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Evaluation of sustainability index for urban water management system in Macau

by

IRIS, LUO SHIMING

Final Year Project Report submitted in partial fulfillment of the requirement of the Degree of

Bachelor of Science in Civil Engineering

2014

Faculty of Science and Technology
University of Macau

DECLARATION

I declare that the project report here submitted is original except for the source materials explicitly acknowledged and that this report as a whole, or any part of this report has not been previously and concurrently submitted for any other degree or award at the University of Macau or other institutions.

I also acknowledge that I am aware of the Rules on Handling Student Academic Dishonesty and the Regulations of the Student Discipline of the University of Macau.

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APPROVAL FOR SUBMISSION

This project report entitled "**Evaluation of sustainability index for urban water management system in Macau**" was prepared by IRIS, LUO SHIMING in partial fulfillment of the requirements for the degree of Bachelor of Science in Civil Engineering at the University of Macau.

Endorsed by,

Signature : ______________________________

Supervisor : Dr. LOU In Chio

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ABSTRACT

Sustainable development of urban water management system is a challenging topic worldwide. Macau is a city which lacks of raw water resources and experiences high pressure in population and economic growth for the recent years. In this study, an evaluation of sustainability index of urban water has been established. It first starts with a general overview for the current urban water situation in Macau, and follows by the analysis of sustainability index using eighteen sustainability indicators from four dimensions, namely social, namely the perspectives of social, economic, environmental and engineering. The evaluation is mainly based on the equal weighting method, while CRITIC method and AHP method are further adopted in this study to conduct a more comprehensive discussion.

Results from the three weighting methods demonstrate that the latest overall urban water sustainability index is in range of 0.55 to 0.65, which is consistent with moderate sustainable level. Deeper consideration is conducted from four dimensions which can be found out that the social dimension maintained relatively high level, the economic dimension experienced instability, while environmental and engineering dimensions have declining tendency during the investigated time period.

From the study, it can be concluded that the sustainability index is effective to provide an overall view about the level of sustainable development of urban water system in Macau. The sustainability index increases gradually in the recent year which implies a move towards sustainable development. Environmental dimension, with the lowest index among all four dimensions, has higher potential of improvement. Further research and the implement in sustainable urban water strategy are necessary in achieving the goal of the sustainable development in Macau.

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CHAPTER 1 INTRODUCTION

1.1 BACKGROUND

With rapid development in the economy, the consumption of water resources tends to increase. The situation that the demand of water exceeds the supply is becoming more and more severe. For those countries or cities which have large population or under rapid population growth, the problem is even more serious. As a result, it is necessary for the decision makers to come up with effectively urban water management system. In order to achieve the goal, the preliminary work is to conduct a comprehensive analysis about the urban water sustainability of the city for the past decade.

The urban water system is a complex system which consists of several subsystems including water supply, water demand and wastewater generation subsystems etc. The urban water resources consist of all the natural water resources and renewable water resources. The urban water system is the basis of formation and development of cities. Furthermore, it is strongly related to the population, economic development as well as the ecological and environmental quality. Hence, only improving the performance of the water supply system is not sufficient to enhance the overall efficiency of urban water resources utilization.

The rapid growth in population, economy and tourist put much pressure on the urban water system. A structured framework for multidimensional assessment of urban water system is developed in this study and it is applied to Macau SAR as a case study. This study is based on previous sustainability index assessment with improvement in the structure, scale in order to make it more applicable to the situation in Macau.

1.2 A CASE STUDY IN MACAU

Macau is selected as the research area in this study. Reasons for selecting Macau are mainly due to great population pressure and limited water resources. The population pressure comes from the natural growth rate, nonlocal employees and tourist visitors. From data shown in 2013, the total population in Macau was 607,000 with total land area of 29.9 square kilometers. For natural resources, Macau lacks of raw water resources all the time. People used to rely on rainfall and well water in the ancient time. Currently, about 98% of water supply is imported from the nearest city Zhuhai. However, the total water consumption in Macau reached 84,577,744 per day in 2012. The urban water system has more apparent influence on the urban development of Macau. Therefore, it is necessary to develop framework to analyze the existing urban water situation in order to gain future sustainable development. This study provides a research for sustainability urban water assessment in Macau through evaluation of the sustainability index.

According to Lai,E. *et al*. (2008), the integrated sustainability assessment is part of a new paradigm for urban water decision making and Multi criteria decision analysis is an integrative frame work used in urban water sustainability assessment. In this study, the literature review in Chapter 2 gives a description of the previous researches about urban water management system and sustainability study. Chapter 3 develops an overview of current water conditions in Macau including analysis of the population change, water consumption, wastewater treatment condition etc. Chapter 4 provides illustration about the chosen dimensions and the selected indicators in each dimension so as to obtain a comprehensive analysis. Calculations are made for the sustainability index using equal weighting method as basis and two other multi-criteria methods as supplementary analysis. With the results shown in Chapter 5, discussion and comparison of the analytical results can be obtained. Finally in Chapter 6, conclusion of this study and recommendations for the future work are presented.

1.3 OBJECTIVE OF THE STUDY

The main purpose of this study is to generate systematic approaches to develop sustainability index that could be used to assess the sustainability of urban water management systems in Macau, which is expressed to be achieved from the following perspectives. First of all, the current status of urban water situation in Macau is summarized. Secondly, the concept of urban water sustainability index and evaluate the index is introduce from four dimensions including social, economic, environmental and engineering dimensions during the investigated time period 2003 to 2012. Thirdly, comparative analysis is conducted between CRITIC Method and AHP method with the Equal Weighting Method in evaluating the urban water sustainability index. Lastly, future prospects are investigated by adopting the renewable water plan 2013-2022.

CHAPTER 2 LITERATURE REVIEW

2.1 URBAN WATER RESOURCE MANAGEMENT

One of the definitions about sustainable water resource system provided by Loucks(1997) is defined as the system designed and managed to contribute fully to the objective of society, now and in the future, at the meanwhile their ecological, environmental and hydrological integrity are maintained. From Morrison,G. *et al.*(2001), the need of freshwater resources consumption is rising worldwide, however, the environmental deterioration and excessive use of limited resources are placing pressure in the urban water and wastewater system. Larsen and Gujer (1997) suggested that functions performed by the urban water system are the water supply, wastewater treatment, urban water for agriculture etc. In some part of the world, lack of fresh drinking water and sufficient sanitation are still existing problems. Solis,S.S. *et al*. (2011) believed it is becoming more and more difficult to achieve sustainable water resource system because of environmental consideration, water scarcity and climate change. Therefore, Evaluation of current situation is necessary in order to obtain comprehensive system in urban water management.

2.2 ASSESSMENT OF SUSTAINABLE DEVELOPMENT

The Sustainable integrated water management (SIUWM) suggests that the sustainable indicators are the useful tool for sustainability analysis. According to Kate *et al*. (2001) the purpose of sustainability assessment is to provide decision makers with an evaluation of global to local integrated nature-society systems in short-term and long-term perspectives so as to assist them to examine which actions should be taken into account and which should not to obtain sustainable development. Kori (2011) suggested that the city sustainability index provides guidance to assess sustainability performance in a city with respect to the environmental, human life and economical aspects.

Hence, it is essential to perform system analysis of the entire urban water cycle by developing sustainability index to measure urban sustainability. Luc,A.A. *et al*. (2004) provided the evaluation for sustainable development and based on fuzzy logic reasoning and sensitivity analysis which used fuzzy logical reasoning and basic indicator to perform modeling in social, economic and environmental aspects. Lee and Huang (2007) developed the sustainability index for Taipei from 51 indicators in 4 dimensions with statistic data adopted through equal weighting method. Tian *et al*. (2010) carried out the sustainable utilization of water resources in Jinan city can be analyzed by two types of index, the development index and the restricting index. Higher value in development index represents a better sustainable utilization of urban resources. One the contrary, the higher value in restricting index indicates a larger restriction in sustainable urban resources utilization. An integrated frame work investigated by Popawala and Shah (2011) regarding to urban water sustainability assessment was achieved by the multi criteria decision analysis.

There are different sustainability assessment methodologies which have been developed in previous research for the sustainability evaluation and they are considered as reference in this study.

2.3 SUSTAINABLE DEVELOPMENT INDICATOR

The sustainable development indicator was first established in developed countries and continuously developing in developing countries in the recent year. Though sustainable development indicators, sustainability index can then be obtained.

Lundin (2003) proposed that indicator is a piece of information which indicates significant property and give trends to relevant target group. The development indicators can be used to carry out comparison, conduct early warning information and to forecast of the future prospect. According to Palme (2010), development indicators have different functions which sometime may overlap. Morrison *et al*. (2000) expressed that the development indicators provide information from different dimensions and generalize the properties from each dimension in order to give useful information to decision makers. To development indicator for particular area, firstly, the system should be divided into several indicators based on several criteria. Then case studies are conducted for examining all indicators and come out with those which are proved to be effective. Those indicators are chosen for further assessment of the sustainability index in that study area.

2.4 METHOD OF WEIGHTING

The weighting methods for sustainability assessment include Equal Weighting Method, Criteria Importance Through Intercriteria Correlation (CRITIC) and Analysis Hierarchy Process (AHP) which were evaluated in order to determine their priorities in different circumstances. There is also combination weighting method which combines the subjective and objective weight to obtain comprehensive weighting. Liu and Zhao (2013) introduced the idea of the subjective and objective approach should both be considered in index weighing determination. Therefore, both subjective and objective weighting methods are evaluated in this study in order to obtain a more comprehensive assessment.

2.4.1 CRITIC Method

CRITIC Method developed by Diakoulaki (1995) estimates the inter-criteria significance among the investigated indicators which reflects an objective approach other than the subjective one. The CRITIC method can be used to obtain the objective weighting which enable the incorporation of interdependent criteria and prevent the intervention of subjective approach. CRITIC method is also proved to be a straightforward method which does not need excessive computational effort. From Zhao *et al.* (2011), the CRITIC method was proposed in the evaluation of HPLC fingerprints while the weightings derived by CRITIC were mainly based on the evaluation matrix for extracting the information in the evaluation criteria. Recent study by Liu and Zhao (2013) adopted CRITIC Method in the assessment to dispose the object data by applying comparative information among the selected indicators.

2.4.2 AHP Method

AHP Method developed by Saaty *et al*. (1980) is performed using the subjective approach through a systematical hierarchical system model to evaluate relative importance between the investigated indicators. The basic steps of AHP method are: 1) identify the problem 2)identify the elements which influence the overall behavior 3) analysis the system through a hierarchical approach 4) make comparison among each element and evaluation for a numerical scale. The scales of AHP method range from 1 to 9 while scales 1, 3, 5, 7, 9 are used more commonly (to 1 for “equal” and to 9 for “absolutely more important than”.

Wolfslehner *et al.* (2005) adopted the analytic network process in analysis of the sustainable forest management, the overall priorities had to be obtained by the single indicators priorities and the cumulative priorities were ranked from 4 different dimensions of management strategies. Recent study implies that the AHP method is widely used in optimizing, planning, allocating of resources, forecasting and other multi criteria decision making process. According to Vaidy and Kumar (2004), the AHP method is used with combination of other techniques in developed countries such as US which can take advantage of AHP with other techniques while developing countries such as India use the analytic hierarchy process in economic developing assessment.

2.4.3 Combined Weighting Method

Combined Weighting Method is a combination of more than one weighting methods in order to gain a more comprehensive analysis. Liu and Zhao (2013) proposed a combination of AHP method and CRITIC method in the study to determine the index weighting in evaluation the regional environmental risk in China from 2003 to 2007. This kind of method contains both subjective and objective approach. Recent study implies that the combination weighting method applies much more data information which ensures a better accuracy in the weighting of sustainable development.

CHAPTER 3 OVERVIEW OF URBAN WATER SITUATION

3.1 WATER RESOURCES

3.1.1 General situation

Figure 3.1 Map of Macau

Macau is located at wthe western side of the Pearl River Delta near Guangdong Province which consists of three main parts, Macau Peninsula, Taipa Island and

Coloane Island. Because of the location in the south of the Tropic of Cancer, it is influenced greatly by the monsoon climate and the ocean. Also, Macau is under subtropical marine climate which leads to a relatively warm weather in winter. The average temperature is approximately 22.3ºC and the annual amplitude of temperature change is about 14ºC. The average rainfall is about 2,000 mm and it is one of the areas in southern China which has large amount of rainfall, especially in the rainy seasons during April to September.

Because of limited land resources in Macau, large water reservoir cannot be built inside the city so that the raw water resources are limited. In the ancient time, people in Macau used to rely on well water or rainfall. Nowadays, there are two main reservoirs in Macau, the MSR and the Seac Pai Wan Reservoir with total capacity of 1.9 million m^3. About 98% raw water in Macau comes from Zhuhai city and the other 2% of fresh water comes from rainfall collected by two reservoirs in Macau. The water supply system in Zhuhai consists of three subsystems, the southern supply system, the northern supply system and the eastern water transfer system. At present, most of the raw water used in Macau is imported from Modaomen Reservoir in Zhuhai which is a part of the southern supply system and the total water capacity is about 3.48 million m^3. The rest of the raw water resources come from the MSR in Macau Peninsula and the Seac Pai Van Reservoir which is located in Coloane.

As the global warming becomes an international problem and the water flow rate in Pearl River is decreasing year by year, the influence caused by the salt tides becomes larger. Also, the rainfall amount in Macau decreases and the cost of raw water treatment increases year by year. There are many reasons which limit the provision of water resources to Macau.

Regarding to the costal water properties, there are twelve monitoring points located around Macau such as in the airport, Hac Sa and etc. In 2012, the costal water quality had great improvement compared to previous years mainly due to the reduction in metal pollutant.

