	23.5	26	26	24.5
Subgroup: 1-2 ML	23.5	26	26	24.5
Subgroup: <1 ML	24.5	25	25	25.5

Table 5.41 Comparison of observed and forecast water use of <5 ML Laundries group in 2011

<5 ML Hotels Subgroups		**Annual water use in 2011 (KL)**	**Water use in each quarter in 2011 (KL)**				***E* value**
			1	**2**	**3**	**4**	
>4-<5 ML	Observed	3,563	903	882	833	946	0.34
	Forecasted	4,362	1,134	1,047	1,069	1,112	
>3-4 ML	Observed	4,218	934	1,229	1,007	1,048	0.58
	Forecasted	3,880	912	970	1,028	970	
>2-3 ML	Observed	2,578	649	694	712	523	0.18
	Forecasted	2,693	633	700	700	660	
1-2 ML	Observed	1,149	300	309	292	248	0.16
	Forecasted	1,226	288	319	319	300	
<1 ML	Observed	383	95	96	96	96	0.94
	Forecasted	380	93	95	95	97	

5.4. Issues and Challenges faced and Limitations of the Study

Water use in restaurants, hospitals, hotels and laundries can vary due to many different factors such as size of the establishment, number of employees, number of beds in hospitals, outdoor gardening, etc. Unfortunately, all this information was not available for this research. If this information was available, they could have been used in modelling water use. Therefore, a different approach was considered in this study by disaggregating the water customer groups (i.e. Restaurants, Hospitals, Hotels and Laundries) into various groups based on the magnitude of the historical annual water use and analysing the water use pattern of these groups, which was used to get the water use forecast for one year ahead. Moreover, as most of the water uses in these groups are for indoor purposes, it was considered that all these factors were same and will be same in near future. However, there are some abrupt changes in water use volume have found in some cases where reasons for these changes were unknown mainly because of lack of data, and lack of access to discuss these issues with the water customers due to confidentiality issues. In addition, there were other issues and limitations specific to the individual group which are discussed below.

5.4.1. Restaurants

Water use in restaurants can vary due to

1) Different types of restaurants have different water use patterns. For example, the Asian style restaurants are unique in their water use patterns. Due to traditional food preparation and cooking practices, the Asian restaurants typically use 2 to 4 times higher volume of water compared to the other types of restaurants (Yarra Valley Water, 2016);

2) The largest use of water in restaurants is associated with equipment and processes that take place in the kitchen. Change in appliances lead to different water use patterns. For example a Boston University cafeteria successfully reduced its water use by 63 percent after upgrading the kitchen with high-efficiency pre-rinse spray valves (US EPA, 2012);

3) Intensity of the activities in the restaurants leads to different water use patterns. For example, different restaurants have different number of days (e.g. seven days, five days, etc.) and hours (e.g. only open for lunch or dinner time or both) open for business. More open hours and days will lead to higher volume of water use.

Data for none of the above factors were available for this research. Therefore, it is recommended that a field survey to get all the above details information will be useful for better water use forecast.

5.4.2. Hospitals

Hospitals have a number of unique water-use activities, which include vacuum systems, medical air and compressor equipment, sterilizers and central sterile operations, water-cooled laboratory and therapeutic equipment, laboratory hood scrubbers, X-ray equipment and film developers, water-treatment systems for kidney dialysis and laboratory water, therapeutic baths and treatments (East Bay Municipal Utility District, 2008). Different types of system available in the hospital can lead to variation in water use pattern.

Water use pattern in a hospital could also be affected by various other factors: 1) Hospitals type: women, public, children, cardiologic, dental, eyes and ears and so on, 2) number of beds and number of employees, 3) efficiency of water use and outdoor water use for gardening, 4) Different activities (classes on medical study can take place in the hospital), and 5) facility of onsite laundry and size of the cafe, onsite pathology, accommodation and so on. Total water use by hospitals can also vary from one year to the subsequent years due to different extension or renovation of the hospitals. Data for none of these factors were available for this research. Therefore, the forecast water use model development for hospitals can be improved by conducting field surveys for collecting above the listed information and to identify their future plan for change in systems in the hospitals that can influence the water use.

5.4.3. Hotels

The water use in hotels can vary greatly not only between regions, but also within a region. Factors influencing the hotel water use can be classified into physical and operational parameters (Bohdanowicz and Martinac, 2007). The physical parameters include size, structure and design of the hotel building (high rise, resort style), geographical and climatic location (urban-rural), age of the facility, type of water systems installed (recycle water to flush toilet and urinals, efficient and low flow shower head), operation and maintenance schemes, types and amounts of water resources available locally, as well as water-use regulations and cost.

The operational features that influence water use in hotels include the service affected by different sub-facilities including catering outlets, laundries, swimming pools and spas, recreational and business centres, fluctuations in occupancy levels, and variations in customer preferences relevant to indoor comfort (e.g. campside, 1-5-star hotel), as well as culture and awareness of water resource consumption (Gossling et al, 2011). Laundry volumes per guest per day in sports and health centres in hotels, as well as affected by textile quality and/or weight of laundry items, including very large towels for spa facilities or beach use results in high water use hotels.

All these information was not available for this research. Moreover, some of these factors, such as the level of environmental awareness of users are difficult to quantify or evaluate as they are mostly qualitative in character. Therefore, significant variations in facility type within the hotel sector make it difficult to provide a general model explaining the water use of these individual facilities. However, as most of the water uses in hotels are for indoor purposes, only historical water use were used for modelling water use in hotels in this research assuming that facility were same and will be same in near future. It was found that high water using hotel’s water uses are very different from year to year. Therefore, to improve water use forecast, a field survey is essential to the high using hotel for collecting the above stated information and their future plan which can affect water use.

5.4.4. Laundries

Water use by the Laundries sector can vary depending on: the types of laundries (e.g. commercial laundries, coin laundries), number of customer using the laundry, types of customers (e.g. hospital, hotel, and restaurants), different types of technologies (continuous-batch washing machines, extractor washing machines) used in laundries etc. Difficulty in accessing these information, limits the water use modelling for laundries in this research to explain the water use variation precisely.

5.5. Summary

Water use modelling was performed to forecast water use one year ahead on a quarterly basis for Restaurants, Hospitals, Hotels and Laundries groups using only the historical water use data, as data for influencing factors in these water use customer groups were not available for the study. Example of such influencing factors include are opening hours for restaurants, number of beds in hospitals, number of rooms in hotels, and number of customers and frequency of use in laundries. Moreover, in general there is no sufficient seasonal variation in water use among these groups as most of the water uses among these groups are for indoor purposes.

All customers in the above four water use customer groups were disaggregated into different subgroups based on the magnitude of the average annual water use. Data analysis was then performed for annual and quarterly water use at disaggregated group levels to identify the water use pattern which were later used for forecast water use model development.

Three different patterns were identified in the annual water use analysis among the disaggregated groups in these four customer groups. They are:

1) The annual water uses were variable over the period (2005-2010).

2) The annual water uses were constant over the period (2005-2010) or over very recent period (2008-2010). and

3) The annual water use followed an increasing or decreasing trend over the period (2005-2010).

Therefore, annual water uses in 2011 were forecasted differently for these three types of customer. In case of type 1, annual water use in 2010; in type 2, average annual water use in 2008-2010 and in type 3, annual water use from the linear regression were considered as the forecast annual water use in 2011. The quarterly forecast water uses were then obtained from the forecast annual water use in 2011 and the disaggregating factors. These disaggregating factors were obtained from the quarterly percentage water use over years (2005-2010). In most of the cases, the quarterly percentage water uses were consistent over the years. Therefore, average quarterly percentage water uses over years (2005-2010) were considered as disaggregating factors to disaggregate the annual forecast to quarterly forecast excluding the exceptional years. Model performances were then measured with the Nash-Sutcliffe model efficiency (*E*). Most of the developed models in this study performed well with good *E* value. There are few cases, models performed poorly and therefore, identified issues, Challenges and limitation of the modelling in this research were presented at the end of the Chapter.

Chapter 6. Water Use Modelling for High Water Users

6.1. Overview

There were thirty-five customers (among the 28,000) use a large portion of the total non-residential water in the Yarra Valley Water (YVW) service area; these non-residential customers were named as High Water Users (HWU) and were considered as a separate group in this research. The customers in this group use around 7,740 ML/year, which is about 33.8% of the average non-residential water use (based on 2005-2009) in a year in the YVW service area. Individually, the annual water use by these HWU customers is >50 ML as per data received for this research and communication with the YVW officers. As the customers in the HWU group use a large volume of water, water use among the customers are analysed and modelled separately in this study. All customers in this group were divided into subgroups based on their different activities such as Manufacturing Companies, Packaging Companies, Shopping Centres, Hospitals, Laundries, Confectionary Factories, Universities, Motor Companies, Poultry Factories and Institutions. This approach of customer grouping and modelling their water demand is useful to the water authority for better water management such as water supply system development, expansion and maintenance, and establishment of water rate. It should be noted that the hospitals and laundries considered in this chapter were not included in Chapter 5, as they use more than 50 ML/year individually.

There are many factors affecting the water use among the above subgroups such as number of users of Shopping Centres, student numbers in Universities, number of beds in Hospitals, and demand for the products in Manufacturing Companies and Confectionary Factories (Dziegielewski, *et al*, 2000). Moreover, after having discussions with the YVW officers, it was found that the driving factors for some of these customers such as Manufacturing Companies and Confectionary Factories are the demand for their goods in foreign countries. However, data for all these influencing factors were not available for this research. It was also noted that most of the water uses of these customers are for indoor purposes, which are not generally affected by climatic factors and water restrictions. Therefore, only the water use data were used for analysis and modelling in this research, and presented in this chapter.

As mentioned in Chapter 1, short term water demand modelling (1 year) was carried out using quarterly time steps in this research. To forecast the future water use, the past water use was analysed first using the quarterly water use data from 2005 to 2010. In this analysis, it was found that the annual water use pattern varies differently over the period among the customers. All the annual water use pattern were categorised into following four types in this study:

Type 1. the annual water use is highly variable over the period,

Type 2. the annual water use is moderately varied (i.e. less varied compared to type 1) over the period,

Type 3. moderately varied over the period and it was fairly constant in 2008-2010, and

Type 4. water use followed an increasing or decreasing trend.

Thereafter, the annual water use in 2011 for the customers in these four categories was forecasted differently. In the case of type 1 and type 2, annual water use in 2011 was considered as the total water use in 2010 assuming that the most recent condition will continue in near future as the driving factors for the past annual water use variation were unknown in this study. For the same reason, annual water use before 2008 were not considered in type 3. In this case, annual water use in 2011 was considered as the average annual water use in 2008-2010. In the case of type 4, water use in 2011 was forecasted using the regression analysis of past annual water use over the period (2005-2010).

From data analysis, it was found that the quarterly percentages of annual water use were consistent for most of the customers over the period of 2005-2010. Therefore, the quarterly disaggregating factors of annual water use were obtained from the average quarterly water use percentages over the past years (2005-2010). It should be noted that the quarters are named as Quarter 1 (January – March), Quarter 2 (April – June), Quarter 3 (July – September) and Quarter 4 (October – December) in this chapter as was done in Chapter 4 and 5. The forecasted annual water use for 2011 was then disaggregated to quarterly water use using the disaggregating factors. Finally, the forecast quarterly water uses were compared with the observed quarterly water use in 2011 and the model performance was measured using the Nash-Sutcliffe efficiency (*E*).

This chapter first describes the historical water use data and the classification of the HWU into different subgroups based on their activities. Water use data analysis and models developed for individual customers in each subgroup are then presented. Thereafter, the limitations of the present work are discussed along with the application of this study. Finally, a summary of the chapter is presented.

6.2. Historical Water Use and Subgroups of HWU

The annual water use variation in HWU group over the study period (2005-2011) is shown in Figure 6.1. From Figure 6.1, it can be seen that the water use has been reduced from around 8,000 ML/year in 2006 to 6,000 ML/year in 2011. This is a huge reduction in water use by only 35 water customers. As was discussed in Chapter 3 (Section 3.4), the possible reason for this reduction could be due to several factors such as the use of alternate water sources, adapting dry process, reuse water in the system and the use of water efficient appliances as part of the water savings measures (Yarra Valley Water, 2008).

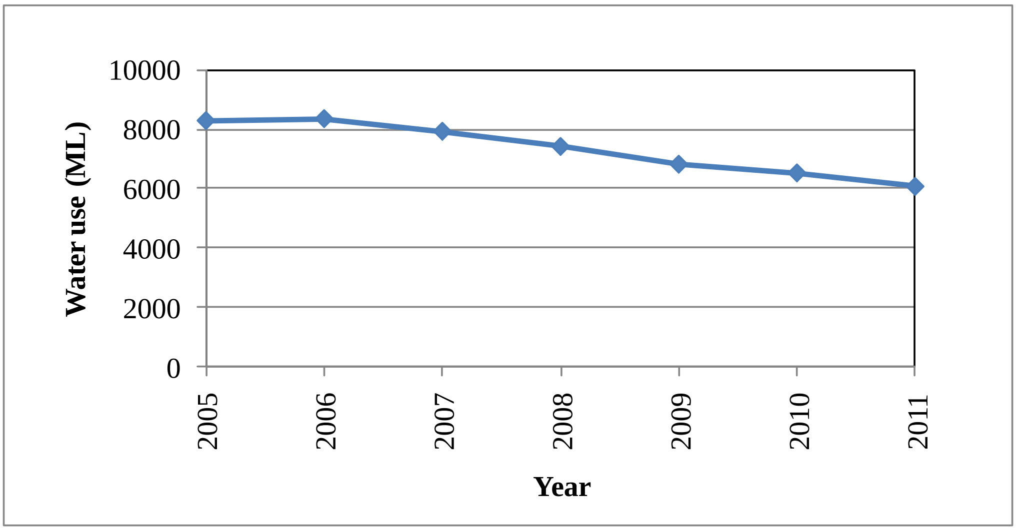


Figure 6.1 Annual water use of HWU group over the study period

All customers in the HWU group were classified into different subgroups based on their activities to analyse the water use pattern and to develop the water use models individually for each customer in these subgroups. These subgroups are shown in Table 6.1 with the number of customers. The percentage of the average annual water use based on 2011 annual water uses by different subgroups are shown Figure 6.2. From this figure, it can be seen that around 44% of the total water use of HWU group were from the manufacturing companies subgroup, followed by the packaging companies.

The annual water uses time series of HWU subgroups are shown in Figure 6.3. From this figure, it is clear that the water use in manufacturing companies, packaging companies and shopping centres gradually reduced over the years since 2007. Moreover, it can also be seen that the water uses among the remaining high user subgroups are fairly constant since 2007.

Table 6.1 HWU Subgroups

Subgroups	**Number of Customers**
Manufacturing Companies	9
Packaging Companies	4
Shopping Centres	5
Hospitals	4
Laundries	3
Confectionary Factories	3
Universities	4
Motor Companies	1
Poultry Factories	1
Institutions	1
Total	**35**