3.1.2 Water Supply Area

Figure 3.2 Water supply area of IV Plant

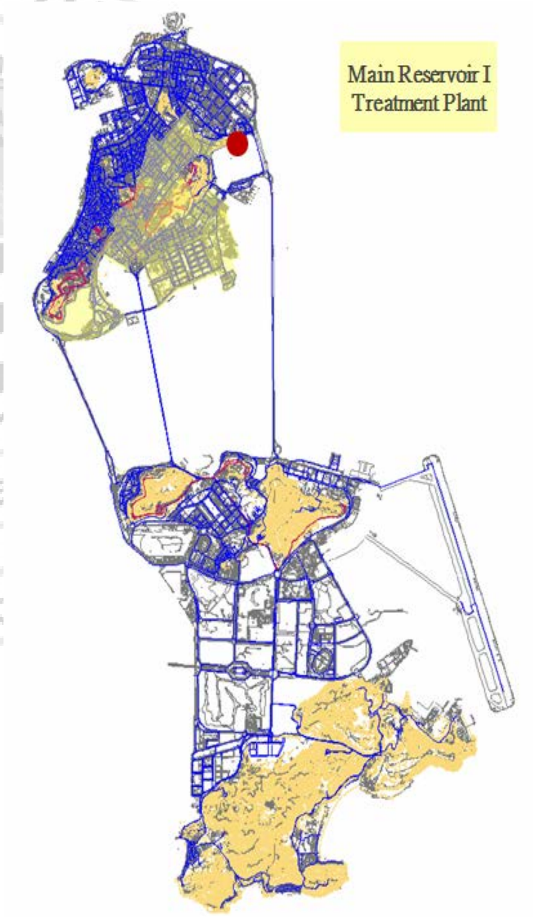

Figure 3.3 Water supply area of MSR I

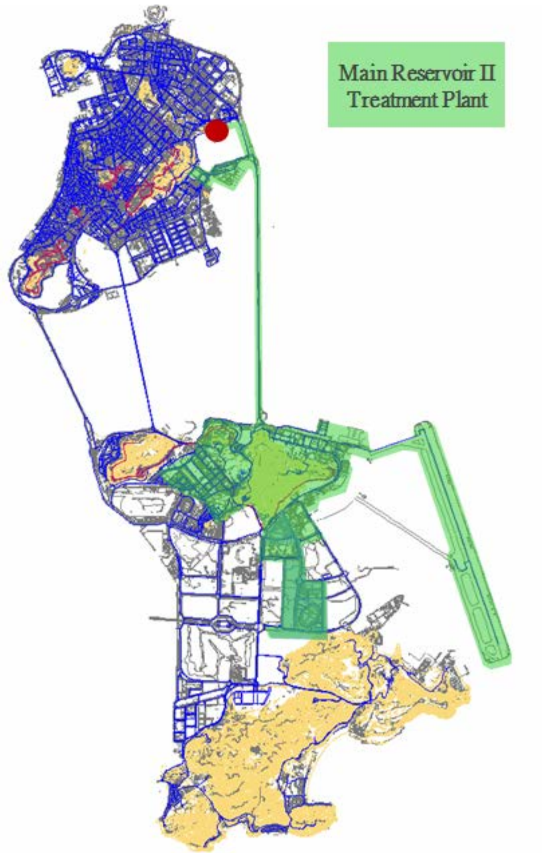

Figure 3.4 Water supply area of MSR II

Figure 3.5 Water supply area of Coloane Plant

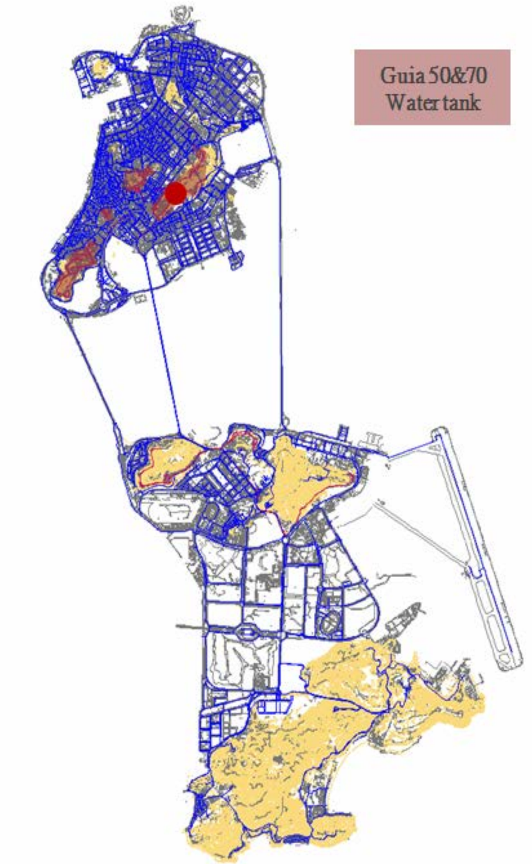

Figure 3.6 Water supply area of Guia tank

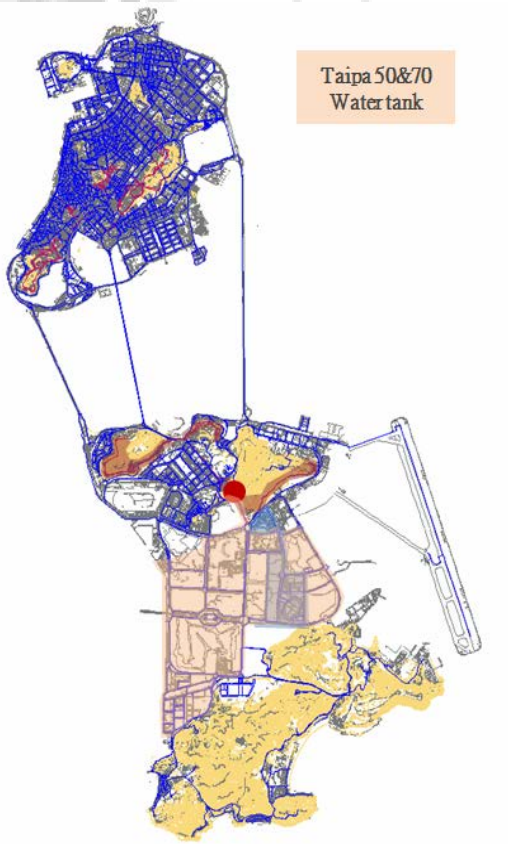

Figure 3.7 Water supply area of Taipa tank

Figure 3.2 to Figure 3.7 show about the water supply areas for the four water plants and two water tanks in Macau. The Ilha Verde Water Plant (IV) mainly supplies water to northern and western districts of Macau Peninsula and the western district of Taipa Island. The Main Reservoir Water Plant I (MSRI) mainly supplies water to central district of Macau Peninsula. The Main Reservoir Water Treatment Plant II (MSRII) mainly supplies water to southeast district of Macau Peninsula and eastern district of Taipa Island. The Coloane Water Plant mainly supplies water to Coloane Island. These four water plants have different supply areas and provide water to residents in different districts in order to meet the need of Macau.

3.1.2 Characteristics of water usage

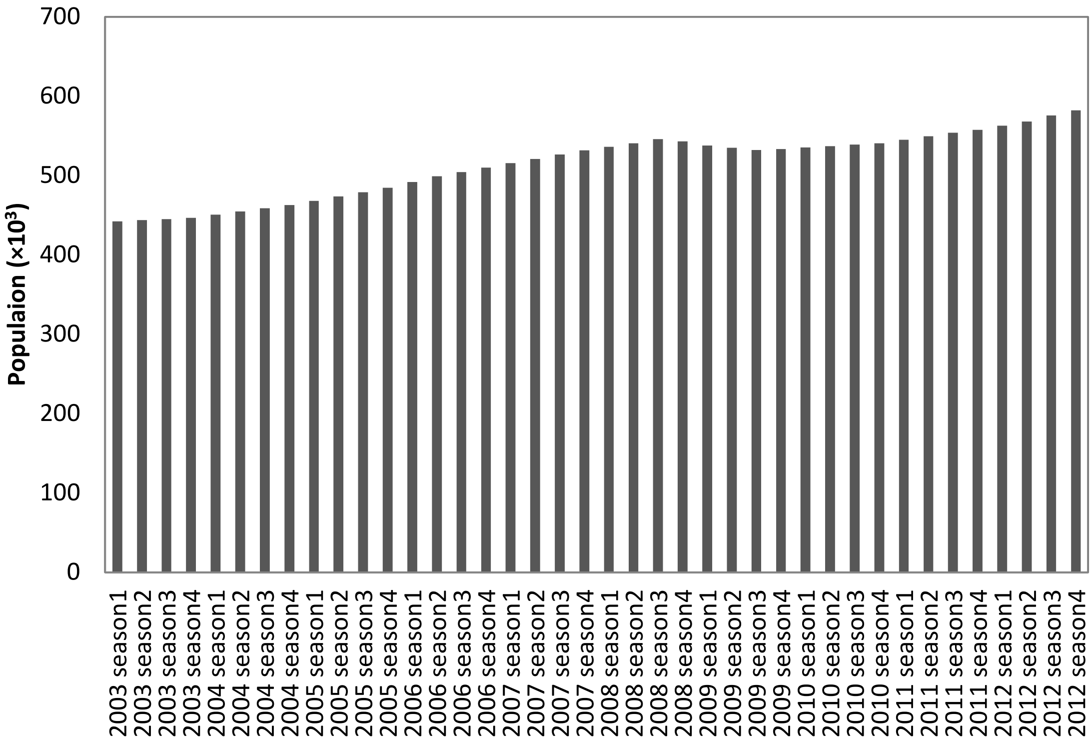

Figure 3.8 Estimated population in Macau

Over 95% of the raw water resources in Macau come from Zhuhai, the chain of water supply network is single. Besides, the non-traditional water utilization rate is low such as the utilization, rainfall and seawater. The population in Macau is growing and

Macau is proved to be one of the cities which have the highest population density in the world as shown in Figure 3.8. Hence, the challenge to supply enough water to all residents in Macau is getting larger. Not only the population in Macau is increasing, so as the amount of tourists. As Macau concentrates on developing its tourism and defines itself as the city of international tourism, more and more large casinos and hotels have been built up which attract more and more tourists from all over the world. The development of tourism gives rise to the water consumption and also increases the reliance of raw water resources from Zhuhai.

The increase in water consumption leads to the increase of wastewater generation and the pressure of the wastewater treatment plants. Macau government carries out measures to solve the problem such as introduce advanced technology in order to enlarger wastewater treatment capacity and the develop recycle water management. The wastewater can be treated in order to remove the pollutants and recycle water can be used to flash toilets, greening and landscape. The utilization of recycle water can reduce the emission of wastewater and slow down the pollution to the ocean.

The water customer types in Macau can be basically divided into three categories-industrial, governmental and residential. The water price is the same to all customers in Macau before 2011, but this kind of water price cannot reflect the value of water resources in different customers. As a result, the water supply company changed the water price system in January of 2011 from charging the same price to charging different prices according to different users. In this new water price system, better allocation of the water resources is achieved. However, there are still no price difference between different seasons such as the dry seasons and the rainy seasons. During the dry seasons, the water resources become limited but the same water price throughout the year cannot remind the customers to cherish water resources during dry seasons. Therefore, due to the current situation in Macau, searching for a better water price system such as charging different price according to different seasons and customers are in great need.

Although Macau has shortage in raw water resources, the water supply amount is ensured to satisfy the need of different customers in Macau with regional cooperation with Zhuhai. But because of low water price and weak water saving consciousness of some customers, the waste of water resource becomes a serious problem. In order to save water, the government encourages building up a water-saving society. It is greatly needed to strengthen the awareness of water saving on occasions such as school, government or company especially in large hotel and casino. Besides, the water supply company should be able to develop new facilities, so that the water loss rate can be maintained in a low value or further reduced.

Apart from the measures which already exist, there are also other ways to improve the water system in Macau. Seawater utilization is proved to be a good way to solve water resources shortage and it gains more and more attention in developed countries. Macau is located in the area by sea which has abundant seawater resources. Better usage of seawater can reduce the raw water supply pressure. At present, the utilization of seawater and rainfall are in their infancy. As for the utilization of seawater, because of the limitation in the seawater purification technology and high cost, the recycle system of seawater resource has not been developed. Compare to Hong Kong, which is also located at the side of Pearl River Delta, the surrounding seawater in Macau has higher sand content and lower water quality. The utilization of seawater requires large amount of investment. However, with the increasing pressure of supply and demand in raw water, it is needed to further speed up the development of seawater resource utilization.

Also, the rainfall collection is another effective way to save water. It has advantages of low-cost and the rain collected can be used for industrial, toilets flash and landscape through simple treatment process. Macau has limited land resource and large population, but it rains a lot during rainy seasons. The utilization of rainfall can open up a way to save more water resources in the water system.

3.2 WATER SUPPLY CONDITION

3.2.1 Total Water Supplement

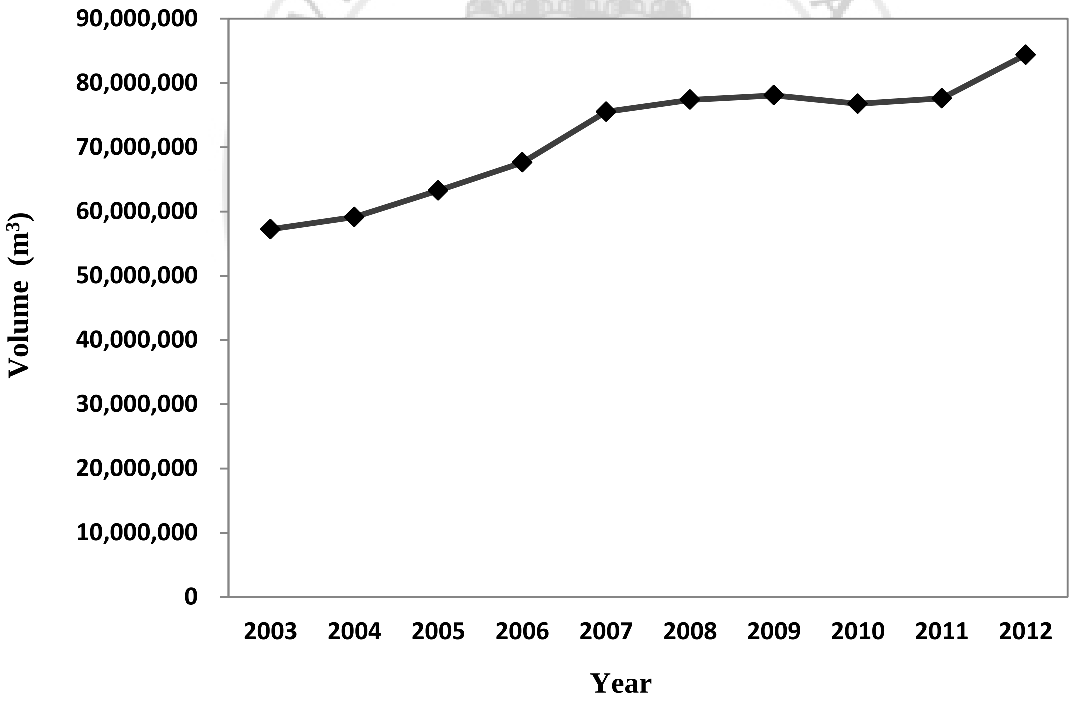

Figure 3.9 Total water supply from 2003 to 2012

With rapid development in tourism and gaming, Macau attracts more and more tourists and migrant population. According to the statistics, the amount of tourist in Macau is increasing every year and had already exceeded 10 million. With the rise in floating population and resident population, the total water consumption is increasing. The rise in water consumption and the water supply difficulties in Pearl River area give great challenges to Macau.

As for the raw water, Figure 3.9 indicates that the yearly water supply for total four water supply plants in Macau is gradually increasing from 2003 to 2012. There is relatively larger rise in year 2003 to 2007. The reason for that probably is the high speed development in economy during those years such as the construction of large casinos. From 2007 to 2011, there is no obvious change in the yearly water supply curve. It may because that from 2007 to 2011, the government carried out the water reuse and saving policy, which may be one of the reasons that the total water supply becomes steady.

3.2.2 Water supply in different areas

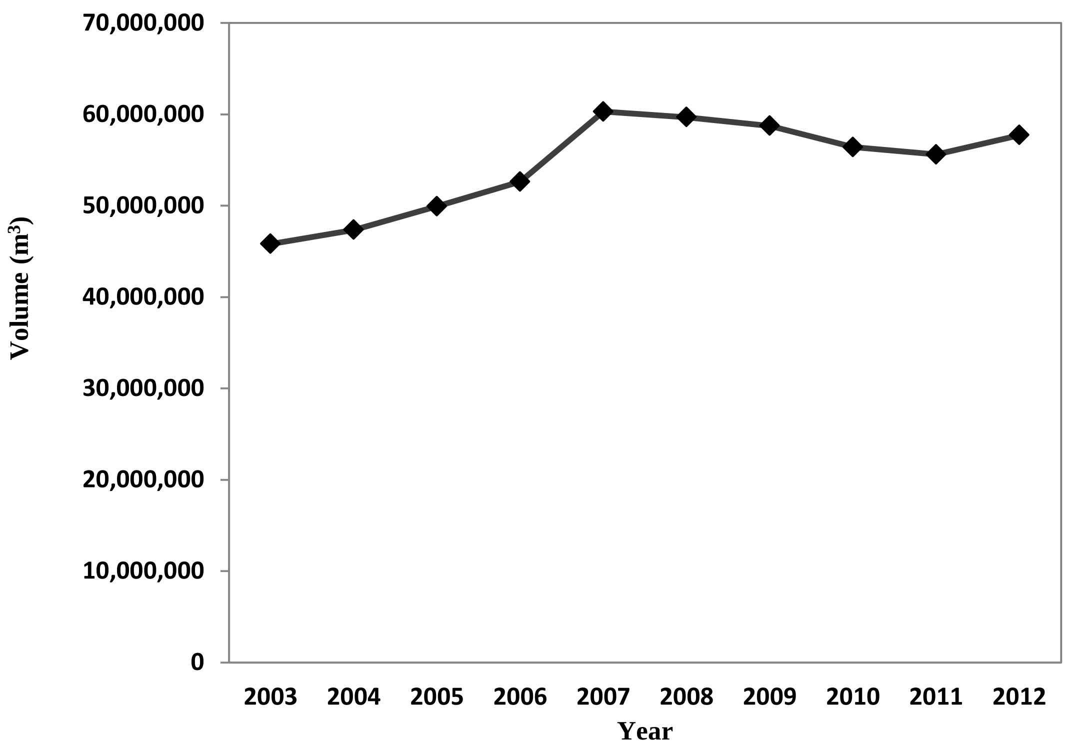

Figure 3.10 Yearly water supply for Macau Peninsula

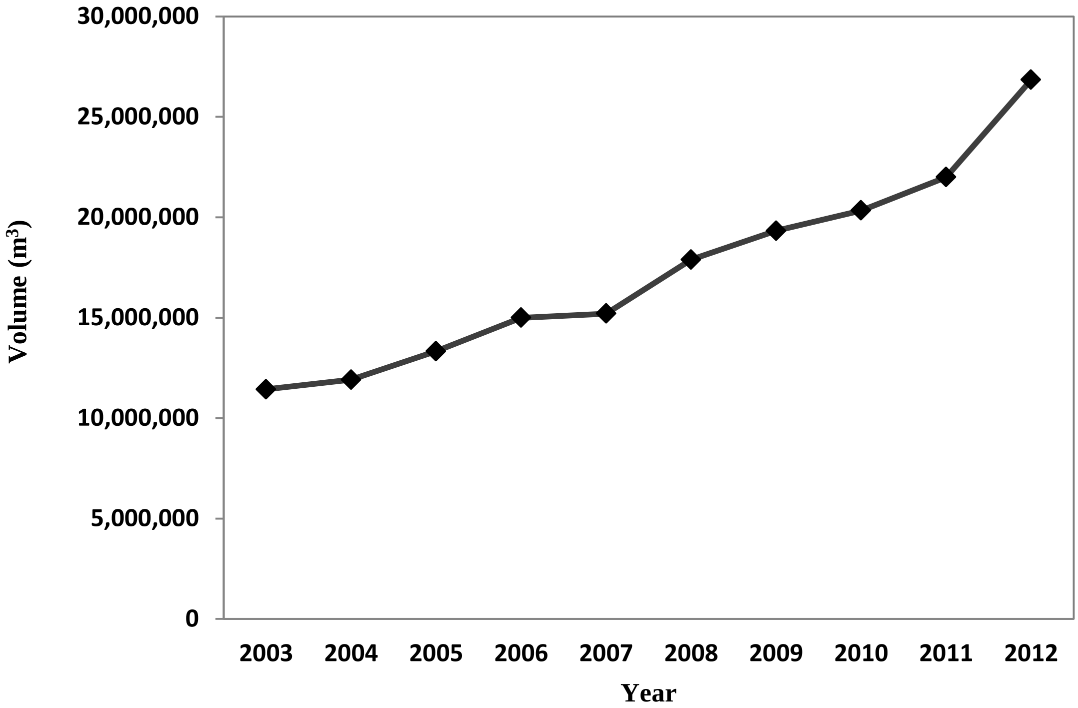

Figure 3.11 Yearly water supply for Taipa & Coloane

From Figure 3.10, the yearly water supply variation of Macau Peninsula is indicated. The curve tends to increase from year 2003 to 2007 and tends to become steady afterwards. Figure 3.11 indicates the yearly water supply variation of islands (Taipa & Coloane). The curve increases continuously from 2003 to 2012. Compare the two curves, it can found out that the increasing of the water supply for the Taipa & Coloane is larger than the water supply for Macau Peninsula which reflects the development of the islands is better than Macau Peninsula in recent years. The Cotai Resort in Taipa is the newly developed areas with large casinos and hotels. It has great contribution in the water consumption these years and it can be prospected that the water consumption in this area will increase continuously in the future.

3.2.3 Water consumption

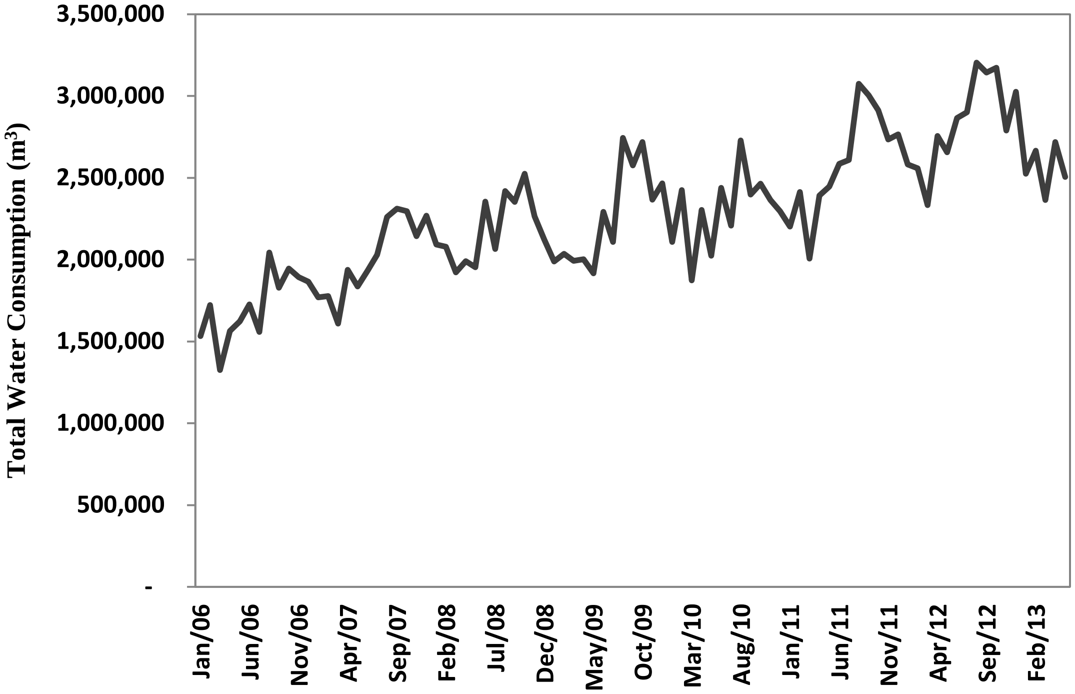

Figure 3.12 Water supply for commercial usage

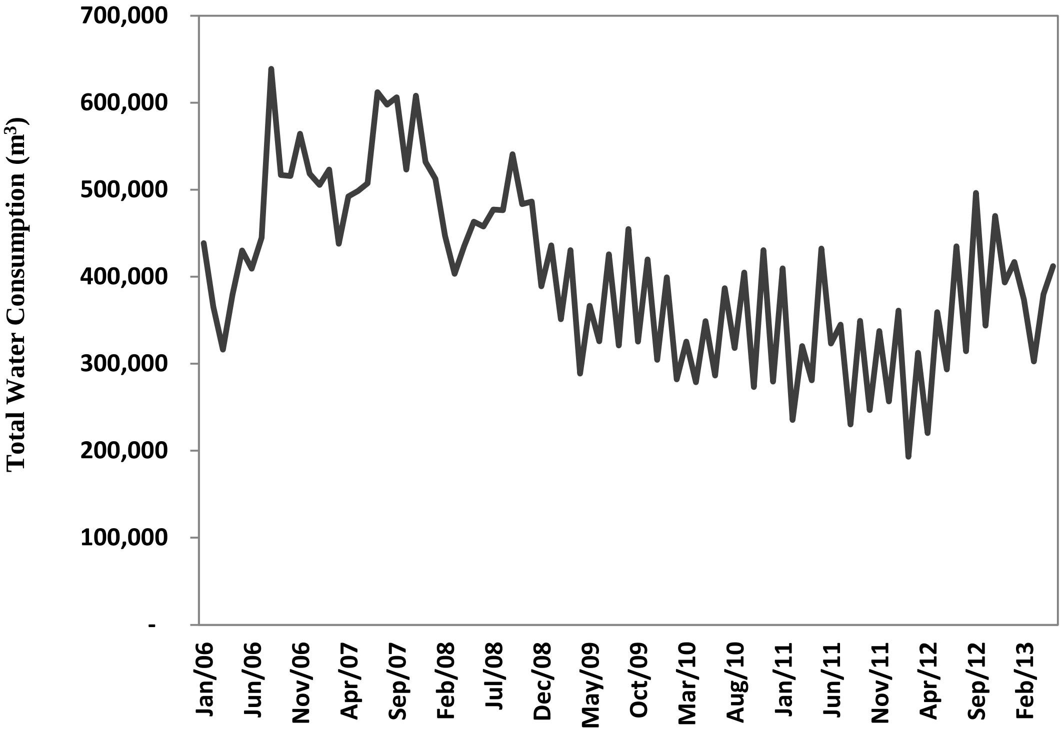

Figure 3.13 Water supply for industrial usage

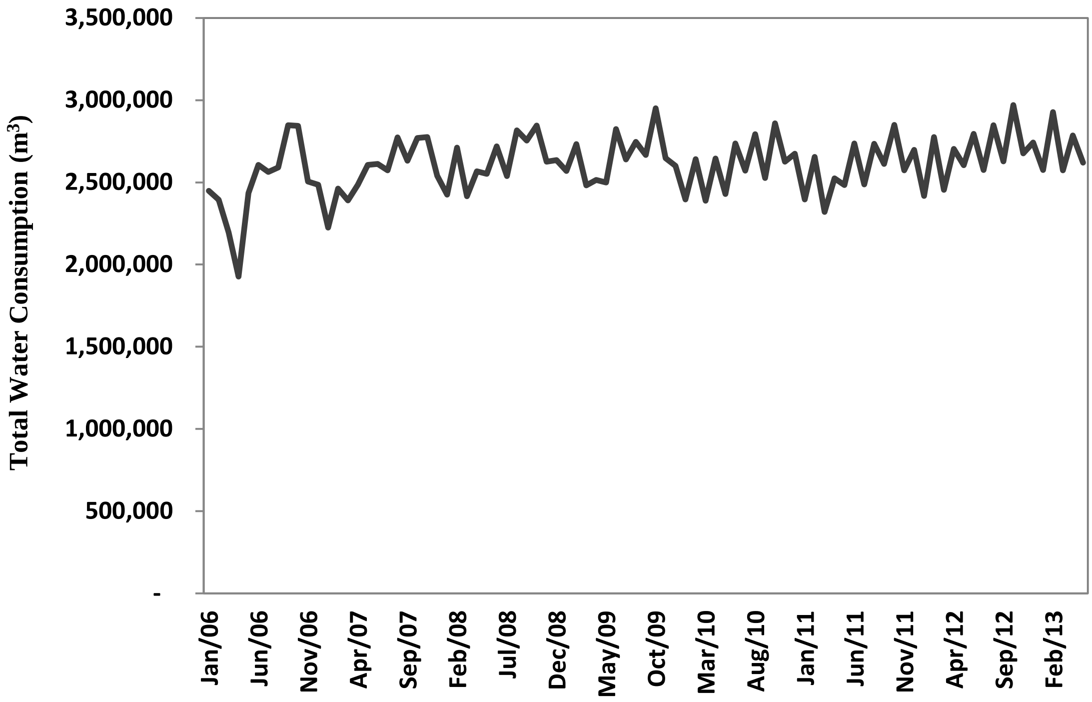

Figure 3.14 Water supply for residential usage

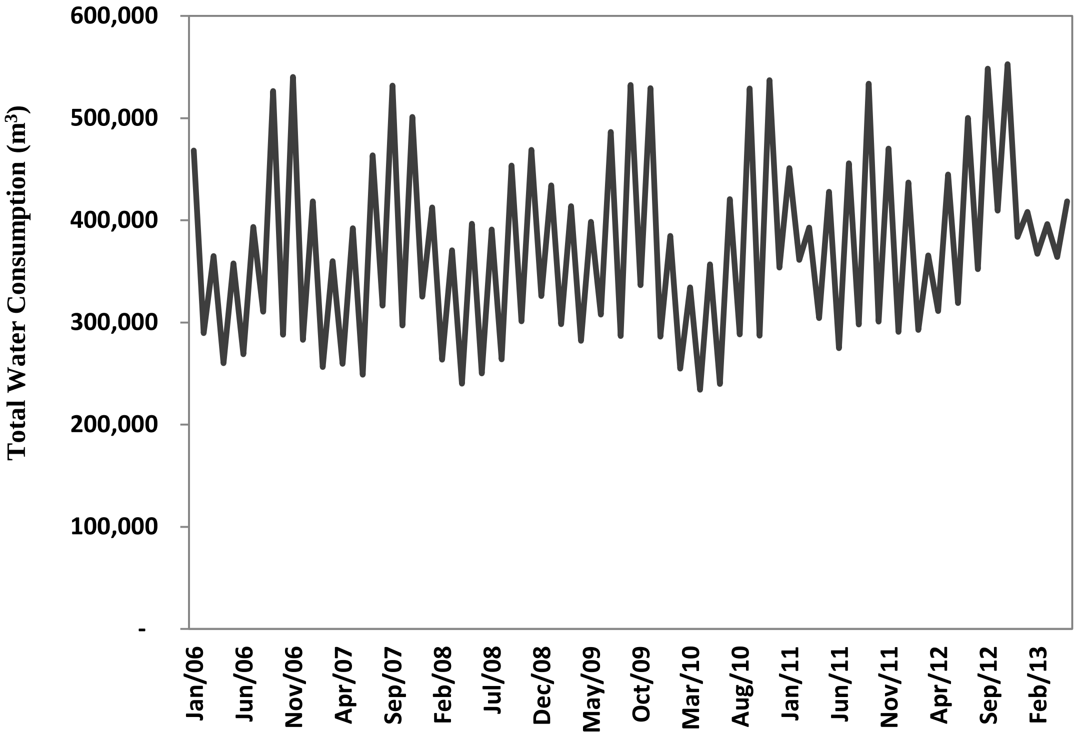

Figure 3.15 Water supply for governmental usage

Figure 3.12 to Figure 3.15 show the monthly variation of the water amount consumed from January 2006 to May 2013 for four different types of customers: Commercial, Industrial, Residential and Governmental customers. According to the statistics, the commercial water consumption is increasing from 2006 to 2012, the residential water consumption and the governmental water consumption maintain stable in general but the industrial water consumption tends to decrease in the recent year.

Because of the development in tourism and gaming, the commercial water consumption tends to increase year by year. In the year of 2012, the commercial consumption reached over 50% of the total water consumption and became the main customer in Macau. As for the industrial and commercial customers, it's necessary to encourage them to install water-saving facilities and promote the knowledge about water-saving in order to reduce the total water consumption and save water resources. As for the governmental water consumption, although the new water price system was carried out in 2011 and the water price became higher, the water consumption does not decrease which implies the new water price system does not have obvious effect on the total water consumption.

3.2.4 Seasonal variation of water consumption

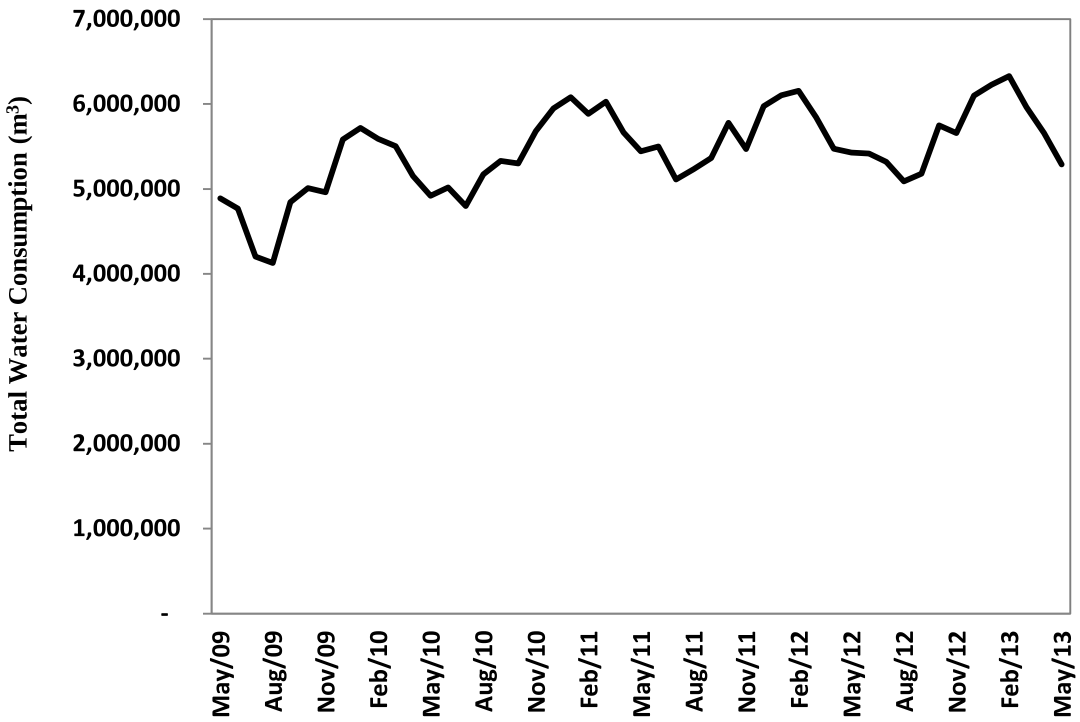

Figure 3.16 Seasonal variation of water consumption

From Figure 3.16, it can be found out that the annual water consumption is increasing in general. The variation of water consumption is regular with higher amount in September and October and lower amount in March and April. The seasonal variation of water consumption reflects the customers' habit in using water resources which has greater water demand in summer time and lower water demand in spring time. The result indicates that the water supply pressure in Macau is higher in summertime than in wintertime.

3.3 WATER CONSERVATION

3.3.1 Meter rental fee

Table 3.1 indicates the variation of meter rental fee in Macau from 1986 to 2000. The meter rental fee tends to increase every time except for the latest change in 2000 which maintain the same meter rental fee as 1998. Meters with different diameters will be charged in different prices. The rise in meter fee can reflect the inflation in the local economy.

Table 3.1 Meter rental fee

METER SIZE		METER RENTAL FEE (per month) ($)							
mm	**inches**	**1986**	**1987**	**1992**	**1995**	**1996**	**1997**	**1998**	**2000**
15	0.50	2.00	2.10	2.30	2.40	2.50	2.60	2.69	2.69
20	0.75	4.00	4.40	4.90	5.10	5.40	5.60	5.80	5.80
25	1.00	6.00	6.60	7.30	7.60	8.00	8.30	8.59	8.59
30	1.25	10.00	11.00	12.20	12.70	13.40	13.90	-	-
40	1.50	15.00	16.50	18.30	19.10	20.10	20.90	21.63	21.63
50	2.00	20.00	22.00	24.40	25.40	26.70	27.80	28.77	28.77
80	3.00	50.00	55.00	61.10	63.60	67.00	69.70	72.14	72.14
100	4.00	80.00	88.00	97.80	101.90	107.20	111.50	115.40	115.40
150	6.00	100.00	220.00	244.40	254.60	268.00	278.70	288.45	288.45
200	8.00	-	-	-	-	430.00	447.20	462.85	462.85

3.3.1 Water fee

In the past few years, Macau had made efforts to save water. The water supply company in Macau installed new facilities and the water loss rate had reduced to 8.8%

in 2011 which is relatively low. However, there are still many problems exist and need to be further improved such as the water supply system of Macau relies heavily on the supply of Zhuhai and the utilization of rainfall, seawater and wastewater in Macau are low. Furthermore, there exists problems in the water price system and the water saving awareness among residents is still insufficient.

The most effective way of water saving is to control the water consumption by water price such as converting improper price system, achieving stage water price or charging different prices due to different seasons and different customers. It's also necessary to learn from other countries, apart from charging for the water, it can also charge for proper sewage treatment fee.