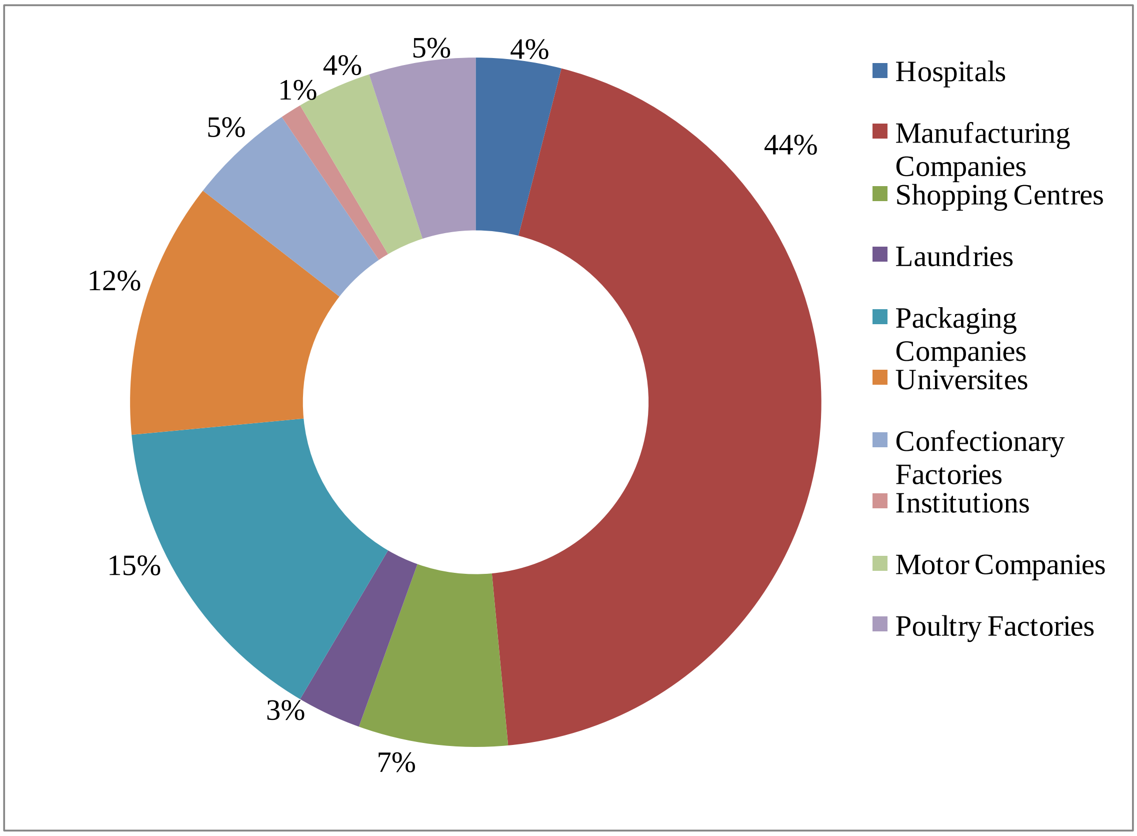


Figure 6.2 Water use percentages by different homogenous HWU subgroups in 2011

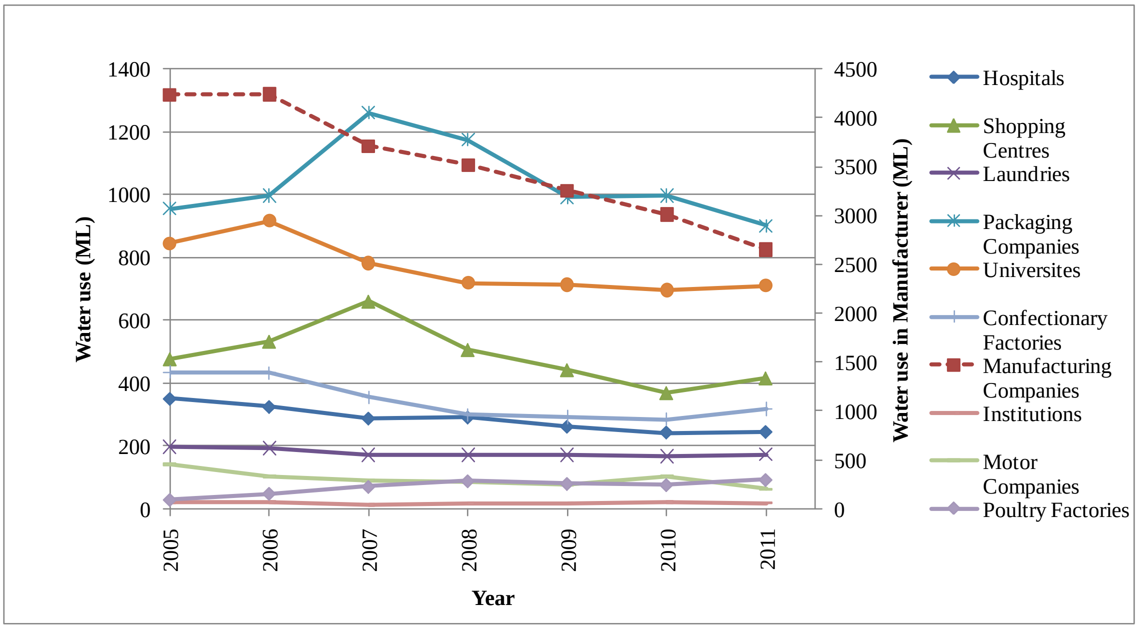


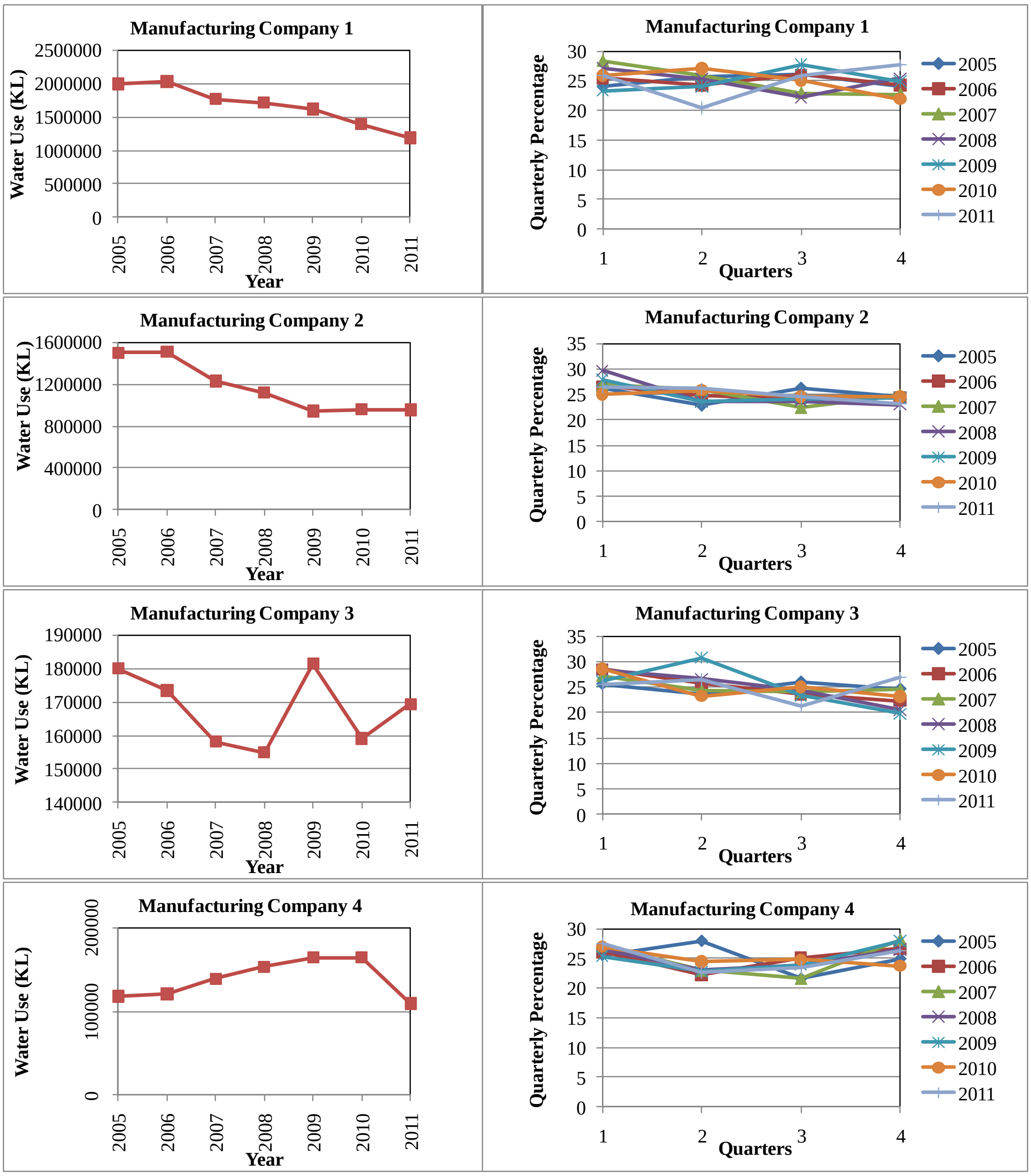
Figure 6.3 Water use time-series by different homogenous HWU subgroups

6.3. Data Analysis and Model Development for Forecast Water use

Many factors affect the water use among the HWU subgroups as discussed in Section 6.1. However, data for those factors were not available for this research due to customers privacy and most of the water uses among the customers are for indoor purposes. Therefore, only water use data for the HWU group customers, which are available, were analysed to develop models for forecasting water use. As outlined in Chapter 4 (in Section 4.4.3), water use data in 2005-2010 were used to determine the forecast annual water use in 2011 and the quarterly disaggregating factors were then used to disaggregate the forecast annual water use (to forecast quarterly water use). The model performance was measured with the Nash-Sutcliffe Efficiency (E). The details of this efficiency criterion can be found in Chapter 4 (Section 4.3.4). Further details on the water use data analysis and model development for each of the HWU subgroups are discussed in the following sub-sections.

6.3.1. Manufacturing Companies

There are nine manufacturing companies in this subgroup. The total water use by these companies is about 44% of total water use of HWU group. The annual water use time series for each manufacturing company are presented in Figure 6.4 along with their quarterly percentage of annual water use over the period of 2005-2010.



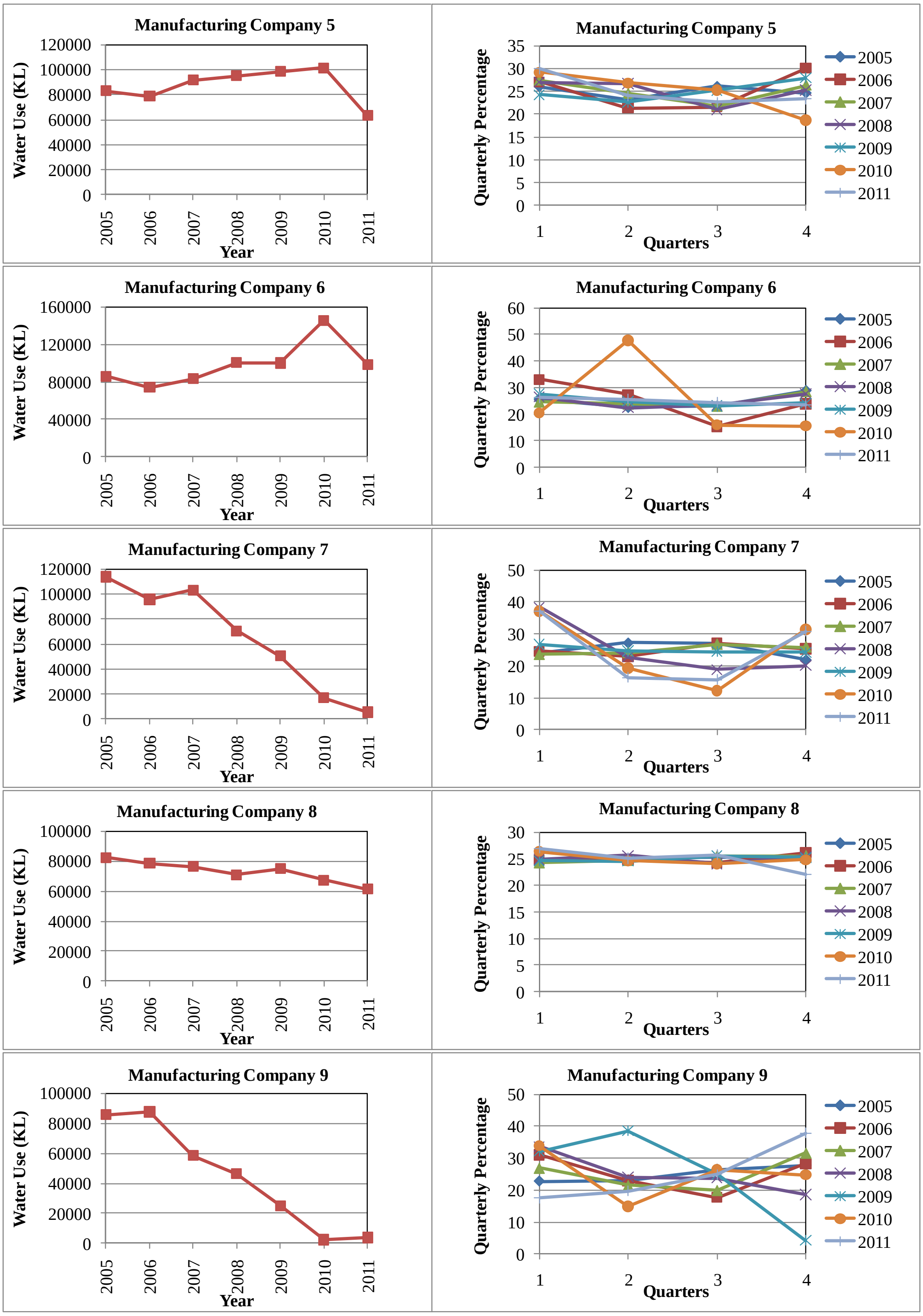


Figure 6.4 Water use pattern of Manufacturing Companies subgroup

From Figure 6.4, it is seen that the annual water uses among the manufacturing companies are not consistent over the years (2005-2010). The annual water use moderately varied in Manufacturing Companies 1, 2, 4, 5 and 8. However, it is also can be seen that there were a decreasing pattern in Manufacturing Companies 1 and 2, and an increasing pattern in Manufacturing Companies 4 and 5. The annual water use of 2008-2010 in Manufacturing Company 8 were fairly constant. In case of Manufacturing Company 3 and 6, annual water use highly varied over the period (2005-2010). It can also be seen from the Figure 6.4 that there is a significant decreasing trend in annual water use of Manufacturing Company 7 and 9 where annual water use reduced to less than 5,000 KL/year from about 100,000 KL/year. However, there was not enough information available in this study to investigate this significant reduction in annual water use.

Therefore, based on this data analysis, regression models were considered to forecast annual water use in 2011 for Manufacturing Companies 1, 2, 4, 5, 7 and 9 as decreasing/increasing trend were identified in their annual water use time series (Figure 6.4). For Manufacturing Companies 3 and 6, the total water uses in 2010 were considered as the forecast annual water uses in 2011. In case of Manufacturing Companies 8, average annual water use of 2008-2010 was considered as forecast annual water use in 2011.

The quarterly water use percentages in Figure 6.4 shows that they were not consistent over the period of 2005-2010 for the Manufacturing Companies 7 and 9. However, they were quite similar for different years in other Manufacturing companies except in Manufacturing Company 6 in 2010. Based on these quarterly water use patterns, the disaggregating factors were obtained for all manufacturing companies (except 7 and 9) from the average quarterly percentages over the different years (2005-2010) excluding the percentages of 2010 for Manufacturing Company 6. For Manufacturing Companies 7 and 9, the quarterly percentages of 2010 were considered as the disaggregating factors. These disaggregating factors were used to disaggregate the forecast annual water use into the quarterly water use in 2011.

A summary of above water use data analysis and modelling approach considered for the different manufacturing companies are presented in Table 6.2. The disaggregating factors obtained using the abovementioned procedures are presented in Table 6.3 for each of the manufacturing companies.

Table 6.2 Summary of water use data analysis and selection of modelling approach for Manufacturing Companies subgroup

Manufacturing Companies	**Variation of annual water use**	**Variation of quarterly water use percentages**	**Approach used for annual water use forecast in 2011**	**Approach used for disaggregating factors (quarterly percentages)**
Manufacturing Company 1	Moderately varied (decreasing trend)	Similar over the years	Regression analysis	Average over 2005-2010
Manufacturing Company 2	Moderately varied (decreasing trend)	Similar over the years	Regression analysis	Average over 2005-2010
Manufacturing Company 3	Highly variable	Similar over the years	Annual water use in 2010	Average over 2005-2010
Manufacturing Company 4	Moderately varied (increasing trend)	Similar over the years	Regression analysis	Average over 2005-2010
Manufacturing Company 5	Moderately varied (increasing trend)	Similar over the years	Regression analysis	Average over 2005-2010
Manufacturing Company 6	Highly variable	Similar over the years	Annual water use in 2010	Average over 2005-2009
Manufacturing Company 7	Decreased in each year	Highly variable over the years	Regression analysis	Percentages of 2010
Manufacturing Company 8	Moderately varied	Similar over the years	Average annual water use in 2008-	Average over 2005-2010
Manufacturing Company 9	Decreased in each year	Highly variable over the years	Regression analysis	Percentages of 2010

Table 6.3 Disaggregating factors for individual Manufacturing company

Manufacturing Companies	**Disaggregating factors for quarters**			
	1	**2**	**3**	**4**
Manufacturing Company 1	25.5	25.5	25.0	24.0
Manufacturing Company 2	27.0	24.5	24.0	24.5
Manufacturing Company 3	27.5	25.5	24.5	22.5
Manufacturing Company 4	26.0	24.0	23.5	26.5
Manufacturing Company 5	27.0	24.0	23.5	25.5
Manufacturing Company 6	26.0	28.0	21.0	25.0
Manufacturing Company 7	37.0	19.5	12.0	31.5
Manufacturing Company 8	25.0	25.0	24.5	25.5
Manufacturing Company 9	34.0	15.0	26.5	24.5

The annual water use in 2011 was forecasted first with the approaches outlined in Table 6.2 for all the manufacturing companies. In case of linear regression approach, trend lines were obtained from the annual water use time series for those manufacturing companies (shown in Figure 6.5). The resulted linear regression models to forecast the annual water use in 2011 for Manufacturing Companies 1, 2, 4, 5, 7 and 9 are given below:

Annual water use of Manufacturing Company 1 = -122396x + 2000000 (6.1)

Annual water use of Manufacturing Company 2 = -128293x + 2000000 (6.2)

Annual water use of Manufacturing Company 4 = 10714x + 105603 (6.3)

Annual water use of Manufacturing Company 5 = 4390.9x + 75986 (6.4)

Annual water use of Manufacturing Company 7 = -18607x + 140131 (6.5)

Annual water use of Manufacturing Company 9 = -17574x + 112432 (6.6)

Where, x = 1, 2, 3,…. (2005=1; 2006= 2; ….. and 2010= 6)

It should be noted that the forecast obtained from the regression analysis of past annual water use for Manufacturing Company 9 resulted in a negative annual water use for 2011. Therefore, the total water use in 2010 was considered as the forecast annual water use in 2011 for the Manufacturing Company 9.

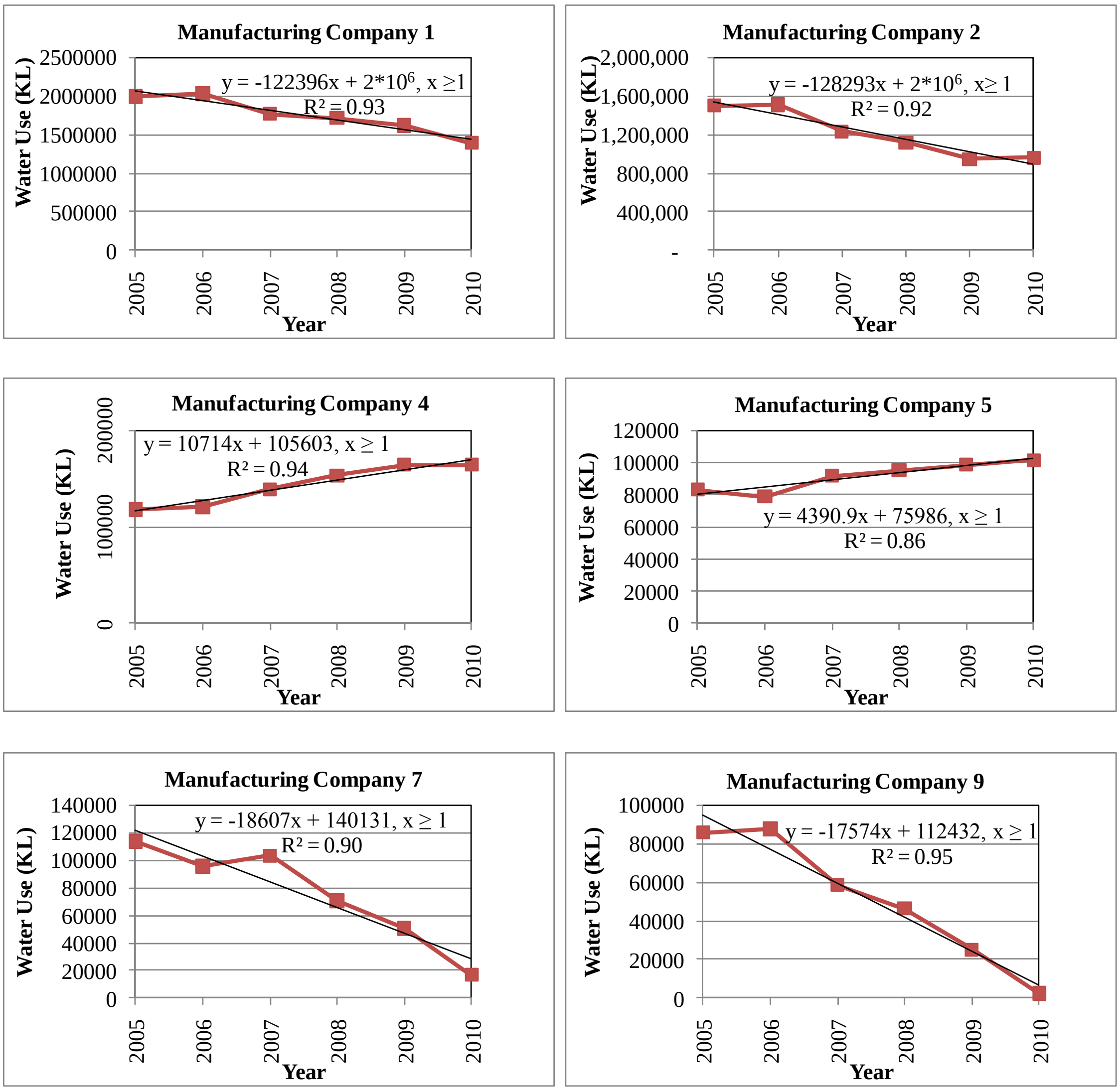


Figure 6.5 Annual water use trend in Manufacturing Companies 1, 2, 4, 5, 7 and 9

The forecast annual water use in 2011 of each manufacturing company was then disaggregated into quarterly water use with the disaggregating factors outlined in Table 6.3. The comparison of observed and forecast water use in 2011 for both annual and quarterly time steps is presented in Table 6.4. The resulted *E* values from the comparison of observed and forecast quarterly water use are also presented in this table. It can be seen from the Table 6.4 that the *E* values were good for Manufacturing Companies 1, 2, 7, 8 and 9. However, in case of other manufacturing companies the *E* values were negative which indicates that the average values would be better predictions than the forecast quarterly water uses. It can be seen from Figure 6.4, the past annual water use pattern changed in 2011 for these manufacturing companies. Therefore, it is recommended that a discussion with the manufacturing companies to know their water use map and plan change ahead will result better water demand forecasting.

Table 6.4 Comparison of observed and modelled water use of Manufacturing Companies subgroup in 2011

Manufacturing Companies		**Annual water use in 2011 (KL)**	**Water use in each quarter in 2011 (KL)**				***E* value**
			1	**2**	**3**	**4**	
Manufacturing Company 1	Observed	1,185,161	307,696	241,995	307,547	327,923	0.93
	Forecasted	1,143,228	291,523	291,523	285,807	274,375	
Manufacturing Company 2	Observed	956,259	251,835	249,662	234,209	220,553	0.64
	Forecasted	1,101,949	297,526	269,978	264,468	269,978	
Manufacturing Company 3	Observed	169,312	43,306	44,715	35,888	45,403	-1.00
	Forecasted	159,089	43,749	40,568	38,977	35,795	
Manufacturing Company 4	Observed	109,425	30,082	24,818	25,691	28,834	-3.20
	Forecasted	180,601	46,956	43,344	42,441	47,859	
Manufacturing Company 5	Observed	63,184	18,942	15,183	14,269	14,790	-1.25
	Forecasted	106,722	28,815	25,613	25,080	27,214	
Manufacturing Company 6	Observed	98,405	25,987	25,332	24,096	22,990	-111.4
	Forecasted	145,494	37,829	40,738	30,554	36,374	
Manufacturing Company 7	Observed	5,628	2,088	919	883	1,738	0.99
	Forecasted	9,882	3,656	1,927	1,186	3,113	
Manufacturing Company 8	Observed	61,220	16,515	15,382	15,762	13,561	0.41
	Forecasted	71,030	17,757	17,757	17,402	18,113	
Manufacturing Company 9	Observed	3,842	674	759	955	1,454	0.99
	Forecasted	2,450	833	367	649	600	

6.3.2. Packaging Companies

There are four packaging companies in this subgroup. The total water use by this subgroup is around 15% of total water use by the HWU group in 2011 in the YVW. The annual water use time-series for each of these companies are presented in Figure 6.6 along with their quarterly percentage of water use over the different years.

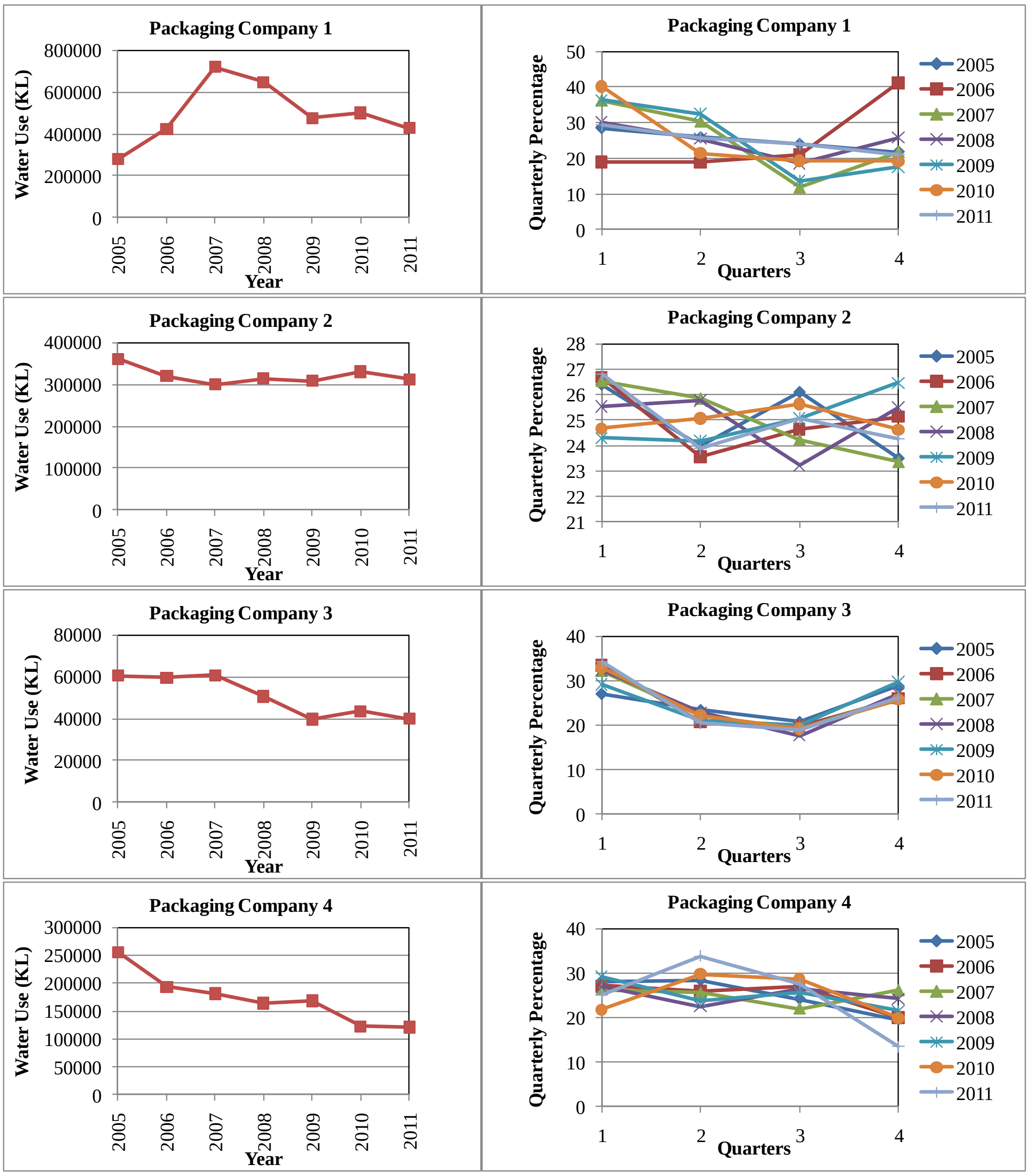


Figure 6.6 Water use pattern of Packaging Companies subgroup

From Figure 6.6, it can be seen that the annual water uses in Packaging Company 1 was highly variable over past years (2005-2010). It can also be seen from the figure that the annual water use of Packaging Company 2 was fairly constant and the annual water use of Packaging Companies 3 and 4 were moderately varied over the same periods. Therefore, it was considered that the total water use in 2010 for Packaging Companies 1, 3 and 4 as the forecast annual water use in 2011 and for Packaging Company 2, the forecast annual water use in 2011 was considered as the average of annual water use in 2008-2010.

From Figure 6.6, it also apparent that quarterly percentages for Packaging Companies 3 and 4 were similar over the years but were not for Packaging Company 1 and 2. Therefore, the disaggregation factors for the Packaging Companies 3 and 4 were obtained from the average value of the quarterly percentages over the years (2005-2010). In case of Packaging Companies 1 and 2, the disaggregation factors were considered as the quarterly percentages in 2010.

A summary of above water use data analysis and the modelling approach considered for the different packaging companies is presented in Table 6.5. The disaggregating factors obtained using the abovementioned procedures are presented in Table 6.6 for each of the packaging companies.

Table 6.5 Summary of water use data analysis and selection of modelling approach for Packaging Companies subgroup

Packaging Companies	**Variation of annual water use**	**Variation of quarterly water use percentages**	**Approach used for annual water use forecast in 2011**	**Approach used for disaggregating factors (quarterly percentages)**
Packaging Company 1	Highly variable	Not consistent over the years	Annual water use in 2010	Same as 2010
Packaging Company 2	Fairly constant	Not consistent over the years	Average annual water use in 2008-2010	Same as 2010
Packaging Company 3	Moderately varied	Similar over the years	Annual water use in 2010	Average over 2005-2010
Packaging Company 4	Moderately varied	Similar over the years	Annual water use in 2010	Average over 2005-2010

Table 6.6 Disaggregating factors for individual Packaging Company subgroup

Packaging Companies	**Disaggregating factors for quarters**			
	1	**2**	**3**	**4**
Packaging Company 1	40.0	21.5	19.5	19.0
Packaging Company 2	25.0	25.0	25.5	24.5
Packaging Company 3	31.0	22.0	19.5	27.5
Packaging Company 4	26.5	26.0	25.5	22.0

The annual water use in 2011 was forecasted first with the approaches outlined in Table 6.5 for all packaging companies. The forecasted annual water use in 2011 was then disaggregated to quarterly water use with the disaggregating factors as outlined in Table 6.6. The observed and modelled water use in 2011 for both annual and quarterly time steps are presented in Table 6.7 with the *E* values from the comparison of observed and forecast quarterly water use. It can be seen from Table 6.7 that the *E* values were good for Packaging Companies 2, 3, and 4. However, in case of Packaging Company 1, the *E* value was negative which indicates that the average values would be better predictions than the forecast quarterly water use. As seen from Figure 6.6, the forecast annual water use in 2011 was very different from the past annual water use.

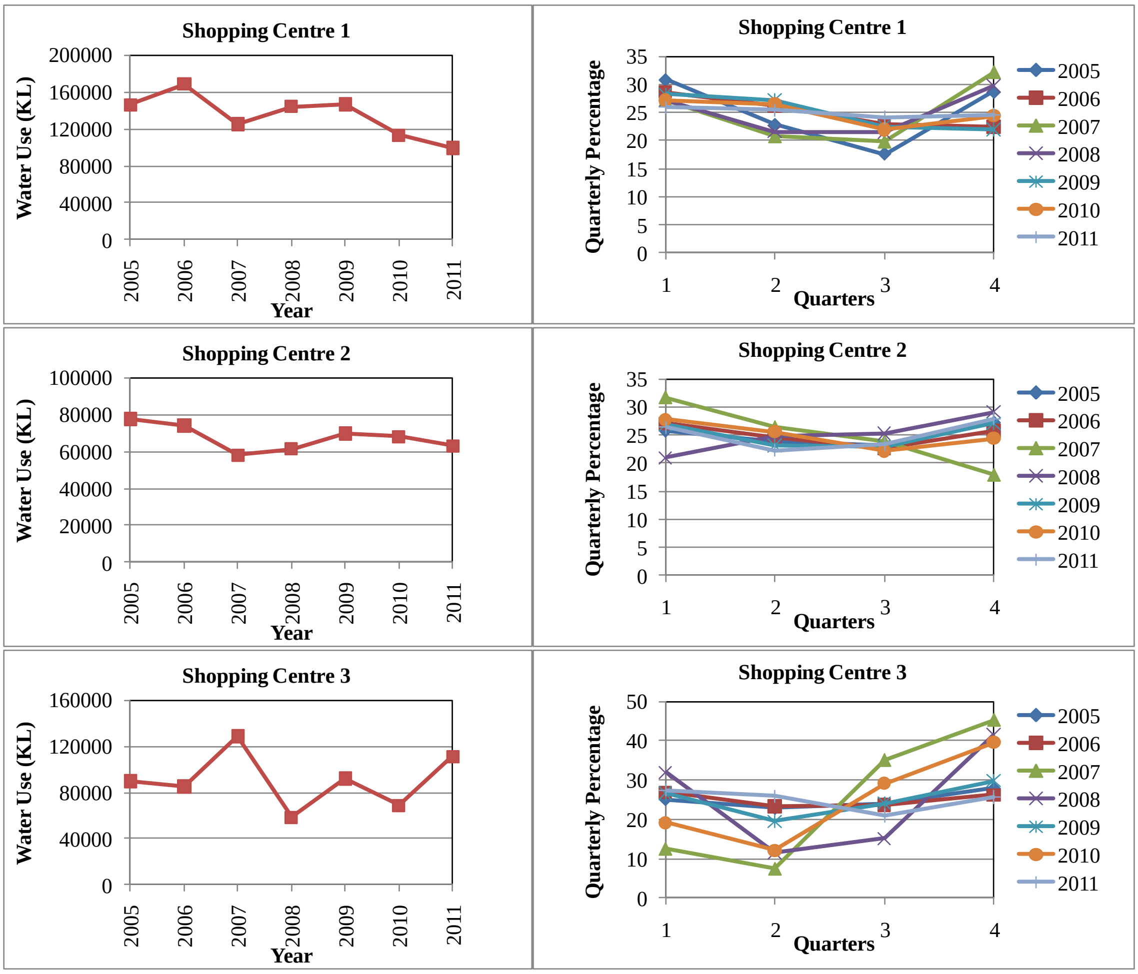
Table 6.7 Comparison of observed and forecast water use of Packaging Companies subgroup in 2011

Packaging companies		**Annual water use in 2011 (KL)**	**Water use in each quarter in 2011 (KL)**				***E* value**
			1	**2**	**3**	**4**	
Packaging company 1	Observed	427,436	125,129	110,344	102,286	89,677	-1.50
	Forecasted	499,461	199,784	107,384	97,395	94,898	
Packaging company 2	Observed	311,616	83,561	74,363	78,119	75,573	0.27
	Forecasted	317,504	79,376	79,376	80,963	77,788	
Packaging company 3	Observed	39,889	13,672	8,199	7,581	10,437	0.91
	Forecasted	43,571	13,507	9,586	8,496	11,982	
Packaging company 4	Observed	121,059	30,462	40,918	33,456	16,223	0.83
	Forecasted	122,566	32,480	31,867	31,254	26,965	

6.3.3. Shopping Centres

There are five shopping centres in this subgroup and the total water use by these shopping centres is about 7% of the total water use by HWU group in the YVW in 2011. The annual water use time-series for all these five shopping centres along with their quarterly water use percentages over the different years are presented in Figure 6.7.

From Figure 6.7, it can be seen that the annual water use of the Shopping Centres 1, 2 and 4 were moderately varied over the years of 2005-2010 and it was constant in 2008-2010 in case of Shopping Centres 2 and 4. However, in case of Shopping Centres 3 and 5, the annual water use was highly variable over the years of 2005-2010. Therefore, the total water uses in 2010 in Shopping Centres 1, 3 and 5 were considered the forecasted annual water use in 2011 and in case of Shopping Centres 2 and 4 the average of annual water use in 2008-2010 were considered as the forecast annual water use in 2011.



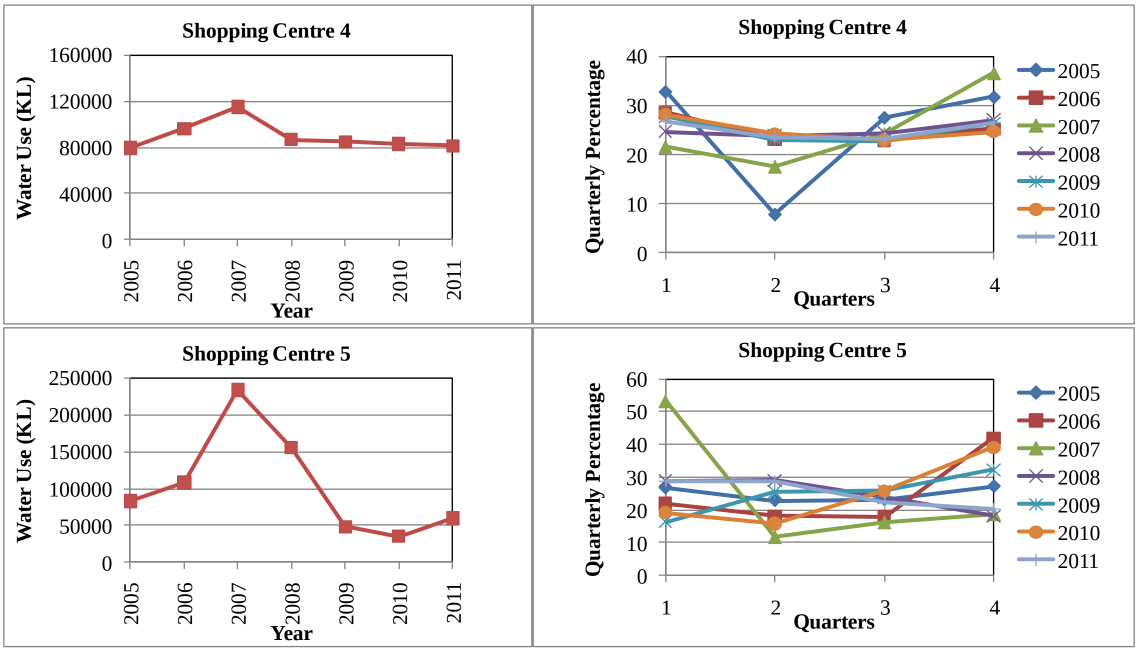


Figure 6.7 Water use pattern of Shopping Centres subgroup

From Figure 6.7, it can be seen that the quarterly water use percentages in Shopping Centres 1 and 2 were consistent over the years and in Shopping Centre 3, the percentages were very different (over the years). In case of Shopping Centres 4 and 5, the quarterly water use percentages were similar over years except those in 2005 and 2007 for Shopping Centre 4, and in 2007 for Shopping Centre 5.

Based on the above data analysis, the quarterly disaggregating factors were obtained differently for each shopping centre is stated below:

- for Shopping Centres 1 and 2, the disaggregating factors were considered as the average of quarterly percentages over the years (2005-2010),
- for Shopping Centre 3, the disaggregating factors were considered same as the quarterly percentages of 2010,
- For Shopping Centres 4 and 5, the disaggregating factors were considered the average of quarterly percentages over the years (2005-2010) excluding the percentages of 2005 and 2007 for Shopping Centre 4 and the percentages of 2007 in Shopping Centre 5.

A summary of the above water use data analysis, and modelling approach considered for the different shopping centres are presented in Table 6.8. The disaggregating factors obtained using the abovementioned procedure are presented in Table 6.9 for each of the shopping centres.

Table 6.8 Summary of water use data analysis and selection of modelling approach for Shopping Centres subgroup

Shopping Centres	**Variation of annual water use**	**Variation of quarterly water use percentages**	**Approach used for annual water use forecast in 2011**	**Approach used for disaggregating factors (quarterly percentages)**
Shopping Centre 1	Moderately varied	Similar over the years	Annual water use in 2010	Average over 2005-2010
Shopping Centre 2	Moderately varied	Similar over the years	Average annual water use in 2008-2010	Average over 2005-2010
Shopping Centre 3	Highly variable	Different over the years	Annual water use in 2010	Same as 2010
Shopping Centre 4	Moderately varied	Similar over the years except in 2005 and 2007	Average annual water use in 2008-2010	Average over 2006-2010 excluding 2007
Shopping Centre 5	Highly variable	Similar over the years except in 2007	Annual water use in 2010	Average over 2005-2010 excluding 2007

Table 6.9 Disaggregating factors for individual Shopping Centre

Shopping Centres	**Disaggregating factors for quarters**			
	1	**2**	**3**	**4**
Shopping Centre 1	28.5	24.0	21.0	26.5
Shopping Centre 2	26.5	24.5	23.5	25.5
Shopping Centre 3	19.0	12.0	29.0	40.0
Shopping Centre 4	27.0	23.5	23.5	26.0
Shopping Centre 5	22.5	22.0	23.5	32.0

The annual water use in 2011 was forecasted first with the approaches outlined in Table 6.8 for all shopping centres. The forecast annual water use in 2011 was then disaggregated to quarterly water use with the disaggregating factors outlined in Table 6.9. The observed and forecast water use in 2011 for both annual and quarterly time steps are presented in Table 6.10 with the *E* values from the comparison of observed and forecast quarterly water use.