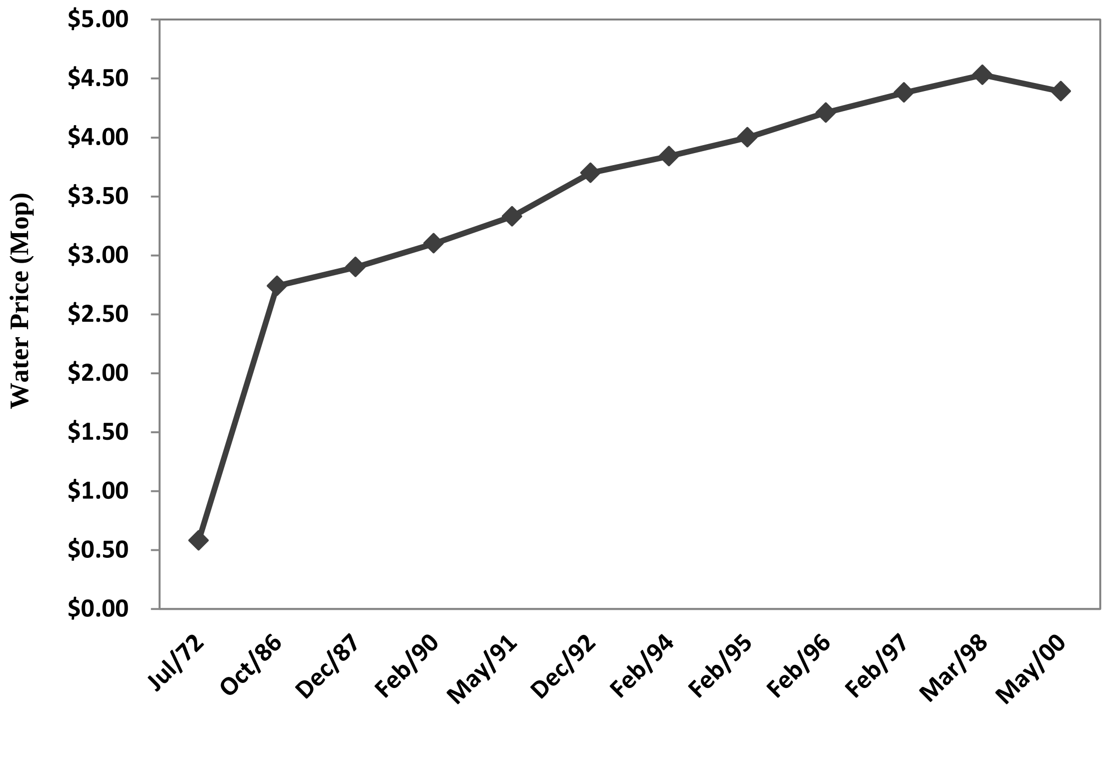

Figure 3.17 Variation of water fee

Figure 3.17 shows the water fee for past years. It can find out that the water fee increases every time apart from May 2000. The adjustment was large in July 1972 and adjustments afterwards were relatively small. In May 2011, the water supply company in Macau decided to reduce the water price from \$4.53 to \$4.39. From January 2011, the Macau water supply company changes the water fee again from charging with the same price to charging with different prices due to different group of users. The new water price calculating system is shown as below.

Table 3.2 Water fee for residential users

Stage	**Water Consumption (m^3/two month)**	**Water Fee (MOP/m^3)**
S1	28 or below	4.35
S2	29 to 56	4.83 *Note : First 28m^3 calculated using 4.35*
S3	57 or above	5.27 *Note: First 28m^3 calculated using 4.35, 29~56m^3 calculated using 4.83*

Table 3.3 Water fee for non-residential users

Type	**Category**	**Water Fee (MOP/m^3)**
Special Use of Water	Casino, Hotel, Spa, Golf Course, Construction, Public Construction, Temporary Water Supply	5.8
General Non- residential Water	General Industry, Government, School, Hospital, Organization etc.	5.27

Table 3.2 and Table 3.3 demonstrate the new water fee calculating system which was put into operation on January 2011. The new system classifies the customers into two main categories, the residential water customer and the non-residential water customer. Residential water is classified into three stages according to the water consumption per two months. The customer with larger water consumption will be charged in a larger water fee. The non-residential water is classified into two types. The first one is special usage of water and second type is general non-residential water. Water fee is larger in the first type than the second type of user. According to Cosier and Shen (2009), the water saving system is the most appropriate mechanism to the non-residential users.

The Macau government carried out survey about the new water fee system to customers including the residential customers, the non-residential customers and the special customers. The survey contained evaluation of the new water price system and users' behaviors. Result showed the respondents believed that the new water price system had positive impact in water saving.

As for the residential users, most of the respondents had score 19 to 20 (full score of 24), which shows good water saving consciousness. Most of the respondents agree with the new system and believe that charging with a stage price system has advantages in water saving and suggest that the price difference between large customers and other customers should be enlarged.

As for the non-residential users, although most of the respondents made positive judgments toward the new price system, most of the users did not change their habit of using water resource. According to the survey conducted, this may because of the water price is low. Generally speaking, the result showed that new water price system has advantages in constructing the water saving society.

3.3.3 Rate of water loss

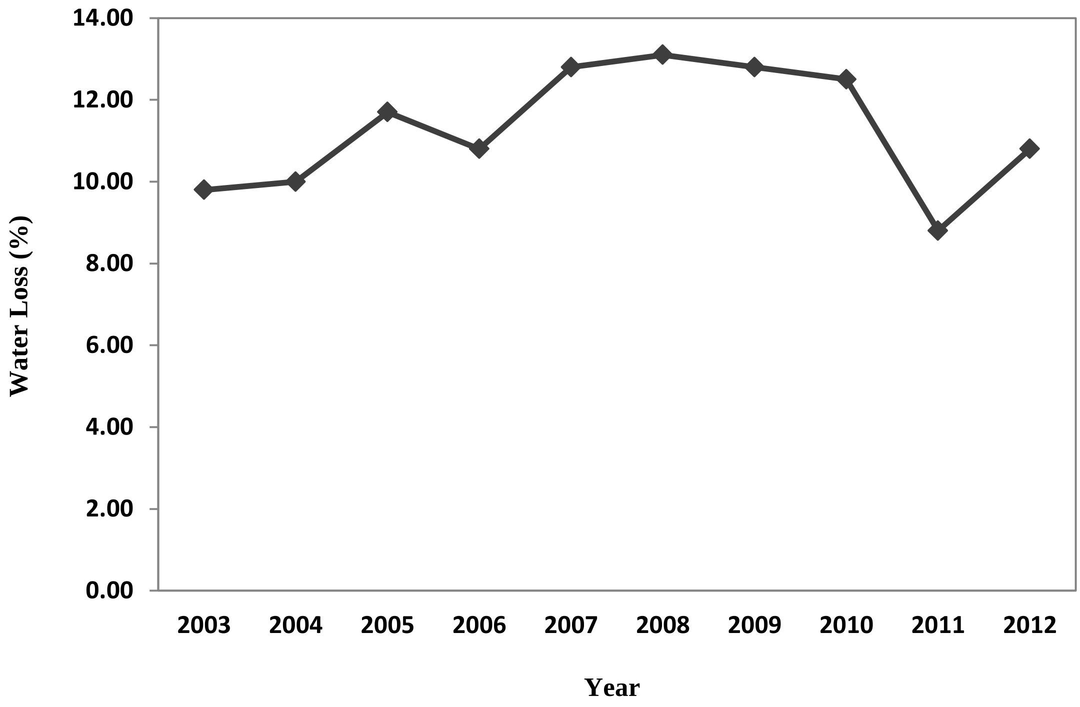

Figure 3.18 Rate of water loss in pipelines

Water loss in pipelines is wastage of water. Methods to reduce the water loss percentage in such long pipelines are significant in the management of water resources in Macau. From Figure 3.18, the water loss rate gradually increases from 2003 to 2010 and has a decrease in 2011 then increase again in 2012. The reason for the water loss rate increase largely in 2012 may because of the Cotai Resort in Taipa which has lots of large construction and the construction work cause damage in the underground pipelines. Therefore the water loss rate increases shapely in 2012. In order to solve the problem, the water supply company has already taken action to improve the situation and hope for better improvement in the future.

3.3.4 Recycle water utilization

➢ Recycle of wastewater

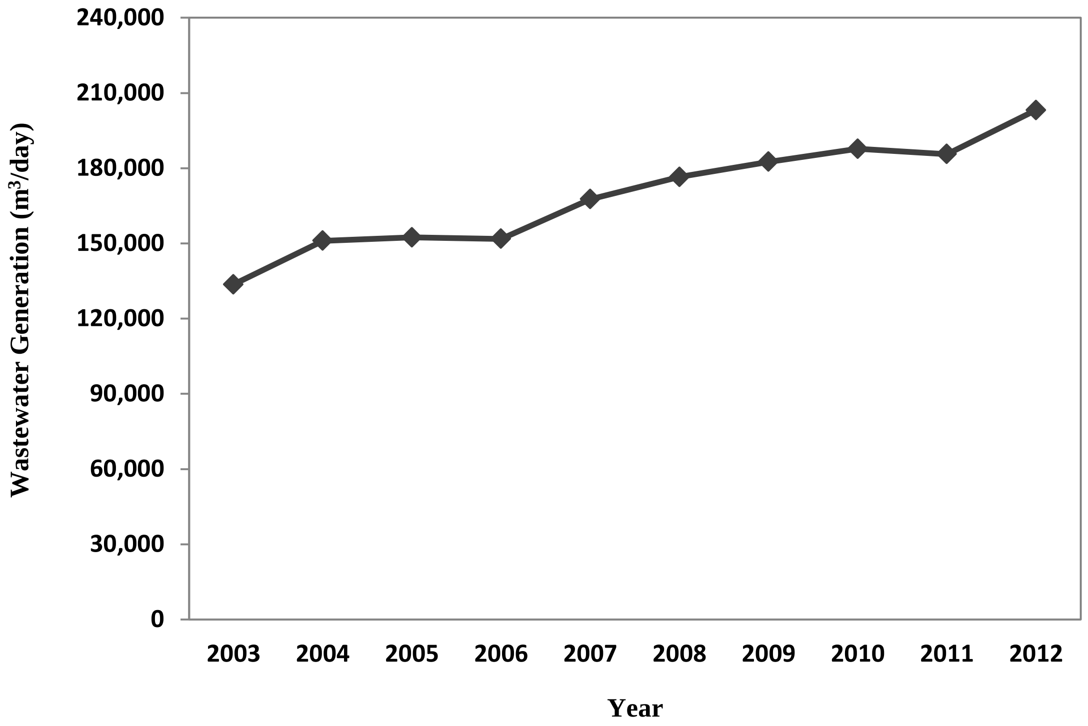

Figure 3.19 Wastewater generation

Renewable water refers to the wastewater which goes through advanced treatments and can be reutilized again. After advanced treatments, the pollutants in wastewater can be removed. The recycle water is able to meet the standard in greening, landscape usage, industrial reused and some other applications. Macau lacks of raw water resources so it is necessary to develop system in recycle of wastewater. The Macau government has carried out the renewable water plan in 2013. Recycle water has advantages of stable water source and not easy to be affected by climate change. The renewable water plan aimed to establish a water system which treats raw water as priority water resource and recycle water as complementary water resource. Under the situation of water shortage, development and utilization of renewable water is an important complement of urban water resources in Macau.

Macau has five wastewater treatment plants which locate in Macau peninsula, Trans-Border Industrial Zone, Taipa Island, Coloane Island and the Macau International Airport. Total designed capacity of wastewater treatment plants in Macau reaches 356,000 m^3 per day. From Figure 3.19, the wastewater generation per day tends to increase from 2003 to 2012. In the year 2012, the yearly water treatment amount reached 740 million m^3. With rapid development in economy, tourism and population growth, the wastewater generation will keep rising in the future, therefore it provides high potential for the recycle water system in Macau.

The construction of wastewater recycle treatment plant in Coloane which has a capacity of 12,000m^3/day are now under construction. However, the applied areas of the reused water are not wide enough, so further planning and management are needed. Another constrain is that roads Macau peninsula didn't reserved enough space for the recycle pipelines, so for those areas the difficulties of installing recycle pipelines become larger. It is necessary to enlarge the intensity of the promotion and increase the awareness of citizens in recycle water. In the construction of new regions, it's necessary to reserved space for the recycle pipeline installation or installing the recycle pipelines while constructing roads.

- Recycle of seawater

The utilization of seawater develops an effective way to solve water resource shortage. It attracts more and more concentration from countries all over the world. But in Macau, the utilization of seawater is relatively weak. Macau is surrounded with ocean so that there are abundant seawater resources in Macau but the recycle of seawater has high technical requirement. Also, the water in Macau has higher sand content which increases the difficulties. Another consideration that the cost of recycle is that recycle of seawater is relatively high. For the case in Macau, it should build up technology and infrastructure in seawater utilization and develop usage of seawater such as toilet flashing etc. Successful examples from other countries can be considered as references for the development of seawater utilization in Macau.

- Rainwater collection

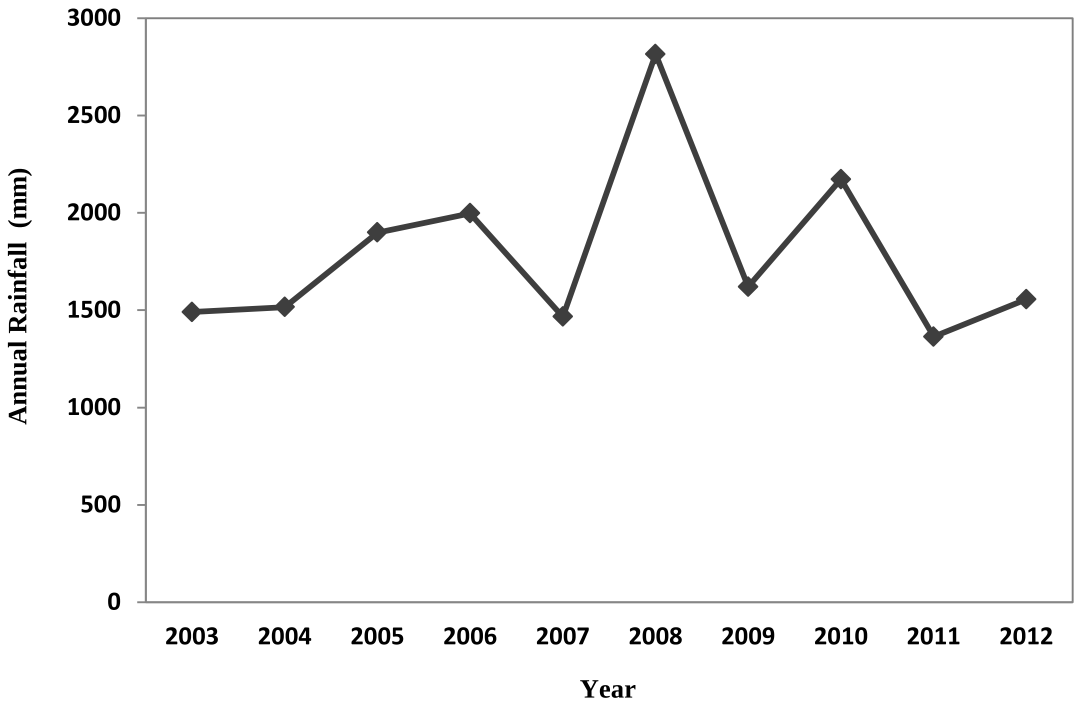

Figure 3.20 Annual rainfall in Macau

The collection of rainwater is significant with benefits on reducing possibility of flood and in the meanwhile solving the problem of water shortage. Figure 3.20 indicates the annual rainfall amount in recent year. It's shown that the rainfall in Macau is not stable in these few years. It reached the highest point in year 2008 but started to decrease from 2011 to 2012. Because of the ocean climate, the rainfall amount is relatively low in winter seasons than in summer seasons. Collecting rainwater can achieve high economic and good environmental benefit. Rainwater is classified as slight polluted water. With simple treatments, rainwater can be used for landscape irrigation or industrial cooling water. In the last century, many other countries had carried out researches in rainwater collection so the technology has become mature. Macau is one of the areas in northern China which has large amount of rainfall. Hence, it is necessary to search for an effective way of rainwater collection such as the collecting rainwater from the roofs. Since the rainwater collection has great advantages such as low cost, high water-saving efficiency and high water quality. The utilization of rainwater is proved to have wide fields of application in Macau.

3.3.5 Strategy plan of government

According to the Marine and Water Bureau in Macau, starting from 2009, the water rate return plan is carried out in every winter and spring season. From September 2012 to April 2013, water customers who successfully save water so that the water consumption can be reduced by 10% to 30% compared to the same period in last year would have up to 250MOP in return. During the water rate return plan, more than 31,000 customers reached the standard and received the refund. Approximately 90% of them are residential water customers. Up to now, over 120,000 customers received the refund.

In addition, with promotion of activities held by government, total 95,000 of water saving appliance are installed with total volume of water saved reaches 750,000 m^3. Also, the Macau government set up the Environmental and Energy Saving Fund in order to encourage commercial and industrial water customers to purchase and install water-saving and energy-saving appliances. Until the end of 2012, 17 applications of purchasing and replacing for water-saving appliance were approved by the government.

Besides, with more than 20 million tourists enter Macau annually, the water consumption from tourists occupies a certain proportion. In order to promote water saving in large hotels and casinos, the hotel water saving plan is carried out and invite local industrials to join the plan. At present, 29 hotels, which are about 5% of the hotels in Macau, show great support to this plan.

CHAPTER 4 METHODOLOGY

4.1 THE STUDY AREA

Macau SAR is one of the two Special Administrative Regions of the People's Republic of China which is located on the western side of the Pearl River Delta near Guangdong Province and facing the South China Sea. Because of the lack of water resources in Macau, most of the fresh water resource currently used comes from Zhuhai city.

4.2 DIMENSION AND INDICATOR

Appropriate dimensions are selected for this sustainability study which can present their relevance to current issues. The sustainable integrated urban water management (SIUWM) is first developed in this study. The index and dimensions proposed in this study is proposed by Popawala and Shah (2011) in development of composite index for urban water study with improvement in the content to make it more applicable and fulfill the requirement of Macau. The selected dimensions and indicators for this study are listed in Table 4.1.

Four dimensions involved in this case study are:

- Social dimension- includes the access to public sanitation, water supply system and equitable resource distribution etc.
- Economic dimension- includes economically principles, maintenance cost and government investment etc.
- Environmental dimension- includes environmental protection, recycle of water resources and behavior of wastewater treatment etc.
- Engineering dimension– includes technological capacity and progress etc.