It can be seen from Table 6.10 that the *E* values were good in most of the shopping centres except Shopping Centre 3. The *E* value was negative in case of Shopping Centre 3, which indicates that the averages of past quarterly water uses would be better predictions than the forecast quarterly water use. As can be seen from Figure 6.7, the observed annual water use in 2011 was very different from the forecast annual water use.

Table 6.10 Comparison of observed and forecast water use of Shopping Centres subgroup in 2011

Shopping Centres		**Annual water use in 2011 (KL)**	**Water use in each quarter in 2011 (KL)**				***E* value**
			1	**2**	**3**	**4**	
Shopping Centre 1	Observed	99,431	25,721	25,256	23,962	24491	0.82
	Forecasted	112,903	32,177	27,097	23,710	29,919	
Shopping Centre 2	Observed	63,089	16,637	14,063	14,773	17,616	0.52
	Forecasted	66,328	17,577	16,250	15,587	16,914	
Shopping Centre 3	Observed	110,967	30,519	28,701	23,245	28,503	-3.30
	Forecasted	68,743	13,061	8,249	19,936	27,497	
Shopping Centre 4	Observed	81,371	21,733	19,174	18,989	21,475	0.89
	Forecasted	84,738	22,879	19,914	19,914	22,032	
Shopping Centre 5	Observed	60,036	17,333	17,217	13,372	12,114	0.69
	Forecasted	35,375	7,959	7,782	8,313	11,320	

6.3.4. Hospitals

There are four hospitals in this subgroup. The total water use by this subgroup is about 4% of the total water use by HWU group in the YVW in 2011. The annual water use time-series and quarterly water use percentages of these hospitals for different years are presented in Figure 6.8.

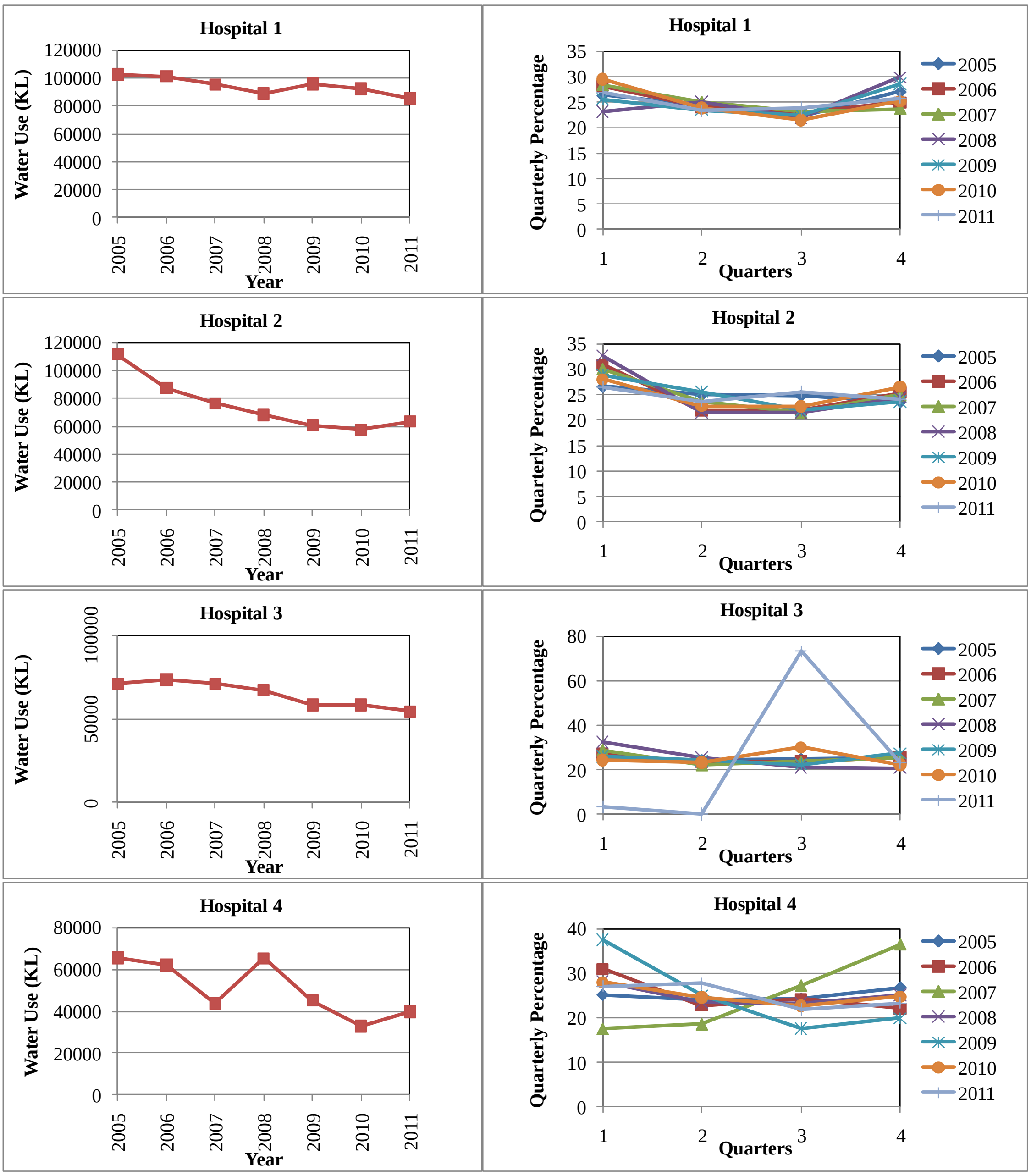


Figure 6.8 Water use pattern of Hospitals subgroup

From Figure 6.8, it can be seen that the annual water uses in Hospitals 1, 2 and 3 are moderately varied but fairly constant in 2008-2010. In case of Hospital 4, the annual water use was highly variable over the period. Therefore, based on this analysis, it was considered that the forecast annual water use in 2011 as the average annual water use in 2008-2010 for Hospitals 1, 2 and 3, and for Hospital 4, the forecast annual water use as the total water use in 2010.

The quarterly percentages in Figure 6.8 show that over the years (2005-2010), they were similar for all hospitals except for Hospital 4 (which were different in 2007 and 2009 compared to the other years). Therefore, the disaggregation factors for Hospitals 1, 2, 3 and 4 were obtained from the average values of the quarterly percentages over the years (2005-2010) excluding the percentages of 2007 and 2009 for case of Hospital 4.

A summary of the above water use data analysis and the modelling approach considered for different hospitals are presented in Table 6.11. The disaggregating factors obtained using the abovementioned procedures are presented in Table 6.12 for each of the hospitals.

Table 6.11 Summary of water use data analysis and selection of modelling approach for Hospitals subgroup

Hospitals	Variation of annual water use	Variation of quarterly water use percentages	Approach used for annual water use forecast in 2011	Approach used for disaggregating factors (quarterly percentages)
Hospital 1	Moderately varied	Similar over the years	Average annual water use in 2008-2010	Average over 2005-2010
Hospital 2	Moderately varied	Similar over the years	Average annual water use in 2008-2010	Average over 2005-2010
Hospital 3	Moderately varied	Similar over the years	Average annual water use in 2008-2010	Average over 2005-2010
Hospital 4	Highly variable	Similar over the years except in 2007 and 2009	Annual water use in 2010	Average over 2005-2010 excluding 2007 and 2009

Table 6.12 Disaggregating factors for individual Hospital

Hospitals	**Disaggregating factors for quarters**			
	1	**2**	**3**	**4**
Hospital 1	27.0	24.0	22.5	26.5
Hospital 2	29.5	23.5	22.5	24.5
Hospital 3	27.5	24.0	24.0	24.5
Hospital 4	28.5	23.5	23.5	24.5

The forecast annual water use was then disaggregated to quarterly water use with the disaggregating factors, which are outlined in Table 6.12. The forecast and observed water use for both annual and quarterly water use in 2011 are presented in Table 6.13. The *E* values obtained from the comparison of the quarterly forecast and observed water use are also presented in Table 6.13. The *E* values show good model performance for Hospitals 1, 2 and 4. For Hospital 3, it was negative *E* value indicating that the average quarterly water uses would be better predictions than the modelled water use. However, from Figure 6.8, it can be seen that the quarterly water use in 2011 are very different from the usual quarterly water use in the past years. The reasons for this sudden change in quarterly water use was not possible to explore due to availability of limited information in this study as outlined in Section 6.1.

Table 6.13 Comparison of observed and forecast water use of Hospitals subgroup in 2011

Hospitals		**Annual water use in 2011**	**Water use in each quarter in 2011 (KL)**				***E* value**
			1	**2**	**3**	**4**	
Hospital 1	Observed	85,354	23,058	19,917	20,348	22,031	0.58
	Forecasted	92,207	24,896	22,130	20,747	24,435	
Hospital 2	Observed	63,164	16,756	14,952	16,184	15,272	0.84
	Forecasted	62,141	18,332	14,603	13,982	15,225	
Hospital 3	Observed	54,348	17,90	30	39,828	12,700	-0.02
	Forecasted	61,210	16,833	14,690	14,690	14,996	
Hospital 4	Observed	39,797	10,763	11,035	8,718	92,81	0.64
	Forecasted	32,883	9,372	7,728	7,728	8,056	

6.3.5. Laundries

There are three laundries in this subgroup and the total water use by these laundries is about 3% of water used by HWU group in the YVW in 2011. The annual water use time-series and the quarterly water use percentages for different years are presented in Figure 6.9 for each laundry in the subgroup.

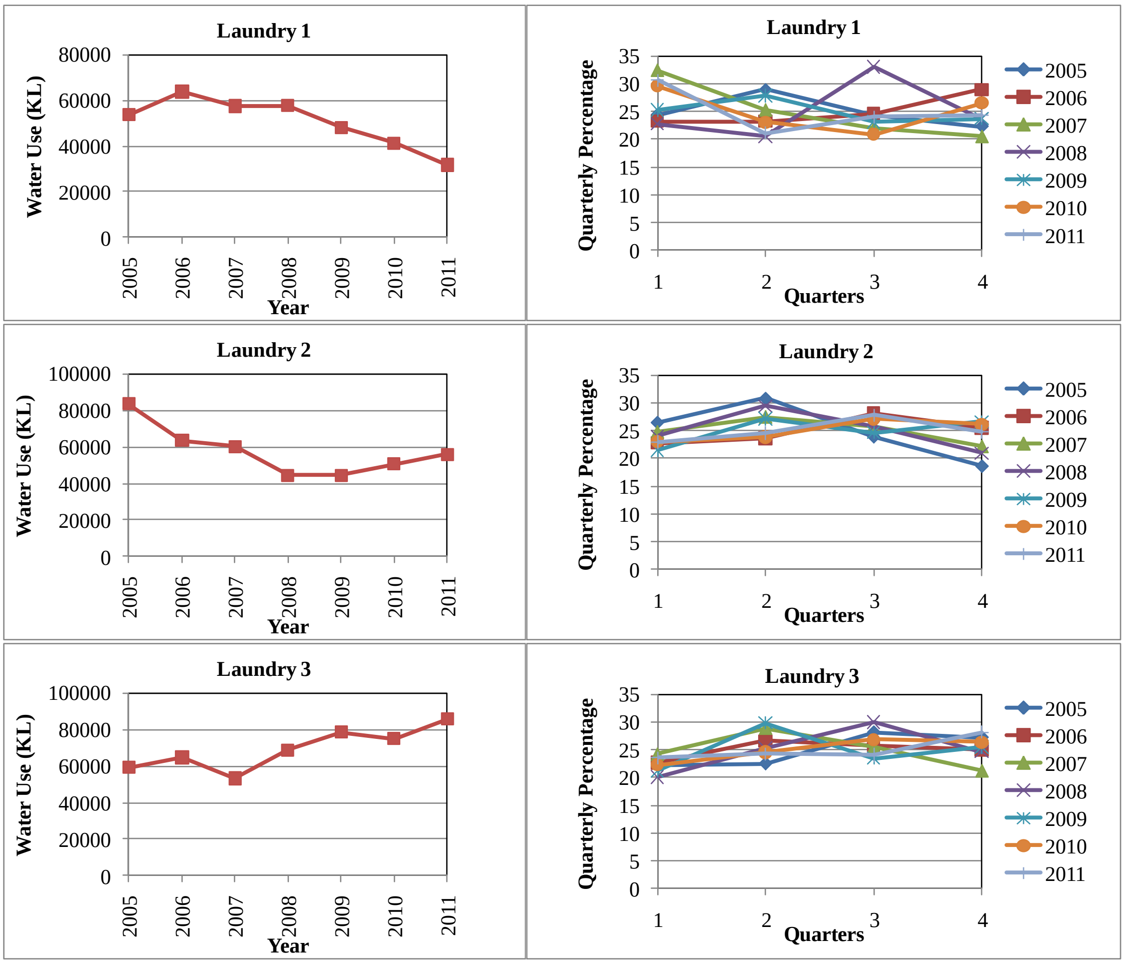


Figure 6.9 Water use pattern of Laundries subgroup

From Figure 6.9, it is apparent that annual water uses were moderately varied over the different years in all three laundries. However, in case of Laundries 2 and 3 the annual water uses of 2008-2010 were fairly constant. Therefore, it was considered that the average annual water use in 2008-2010 as the forecasted annual water use in 2011 for Laundries 2 and 3, and for Laundry 1, the forecasted annual water use in 2011 was considered similar to the total water use was in 2010.

The quarterly water use percentages in Figure 6.9 for different years also show that they were fairly similar in all laundries except for Laundry 1 in 2008. Based on this analysis, the disaggregation factors for all laundries were obtained from the average value of the quarterly percentages over the years (2005-2010) excluding the percentages of 2008 for Laundry 1.

A summary of the above water use data analysis and the modelling approach considered for different laundries are presented in Table 6.14. The disaggregating factors obtained using the abovementioned procedures are presented in Table 6.15 for each laundry in this subgroup.

Table 6.14 Summary of water use data analysis and selection of modelling approach for Laundries subgroup

Laundries	**Variation of annual water use**	**Variation of quarterly water use percentages**	**Approach used for annual water use forecast in 2011**	**Approach used for disaggregating factors (quarterly percentages)**
Laundry 1	Moderately varied	Similar over the years except in 2008	Annual water use in 2010	Average over 2005-2010 excluding 2008
Laundry 2	Moderately varied	Similar over the years	Average annual water use in 2008-2010	Average over 2005-2010
Laundry 3	Moderately varied	Similar over the years	Average annual water use in 2008-2010	Average over 2005-2010

Table 6.15 Disaggregating factors for individual Laundry

Laundries	**Disaggregating factors for quarters**			
	1	**2**	**3**	**4**
Laundry 1	27.0	25.5	23.0	24.5
Laundry 2	23.5	27.0	26.0	23.5
Laundry 3	22.0	26.5	26.5	25.0

The forecast annual water uses in 2011 were than disaggregated into quarterly water uses with the disaggregating factors outlined in Table 6.15. The forecast and observed water uses in 2011 are presented in Table 6.16 for both annual and quarterly time steps. The *E* values were obtained from the comparison of forecast and observed quarterly water uses for all three laundries are also presented in Table 6.16. From the table, it is apparent that the models performed well for Laundries 1 and 3. However, in case of Laundry 2, the *E* value was negative indicating that the average quarterly water use would be a better forecast.

Table 6.16 Comparison of observed and modelled water use of Laundries subgroup in 2011

Laundries		**Annual water use in 2011**	**Water use in each quarter in 2011 (KL)**				***E* value**
			1	**2**	**3**	**4**	
Laundry 1	Observed	31,646	9,685	6,672	7,607	7,682	0.79
	Forecasted	41,199	11,124	10,506	9,476	10,094	
Laundry 2	Observed	55,867	12,788	13,727	15,512	13,840	-4.29
	Forecasted	46,496	10,927	12,554	12,089	10,927	
Laundry 3	Observed	85,547	20,116	20,754	20,600	24,077	0.52
	Forecasted	74,048	16,290	19,623	19,623	18,512	

6.3.6. Confectionary Factories

There are three confectionary factories in this subgroup. The total water use by these confectionary factories is about 5% of the total water use by the HWU group in the YVW in 2011. The annual water use time-series and quarterly water use percentages for each year are shown in Figure 6.10 for these confectionary factories.

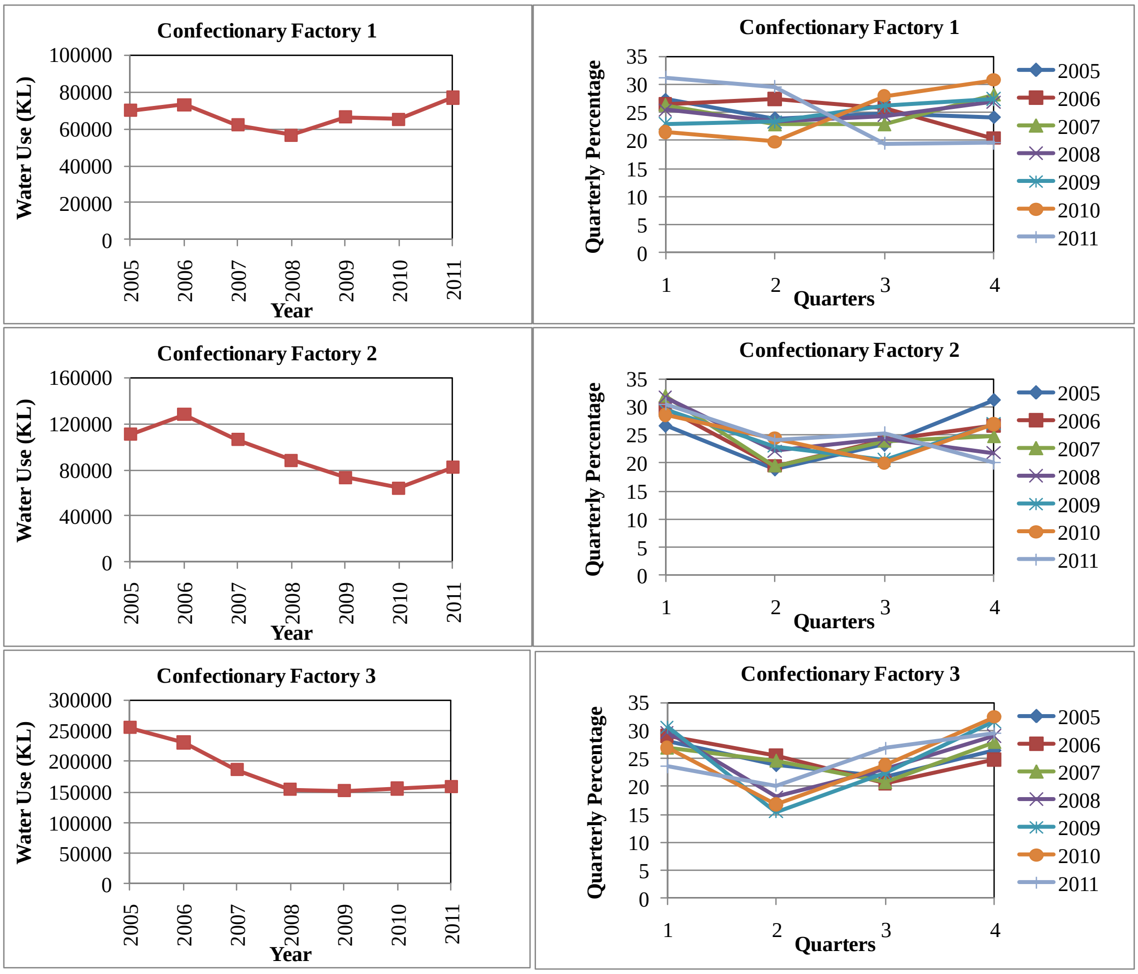


Figure 6.10 Water use pattern of Confectionary Factories subgroup

From Figure 6.10, it can be seen that in Confectionary Factories 1 and 3, the annual water use in 2008-2010 were fairly constant although annual water uses were moderately varied over different years. In Confectionary Factory 2, the annual water use gradually decreased from 2006 to 2010. Therefore, based on this analysis the average annual water uses in 2008-2010 were considered as the forecast annual water use in 2011 for Confectionary Factories 1 and 3. For Confectionary Factory 2, a regression model was considered to forecast annual water use in 2011.