Table 4.1- Selected indicators and dimensions in sustainability index assessment

	Dimensions	Indicators	
Sustainability Index for Urban Water Management System	Social	C1	Access to water supply
		C2	Access to sanitation
		C3	Water availability per capita per day
		C4	Supply hours
		C5	Service complaints
		C6	Flood prone area
	Economic	C7	Capita investment
		C8	Cost recovery, operation and maintenance cost
		C9	Research and development investment
	Environmental	C10	Water withdrawal
		C11	Energy consumption
		C12	Pollution load on environment
		C13	Waste water treatment performance
		C14	Water reuse
		C15	Recycling of nutrients and sludge reuse
		C16	Rain water harvesting and recharging
	Engineering	C17	Metered connection
		C18	Service interruption and water losses

4.3 DATA COLLECTION

Imputation of incorrect data would result in misleading sustainability index therefore the data collection is significant aspect. The non-availability of data is the largest constraint for the specific indicator thus either substitution or exclusion of data is adopted. The data adopted in this study were mainly collected from the statistical report in the Macau Statistics Department and the Macau Water Supply Company.

4.4 INDICATOR STANDARDIZATION

The indicator standardization follows the approach used by Lee and Huang (2007) in the development of sustainability indicators.

Standardized value:

$$Z = (Xi - \mu) / \sigma \tag{4.1}$$

To standardized value of indicators, standard deviation σ and the average value μ are applied. While Z denotes the standardized value and Xi represents the value of the sample. If the standardized value is negative, the value of indicator is smaller than the average value over the years. If the standardized value is positive, the value of indicator is larger than the average value over the years.

$$Y = (Zi - a)/(e - a) \tag{4.2}$$

While Zi is between a to e, where a denotes the minimum value and represents the maximum value and thus Y lies 0 to 1.0.

Calculation result that trends toward 1.0 do not necessarily indicate a higher level of sustainability. For some indicators, trending to 1.0 indicated a lower level of sustainability therefore such indicators need to be standardized using following formula:

$$Y* = 1 - Y \tag{4.3}$$

So that the value approaching 1.0 indicate progress towards sustainability for all the indicators.

4.5 METHOD OF WEIGHTING

The index weighting can be calculated using different multi-criteria methods such as equal weighting method (EW), Criteria Importance Through Inter-criteria Correlation (CRITIC) and Analytic Hierarchical Process (AHP). Both weighting system using subjective judgment and objective approach are investigated in this study in order to prevent drawback from single involvement of the weighting system. The weighting assigned to each indicator is listed in Appendix A.

4.5.1 Equal Weighting Method

In first part of the study, an equal weighting method is applied as the basis for integrating and analyzing the sustainability index of each dimension and the overall sustainability index. The detail of calculation is shown as follow:

$$\text{Sustainability index of social dimension} = 1/6\,(C1 + C2 + C3 + C4 + C5 + C6) \tag{4.4}$$

$$\text{Sustainability index of economic dimension} = 1/3(C7 + C8 + C9) \tag{4.5}$$

$$\text{Sustainability index of environmental dimension} = 1/7(C10 + C11 + C12 + C13 + C14 + C15 + C16) \tag{4.6}$$

$$\text{Sustainability index of engineering dimension} = 1/2(C17 + C18) \tag{4.7}$$

$$\text{Overall urban water sustainability index} \\ = 1/4(\text{social index} + \text{economic index} + \\ \text{environmental index} + \text{engineering index}) \quad (4.8)$$

4.5.2 CRITIC Method

CRITIC (Criteria Importance Through Inter-criteria Correlation) was first developed by Diakoulaki *et.al* (1995). Since the equal weighting method is a simplify method for preliminary analysis. In multi-criteria situation, the weightings of criteria in each dimension should not be the equivalent. The CRITIC method is established to determine the weighting of relative importance in multiple criteria decision method.

A finite set A of n alternatives and a given system of m and an evaluation criteria f_j, the general form can be expressed as:

$$\{f_{1(a)}, f_{2(a)}, \dots, f_{m(a)} \ \ which\ a\epsilon A\} \quad (4.9)$$

For every criterion f_j , a function x_j is defined to normalize the value f_j to interval 0 to 1.0, which can be expressed as the following formula 4.10.

$$x_{aj} = \frac{f_{j(a)} - f_{j(min)}}{f_{j\,(\max)} - f_{j\,(min)})} \quad (4.10)$$

Where x_{aj} represents the degree of closure which the alternative *a* is close to the ideal value $f_{j\,(\max)}$ which represent the best performance in criterion *j*. $f_{j\,(min)}$ is the anti-ideal value which represent the worst performance in criterion *j*.

By examine the *j*th criterion, a vector x_j is generated:

$$Xj = \{x_{j(1)}, x_{j(2)}, \ldots, x_{j(m)}\} \tag{4.11}$$

Where each vector x_j is characterized by the standard deviation σ_j which indicates he contrast intensity of the corresponding criterion.

The symmetric matrix is constructed with dimension m×m and the generic element r_{jk} is the linear correlation coefficient between x_j and x_k. The sum represents a measure of conflict created by criterion *j* is defined as:

$$\sum_{k=1}^{m} (1 - r_{jk}) \tag{4.12}$$

The amount of information C_j is emitted by the *j*th criterion which can be determined by composing the measures through the following multiplicative aggregation formula 4.13.

$$C_j = \sigma_j \cdot \sum_{k=1}^{m} (1 - r_{jk}) \tag{4.13}$$

With reference of the previous research, the higher the C_j, the larger of amount of information transmitted by the corresponding criterion and the higher its relative importance for the decision making.

The weighting determined by the objective approach can be shown by normalizing the values to unity according to formula 4.14:

$$w_j = \frac{C_j}{\sum_{k=1}^{m} (C_k)} \tag{4.14}$$

4.5.3 AHP Method

AHP (Analytic Hierarchy Process) is a method used to solve complex decision problems by dividing the system into components which can clearly define the layer in a hierarchical format.

AHP method consists of two stages. The first stage is to break the investigated system into detailed components and the second stage is to assign relative weighting to the component by subjective approach. In this study, the urban water system is decomposed into four dimensions and then further divided into indicators. Then relative scale is assigned to each indicator based on the attribution of each indicator. Finally, the relative weighting can be estimated and assigned in the sustainability index calculation.

The basic steps of AHP method can be summarized as follow:

1) Identify the problem
2) Identify the elements which influence the overall behavior
3) Analysis the system through a hierarchical approach
4) Make comparison among each element and evaluation for a numerical scale.

As for the scale, it ranges from 1 to 9 (to 1 for "equal" and to 9 for "absolutely more important than"). Because 1, 3, 5, 7, 9 are the most commonly used scale, hence, these five scales are adopted in this study.

CHAPTER 5 RESULTS AND DISCUSSION

5.1 EQUAL WEIGHTING METHOD

5.1.1 The Social Dimension

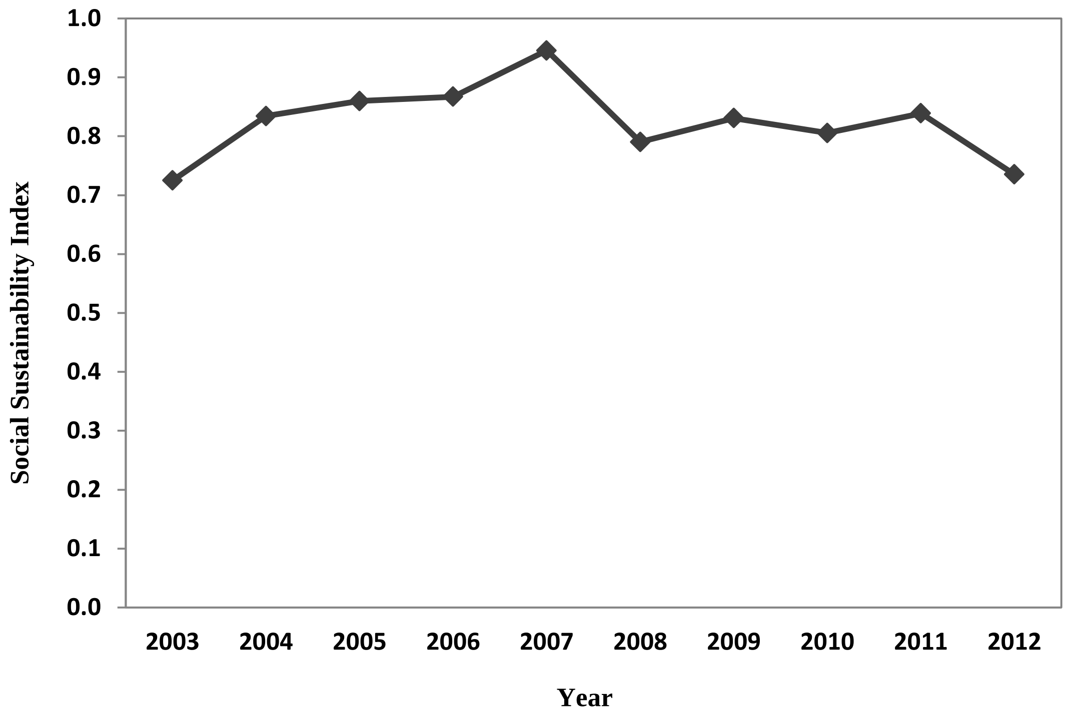

Figure 5.1 Sustainability trend of social dimension

Figure 5.1 implies the sustainability trend of social dimension. It is shown that the sustainability index of social dimension gradually increases from 2003 to 2007 and reaches the maximum in 2007. However, the index has experienced decline during 2008 and 2010. From 2011 to 2012, it resumes a downward progress during the last two years. Generally speaking, the social dimension appears to be stable and maintains high level during the investigated time period.

5.1.2 The Economic Dimension

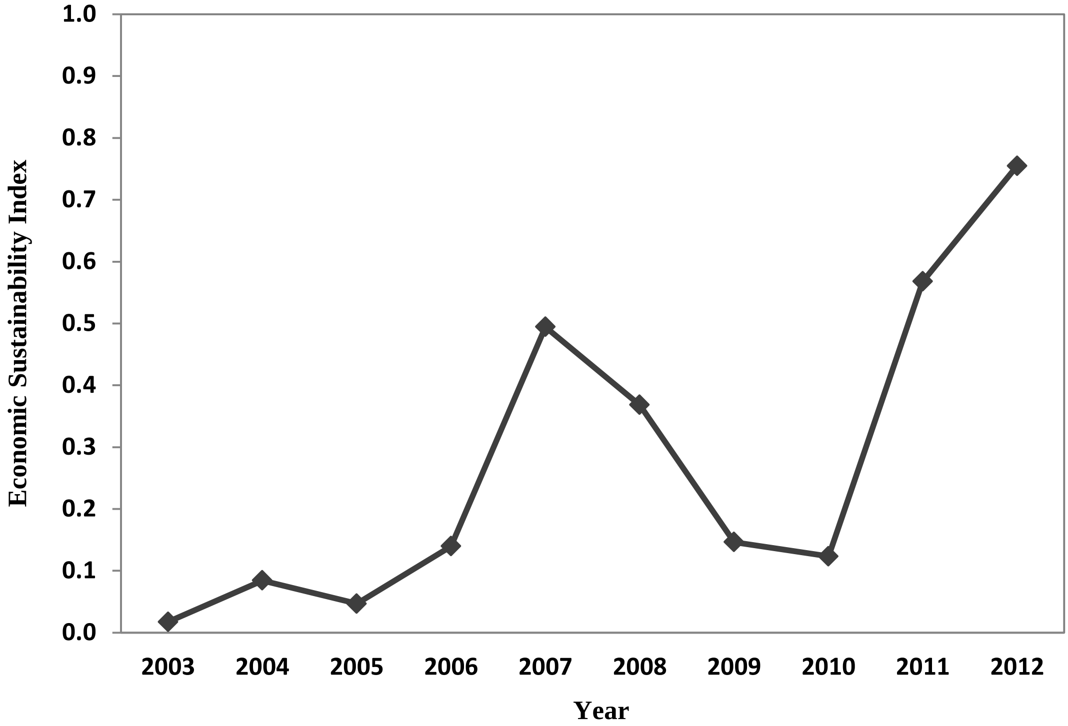

Figure 5.2 Sustainability trend of economic dimension

Figure 5.2 indicates the sustainability trend of economic dimension. It is shown that the sustainability index for economic dimension generally increased before 2007. However, the economic index tends to decrease from 2007 to 2010. Finally, the index tends to increase sharply during the past three year. The economic dimension has large fluctuation from 0 to 0.8 which indicates the instability during the investigated time period. The economic dimension of the sustainability index appears to have a larger variation and experiences large difference from 2006 to 2012.

5.1.3 The Environmental Dimension

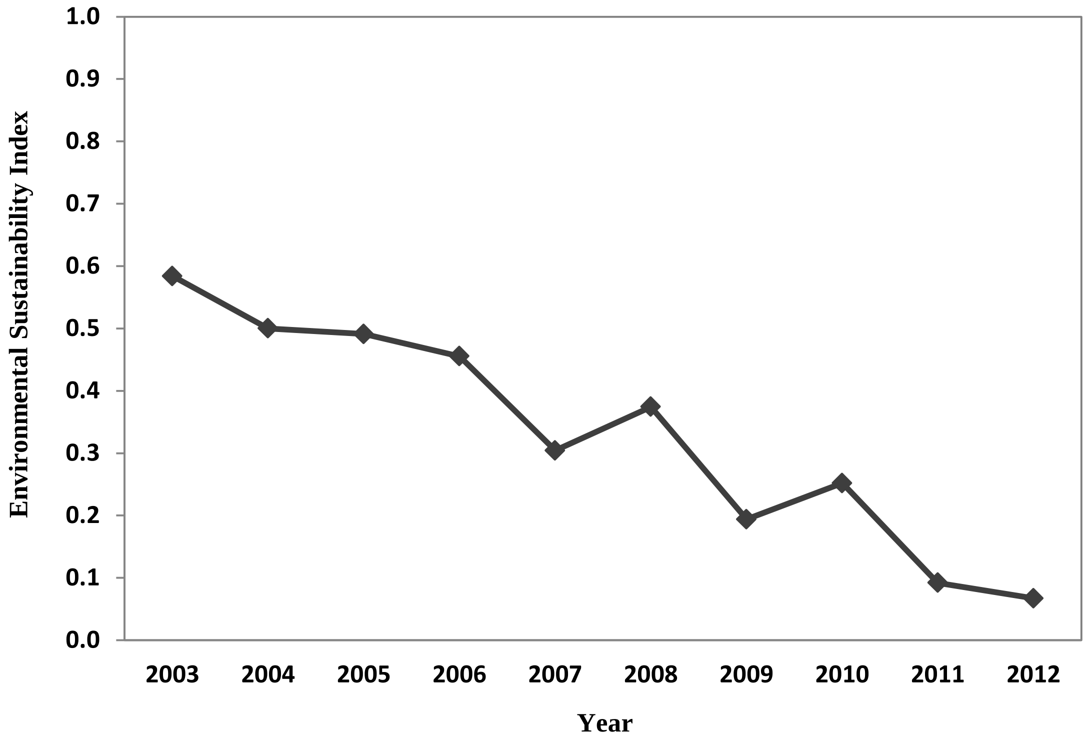

Figure 5.3 Sustainability trend of environmental dimension

Figure 5.3 demonstrates the sustainability trend of environmental dimension. It is shown in the figure that the sustainability index of the environmental dimension is gradually decreasing during the investigated time interval, except for 2008 and 2010 which have a short-term increase. However, the decrease in the sustainability index of indicates that it moves away from the sustainable development in the environmental dimension. In 2012, the environmental dimension drops to 0.067 which is the lowest value among all four dimensions.

5.1.4 The Engineering Dimension

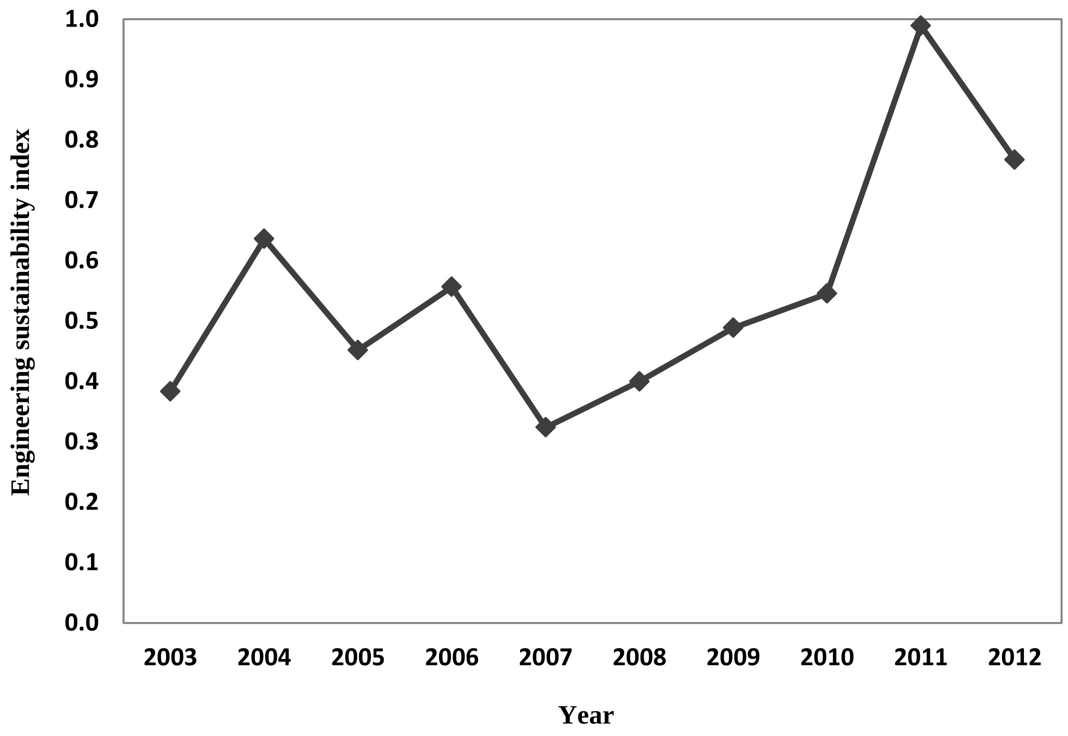

Figure 5.4 Sustainability trend of engineering dimension

Figure 5.4 indicates that the sustainability trend of engineering dimension. It is shown in the figure that sustainability index of engineering dimension has a fluctuation from 2003 to 2007 and started to increase steadily from 2007 to 2010. It encounters a sudden increase in 2011 follows by a sharp decrease in 2012. The reason for the variance may due to the indicator for metered connection kept increasing in the past 10 years but the data for water losses varied each year which shows that the percentage of water losses has great influence in the engineering dimension. The engineering dimension has large fluctuation which implies the instability during the investigated time period.

5.1.4 Overall Urban Water Sustainability Index

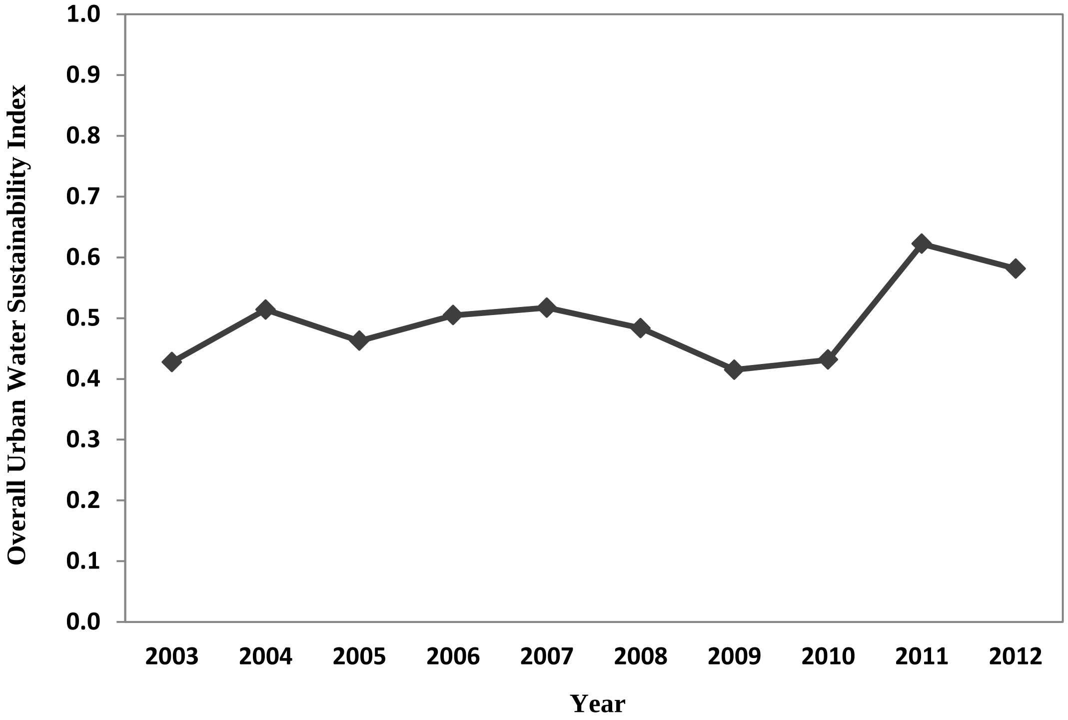

Figure 5.5 Trend of overall urban water sustainability

Figure 5.5 shows the trend of overall urban water sustainability index for the past decade. If the overall sustainability index approaches 1.0, a trend towards sustainable development (SD) is indicated. On the contrary, if the sustainability index gradually approaches zero, the city is moving away from sustainable development. The figure indicates that the overall urban water sustainability index for Macau from 2003 to 2012 generally increases until 2007, but experienced a continual decrease from 2008 to 2010. Starting from the year 2010, it increased again and maintained stable in 2012. The result shows that in 2012, Macau is moving away from the sustainable development of urban water through a slight decrease in overall sustainability index, which implies a negative impact in the urban water system.

Table 5.1 Sustainability index for Macau based on equal weighting method

Year	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Social	0.725	0.834	0.860	0.867	0.946	0.790	0.831	0.806	0.839	0.735
Economic	0.017	0.084	0.047	0.140	0.494	0.368	0.146	0.123	0.568	0.755
Environmental	0.584	0.500	0.491	0.455	0.304	0.374	0.194	0.252	0.092	0.067
Engineering	0.384	0.636	0.452	0.557	0.324	0.400	0.489	0.545	0.989	0.767
Overall	0.427	0.514	0.462	0.505	0.517	0.483	0.415	0.432	0.622	0.581

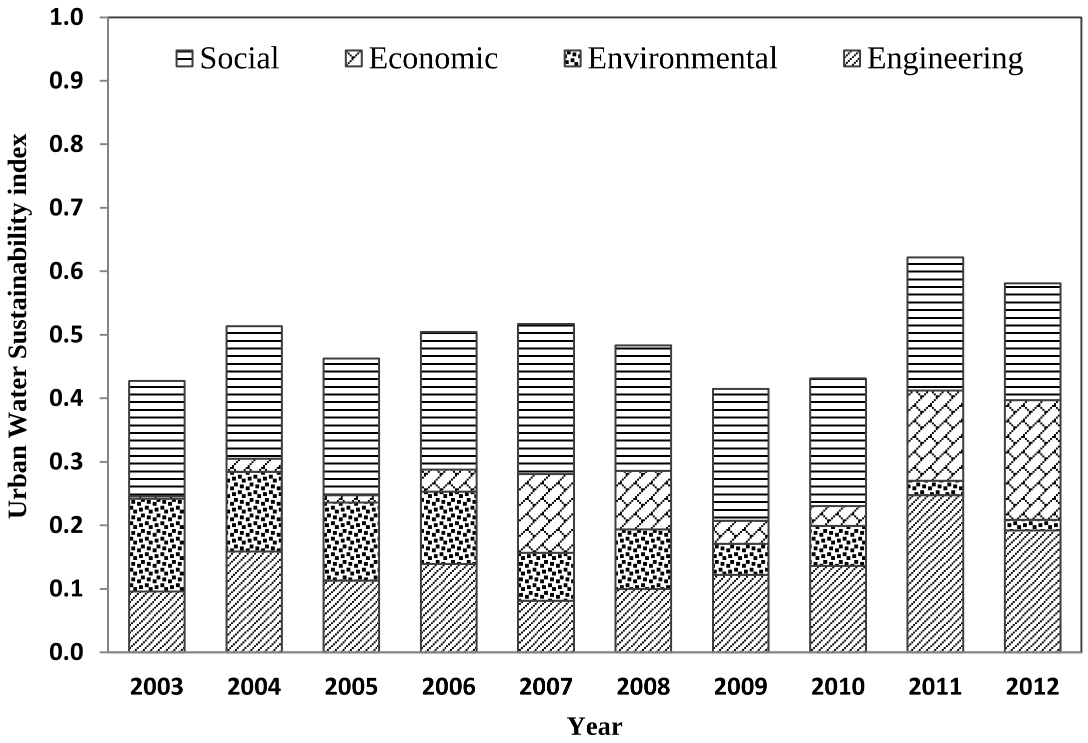

Figure 5.6 Urban water sustainability index based on equal weighting method

Table 5.2 Classification of sustainable level

Sustainability index	Classification
≥0.75	Sustainable
≥0.5, < 0.75	Moderate
≥0.25, < 0.5	Weak
< 0.25	Unsustainable

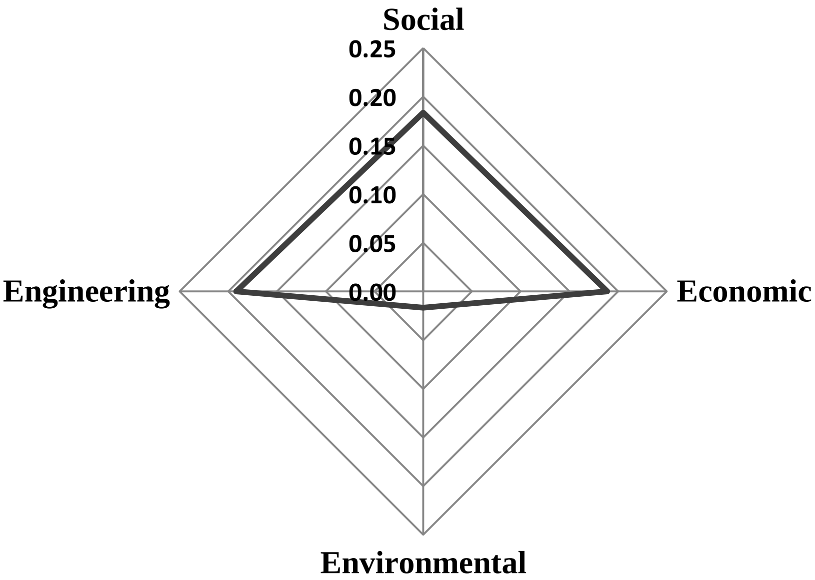

Figure 5.7 Performance of four dimensions in 2012

This study applied a systematical framework, combined with an equal weighting method as basis to evaluate the urban water sustainability index from the social, economic, environmental and engineering dimensions. In this study, an equal weighting method is used to evaluate the overall sustainability index for Macau during the past decade. The relevant index of each dimensions are listed in Table 5.1 and the composition of the overall sustainability index is shown in Figure 5.6. Also, the classification of sustainable level is shown in Table 5.2 in accordance with Choon *et al*. (2011).

The relevant values and trends for the investigated time period demonstrate that the environmental sustainable index is gradually decreasing in the past decade. According to the data shown, the water reuse and the recycling of nutrients as well as the sludge reuse in environmental dimension are both equal to zero, which are the mainly reasons for poor performance of environmental dimensions. The social sustainable index maintained stable and high level in the past decade. The economic sustainable index and the engineering sustainable index both have relatively large fluctuation. For the economic sustainable index, it appears to increase in the last few years while the engineering sustainable index has a sudden decrease in 2012.

Particularly, the latest data of the year 2012 is investigated. The result shown in Figure 5.7 could be used to represent the current situation of Macau. According to the figure, the social, economic and engineering have similar value that are approximately 0.18 while the environmental dimension has great difference and appears to be the lowest in the year of 2012. It can also be found out that social, economic and engineering dimensions are at sustainable level the environmental dimension is classify as weak level. It can also be found out that the overall sustainability index for 2012 is 0.581 which is located at the moderate sustainable level with composite index scoring of social, economic, environmental and engineering are 0.184, 0.189, 0.017 and 0.192, respectively.

In order to achieve the goal of urban water sustainable development, improvements should be made to the social, economic, environmental and engineering dimensions. The environmental dimension, which has the lowest index among all four dimensions, has higher potential for improvement. The environmental dimensions of sustainability index can be raised by implement of renewable water resource and adoption of advanced technologies. For the economic and engineering dimensions, they are generally increasing for the past decade but involve larger fluctuation. Improvement to these two dimensions can be achieved by raising the investment in urban infrastructure. For the social dimension, although it maintains steady and relatively high in the investigated time period, it can be improved through construction of the water conservation society and to increase the water saving awareness among citizens. In general, achieving urban water sustainable development is a long term goal which requires the cooperation from all sectors of the community.

5.2 COMPARATIVE ANALYSIS

- CRITIC Method

Table 5.3 Sustainability index for Macau based on CRITIC method

Year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Social	0.404	0.471	0.519	0.517	0.896	0.273	0.596	0.307	0.449	0.502
Economic	0.016	0.087	0.053	0.147	0.505	0.377	0.126	0.134	0.561	0.725
Environmental	0.691	0.606	0.636	0.602	0.353	0.595	0.252	0.380	0.113	0.089
Engineering	0.408	0.642	0.444	0.555	0.308	0.375	0.462	0.520	0.990	0.753
Overall	0.380	0.451	0.413	0.455	0.516	0.405	0.359	0.335	0.528	0.517

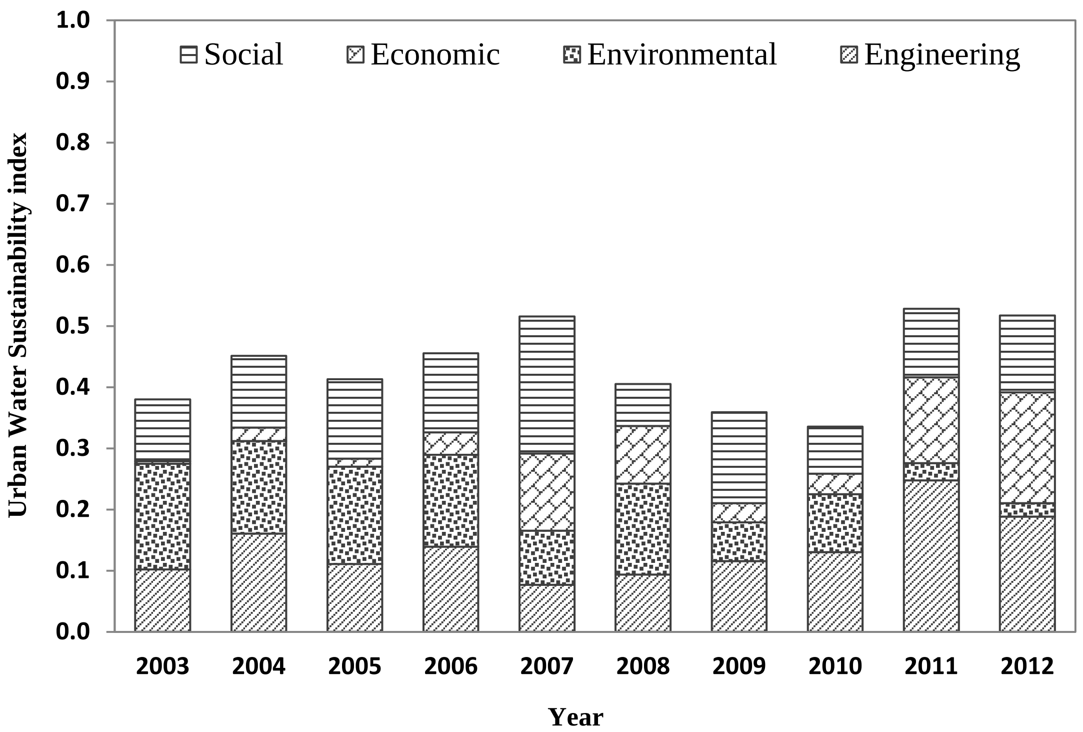

Figure 5.8 Urban water sustainability index based on CRITIC method

➢ AHP Method

Table 5.4 Sustainability index for Macau based on AHP method

Year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Social	0.822	0.856	0.873	0.887	0.962	0.926	0.941	0.929	0.941	0.937
Economic	0.022	0.070	0.024	0.102	0.403	0.301	0.202	0.092	0.627	0.879
Environmental	0.646	0.547	0.512	0.459	0.338	0.359	0.202	0.272	0.092	0.099
Engineering	0.576	0.679	0.389	0.546	0.197	0.200	0.279	0.342	0.995	0.651
Overall	0.516	0.538	0.449	0.498	0.475	0.446	0.406	0.409	0.663	0.642