It also can be seen from Figure 6.10 that the quarterly water use percentages of annual use were fairly similar over the years (2005-2010) for all confectionary factories. Therefore, the disaggregation factors to disaggregate the forecast annual water use to quarterly water use in 2011 were obtained from the average quarterly percentages over the period.

A summary of the above data analysis, and the modelling approach used for the different confectionary factories are presented in Table 6.17. The disaggregating factors obtained using the abovementioned procedures are presented in Table 6.18 for each confectionary factory.

Table 6.17 Summary of water use data analysis and selection of modelling approach for Confectionary Factories subgroup

Confectionary Factories	**Variation of annual water use**	**Variation of quarterly water use percentages**	**Approach used for annual water use forecast in 2011**	**Approach used for disaggregating factors (quarterly percentages)**
Confectionary Factory 1	Moderately varied	Similar over the years	Average annual water use in 2008-2010	Average over 2005-2010
Confectionary Factory 2	Decreased in each year	Similar over the years	Regression model developed	Average over 2005-2010
Confectionary Factory 3	Moderately varied	Similar over the years	Average annual water use in 2008-2010	Average over 2005-2010

Table 6.18 Disaggregating factors for individual Confectionary Factory

Confectionary Factories	**Disaggregating factors for quarters**			
	1	**2**	**3**	**4**
Confectionary Factory 1	25.5	24.0	25.0	25.5
Confectionary Factory 2	29.5	21.0	23.0	26.5
Confectionary Factory 3	28.5	21.0	22.0	28.5

The annual water use in 2011 were forecasted for all confectionary factories with the approaches outlined in Table 6.17. The equation used for developing the linear regression model to forecast annual water use in 2011 for Confectionary Factory 2 is given below:

$$\text{Annual water use of Confectionary Factory 2} = -11829x + 136514 \tag{6.3}$$

Where, x =1, 2, 3,….(2005 = 1; 2006 = 2; ….. and 2011 = 6)

The resulted trend lines of the annual water use Confectionary Factory 2 with the regression equation is shown in Figure 6.11.

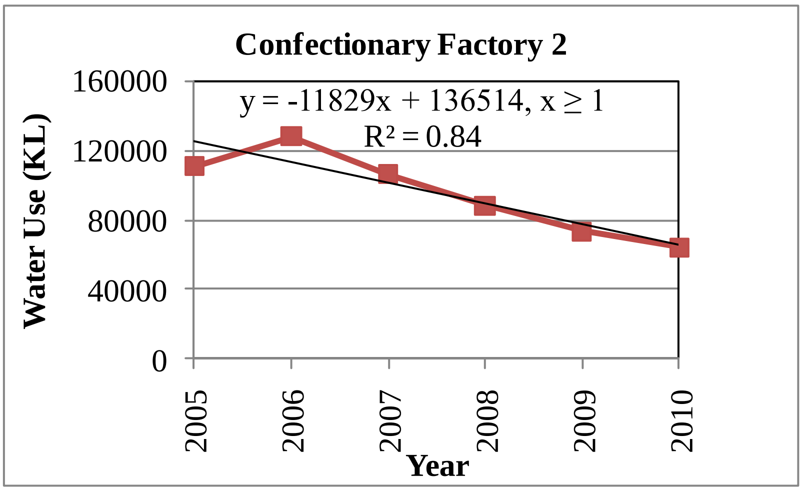


Figure 6.11 Annual water use trend in Confectionary Factory 2

The forecast annual water uses were then disaggregated into quarterly water use with the disaggregating factors outlined in Table 6.18. The forecast and observed water uses for both annual and quarterly time steps are presented in Table 6.19. The *E* values for all confectionary factories were obtained from the comparison of forecast and observed quarterly water use in 2011, are also presented in Table 6.19. From the Table 6.19, it is apparent that the *E* values in case of Confectionary Factories 1 and 2 were negative indicating that average quarterly water uses would be better predictions for these two customers. It is seen from Figure 6.10 that the annual water use in 2011 is quite different to the past annual water use considered for modelling.

Table 6.19 Comparison of observed and forecast water use of Confectionary Factories subgroup in 2011

Confectionaries		**Annual water use in 2011 (KL)**	**Water use in each quarter in 2011 (KL)**				***E* value**
			1	**2**	**3**	**4**	
Confectionary Factory 1	Observed	76,923	24,055	22,771	14,980	15,117	-0.22
	Forecasted	62,605	15,964	15,025	15,651	15,964	
Confectionary Factory 2	Observed	82,226	25,079	19,765	20,868	16,514	-1.90
	Forecasted	53,711	15,845	11,279	12,354	14,233	
Confectionary Factory 3	Observed	158,647	37,447	31,961	42,520	46,719	0.64
	Forecasted	153,600	43,776	32,256	33,792	43,776	

6.3.7. Universities

There are four universities in this subgroup and the total water use by these universities is 12% of the total water use by the HWU group in the YVW in 2011. The annual water use time-series for these universities are shown in Figure 6.12 along with their quarterly percentages of annual water use in different years (2005-2010).

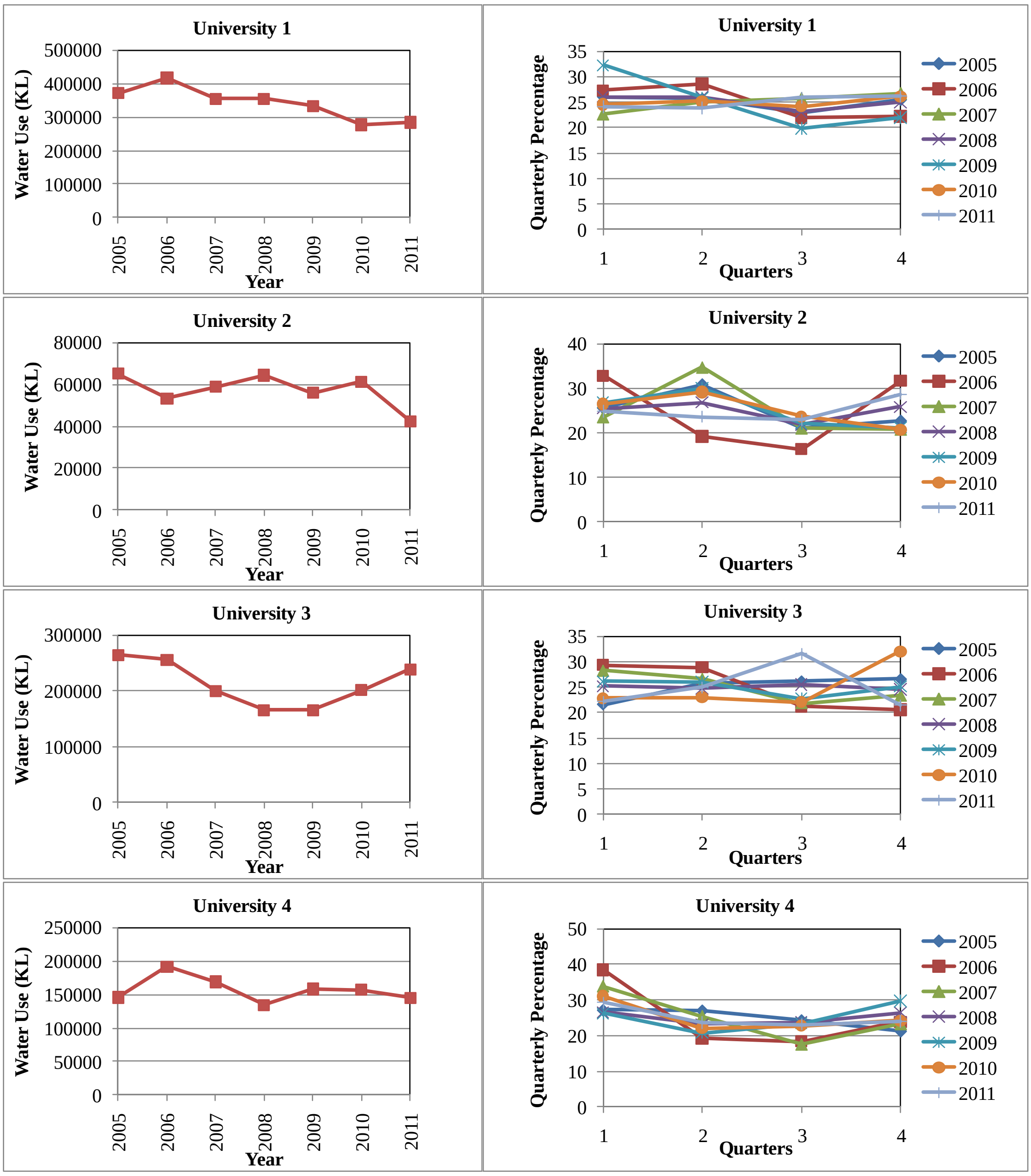


Figure 6.12 Water use pattern of Universities subgroup

From Figure 6.12, it is clear that annual water uses of Universities 1, 2, and 4 were moderately varied over 2005-2010. However, in case of Universities 2 and 4 annual water uses were fairly constant in 2008-2010. The annual water uses in University 3, was highly variable over the period of 2005-2010. Based on this analysis, the forecasted annual water use in 2011 for Universities 2 and 4 was considered as the average annual water use in 2008-2010, and for Universities 1 and 3 it was considered to be the same as the annual water use in 2010.

From Figure 6.12, it can be seen that quarterly water use percentages over different years in 2005-2010 were similar in all four universities except in University 2 for 2006. Therefore, the quarterly percentages of 2006 were not included for the disaggregating factors obtained from the average quarterly percentages over the years (2005-2010) in University 2.

A summary of the above data analysis, and the modelling approach used for the different universities are presented in Table 6.20. The disaggregating factors obtained using the abovementioned procedures are presented in Table 6.21 for each of the universities.

Table 6.20 Summary of water use data analysis and selection of modelling approach for Universities subgroup

Universities	**Variation of annual water use**	**Variation of quarterly water use percentages**	**Approach used for annual water use forecast in 2011**	**Approach used for disaggregating factors (quarterly percentages)**
University 1	Moderately varied	Similar over the years	Annual water use in 2010	Average over 2005-2010
University 2	Moderately varied	Similar over the years except in 2006	Average annual water use in 2008-2010	Average over 2005-2010 excluding 2006.
University 3	Highly Variable	Similar over the years	Annual water use in 2010	Average over 2005-2010
University 4	Moderately varied	Similar over the years	Average annual water use in 2008-2010	Average over 2005-2010

Table 6.21 Disaggregating factors for Universities Subgroup

Universities	Disaggregating factors for quarters			
	1	2	3	4
University 1	26.5	26.0	23.0	24.5
University 2	25.5	30.5	22.0	22.0
University 3	25.5	26.0	23.5	25.0
University 4	30.5	23.0	22.0	25.0

The annual water uses in 2011 were forecasted for all universities with the approaches outlined in Table 6.20. The forecast annual water use in 2011 was then disaggregated into quarterly water use with the disaggregating factors in Table 6.21. The observed and forecast water use are presented in Table 6.4 for both time steps. The *E* values obtained from the comparison observed and forecast quarterly water uses in 2011 for all universities are also presented in Table 6.22. It can be seen from Table 6.22 that the *E* values were negative in case of Universities 2 and 3, indicating that average quarterly water uses would be better predictions for these two Universities. It is seen from Figure 6.12 that the annual water use in 2011 are different to the past annual water use considered for modelling in these two universities.

Table 6.22 Comparison of observed and Forecast water use of Universities subgroup in 2011

Universities		Annual water use in 2011 (KL)	Water use in each quarter in 2011 (KL)				*E* value
			1	2	3	4	
University 1	Observed	284,304	68,508	67,883	73,584	74,329	0.84
	Forecasted	277,422	73,517	72,130	63,807	67,968	
University 2	Observed	42,387	10,517	10,002	9,705	12,163	-0.38
	Forecasted	60,488	15,425	18,449	13,307	13,307	
University 3	Observed	238,477	52,706	59,443	75,314	51,014	-0.42
	Forecasted	200,819	51,209	52,213	47,192	50,205	
University 4	Observed	144,801	42,419	34,161	33,460	34,761	0.82
	Forecasted	150,529	45,683	34,449	32,952	37,445	

6.3.8. Motor Companies

There is only one motor company in this subgroup, and it uses 3.5% of total water use by HWU group in 2011. The annual water use time-series along with their quarterly water use percentages of annual water use over different years (2005-2011) are shown in Figure 6.13.

From Figure 6.13, it can be seen that the annual water use are moderately varied over past years (2005-2010). Therefore, the forecasted annual water use in 2011 was considered as the annual water use in 2010. It also can be seen from the figure that quarterly water use percentages were similar over the years (2005-2010) excluding the quarterly percentages of 2010. Therefore, the disaggregating factors were obtained from the average quarterly percentages of 2005-2009.

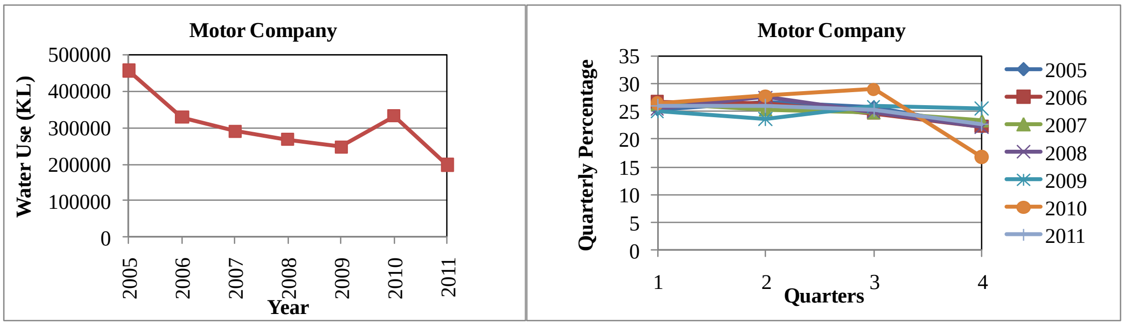


Figure 6.13 Water use pattern of motor Companies subgroup

A summary of above water use data analysis, and the modelling approach used for the Motor Companies subgroup is presented in Table 6.23. The disaggregating factors obtained using the abovementioned procedure are presented in Table 6.24.

Table 6.23 Summary of water use data analysis and selection of modelling approach for Motor Companies subgroup

Motor Companies	Variation of annual water use	Variation of quarterly water use percentages	Approach used for annual water use forecast in 2011	Approach used for disaggregating factors (quarterly percentages)
Motor Company	Moderately varied	Similar over the years	Annual water use in 2010	Average over 2005-2009

Table 6.24 Disaggregating factors for individual Motor Company

Motor Companies	Disaggregating factors for quarters			
	1	2	3	4
Motor Company	26.0	26.0	25.0	23.0

The forecast annual water use in 2011 was then disaggregated into quarterly water use using the disaggregating factors in Table 6.24. The observed and forecast water uses in 2011 for both annual and quarterly time steps are presented in Table 6.25. The *E* values obtained from the comparison of observed and forecast quarterly water use are also presented in this table. It can be seen from the Table 6.25 that the *E* values was negative, indicating that the average quarterly water use would be a better forecast. As can be seen from Figure 6.13, the observed annual water use in 2011 was very different from the forecast annual water use.

Table 6.25 Comparison of observed and forecast water use of Motor Companies subgroup in 2011

Motor company		Annual water use in 2011 (KL)	Water use in each quarter in 2011 (KL)				*E* value
			1	2	3	4	
Motor company	Observed	197,972	51,604	51,411	50,096	44,861	-0.20
	Forecasted	332,236	86,381	86,381	83,059	76,414	

6.3.9. Poultry Factories

There is only one poultry factory in this subgroup. The annual water use by this factory is about 5% of the total water use of HWUs group in 2011. The annual water use time-series along with their quarterly water use percentages of annual water use over different years (2005-2010) are shown in Figure 6.14.

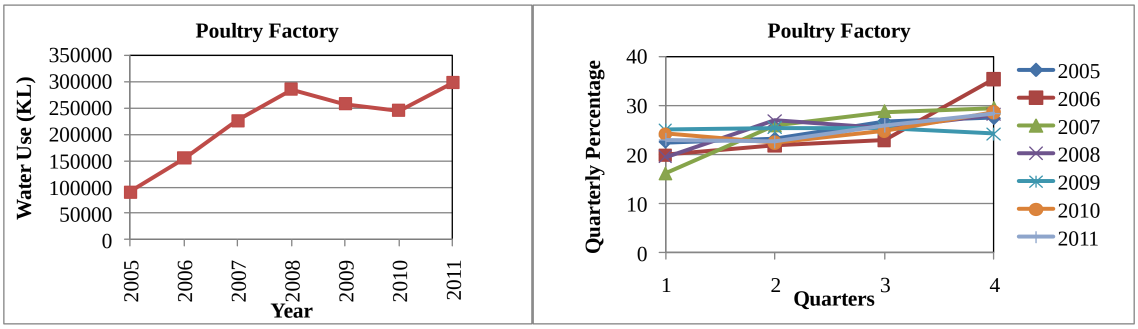


Figure 6.14 Water use pattern of Poultry Factories subgroup

From Figure 6.14, it can be seen that the water use in the poultry factory increased from 2005 to 2008 and then water use decreased until 2010. As the annual water use are highly variable in the 2005-2010, the forecasted annual water use in 2011 was considered as the annual water use in 2010. From Figure 6.14, it is also clear that the quarterly water use percentages in different years were fairly similar. Therefore, the average quarterly percentages over different years (2005-2010) were considered as the disaggregating factors to disaggregate the forecast annual water use in 2011 to quarterly water use.

A summary of the above water use data analysis, and the modelling approach used for the Poultry Factory is presented in Table 6.26. The disaggregating factors obtained using the abovementioned procedure is presented in Table 6.27.

Table 6.26 Summary of water use data analysis and selection of modelling approach for Poultry Factories subgroup

Poultry Factories	**Variation of annual water use**	**Variation of quarterly water use percentages**	**Approach used for annual water use forecast in 2011**	**Approach used for disaggregating factors (quarterly percentages)**
Poultry Factory	Highly variable	Similar over the years	Annual water use in 2010	Average over 2005-2010

Table 6.27 Disaggregating factors for individual Poultry Factory

Poultry Factories	**Disaggregating factors for quarters**			
	1	**2**	**3**	**4**
Poultry Factory	21.0	24.5	25.5	29.0

The forecast annual water use in 2011 were then disaggregated into quarterly water use using the disaggregating factors in Table 6.27. The comparisons of observed and forecast water use in 2011 for both annual and quarterly time steps are presented in Table 6.29. The *E* values obtained from the comparison of observed and forecast quarterly water use are also presented in this table. It can be seen from the Table 6.29 that the *E* value was good for the Poultry Factory.