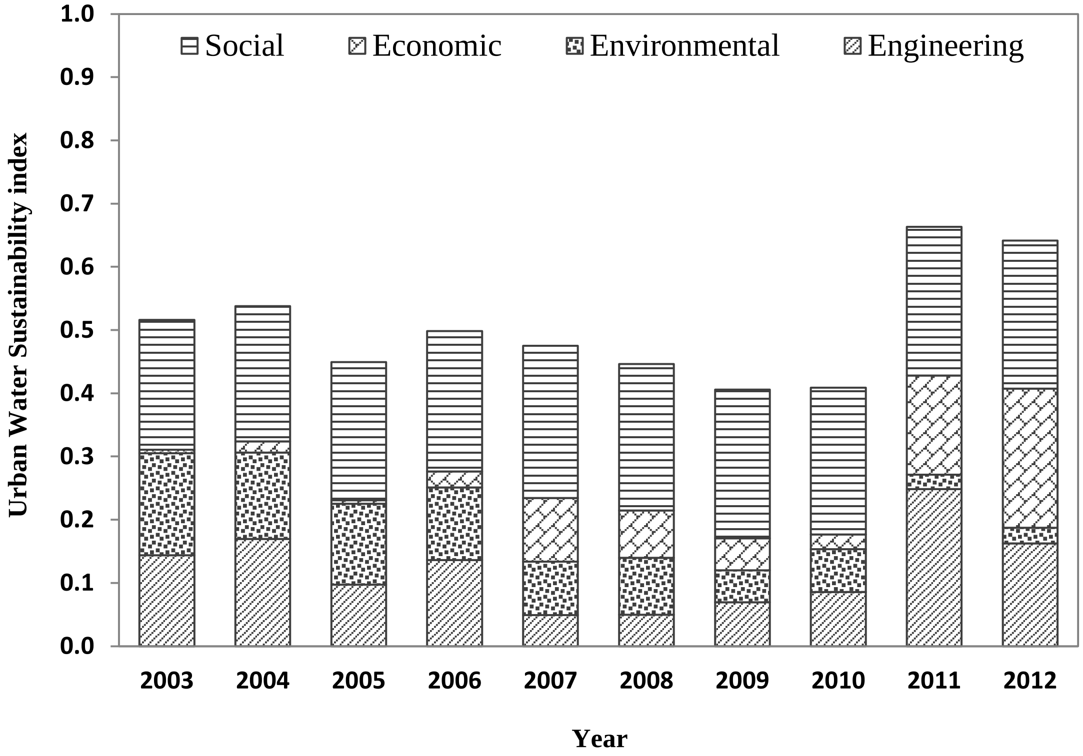

Figure 5.9 Urban water sustainability index based on AHP method

➢ Comparison of three curves

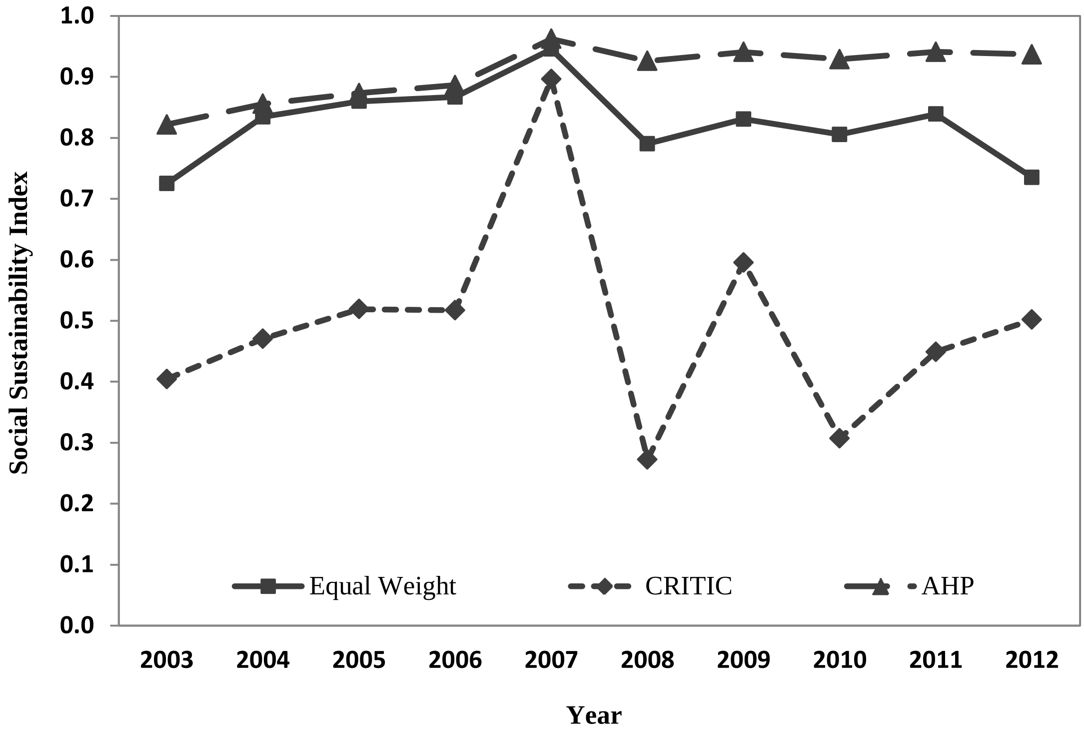

Figure 5.10 Comparison of social dimension

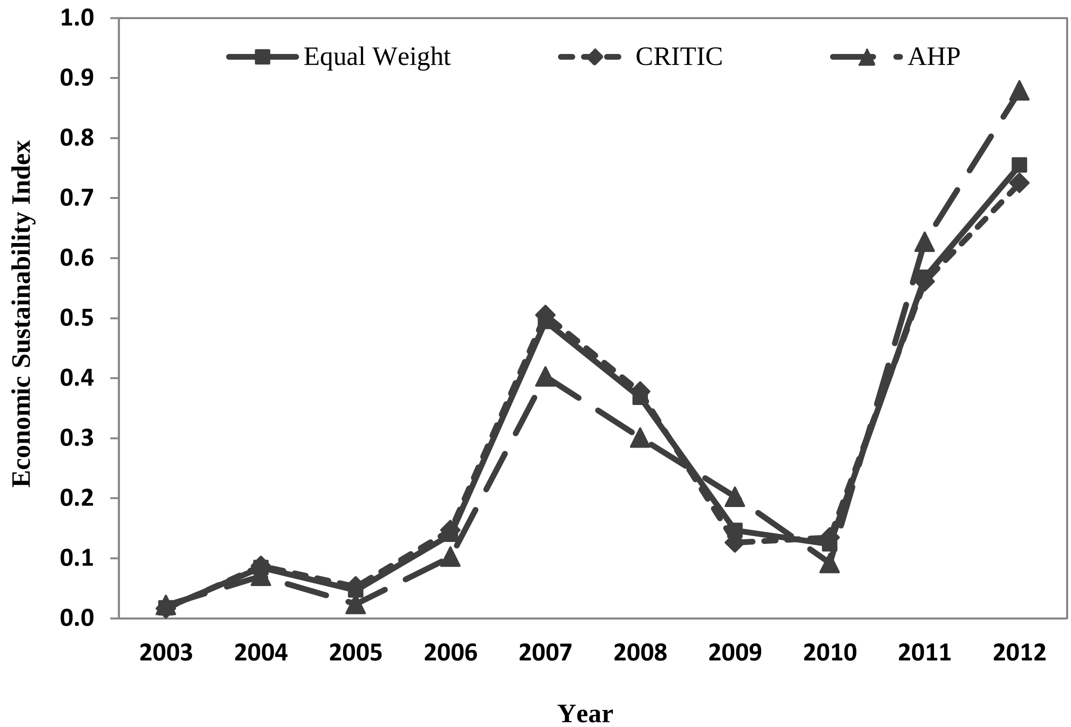

Figure 5.11 Comparison of economic dimension

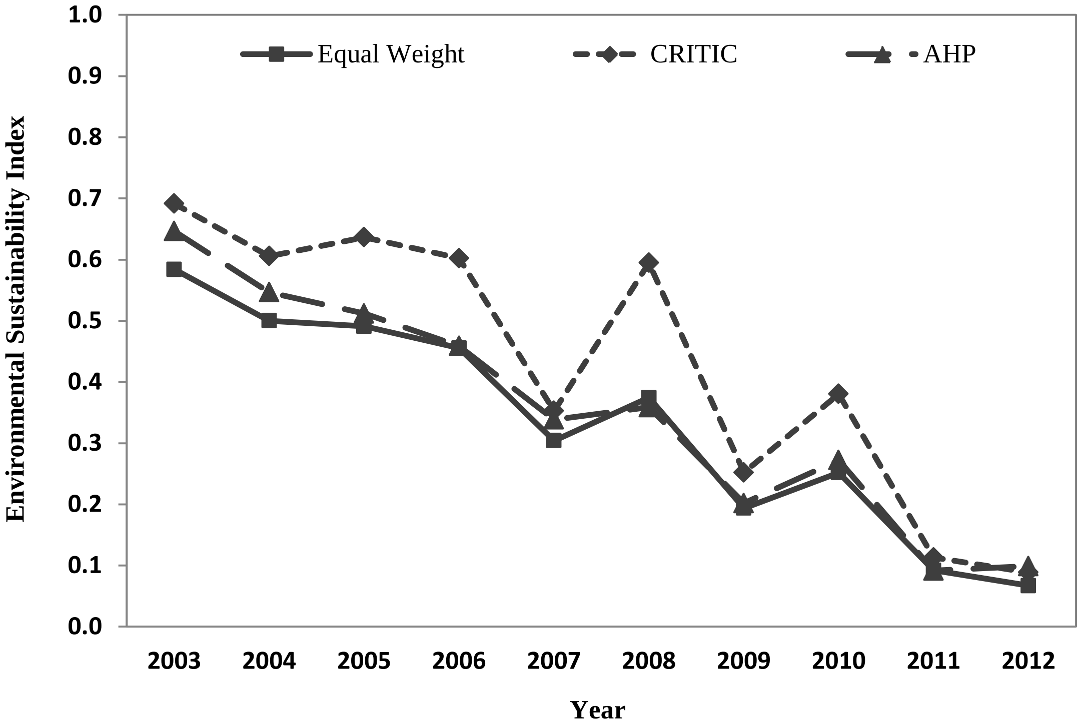

Figure 5.12 Comparison of environmental dimension

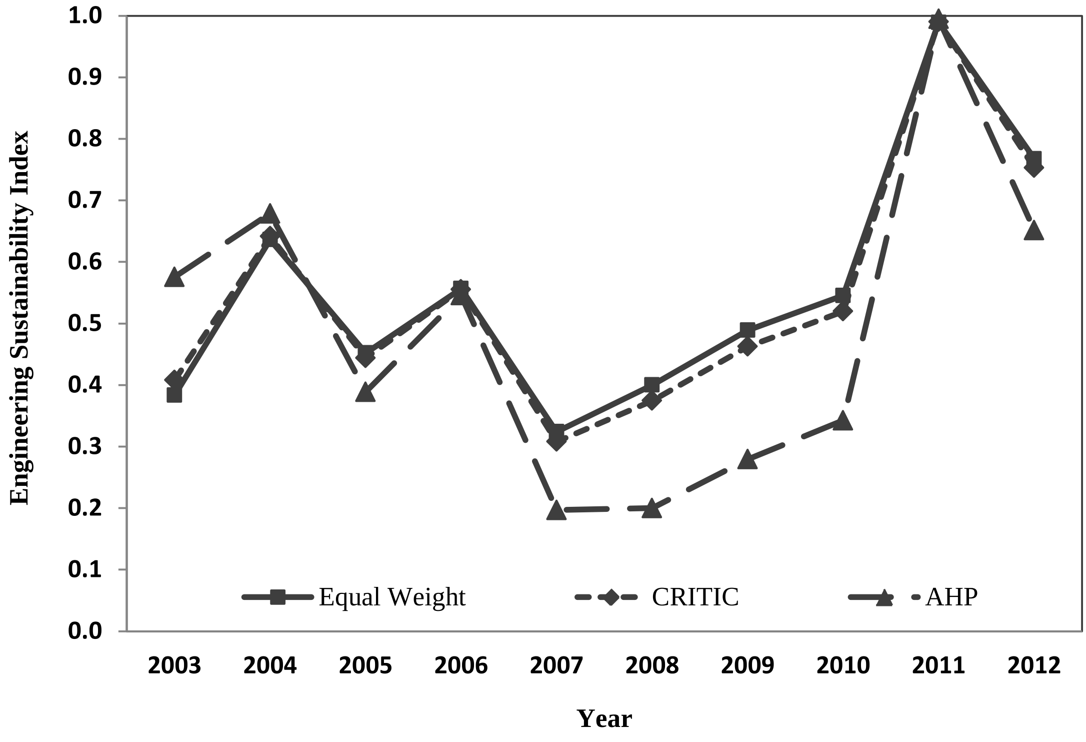

Figure 5.13 Comparison of engineering dimension

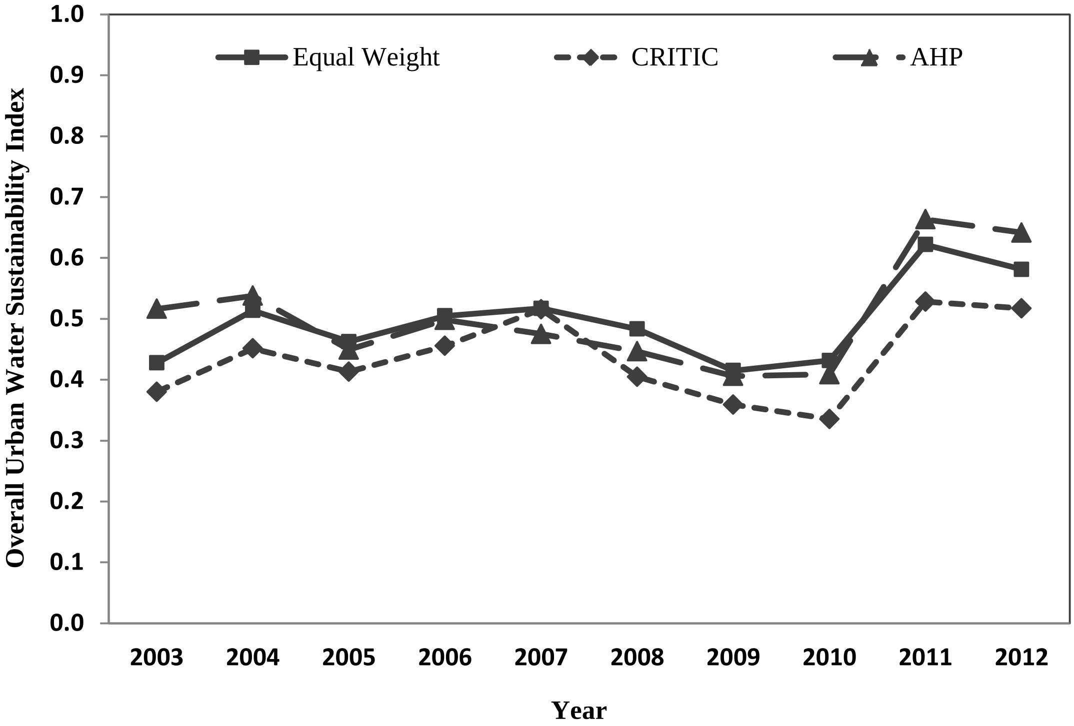

Figure 5.14 Comparison of overall urban water sustainability index

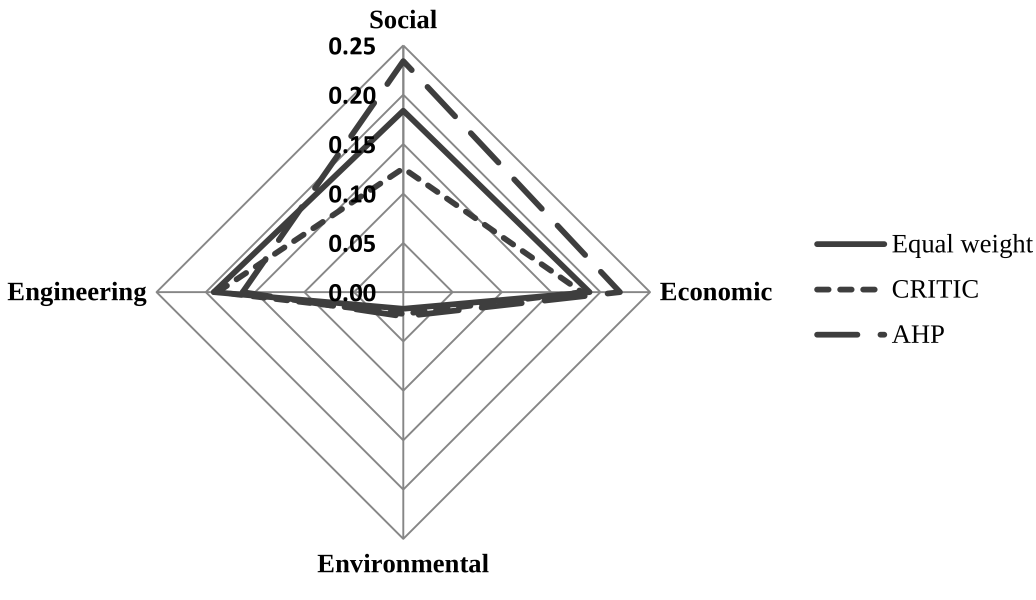

Figure 5.15 Comparison of performance of four dimensions in 2012

The evaluation of urban water sustainability index using CRITIC Method and AHP method can be obtained in Table 5.3 and Table 5.4 with comparison to the equal weighting method in Table 5.1.

From Figure 5.10 to Figure 5.14, the difference between equal weighting method, CRITIC method and AHP method can be obtained through comparison of three curves in four dimensions. The result obtained by equal weighting method is compared by two other multi-criteria methods: 1) CRITIC method and 2) AHP method. It can be found in the figures, the three curves show satisfying consistency among all the three methods.

As for the social dimension, AHP method experiences the highest sustainability index which has the range from 0.82 to 0.97, the equal weighting method has the range from 0.70 to 0.95 and the CRITIC method has lowest range from 0.25 to 0.90 but larger fluctuations during the investigated time period.

As for the economic dimension, equal weighting method and CRITIC method have very similar trend which are nearly the same, while AHP method has slightly different value in the maximum and minimum sustainability index.

As for the environmental dimension, equal weighting method and AHP method have very similar tendency for the investigated time period while CRITIC method has experienced greater fluctuation and has relatively large value during the time interval of 2005 to 2010.

As for the engineering dimension, equal weighting method and CRITIC method again have similar trend, while AHP method is slightly lower than the other two methods.

Again the trends of the three curves are very similar which indicates a high consistency among all the three methods in this dimension.

As for the overall urban water sustainability index, it can be found out that equal weighting method and AHP method have similar tendency, which is due to similarity in sub dimensions estimation. In general, the overall urban water sustainability index evaluated by CRITIC method has the lowest sustainability index among three, the reason for that may because of a lower value in the social dimension while using CRITIC for assessment.

Particularly, the urban water sustainability index for the latest investigated year 2012 in Figure 5.15 shows clearly about the interrelation among three methods in four dimensions. Generally, the three curves appear to show satisfying consistency, but variation still exists. In social dimension, sustainability index for AHP method is larger than equal weighting method while CRITIC method appears to be the lowest. In economic dimension, the sustainability index for AHP method is larger than the other two while equal weighting and CRITIC has similar value. In the environmental and engineering dimensions, there is less difference among the three methods. In 2012, the overall urban water sustainability index for Equal Weighting, CRITIC and AHP are 0.581, 0.517 and 0.642. It is noted that the sequence for the sustainable development level is: AHP Method > Equal Weighting Method >CRITIC Method. With refer to Table 5.1 all three methods indicate that the urban water sustainable level for Macau in 2012 is moderate.

According to the figures, all three methods experienced similar trends which indicate that the urban water sustainability index assessment for Macau is representable. The curve using CRITIC method for weighting has larger fluctuation than other two methods, while the equal weighting method and the AHP method are closer to each other. The equal weighting method is a simplified method which neglects different significance among indicators. The AHP method is a subjective method which based strongly on the researcher's judgment. The CRITIC method is established to determine the weighting of relative importance of indicators in multi-criteria problem. Difference between subjective and objective weighting is that subjective weighting represents the estimator's judgment, while the objective weighting represents the data information.