Table 6.28 Comparison of observed and forecast water use of Poultry Factories subgroup in 2011

Poultry Factories		**Annual water use in 2011 (KL)**	**Water use in each quarter in 2011 (KL)**				***E* value**
			1	**2**	**3**	**4**	
Poultry Factory	Observed	297,551	68,604	67,326	77,157	84,464	0.64
	Forecasted	244,362	51,316	59,869	62,312	70,865	

6.3.10. Institutions

Only one institute is in this subgroup and it uses around 1% of the total water use of HWU group in 2011. The average annual water use of this institute is around 57 ML. The annual water use time-series along with the quarterly water use percentages of annual water uses over different years (2005-2010) are shown in Figure 6.15.

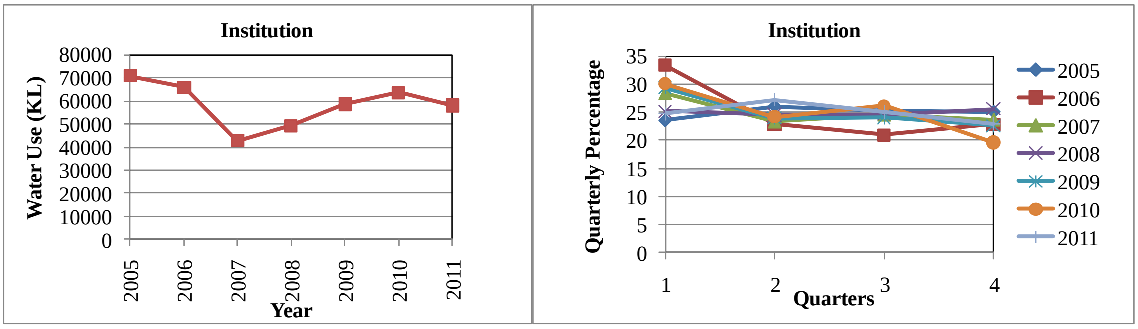


Figure 6.15 Water use pattern of Institutions subgroup

From Figure 6.15 it can be seen that the annual water use were moderately varied over the past years. Therefore, the forecasted annual water use in 2011 was considered as the annual water use in 2010. It is also clear from Figure 6.15 that the quarterly water use percentages were similar over different years (2005-2010). Therefore, the average quarterly percentages over different years (2005-2010) were considered as the disaggregating factors to disaggregate the forecast annual water use in 2011 to quarterly water use.

A summary of above water use data analysis and the modelling approach used for the Institutions subgroup are presented in Table 6.29. The disaggregating factors obtained using the abovementioned procedure are presented in Table 6.30.

Table 6.29 Summary of water use data analysis and selection of modelling approach for Institutions subgroup

Institutions	**Variation of annual water use**	**Variation of quarterly water use percentages**	**Approach used for annual water use forecast in 2011**	**Approach used for disaggregating factors (quarterly percentages)**
Institution	Moderately varied	Similar over the years	Annual water use in 2010	Average over 2005-2010

Table 6.30 Disaggregating factors for individual Institutions

Institutions	**Disaggregating factors for quarters**			
	1	**2**	**3**	**4**
Institution	28.5	24.0	24.5	23.0

The forecast annual water use in 2011 was then disaggregated into quarterly water use using the disaggregating factors in Table 6.30. The comparison of observed and forecast water use in 2011 for both annual and quarterly time steps are presented in Table 6.31. The *E* values obtained from the comparison of observed and forecast quarterly water use are also presented in the same table. It can be seen from Table 6.31 that the *E* value was negative, indicating that the average quarterly water use would be a better forecast. As can be seen from Figure 6.15, the observed annual water use in 2011 was different from the forecast annual water use.

Table 6.31 Comparison of observed and modelled water use of Institutions subgroup in 2011

Institutions		**Annual water use in 2011 (KL)**	**Water use in each quarter in 2011 (KL)**				***E* value**
			1	**2**	**3**	**4**	
Institution	Observed	58,040	14,330	15,820	14,540	13,350	-4.50
	Forecasted	63,600	18,126	15,264	15,582	14,628	

6.4. Limitations of the Study and Applications

The grouping of HWU customers into different subgroups in this study provides more homogeneous groups of non-residential water demand. Water use in these HWU can vary due to different factors (as mentioned in Section 6.1) such as size of establishment, number of employee, number of customers benefited from their services, outdoor gardening, types and difference in technology used. There were no such details available on these HWU at the time of the study and it was not possible to contact these customers to obtain the required information due to confidentiality reasons. Therefore, only past water use data were analysed and used for forecasting quarterly water use for the following year in different subgroups (as outlined in Section 6.2).

As mentioned in Chapter 3, water use data before 2005 were not used in this research as it was found that water use pattern were very different before and after 2005. Therefore, it is recommended to incorporate recent water use data to account current water use pattern to ensure better model performance with the modelling approach used in this study.

Water use modelling were performed individually for each customer in the HWU subgroups in this research. The modelling approach at disaggregated level will also provide customer base knowledge to the authority. This highly disaggregated forecast in combination with the customer's geographic locations will allow the visualization and evaluation of water demand information at different spatial scale (i.e. water distribution zone, census tract), at the same time total quarterly water demand for each subgroups. These information will be useful for upgrading and maintenance of existing urban water supply system, enhancing conservation programs, implementing land use policy and initiating water resources project (Polebitski and Palmer 2010). Moreover, water authority interested in spatial pricing schemes, which will also be benefited with this modelling approach.

6.5. Summary

Water use modelling was performed for the HWU group in the YVW (Yarra Valley Water) service area. There are many influencing factors affects the water usage of these customers were not available for the study. Examples of such factors include the size of establishment, number of employees, number of customers benefited from their services, outdoor gardening, types of different technology used, etc. However, it should be noted that water use of most of the customers in this group are mainly for indoor purposes, which are not affected by weather and water restrictions level. Therefore, only the historical water use data were used in this study.

All customers in this HWU group were classified into different subgroups based on the activity such as manufacturing companies, packaging companies, shopping centres, hospitals, laundries, confectionary factories, universities, motor companies, poultry factories and institutions. Data analysis was then performed for annual and quarterly water use for each HWU in the subgroups separately to identify the annual water use patterns and the quarterly disaggregating factors, which were used in forecasting quarterly water use.

Based on the annual water use variation in 2005-2010, the total water use in 2011 was forecasted first for each HWU customers. It was found that there were four different types of patterns based on the analysis of annual water use time series. These annual water use patterns are presented in Table 6.32. The annual water uses in 2011 of these four types of customers were forecast differently and presented in the same table.

Table 6.32 Types of Annual Water Use Pattern and Approach Used to Forecast Water Use in 2011

Annual Water Use Pattern	**Approach Used to Forecast Annual Water use in 2011**
1) Highly variable over the period	Total water use in 2010
2) Moderately varied (i.e. less varied compared type 1) over the period	Total water use in 2010
3) Moderately varied over the period and it was fairly constant in 2008-2010	Average annual water use of 2008-2010
4) Followed an increasing or decreasing trend	Modelled with regression analysis

From Table 6.32, it can be seen that the annual water uses in 2011 of these four types of customers were forecast differently. For the customers in type 1 and type 2 categories, the forecast annual water use in 2011 was considered as the total water use in 2010 and for type 3 category the forecast annual water use in 2011 was considered as the average annual water use of 2008-2010. In case of customers of type 4 category, the forecast annual water use in 2011 was modelled with regression analysis.

The forecast annual water use was then disaggregated into quarterly water use using the disaggregating factors. Finally, the Nash-Sutcliffe model efficiency (*E*) was obtained from the comparison of observed and forecast quarterly water use in 2011. The *E* values show that in most of the cases models performed well. However, in some cases the *E* values were negative indicating that the average quarterly water use was a better prediction for forecast. It should be noted that from the analysis, it was found that the annual water use in 2011 were very different for those HWU although the quarterly percentages were similar.

As the customers in HWU group are the highest water users in the YVW service area, a field survey to get their future plan for production of their goods along with the details of the onsite water use management technology would be important for better forecasting results.

Chapter 7. Summary, Conclusions, and Recommendations

7.1. Summary

The primary aim of this research was to develop water demand models for forecasting short term non-residential water demand at disaggregated customer group levels. Therefore, a detail data analysis was performed in this study to disaggregate the non-residential water use customers and to identify the water use patterns among the different customer groups at disaggregated levels. These were done using the Yarra Valley Water (YVW) service area in Melbourne, Victoria (Australia) as the case study area. The aim of the study was achieved by undertaking the following tasks:

1. Review of urban water demand modelling approaches
2. Selection of study area, and data sources and processing
3. Water use modelling for Schools, Sports and Councils
4. Water use modelling for Restaurants, Hospitals, Hotels and Laundries
5. Water use modelling for High Water Users

A brief summary drawn from each of these tasks are presented in the following sections.

7.1.1. Review of Urban Water Demand Modelling Approaches

Several urban water demand modelling approaches have been used in the past for estimating urban water use. A review on the existing urban water demand modelling approaches (applied in both residential and non-residential sectors) was conducted to understand and select the appropriate non-residential water demand modelling approach to use in this research. It should be noted that although the focus of this research was on non-residential water demand modelling, literature review was also extended to the work done in the residential sector as only few studies were found on water demand modelling in the non-residential sector.

In general, it was found that there are eight general modelling approaches, which were widely used for urban water demand modelling. They are: historical average or pattern based approach; climate correction; trend analysis; analysis of base and seasonal use; regression modelling; end-use modelling; agent based modelling; and artificial intelligence methods. Some of these modelling approaches are suitable for scenario analysis rather than for actual estimation of water use and some approaches require an extensive micro scale data in shorter time scale which are not readily available in the non-residential sector. Moreover, some of these modelling approaches were found to be simple and their applications are limited to certain extends; often used as part of other modelling approaches such as regression modelling approach where some of their limitations were overcome.

Based on the data available in this research, the regression modelling approach; particularly the stepwise multiple linear regressions (MLR) technique was found to be suitable for developing non-residential water demand models for Schools, Sports grounds and Councils. It should be noted that due to limitation in data availability, the MLR approach was not used for water demand models development in Hotels, Hospitals, Restaurants, Laundries and High users groups. A historical average or pattern based approaches were used for modelling water demand in these groups.

7.1.2. Selection of Study Area, and Data Sources and Processing

The Yarra Valley Water (YVW) service area located in Melbourne, Australia was selected as the case study area in this research. It is managed by the YVW retailer. The YVW is the largest water retailer in Melbourne provides essential water and sanitation services for a large population (more than 1.76 million people) in the northern and eastern suburbs. As the YVW provides water service to more people than the two other water retailers (i.e. City West Water and South East Water), it was considered to have more variation in different types of non-residential customers (e.g. industrial, commercial and institutional) than the two other water retailers in Melbourne. Therefore, considering the valuable contributions to Melbourne’s community in water service delivery and large number of non-residential customers, modelling non-residential water demand considered to be useful for the YVW service area.

Water use billing data and historical water restrictions data were obtained for around 36,000 customers from the YVW retailer. However, customers with missing data were not used in this study. Climate data such as rainfall and temperature record was collected from the Bureau of Meteorology at Melbourne Regional Office (Station #86071) station as most of the water use customers are located nearby this station. These data were used in this study to develop non-residential water use models for some customers groups at various disaggregated levels.

Data for different variables were obtained in several time scales. Water use billing data for most of the customers were in quarterly time scale and only few customers’ water use billing data were in monthly time scale. Moreover, it was found that there were inconsistency in water use billing period (i.e. number of billing days were not same) among various non-residential water use customers. Therefore, data processing was required to make a consistent time series data across all customers’ water use data and all types of variables’ data.

All data were transformed into the quarterly time scale, and the quarterly time scale was used in non-residential water use models development in this research as it is the usual water use billing period in the YVW. Water use billing data were obtained from 2000 to 2011. However, it was found that water use pattern significantly different before and after 2005, when Permanent Water Savings Rule (PWSR) was introduced. It was considered that this water use pattern will continue in future and therefore, data record from 2005 to 2011 was used for model development and validation in this study.

Disaggregation of non-residential customer was performed to capture the best hidden nature of water use behaviour during model development in this study. This was done based on the homogeneous nature of water use customers and their annual average water use. There were seven homogeneous customer groups: Schools, Sports Grounds, Councils, Restaurants, Hospitals, Hotels, and Laundries. Each of these homogenous groups was further disaggregated into five groups: >20 ML, >15-20 ML, >10-15 ML, 5-10 ML and <5 ML. As mentioned above, non-residential water use models were developed individually for each of these subgroups in this research. Customers using >50 ML/year were also considered as a separate group in this study for modelling due to their high percentage of water use, and named as High Water Users.

7.1.3. Water Use Modelling for Schools, Sports Grounds and Councils

A single modelling approach was used for modelling quarterly water use in Schools, Sports Grounds and Councils groups as similar quarterly water use pattern was identified during data analysis (in Chapter 3). As mentioned in Section 7.1.2, all the customers in these homogenous groups were further disaggregated into different groups based on the average annual water use volume (i.e. >20 ML, >15-20 ML, >10-15 ML, 5-10 ML, and <5 ML) to develop models at these disaggregated levels. It should be noted that customers in high user group (i.e. >20 ML, >15-20 ML and >10-15 ML) are modelled individually as these few customers uses large amount of water with compare to the low user groups (i.e. 5-10 ML and <5 ML) having many customers. Water use of low user customers was modelled at the group level. However, the developed models at the group level can be used to forecast water use of any individual customer.

The MLR technique was used for water use models development for the abovementioned groups. Based on the past literature and data availability; total rainfall, mean maximum daily temperature, water use restrictions, past water use in terms of (t-1) and (t-4) time-lagged and fixed quarterly effects were used as the independent variables during the models development. Before developing the MLR models, all the dependent and independent variables data were transformed using log function to make the data normally distributed. A correlation analysis was also carried out between the dependent and independent variables and also among the independent variables to identify the degree of correlation. Most of the independent variables were found not inter-correlated. Only few cases independent variables were found inter-correlated, and in those cases one of the independent variable was not included during MLR model development. Data from 2005-2010 was used for model calibration and data in 2011 was used for model validation. The model performance was measured with the Nash-Sutcliffe efficiency (*E*) and the significance test for model parameters were done using *p* value.

In general, the observed and modelled water uses were well matched, and high *E* values were obtained in most cases. Among the independent variables used in this study, different variables were found to have significant effects on the current water use in different groups (i.e. Schools, Sports Grounds and Councils). Moreover, the significant variables were found to vary from high to low water users within the same group.

7.1.4. Water Use Modelling for Restaurants, Hospitals, Hotels and Laundries

Water use in Restaurants, Hospitals, Hotels and Laundries were modelled using only the historical water use data. During data analysis, no seasonal effect was identified among these groups (Chapter 3) and water uses among the groups are mainly for indoor purposes. Moreover, data on influencing factors for water uses in these groups (e.g. opening hours for Restaurants, number of beds in Hospitals, number of rooms in Hotels, and number of customers and frequency of use in Laundries) were not available in this study. Therefore, only historical water use data were analysed and used for forecasting. Quarterly water use data from 2005 to 2010 were used for data analysis and to forecast quarterly water demand in 2011.

All the customers in Restaurants, Hospitals, Hotels and Laundries were disaggregated into different groups based on the annual water use volume (i.e. >20 ML, >15-20 ML, >10-15 ML, 5-10 ML, and <5 ML) as outlined in Section 7.1.2.

Thereafter, data analysis was performed at these disaggregated levels to identify the historical annual and quarterly water use pattern. There were three different patterns were identified and they are: 1) the annual water uses were variable over the period (2005-2010), 2) the annual water use were constant over the very recent period (2008-2010) or over the period of 2005-2010, and 3) the annual water use followed an increasing and decreasing trend. Based on these water use patterns annual water use in 2011 were forecasted. During data analysis, it was found that most of the customers among these four groups (i.e. Restaurants, Hospitals, Hotels and Laundries) follow consistent quarterly percentages of annual water use over the period (2005-2010) except for few years for some cases. Therefore, average quarterly percentages were considered as the quarterly disaggregating factors (excluding the exceptional years) in this study. These factors were used to forecast quarterly water use in 2011 from the forecast annual water use. Comparisons of the forecast quarterly water use were carried out with the observed water use in 2011 and models performance was measured with the Nash-Sutcliffe efficiency (E) in this study. Results show that most of the developed models in this study performed well with good E value. In few cases models performed poorly and therefore, challenges and limitation of the modelling in this research were also identified and presented.

7.1.5. Water Use Modelling for High Water Users

There are thirty five customers who use a large percentage (33.8%) of total non-residential water use in 2011 in the YVW service area named as High Water User (HWU) group in this research. The annual water use by these HWU customers is >50 ML as per data received and based on the communications with the YVW officers. As these customers use large amount of water, water use in these customers were analysed and forecast separately in this study.

All the customers in this group were divided into subgroups based on the different activities such as Manufacturing Companies, Packaging Companies, Shopping Centres, Hospitals, Laundries, Confectionary Factories, Universities, Motor Companies, Poultry Factories and Institutions. There are many factors affecting the water use among the above subgroups (e.g. number of users of Shopping Centres, student numbers in Universities, number of beds in Hospitals, and demand for the products in Manufacturing Companies and Confectionary Factories) were not available in this study. Moreover, it was found that, the driving factors for some of these customers such as Manufacturing Companies and Confectionary Factories are the demand for their goods in foreign countries (from discussions with the YVW officers). Therefore, as most of the water uses are for indoor purposes, only the water use data of 2005-2010 were analysed and modelled to forecast quarterly water use in 2011 using the similar approach outlined in Section 7.1.4.

The Nash-Sutcliffe efficiency (*E*) was used for measuring model performance in this study. The *E* values show that most of the developed models in this study performed well. However, in some cases negative *E* value indicating that the average quarterly water use would be better predictions. It was also found that in those cases annual water use in 2011 were very different although the quarterly percentages were similar. Therefore, it is recommended to conduct a field survey to get their onsite water use management technology details and future plan (e.g. productions of goods, changes in services, and future renovation or constructions) for better forecast as they are the highest water users in the YVW service area.

7.2. Conclusions

The following conclusions are drawn in this study against the aims stated in Chapter 1 (Section 1.3):

1. Disaggregation of non-residential water use was performed based on the homogenous water use activities and it was found that there were seven homogeneous customer groups: Schools, Sports Grounds, Councils, Restaurants, Hospitals, Hotels, and Laundries. Furthermore, each of these homogenous groups was disaggregated into five different groups based on average annual water use such as >20 ML, >15-20 ML, >10-15 ML, 5-10 ML and <5 ML.

2. Quarterly water use pattern were identified for the different homogenous customer groups in this study. It was found that the Schools, Sports Grounds and Councils have similar water use pattern and has seasonal climatic effect due to their outdoor water use. In case of Restaurants, Hospitals, Hotels and Laundries, most of the water use were for indoor purposes and there were no variation identified in their quarterly water use pattern over the year. Moreover, data analysis at disaggregated level showed that quarterly water use pattern also varied from high water users to low water users.

3. It was possible to develop water demand model for Schools, Sports Grounds and Councils using multiple linear regression technique in this study. For other groups, water demand was modelled based on historical water use patterns. There were significant issues and challenges identified in modelling non-residential urban water use which are not limited to the availability of historical water use data, also related to the variability of water uses at temporal scale.

7.3. Limitation of the Study and Recommendations for Future Research

Based on the data analysis and modelling of non-residential water use in this research, some limitations of the present study were identified. A number of recommendations for future studies to lessen these limitations are discussed below.

There were around 36,000 non-residential customers’ data available in this study. Around 8,000 customers were identified with their major homogeneous activities, use around half of the total non-residential water use. Water use modelling were performed for these customers in this research. Rest of the 28,000 customers were falls into many smaller homogeneous activities and not modelled in this study. Therefore, the present work could be extended to more homogeneous customer groups in future.

There were many influential independent variable data were not available for different homogeneous customer groups in this study. Also, for some groups sudden change in water use pattern was observed where reason for this sudden changes were unknown. Therefore, modelling among these customer groups is limited in unexpected water use variation. It is recommended to conduct field survey to obtain data on the different factors outlined in this study (in different chapters) for future research on modelling water use in non-residential sectors.

The proposed approach in this study can be adopted in other water service areas. However, it is recommend to carefully consider the independent variables as in different cities may have different climatic conditions, population densities and cultural background varying the water use pattern. Moreover, there were significant effort had been put in this research on data processing and modelling non-residential water use at disaggregated level. Therefore, it is also recommend to develop a computer programming package for efficiently applying the proposed modelling approach and for future update.

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Appendix: Correlation Coefficient between the Independent Variables

Appendix A: Correlation coefficient between the independent variables for Schools group

Table A1 School group >20 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	.02	-.11	-.51	-.12	.66	-.24	-.74
$Log_{10}(WU_{t-4})$	.02	1.00	.90	.09	.06	-.22	-.75	.29
$Log_{10}(T)$	-.11	.90	1.00	.06	.12	-.41	-.68	.35
$Log_{10}(Rn)$	-.51	.09	.06	1.00	-.09	-.27	.06	.33
R	-.12	.06	.12	-.09	1.00	-.08	-.08	.24
D_2	.66	-.22	-.41	-.27	-.08	1.00	-.33	-.33
D_3	-.24	-.75	-.68	.06	-.08	-.33	1.00	-.33
D_4	-.74	.29	.35	.33	.24	-.33	-.33	1.00

Table A2 School 1 in group >15-20 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.17	-0.13	-0.32	-0.44	0.67	-0.25	-0.68
$Log_{10}(WU_{t-4})$	0.17	1.00	0.84	-0.20	-0.04	-0.20	-0.69	0.20
$Log_{10}(T)$	-0.13	0.84	1.00	0.06	0.12	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.32	-0.20	0.06	1.00	-0.09	-0.27	0.06	0.33
R	-0.44	-0.04	0.12	-0.09	1.00	-0.08	-0.08	0.24
D_2	0.67	-0.20	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	-0.25	-0.69	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.68	0.20	0.35	0.33	0.24	-0.33	-0.33	1.00

Table A3 School 2 in group >15-20 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.56	0.02	-0.16	-0.57	0.44	-0.31	-0.29
$Log_{10}(WU_{t-4})$	0.56	1.00	0.47	-0.27	-0.38	-0.18	-0.31	0.01
$Log_{10}(T)$	0.02	0.47	1.00	0.06	0.12	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.16	-0.27	0.06	1.00	-0.09	-0.27	0.06	0.33
R	-0.57	-0.38	0.12	-0.09	1.00	-0.08	-0.08	0.24
D_2	0.44	-0.18	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	-0.31	-0.31	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.29	0.01	0.35	0.33	0.24	-0.33	-0.33	1.00

Table A4 School 1 in group >10-15 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.08	-0.15	-0.41	-0.25	0.64	-0.29	-0.38
$Log_{10}(WU_{t-4})$	0.08	1.00	0.65	-0.11	-0.25	-0.20	-0.42	-0.01
$Log_{10}(T)$	-0.15	0.65	1.00	0.06	0.14	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.41	-0.11	0.06	1.00	-0.08	-0.27	0.06	0.33
R	-0.25	-0.25	0.14	-0.08	1.00	-0.08	-0.08	0.24
D_2	0.64	-0.20	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	-0.29	-0.42	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.38	-0.01	0.35	0.33	0.24	-0.33	-0.33	1.00

Table A5 School 2 in group >10-15 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.79	0.05	-0.43	-0.66	0.03	-0.04	-0.15
$Log_{10}(WU_{t-4})$	0.79	1.00	0.12	-0.26	-0.50	0.07	-0.11	-0.09
$Log_{10}(T)$	0.05	0.12	1.00	0.06	0.12	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.43	-0.26	0.06	1.00	-0.09	-0.27	0.06	0.33
R	-0.66	-0.50	0.12	-0.09	1.00	-0.08	-0.08	0.24
D_2	0.03	0.07	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	-0.04	-0.11	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.15	-0.09	0.35	0.33	0.24	-0.33	-0.33	1.00

Table A6 School 3 in group >10-15 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.17	-0.01	-0.39	-0.46	0.26	-0.15	-0.28
$Log_{10}(WU_{t-4})$	0.17	1.00	0.53	-0.09	-0.04	-0.24	-0.29	0.07
$Log_{10}(T)$	-0.01	0.53	1.00	0.06	0.12	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.39	-0.09	0.06	1.00	-0.09	-0.27	0.06	0.33
R	-0.46	-0.04	0.12	-0.09	1.00	-0.08	-0.08	0.24
D_2	0.26	-0.24	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	-0.15	-0.29	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.28	0.07	0.35	0.33	0.24	-0.33	-0.33	1.00

Table A7 School subgroup >9-10 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.48	-0.17	-0.05	-0.83	0.24	-0.01	-0.36
$Log_{10}(WU_{t-4})$	0.48	1.00	0.34	-0.23	-0.34	0.08	-0.42	0.03
$Log_{10}(T)$	-0.17	0.34	1.00	0.06	0.14	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.05	-0.23	0.06	1.00	-0.08	-0.27	0.06	0.33
R	-0.83	-0.34	0.14	-0.08	1.00	-0.08	-0.08	0.24
D_2	0.24	0.08	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	-0.01	-0.42	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.36	0.03	0.35	0.33	0.24	-0.33	-0.33	1.00

Table A8 School subgroup >8-9 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.68	-0.01	0.00	-0.65	-0.02	0.05	-0.09
$Log_{10}(WU_{t-4})$	0.68	1.00	0.14	-0.24	-0.41	0.07	-0.17	-0.09
$Log_{10}(T)$	-0.01	0.14	1.00	0.06	0.12	-0.41	-0.68	0.35
$Log_{10}(Rn)$	0.00	-0.24	0.06	1.00	-0.09	-0.27	0.06	0.33
R	-0.65	-0.41	0.12	-0.09	1.00	-0.08	-0.08	0.24
D_2	-0.02	0.07	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	0.05	-0.17	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.09	-0.09	0.35	0.33	0.24	-0.33	-0.33	1.00

Table A9 School subgroup >7-8 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.34	-0.07	-0.24	-0.32	0.17	0.00	-0.29
$Log_{10}(WU_{t-4})$	0.34	1.00	0.33	-0.15	-0.20	0.03	-0.33	0.03
$Log_{10}(T)$	-0.07	0.33	1.00	0.06	0.14	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.24	-0.15	0.06	1.00	-0.08	-0.27	0.06	0.33
R	-0.32	-0.20	0.14	-0.08	1.00	-0.08	-0.08	0.24
D_2	0.17	0.03	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	0.00	-0.33	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.29	0.03	0.35	0.33	0.24	-0.33	-0.33	1.00

Table A10 School subgroup >6-7 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.56	-0.01	-0.13	-0.29	0.05	-0.02	-0.09
$Log_{10}(WU_{t-4})$	0.56	1.00	0.09	-0.24	-0.16	0.02	-0.09	-0.03
$Log_{10}(T)$	-0.01	0.09	1.00	0.06	0.14	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.13	-0.24	0.06	1.00	-0.08	-0.27	0.06	0.33
R	-0.29	-0.16	0.14	-0.08	1.00	-0.08	-0.08	0.24
D_2	0.05	0.02	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	-0.02	-0.09	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.09	-0.03	0.35	0.33	0.24	-0.33	-0.33	1.00

Table A11 School subgroup >5-6 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.48	0.02	-0.29	-0.42	0.11	-0.08	-0.17
$Log_{10}(WU_{t-4})$	0.48	1.00	0.20	-0.17	-0.25	-0.04	-0.15	-0.01
$Log_{10}(T)$	0.02	0.20	1.00	0.06	0.14	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.29	-0.17	0.06	1.00	-0.08	-0.27	0.06	0.33
R	-0.42	-0.25	0.14	-0.08	1.00	-0.08	-0.08	0.24
D_2	0.11	-0.04	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	-0.08	-0.15	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.17	-0.01	0.35	0.33	0.24	-0.33	-0.33	1.00

Table A12 School subgroup >4-5 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.66	-0.03	-0.11	-0.41	0.08	-0.02	-0.11
$Log_{10}(WU_{t-4})$	0.66	1.00	0.10	-0.18	-0.28	0.03	-0.11	-0.07
$Log_{10}(T)$	-0.03	0.10	1.00	0.06	0.14	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.11	-0.18	0.06	1.00	-0.08	-0.27	0.06	0.33
R	-0.41	-0.28	0.14	-0.08	1.00	-0.08	-0.08	0.24
D_2	0.08	0.03	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	-0.02	-0.11	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.11	-0.07	0.35	0.33	0.24	-0.33	-0.33	1.00

Table A13 School subgroup >3-4 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.40	0.02	-0.17	-0.36	0.07	-0.05	-0.12
$Log_{10}(WU_{t-4})$	0.40	1.00	0.13	-0.18	-0.19	-0.01	-0.11	0.00
$Log_{10}(T)$	0.02	0.13	1.00	0.06	0.14	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.17	-0.18	0.06	1.00	-0.08	-0.27	0.06	0.33
R	-0.36	-0.19	0.14	-0.08	1.00	-0.08	-0.08	0.24
D_2	0.07	-0.01	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	-0.05	-0.11	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.12	0.00	0.35	0.33	0.24	-0.33	-0.33	1.00

Table A14 School subgroup >2-3 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.43	-0.05	-0.15	-0.34	0.05	0.01	-0.09
$Log_{10}(WU_{t-4})$	0.43	1.00	0.09	-0.23	-0.22	0.04	-0.09	-0.07
$Log_{10}(T)$	-0.05	0.09	1.00	0.06	0.14	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.15	-0.23	0.06	1.00	-0.08	-0.27	0.06	0.33
R	-0.34	-0.22	0.14	-0.08	1.00	-0.08	-0.08	0.24
D_2	0.05	0.04	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	0.01	-0.09	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.09	-0.07	0.35	0.33	0.24	-0.33	-0.33	1.00

Table A15 School subgroup 1-2 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.48	-0.02	-0.07	-0.20	0.00	0.01	-0.04
$Log_{10}(WU_{t-4})$	0.48	1.00	0.03	-0.13	-0.13	0.03	-0.04	-0.04
$Log_{10}(T)$	-0.02	0.03	1.00	0.06	0.14	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.07	-0.13	0.06	1.00	-0.08	-0.27	0.06	0.33
R	-0.20	-0.13	0.14	-0.08	1.00	-0.08	-0.08	0.24
D_2	0.00	0.03	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	0.01	-0.04	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.04	-0.04	0.35	0.33	0.24	-0.33	-0.33	1.00

Table A16 School subgroup <1 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.77	0.00	-0.04	-0.18	-0.01	0.00	-0.03
$Log_{10}(WU_{t-4})$	0.77	1.00	0.00	-0.09	-0.12	0.01	-0.01	-0.01
$Log_{10}(T)$	0.00	0.00	1.00	0.06	0.14	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.04	-0.09	0.06	1.00	-0.08	-0.27	0.06	0.33
R	-0.18	-0.12	0.14	-0.08	1.00	-0.08	-0.08	0.24
D_2	-0.01	0.01	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	0.00	-0.01	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.03	-0.01	0.35	0.33	0.24	-0.33	-0.33	1.00

Appendix B: Correlation coefficient between the independent variables for sports grounds group

Table B1 Sports grounds group >15-20 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.36	0.08	-0.46	-0.51	0.48	-0.29	-0.63
$Log_{10}(WU_{t-4})$	0.36	1.00	0.73	-0.13	-0.27	-0.24	-0.59	0.32
$Log_{10}(T)$	0.08	.73	1.00	0.06	0.12	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.46	-0.13	0.06	1.00	-0.09	-0.27	0.06	0.33
R	-0.51	-0.27	0.12	-0.09	1.00	-0.08	-0.08	0.24
D_2	0.48	-0.24	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	-0.29	-0.59	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.63	0.32	0.35	0.33	0.24	-0.33	-0.33	1.00

Table B2 Sports grounds 1 in group >10-15 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.15	0.23	-0.45	-0.36	0.37	-0.38	-0.33
$Log_{10}(WU_{t-4})$	0.15	1.00	0.70	0.24	-0.09	-0.16	-0.60	0.20
$Log_{10}(T)$	0.23	0.70	1.00	0.06	0.12	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.45	0.24	0.06	1.00	-0.09	-0.27	0.06	0.33
R	-0.36	-0.09	0.12	-0.09	1.00	-0.08	-0.08	0.24
D_2	0.37	-0.16	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	-0.38	-0.60	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.33	0.20	0.35	0.33	0.24	-0.33	-0.33	1.00

Table B3 Sports grounds 2 in group >10-15 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	-0.01	-0.02	-0.54	-0.40	0.53	-0.21	-0.69
$Log_{10}(WU_{t-4})$	-0.01	1.00	0.83	0.01	0.06	-0.24	-0.68	0.36
$Log_{10}(T)$	-0.02	0.83	1.00	0.06	0.12	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.54	0.01	0.06	1.00	-0.09	-0.27	0.06	0.33
R	-0.40	0.06	0.12	-0.09	1.00	-0.08	-0.08	0.24
D_2	0.53	-0.24	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	-0.21	-0.68	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.69	0.36	0.35	0.33	0.24	-0.33	-0.33	1.00

Table B4 Sports grounds 3 in group >10-15 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.16	0.06	-0.32	-0.32	0.54	-0.35	-0.60
$Log_{10}(WU_{t-4})$	0.16	1.00	0.79	-0.04	0.02	-0.21	-0.68	0.36
$Log_{10}(T)$	0.06	0.79	1.00	0.06	0.12	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.32	-0.04	0.06	1.00	-0.09	-0.27	0.06	0.33
R	-0.32	0.02	0.12	-0.09	1.00	-0.08	-0.08	0.24
D_2	0.54	-0.21	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	-0.35	-0.68	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.60	0.36	0.35	0.33	0.24	-0.33	-0.33	1.00

Table B5 Sports grounds 4 in group >10-15 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.33	0.05	-0.46	-0.36	0.57	-0.34	-0.60
$Log_{10}(WU_{t-4})$	0.33	1.00	0.68	-0.22	-0.13	-0.20	-0.58	0.30
$Log_{10}(T)$	0.05	0.68	1.00	0.06	0.12	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.46	-0.22	0.06	1.00	-0.09	-0.27	0.06	0.33
R	-0.36	-0.13	0.12	-0.09	1.00	-0.08	-0.08	0.24
D_2	0.57	-0.20	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	-0.34	-0.58	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.60	0.30	0.35	0.33	0.24	-0.33	-0.33	1.00

Table B6 Sports grounds 5 in group >10-15 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.10	-0.03	-0.64	-0.27	0.56	-0.24	-0.68
$Log_{10}(WU_{t-4})$	0.10	1.00	0.88	-0.02	0.10	-0.22	-0.72	0.32
$Log_{10}(T)$	-0.03		1.00	0.06	0.12	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.64	-0.02	0.06	1.00	-0.09	-0.27	0.06	0.33
R	-0.27	0.10	0.12	-0.09	1.00	-0.08	-0.08	0.24
D_2	0.56	-0.22	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	-0.24	-0.72	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.68	0.32	0.35	0.33	0.24	-0.33	-0.33	1.00

Table B7 Sports grounds subgroup >9-10 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.20	-0.04	-0.36	-0.43	0.34	-0.12	-0.51
$Log_{10}(WU_{t-4})$	0.20	1.00	0.54	-0.11	-0.21	-0.12	-0.46	0.21
$Log_{10}(T)$	-0.04	0.54	1.00	0.06	0.12	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.36	-0.11	0.06	1.00	-0.09	-0.27	0.06	0.33
R	-0.43	-0.21	0.12	-0.09	1.00	-0.08	-0.08	0.24
D_2	0.34	-0.12	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	-0.12	-0.46	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.51	0.21	0.35	0.33	0.24	-0.33	-0.33	1.00

Table B8 Sports grounds subgroup >8-9 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.09	-0.05	-0.26	-0.42	0.42	-0.16	-0.53
$Log_{10}(WU_{t-4})$	0.09	1.00	0.55	-0.04	-0.20	-0.13	-0.47	0.18
$Log_{10}(T)$	-0.05	0.55	1.00	0.06	0.12	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.26	-0.04	0.06	1.00	-0.09	-0.27	0.06	0.33
R	-0.42	-0.20	0.12	-0.09	1.00	-0.08	-0.08	0.24
D_2	0.42	-0.13	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	-0.16	-0.47	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.53	0.18	0.35	0.33	0.24	-0.33	-0.33	1.00

Table B9 Sports grounds subgroup >7-8 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.34	-0.10	-0.47	-0.42	0.40	-0.10	-0.54
$Log_{10}(WU_{t-4})$	0.34	1.00	0.57	-0.25	-0.24	-0.05	-0.51	0.13
$Log_{10}(T)$	-0.10	0.57	1.00	0.06	0.12	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.47	-0.25	0.06	1.00	-0.09	-0.27	0.06	0.33
R	-0.42	-0.24	0.12	-0.09	1.00	-0.08	-0.08	0.24
D_2	0.40	-0.05	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	-0.10	-0.51	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.54	0.13	0.35	0.33	0.24	-0.33	-0.33	1.00

Table B10 Sports grounds subgroup >6-7 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.48	0.00	-0.34	-0.39	0.33	-0.16	-0.41
$Log_{10}(WU_{t-4})$	0.48	1.00	0.49	-0.06	-0.15	-0.10	-0.42	0.15
$Log_{10}(T)$	0.00	0.49	1.00	0.06	0.12	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.34	-0.06	0.06	1.00	-0.09	-0.27	0.06	0.33
R	-0.39	-0.15	0.12	-0.09	1.00	-0.08	-0.08	0.24
D_2	0.33	-0.10	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	-0.16	-0.42	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.41	0.15	0.35	0.33	0.24	-0.33	-0.33	1.00

Table B11 Sports grounds subgroup 5-6 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.35	0.00	-0.25	-0.34	0.29	-0.16	-0.33
$Log_{10}(WU_{t-4})$	0.35	1.00	0.40	-0.06	-0.18	-0.12	-0.31	0.14
$Log_{10}(T)$	0.00	0.40	1.00	0.06	0.13	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.25	-0.06	0.06	1.00	-0.09	-0.27	0.06	0.33
R	-0.34	-0.18	0.13	-0.09	1.00	-0.08	-0.08	0.24
D_2	0.29	-0.12	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	-0.16	-0.31	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.33	0.14	0.35	0.33	0.24	-0.33	-0.33	1.00