Besides, according to Zhao *et al.* (2011), the difference between minimum and maximum value can represent the rationale which demonstrates that the range between maximum and minimum weight represents the rational of applied weighting method. A better weighting method has larger difference between the minimum and maximum value. In this study, it can be found out that CRITIC method has the largest difference between extreme values. The sequence range for the investigated weighting methods are: CRITIC Method > AHP Method > Equal Weighting Method. It is noticed that the CRITIC method is the most reasonable weighting method in this case.

In this study, comparisons are made between three methods of weighting. All three methods have their quantitative characteristics. After illustration, CRITIC method is believed to be a more reliable and representable method for urban water sustainability assessment in Macau. A systems approach could be used to assess the sustainability of urban water systems in Macau through CRITIC method and provide a perform system analysis of entire urban water cycle by developing simple criteria and measures to guide decision-makers.

5.3 THE RENEWABLE WATER PLAN (2013-2022)

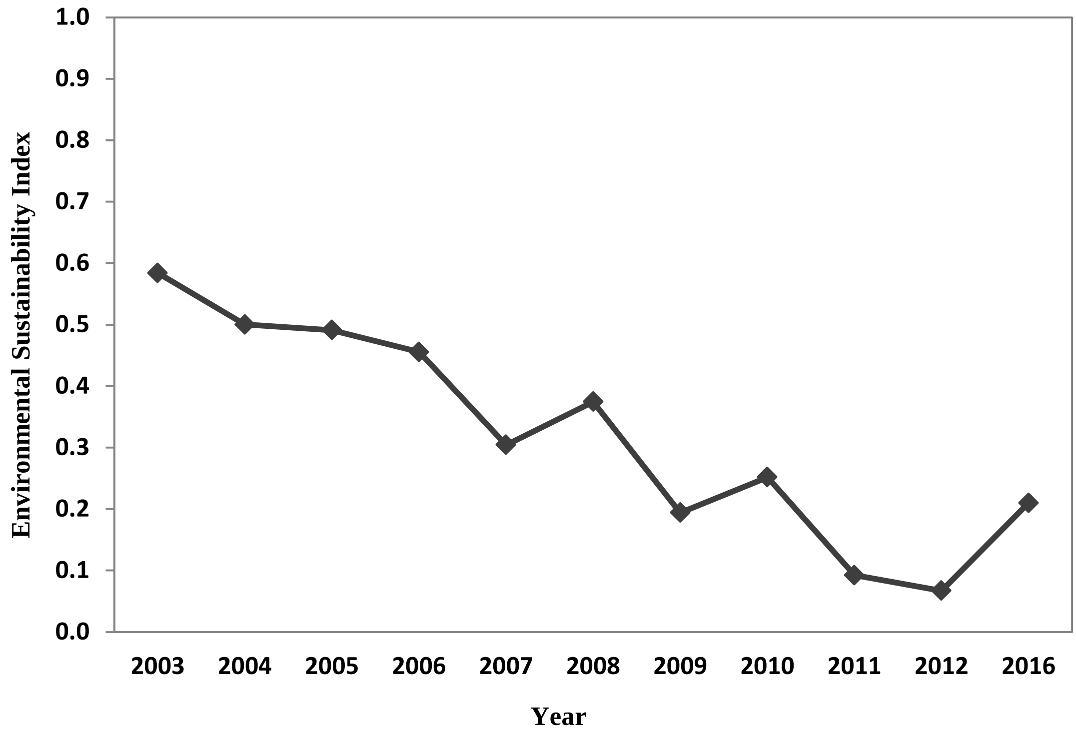

Figure 5.16 Sustainability trend of environmental dimension until 2016

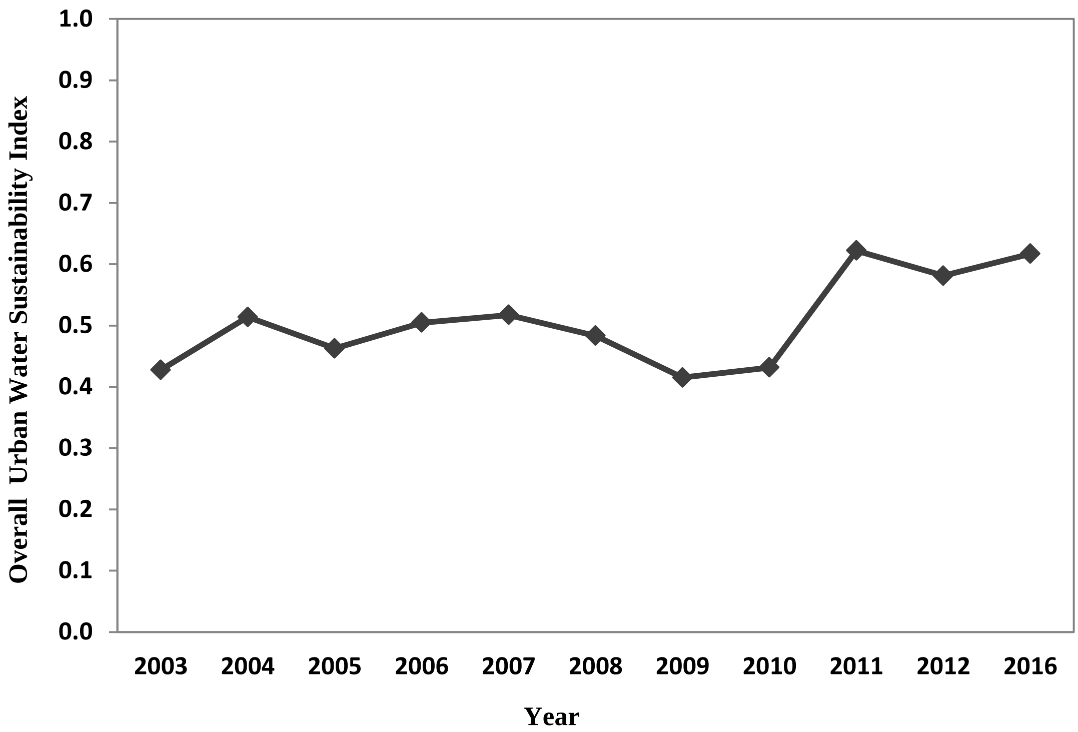

Figure 5.17 Overall trend of urban water sustainability until 2016

According to the Macau renewable water plan (2013-2022), in order to find the solution for the increasing water pressure, it is necessary to find new ways to development renewable water resources. One of the effective measures is to collect the discharge of wastewater and reuse the wastewater after treatment. The short term goal of the renewable-water plan is to build the Coloane Reuse Water Plant in 2016 and achieve a renewable water generation amount of 12,000m^3 per day. In this study, the water reuse is one of the indicators selected in the environmental dimension. Therefore, this renewable water plan could affect the environmental dimension so as the affect the urban water sustainability index.

From the result shown in the previous section, the environmental dimension is the lowest value among all four dimensions, which indicates a higher potential of improvement in the environmental dimension. In this section, an improvement of sustainability index for environmental dimension is carried out particularly based on the renewable water plan. Assume other indicators remain unchanged from 2012 to 2016 and only the reuse water value changes from zero to 12,000m^3 /day in year 2016 as stated in the plan. The sustainability trend of environmental dimension and the change of overall urban water sustainability are shown in Figure 5.16 and Figure 5.17.

The effect on overall sustainability index can be found in Figure 5.16, showing a rise of sustainability index in environmental dimension from 0.067 to 0.21. Figure 5.17 also implies an increase of overall urban water sustainability index from 0.58 to 0.62, which indicates a move toward urban water sustainable development. Results present the effect for environmental dimensions and overall result after adopting the renewable water plan. Compared the urban water sustainability index in 2016 with the result shown in 2012, it can be found out that there is an improvement due to the recycle of wastewater.

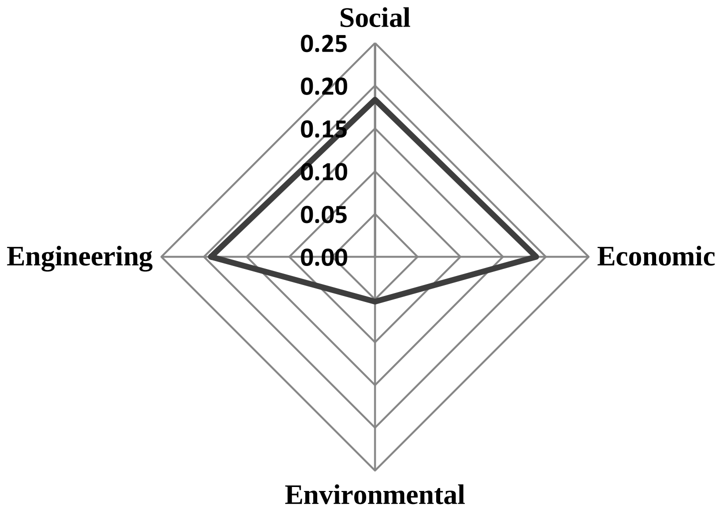

Figure 5.18 Estimated performance of four dimensions in 2016

Figure 5.18 demonstrates the estimated performance of four dimensions in 2016. For the assumption, the social, engineering and economic dimensions remain unchanged. Compare with Figure 5.7, which shows the performance of four dimensions in 2012, the environmental dimension has better performance in 2016 than 2012, which demonstrates an improvement in the environmental dimension. With the overall sustainability index moves toward 1.0, it implies a trend moving towards sustainable development in Macau. Therefore, it can be found out that the measure for this renewable water plan has effective impact on the sustainable development of Macau.

CHAPTER 6 CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

With rapid development in the economy, special geographical environment, growth of population and tourism, increase of the water consumption and wastewater generation, the pressure on the urban water system in Macau is becoming higher and higher. The government and the water supply company have carried out water conservation strategy in order to obtain a better urban water management system. As a result, it is necessary to carry out research for the sustainability urban water assessment.

This study builds up an urban water sustainable development framework for Macau. By adopting 18 important sustainability indicators in four dimensions, the sustainability of urban water management system in Macau can be simply investigated. According to Lee and Huang (2007), sustainability indicators are effective means of determining whether a city is moving towards sustainable development. The main achievement of this study in introducing sustainability index is to strike a balance between ecology and the human inhabitance. In this study, if the sustainability index approaches 1.0, it indicates a trend towards sustainable development. On the contrary, if the sustainability index gradually approaches zero, it indicates that the city is moving away from sustainable development.

First of all, the estimation of urban water sustainability using equal weighting method as basis is analyzed among social, economic, environmental and engineering dimensions. As for social dimension, the sustainability index has remained stable for the investigated time period, while the engineering and economic dimensions have generally moved towards sustainable development. However, the environmental dimension performed poorly and has gradually moved away from sustainable development. As for the overall result, compared to the past, the sustainable index has been improved in recent years and it can be concluded that the sustainability for Macau is currently consistent with the moderate sustainable level.

Among all four dimensions, the environmental dimension tends to decrease during the investigated time interval. The reasons for that are mainly due to low values in water and sludge reuse as well as the increasing pollution load to the environment. The environmental dimension has the lowest value which indicates a higher potential for improvement. In order to achieve further sustainable development in the environmental dimensions, it is necessary to carry out concrete policies such as develop systems in recycled water and reduce the emission of pollutant into the environmental. Also, citizens are encouraged to contribute their effort in the future.

In addition, the CRITIC method and the AHP method are introduced to make comparison to equal weighting method. It can be found out from the comparative analysis that satisfying consistency is shown among all the three methods. While equal weighting method neglect relative importance among different indicator and AHP method provides a subjective approach reflecting estimator's judgment, CRITIC method which adopts the objective approach is believed to be more representable for urban water sustainability assessment in Macau.

Furthermore, future prospect is further estimated which is based on the renewable water plan 2013-2022. The result presents an improvement in the environmental dimensions after adopting the renewable water plan which is mainly due to the recycle of wastewater. The effect on overall sustainability index is improved which shows that the renewable water plan has positive effect in the urban water sustainable development.

Although the methodology proposed this study cannot provide an absolute and precise measure for the sustainable development in Macau, it helps to provide a preliminary study of whether Macau has achieved progress towards sustainable development or moved away from sustainable development during 2003 to 2012. Also, it gives a reference to decision makers and local authorities with more comprehensive information on the city urban water management system in Macau.

6.2 RECOMMENDATIONS

As for recommendations of the future work, this study provides a preliminary study of comprehensive index with 18 indicators in 4 dimensions. It is encouraging to adopt other methods in estimating the urban sustainability index and make comparison with results shown in this study. Different weighting methods can be further investigated in the future so as to find out the most suitable weighting approach for Macau. Moreover, the importance of the indicators may also change over time, therefore, it's necessary to adjust the selected indicators in order to gain more precise results. Since regional analysis can provide a more comprehensive overview of sustainability in urban water management system, study should not only focus on the integrated sustainable development. Further research can be carried out in assessment for different regional areas in Macau. Comparison can be made between Macau and other cities in similar nature so as to provide a global perspective in urban water sustainability assessment.

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APPENDIX

➢ Weighting for AHP Method

Table A.1 Assigned priories and weighting in social dimension

	C1	C2	C3	C4	C5	C6	weighting
C1	1.00	3.00	5.00	5.00	7.00	7.00	0.45
C2	0.33	1.00	3.00	3.00	5.00	5.00	0.24
C3	0.20	0.33	1.00	1.00	5.00	3.00	0.12
C4	0.20	0.33	1.00	1.00	5.00	3.00	0.12
C5	0.14	0.20	0.20	0.20	1.00	1.00	0.04
C6	0.14	0.20	0.33	0.33	1.00	1.00	0.04

Table A.2 Assigned priories and weighting in economic dimension

	C6	C7	C9	weighting
C7	1.00	0.33	1.00	0.16
C8	3.00	1.00	3.00	0.49
C9	3.00	1.00	1.00	0.34

Table A.3 Assigned priories and weighting in environmental dimension

	C10	C11	C12	C13	C14	C15	C16	weighting
C10	1.00	5.00	1.00	3.00	1.00	5.00	3.00	0.26
C11	0.20	1.00	0.20	0.33	0.20	1.00	0.33	0.03
C12	1.00	5.00	1.00	3.00	1.00	5.00	3.00	0.26
C13	0.33	3.00	0.33	1.00	0.33	3.00	1.00	0.09
C14	1.00	5.00	1.00	3.00	1.00	3.00	3.00	0.24
C15	0.20	1.00	0.20	0.33	0.33	1.00	0.33	0.04
C16	0.33	3.00	0.33	1.00	0.33	3.00	1.00	0.09

Table A.4 Assigned priories and weighting in engineering dimension

	C15	C16	weighting
C17	1.00	0.33	0.25
C18	3.00	1.00	0.75

- Weighting for CRITIC Method

Table A.5 Symmetric matrix and weighting in social dimension

	C1	C2	C3	C4	C5	C6	weighting
C1	1.00	1.00	0.82	1.00	0.94	0.73	0.00
C2	1.00	1.00	0.82	1.00	0.94	0.73	0.00
C3	0.82	0.82	1.00	0.82	0.67	0.79	0.32
C4	1.00	1.00	0.82	1.00	0.94	0.73	0.00
C5	0.94	0.94	0.67	0.94	1.00	0.62	0.23
C6	0.73	0.73	0.79	0.73	0.62	1.00	0.45

Table A.6 Symmetric matrix and weighting in economic dimension

	C7	C8	C9	weighting
C7	1.00	0.40	0.30	0.37
C8	0.40	1.00	0.68	0.27
C9	0.30	0.68	1.00	0.35

Table A.7 Symmetric matrix and weighting in environmental dimension

	C10	C11	C12	C13	C14	C5	C16	weighting
C10	1.00	0.98	0.85	0.98	0.74	0.74	0.53	0.19
C11	0.98	1.00	0.90	0.99	0.72	0.72	0.56	0.19
C12	0.85	0.90	1.00	0.89	0.84	0.84	0.72	0.13
C13	0.98	0.99	0.89	1.00	0.77	0.77	0.57	0.15
C14	0.74	0.72	0.84	0.77	1.00	1.00	0.66	0.00
C15	0.74	0.72	0.84	0.77	1.00	1.00	0.66	0.00
C16	0.53	0.56	0.72	0.57	0.66	0.66	1.00	0.34

Table A.8 Symmetric matrix and weighting in engineering dimension

	C17	**C18**	**weighting**
C17	1.00	0.46	0.47
C18	0.46	1.00	0.53

Table A.9 Weighting by three methods

Dimension	NO.	Indicator	EW	CRITIC	AHP
Social	C1	Access to water supply	0.17	0.00	0.45
	C2	Access to sanitation	0.17	0.00	0.24
	C3	Water availability per capita per day	0.17	0.32	0.12
	C4	Supply hours	0.17	0.00	0.12
	C5	Service complaints	0.17	0.23	0.04
	C6	Flood prone area	0.17	0.45	0.04
Economic	C7	Capita investment	0.33	0.37	0.16
	C8	Cost recovery, operation and maintenance cost	0.33	0.27	0.49
	C9	Research and development investment	0.33	0.35	0.34
Environ-mental	C10	Water withdrawal	0.14	0.19	0.26
	C11	Energy consumption	0.14	0.19	0.03
	C12	Pollution load on environment	0.14	0.13	0.26
	C13	Waste water treatment performance	0.14	0.15	0.09
	C14	Water reuse	0.14	0.00	0.24
	C15	Recycling of nutrients and sludge reuse	0.14	0.00	0.04
	C16	Rain water harvesting and recharging	0.14	0.34	0.09
Engineer-ing	C17	Metered connection	0.50	0.47	0.25
	C18	Service interruption and water losses	0.50	0.53	0.75