Table B12 Sports grounds subgroup >4-<5 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.30	0.01	-0.22	-0.35	0.29	-0.16	-0.36
$Log_{10}(WU_{t-4})$	0.30	1.00	0.43	-0.04	-0.17	-0.12	-0.35	0.17
$Log_{10}(T)$	0.01	0.43	1.00	0.06	0.13	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.22	-0.04	0.06	1.00	-0.09	-0.27	0.06	0.33
R	-0.35	-0.17	0.13	-0.09	1.00	-0.08	-0.08	0.24
D_2	0.29	-0.12	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	-0.16	-0.35	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.36	0.17	0.35	0.33	0.24	-0.33	-0.33	1.00

Table B13 Sports grounds subgroup >3-4 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.29	-0.03	-0.19	-0.36	0.24	-0.10	-0.31
$Log_{10}(WU_{t-4})$	0.29	1.00	0.37	0.00	-0.21	-0.06	-0.31	0.11
$Log_{10}(T)$	-0.03	0.37	1.00	0.06	0.13	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.19	0.00	0.06	1.00	-0.09	-0.27	0.06	0.33
R	-0.36	-0.21	0.13	-0.09	1.00	-0.08	-0.08	0.24
D_2	0.24	-0.06	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	-0.10	-0.31	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.31	0.11	0.35	0.33	0.24	-0.33	-0.33	1.00

Table B14 Sports grounds subgroup >2-3 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.43	-0.03	-0.19	-0.46	0.21	-0.09	-0.25
$Log_{10}(WU_{t-4})$	0.43	1.00	0.31	-0.13	-0.30	-0.05	-0.26	0.03
$Log_{10}(T)$	-0.03	0.31	1.00	0.06	0.13	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.19	-0.13	0.06	1.00	-0.09	-0.27	0.06	0.33
R	-0.46	-0.30	0.13	-0.09	1.00	-0.08	-0.08	0.24
D_2	0.21	-0.05	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	-0.09	-0.26	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.25	0.03	0.35	0.33	0.24	-0.33	-0.33	1.00

Table B15 Sports grounds subgroup 1-2 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.46	0.01	-0.07	-0.48	0.15	-0.11	-0.18
$Log_{10}(WU_{t-4})$	0.46	1.00	0.26	-0.08	-0.31	-0.07	-0.20	0.06
$Log_{10}(T)$	0.01	0.26	1.00	0.06	0.13	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.07	-0.08	0.06	1.00	-0.09	-0.27	0.06	0.33
R	-0.48	-0.31	0.13	-0.09	1.00	-0.08	-0.08	0.24
D_2	0.15	-0.07	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	-0.11	-0.20	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.18	0.06	0.35	0.33	0.24	-0.33	-0.33	1.00

Table B16 Sports grounds subgroup <1 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.68	0.01	-0.12	-0.32	0.04	-0.02	-0.10
$Log_{10}(WU_{t-4})$	0.68	1.00	0.10	-0.13	-0.28	0.02	-0.10	-0.03
$Log_{10}(T)$	0.01	0.10	1.00	0.06	0.12	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.12	-0.13	0.06	1.00	-0.09	-0.27	0.06	0.33
R	-0.32	-0.28	0.12	-0.09	1.00	-0.08	-0.08	0.24
D_2	0.04	0.02	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	-0.02	-0.10	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.10	-0.03	0.35	0.33	0.24	-0.33	-0.33	1.00

Appendix C: Correlation coefficient between the independent variables for Councils group

Table C1 Council 1 in group >20 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.57	0.02	-0.18	-0.85	0.22	-0.14	-0.32
$Log_{10}(WU_{t-4})$	0.57	1.00	0.30	-0.19	-0.44	-0.08	-0.23	0.06
$Log_{10}(T)$	0.02	0.30	1.00	0.06	0.12	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.18	-0.19	0.06	1.00	-0.09	-0.27	0.06	0.33
R	-0.85	-0.44	0.12	-0.09	1.00	-0.08	-0.08	0.24
D_2	0.22	-0.08	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	-0.14	-0.23	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.32	0.06	0.35	0.33	0.24	-0.33	-0.33	1.00

Table C2 Council 2 in group >20 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.08	0.00	-0.39	-0.20	0.32	-0.21	-0.24
$Log_{10}(WU_{t-4})$	0.08	1.00	0.34	-0.44	-0.26	-0.15	-0.20	0.00
$Log_{10}(T)$	0.00	0.34	1.00	0.06	0.12	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.39	-0.44	0.06	1.00	-0.09	-0.27	0.06	0.33
R	-0.20	-0.26	0.12	-0.09	1.00	-0.08	-0.08	0.24
D_2	0.32	-0.15	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	-0.21	-0.20	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.24	0.00	0.35	0.33	0.24	-0.33	-0.33	1.00

Table C3 Council 3 in group >20 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.11	-0.03	-0.53	-0.31	0.55	-0.29	-0.54
$Log_{10}(WU_{t-4})$	0.11	1.00	0.74	-0.12	-0.08	-0.24	-0.54	0.22
$Log_{10}(T)$	-0.03	0.74	1.00	0.06	0.12	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.53	-0.12	0.06	1.00	-0.09	-0.27	0.06	0.33
R	-0.31	-0.08	0.12	-0.09	1.00	-0.08	-0.08	0.24
D_2	0.55	-0.24	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	-0.29	-0.54	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.54	0.22	0.35	0.33	0.24	-0.33	-0.33	1.00

Table C4 Council 4 in group >20 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.59	0.14	0.34	0.17	0.08	-0.18	-0.22
$Log_{10}(WU_{t-4})$	0.59	1.00	0.10	0.10	0.29	-0.11	0.21	-0.18
$Log_{10}(T)$	0.14	0.10	1.00	0.34	0.39	-0.47	-0.15	-0.27
$Log_{10}(Rn)$	0.34	0.10	0.34	1.00	0.06	0.12	-0.41	-0.68
R	0.17	0.29	0.39	0.06	1.00	-0.09	-0.27	0.06
D_2	0.08	-0.11	-0.47	0.12	-0.09	1.00	-0.08	-0.08
D_3	-0.18	0.21	-0.15	-0.41	-0.27	-0.08	1.00	-0.33
D_4	-0.22	-0.18	-0.27	-0.68	0.06	-0.08	-0.33	1.00

Table C5 Council 1 in group >15-20 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.31	0.00	-0.21	-0.33	0.33	-0.19	-0.31
$Log_{10}(WU_{t-4})$	0.31	1.00	0.40	0.03	-0.45	-0.15	-0.28	0.07
$Log_{10}(T)$	0.00	0.40	1.00	0.06	0.12	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.21	0.03	0.06	1.00	-0.09	-0.27	0.06	0.33
R	-0.33	-0.45	0.12	-0.09	1.00	-0.08	-0.08	0.24
D_2	0.33	-0.15	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	-0.19	-0.28	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.31	0.07	0.35	0.33	0.24	-0.33	-0.33	1.00

Table C6 Council 2 in group >15-20 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	-0.43	-0.09	-0.25	-0.20	-0.11	0.21	0.05
$Log_{10}(WU_{t-4})$	-0.43	1.00	-0.50	-0.13	0.20	0.42	0.27	-0.43
$Log_{10}(T)$	-0.09	-0.50	1.00	0.06	0.12	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.25	-0.13	0.06	1.00	-0.09	-0.27	0.06	0.33
R	-0.20	0.20	0.12	-0.09	1.00	-0.08	-0.08	0.24
D_2	-0.11	0.42	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	0.21	0.27	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	0.05	-0.43	0.35	0.33	0.24	-0.33	-0.33	1.00

Table C7 Council 3 in group >15-20 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	-0.02	-0.02	0.20	0.07	-0.18	0.04	0.17
$Log_{10}(WU_{t-4})$	-0.02	1.00	0.02	-0.34	0.48	-0.06	0.01	0.21
$Log_{10}(T)$	-0.02	0.02	1.00	0.06	0.12	-0.41	-0.68	0.35
$Log_{10}(Rn)$	0.20	-0.34	0.06	1.00	-0.09	-0.27	0.06	0.33
R	0.07	0.48	0.12	-0.09	1.00	-0.08	-0.08	0.24
D_2	-0.18	-0.06	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	0.04	0.01	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	0.17	0.21	0.35	0.33	0.24	-0.33	-0.33	1.00

Table C8 Council 4 in group >15-20 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	-0.06	-0.24	-0.10	0.09	0.58	-0.04	-0.70
$Log_{10}(WU_{t-4})$	-0.06	1.00	0.77	0.07	0.42	-0.17	-0.66	0.28
$Log_{10}(T)$	-0.24	0.77	1.00	0.06	0.12	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.10	0.07	0.06	1.00	-0.09	-0.27	0.06	0.33
R	0.09	0.42	0.12	-0.09	1.00	-0.08	-0.08	0.24
D_2	0.58	-0.17	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	-0.04	-0.66	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.70	0.28	0.35	0.33	0.24	-0.33	-0.33	1.00

Table C9 Council 1 in group >10-15 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.58	0.16	-0.09	-0.58	0.14	-0.32	0.16
$Log_{10}(WU_{t-4})$	0.58	1.00	0.11	-0.18	-0.28	-0.24	0.13	-0.11
$Log_{10}(T)$	0.16	0.11	1.00	0.06	0.12	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.09	-0.18	0.06	1.00	-0.09	-0.27	0.06	0.33
R	-0.58	-0.28	0.12	-0.09	1.00	-0.08	-0.08	0.24
D_2	0.14	-0.24	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	-0.32	0.13	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	0.16	-0.11	0.35	0.33	0.24	-0.33	-0.33	1.00

Table C10 Council 2 in group >10-15 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.52	-0.15	0.48	0.25	0.07	0.09	-0.08
$Log_{10}(WU_{t-4})$	0.52	1.00	0.01	0.29	0.04	0.07	-0.14	0.06
$Log_{10}(T)$	-0.15	0.01	1.00	0.06	0.12	-0.41	-0.68	0.35
$Log_{10}(Rn)$	0.48	0.29	0.06	1.00	-0.09	-0.27	0.06	0.33
R	0.25	0.04	0.12	-0.09	1.00	-0.08	-0.08	0.24
D_2	0.07	0.07	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	0.09	-0.14	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.08	0.06	0.35	0.33	0.24	-0.33	-0.33	1.00

Table C11 Council 3 in group >10-15 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.17	-0.14	-0.65	-0.28	0.44	-0.03	-0.70
$Log_{10}(WU_{t-4})$	0.17	1.00	0.74	-0.18	-0.11	-0.03	-0.71	0.19
$Log_{10}(T)$	-0.14	0.74	1.00	0.06	0.12	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.65	-0.18	0.06	1.00	-0.09	-0.27	0.06	0.33
R	-0.28	-0.11	0.12	-0.09	1.00	-0.08	-0.08	0.24
D_2	0.44	-0.03	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	-0.03	-0.71	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.70	0.19	0.35	0.33	0.24	-0.33	-0.33	1.00

Table C12 Council 4 in group >10-15 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.08	0.19	-0.46	0.08	-0.11	-0.03	-0.01
$Log_{10}(WU_{t-4})$	0.08	1.00	-0.06	-0.23	-0.27	-0.03	0.08	0.01
$Log_{10}(T)$	0.19	-0.06	1.00	0.06	0.12	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.46	-0.23	0.06	1.00	-0.09	-0.27	0.06	0.33
R	0.08	-0.27	0.12	-0.09	1.00	-0.08	-0.08	0.24
D_2	-0.11	-0.03	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	-0.03	0.08	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.01	0.01	0.35	0.33	0.24	-0.33	-0.33	1.00

Table C13 Council 5 in group >10-15 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	-0.07	0.30	-0.35	0.09	0.49	-0.60	-0.38
$Log_{10}(WU_{t-4})$	-0.07	1.00	0.68	0.29	-0.27	-0.52	-0.36	0.40
$Log_{10}(T)$	0.30	0.68	1.00	0.06	0.12	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.35	0.29	0.06	1.00	-0.09	-0.27	0.06	0.33
R	0.09	-0.27	0.12	-0.09	1.00	-0.08	-0.08	0.24
D_2	0.49	-0.52	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	-0.60	-0.36	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.38	0.40	0.35	0.33	0.24	-0.33	-0.33	1.00

Table C14 Council subgroup >9-10 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.42	0.02	-0.44	-0.42	0.34	-0.18	-0.42
$Log_{10}(WU_{t-4})$	0.42	1.00	0.51	-0.22	-0.13	-0.11	-0.40	0.15
$Log_{10}(T)$	0.02	0.51	1.00	0.06	0.12	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.44	-0.22	0.06	1.00	-0.09	-0.27	0.06	0.33
R	-0.42	-0.13	0.12	-0.09	1.00	-0.08	-0.08	0.24
D_2	0.34	-0.11	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	-0.18	-0.40	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.42	0.15	0.35	0.33	0.24	-0.33	-0.33	1.00

Table C15Council subgroup >8-9 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.27	0.23	0.03	-0.71	0.07	-0.31	0.07
$Log_{10}(WU_{t-4})$	0.27	1.00	0.21	-0.13	-0.20	-0.10	-0.11	0.06
$Log_{10}(T)$	0.23	0.21	1.00	0.06	0.12	-0.41	-0.68	0.35
$Log_{10}(Rn)$	0.03	-0.13	0.06	1.00	-0.09	-0.27	0.06	0.33
R	-0.71	-0.20	0.12	-0.09	1.00	-0.08	-0.08	0.24
D_2	0.07	-0.10	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	-0.31	-0.11	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	0.07	0.06	0.35	0.33	0.24	-0.33	-0.33	1.00

Table C16 Council subgroup >7-8 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.54	0.04	-0.17	-0.23	0.09	-0.07	-0.13
$Log_{10}(WU_{t-4})$	0.54	1.00	0.14	-0.15	-0.12	-0.06	-0.10	0.06
$Log_{10}(T)$	0.04	0.14	1.00	0.06	0.12	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.17	-0.15	0.06	1.00	-0.09	-0.27	0.06	0.33
R	-0.23	-0.12	0.12	-0.09	1.00	-0.08	-0.08	0.24
D_2	0.09	-0.06	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	-0.07	-0.10	-0.68	0.06	-0.08		1.00	-0.33
D_4	-0.13	0.06	0.35	0.33	0.24	-0.33	-0.33	1.00

Table C17 Council subgroup >6-7 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.23	0.06	-0.09	-0.24	0.18	-0.16	-0.22
$Log_{10}(WU_{t-4})$	0.23	1.00	0.31	0.01	0.00	-0.15	-0.21	0.17
$Log_{10}(T)$	0.06	0.31	1.00	0.06	0.12	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.09	0.01	0.06	1.00	-0.09	-0.27	0.06	0.33
R	-0.24	0.00	0.12	-0.09	1.00	-0.08	-0.08	0.24
D_2	0.18	-0.15	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	-0.16	-0.21	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.22	0.17	0.35	0.33	0.24	-0.33	-0.33	1.00

Table C18 Council subgroup 5-6 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.31	0.04	-0.17	-0.18	0.22	-0.14	-0.27
$Log_{10}(WU_{t-4})$	0.31	1.00	0.33	0.18	-0.04	-0.11	-0.27	0.17
$Log_{10}(T)$	0.04	0.33	1.00	0.06	0.12	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.17	0.18	0.06	1.00	-0.09	-0.27	0.06	0.33
R	-0.18	-0.04	0.12	-0.09	1.00	-0.08	-0.08	0.24
D_2	0.22	-0.11	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	-0.14	-0.27	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.27	0.17	0.35	0.33	0.24	-0.33	-0.33	1.00

Table C19 Council subgroup >4-<5 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.28	-0.02	-0.16	-0.29	0.19	-0.07	-0.25
$Log_{10}(WU_{t-4})$	0.28	1.00	0.27	0.02	-0.05	-0.02	-0.25	0.09
$Log_{10}(T)$	-0.02	0.27	1.00	0.06	0.13	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.16	0.02	0.06	1.00	-0.09	-0.27	0.06	0.33
R	-0.29	-0.05	0.13	-0.09	1.00	-0.08	-0.08	0.24
D_2	0.19	-0.02	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	-0.07	-0.25	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.25	0.09	0.35	0.33	0.24	-0.33	-0.33	1.00

Table C20 Council subgroup >3-4 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.39	0.01	-0.22	-0.25	0.16	-0.09	-0.20
$Log_{10}(WU_{t-4})$	0.39	1.00	0.25	-0.05	-0.13	-0.07	-0.17	0.06
$Log_{10}(T)$	0.01	0.25	1.00	0.06	0.13	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.22	-0.05	0.06	1.00	-0.09	-0.27	0.06	0.33
R	-0.25	-0.13	0.13	-0.09	1.00	-0.08	-0.08	0.24
D_2	0.16	-0.07	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	-0.09	-0.17	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.20	0.06	0.35	0.33	0.24	-0.33	-0.33	1.00

Table C21 Council subgroup >2-3 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.34	-0.04	-0.14	-0.24	0.18	-0.06	-0.22
$Log_{10}(WU_{t-4})$	0.34	1.00	0.25	-0.03	-0.13	-0.02	-0.23	0.04
$Log_{10}(T)$	-0.04	0.25	1.00	0.06	0.13	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.14	-0.03	0.06	1.00	-0.09	-0.27	0.06	0.33
R	-0.24	-0.13	0.13	-0.09	1.00	-0.08	-0.08	0.24
D_2	0.18	-0.02	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	-0.06	-0.23	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.22	0.04	0.35	0.33	0.24	-0.33	-0.33	1.00

Table C22 Council subgroup 1-2 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.48	0.02	-0.18	-0.24	0.15	-0.09	-0.19
$Log_{10}(WU_{t-4})$	0.48	1.00	0.24	-0.08	-0.11	-0.06	-0.18	0.06
$Log_{10}(T)$	0.02	0.24	1.00	0.06	0.13	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.18	-0.08	0.06	1.00	-0.09	-0.27	0.06	0.33
R	-0.24	-0.11	0.13	-0.09	1.00	-0.08	-0.08	0.24
D_2	0.15	-0.06	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	-0.09	-0.18	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.19	0.06	0.35	0.33	0.24	-0.33	-0.33	1.00

Table C23 Council subgroup <1 ML

Pearson Correlation	$Log_{10}(WU_{t-1})$	$Log_{10}(WU_{t-4})$	$Log_{10}(T)$	$Log_{10}(R_n)$	R	D_2	D_3	D_4
$Log_{10}(WU_{t-1})$	1.00	0.78	-0.01	-0.03	-0.09	0.01	0.01	-0.02
$Log_{10}(WU_{t-4})$	0.78	1.00	0.02	-0.05	-0.06	0.01	-0.02	-0.02
$Log_{10}(T)$	-0.01	0.02	1.00	0.06	0.13	-0.41	-0.68	0.35
$Log_{10}(Rn)$	-0.03	-0.05	0.06	1.00	-0.09	-0.27	0.06	0.33
R	-0.09	-0.06	0.13	-0.09	1.00	-0.08	-0.08	0.24
D_2	0.01	0.01	-0.41	-0.27	-0.08	1.00	-0.33	-0.33
D_3	0.01	-0.02	-0.68	0.06	-0.08	-0.33	1.00	-0.33
D_4	-0.02	-0.02	0.35	0.33	0.24	-0.33	-0.33	1.00