RESEARCH AND DEVELOPMENT INSTITUTE

RAJAMANGALA UNIVERSITY OF TECHNOLOGY SRIVIJAYA

RESEARCH REPORT

(รายงานการวิจัย)

ON

THE POTENTIAL OF RAINWATER HARVESTING FOR HOUSEHOLD USE
(ศักยภาพของการเก็บเกี่ยวน้ำฝนเพื่อใช้ในครัวเรือน)

by

ASST PROF BANCHERD KANCHANACHETANEE

(ผศ.บรรเจิด กาญจนเจตนี)

ASST PROF PANU PROMPUTTHANGKOON, PHD

(ผศ.ดร.ภาณุ พร้อมพุทธางกูร)

A RESEARCH REPORT SUBMITTED TO RAJAMANGALA UNIVERSITY OF TECHNOLOGY SRIVIJAYA

(ได้รับการสนับสนุนทุนวิจัยจากมหาวิทยาลัยเทคโนโลยีราชมงคลศรีวิชัย
งบประมาณแผ่นดิน พ.ศ. 2558)

MARCH 2016

คำนำ

ในอดีต แหล่งน้ำดื่มสำหรับคนทั่วไปคือ น้ำฝน น้ำบ่อ และน้ำบาดาล โดยน้ำฝนถือเป็นแหล่งสำคัญที่สุด ต่อมาเมื่อเริ่มมีการพัฒนาอุตสาหกรรม ทำให้เกิดความเชื่อว่า น้ำฝนมีการปนเปื้อนไม่สามารถดื่มได้อย่างปลอดภัยอีกต่อไป คำกล่าวนี้มีส่วนจริงอยู่ถ้าฝนตกในเขตพื้นที่อุตสาหกรรมหนาแน่น ปัจจุบันนี้ คนไทยเสียค่าใช้จ่ายกับน้ำดื่มเป็นจำนวนมาก ทั้งๆ ที่ประเทศไทยมีฝนชุกเพียงพอสำหรับการรองรับน้ำฝนไว้ดื่มกินตลอดปี งานวิจัยนี้จึงสนใจที่จะทดสอบคุณภาพของน้ำฝนอย่างเป็นระบบ เพื่อหาคำตอบเชิงวิทยาศาสตร์ว่า จริงๆ แล้ว น้ำฝนในปัจจุบันดื่มได้หรือไม่ การเก็บน้ำฝนกระทำอย่างระมัดระวังในเขตจังหวัดสงขลาและนครศรีธรรมราช นอกจากน้ำฝนกลางหาวแล้ว ยังมีการเก็บตัวอย่างน้ำฝนไหลผ่านหลังคา เก็บไว้ในแท็งค์ น้ำฝนผ่านการต้ม และน้ำบ่อ ผลการทดสอบคุณภาพน้ำตามมาตรฐานกระทรวงสาธารณสุขชี้ให้เห็นว่า ถ้ากักเก็บอย่างถูกวิธีและผ่านการต้ม น้ำฝนสามารถดื่มได้อย่างปลอดภัย ดังนั้นจึงเป็นการสมควรที่จะหันกลับมาดื่มน้ำฝน ซึ่งจะทำให้ประชาชนมีเงินเหลือใช้สำหรับอย่างอื่นที่จำเป็นต่อชีวิตต่อไป

นักวิจัยได้เลือกภาษาอังกฤษสำหรับการเขียนรายงานวิจัยฉบับนี้ เนื่องจากวัตถุประสงค์หลักอีกอย่างหนึ่งของโครงการวิจัย คือ การนำผลงานวิจัยออกไปเผยแพร่ในระดับนานาชาติ ซึ่งหมายความว่าต้องใช้ภาษาอังกฤษเป็นภาษาหลัก ดังนั้นการเขียนรายงานวิจัยเป็นภาษาอังกฤษจะทำให้สามารถนำผลการวิจัยออกไปเผยแพร่ในระดับนานาขาติได้ทันทีไม่ต้องมีการเขียนใหม่เป็นครั้งที่สอง หรืออาจมีการปรับปรุงเพียงเล็กน้อยเมื่อมีข้อมูลใหม่เพิ่มเติมเข้ามา

อนึ่ง เนื่องจากภาษาอังกฤษไม่ใช่ภาษาแม่ของนักวิจัย ดังนั้นข้อผิดพลาดทางด้านภาษา เช่น หลักไวยกรณ์ต่างๆ อาจเกิดขึ้นได้ กรณีที่มีข้อผิดพลาดใดๆ ที่เกี่ยวข้องกับหลักการใช้ภาษาอังกฤษ ผู้วิจัยขอน้อมรับไว้แต่เพียงผู้เดียว

งานวิจัยครั้งนี้สำเร็จลงได้ตามแผนงานวิจัย ก็เนื่องจากว่าได้รับความช่วยเหลือจากหลายฝ่าย โดยเฉพาะในส่วนของงบประมาณโครงการ ซึ่งได้รับการสนับสนุนจากมหาวิทยาลัยเทคโนโลยีราชมงคลศรีวิชัย งบประมาณแผ่นดิน พ.ศ. 2558 ซึ่งผู้วิจัยขอกราบขอบพระคุณมา ณ ที่นี้ เป็นอย่างสูง

ABSTRACT

In the past drinking water sources were mainly rainwater, well water, and ground water. All of which the rainwater was the most drinking water consumed. As the industry has been developed all over the world, people now think that the rainwater is toxic. As a result they are paying for drinking water. Unfortunately, this has also been the case for Thailand. As such, this research attempted to show that rainwater actually is still drinkable. If the result was positive, then people would have more money left in their pockets thereby having more to spend on other essential things.

To achieve those objectives five different types of rainwater and one groundwater were systematically collected and tested according to the drinking water standards announced by the ministry of public health. Please be noted that the rainwater samples were collected in the areas of Songkhla and Nakhon si thammarat because they are big compared to their counterparts in the South in terms of both area and population. In addition, both provinces have relatively large amounts of annual rainfall thereby possible for harvesting rainfall.

The rainwater samples included pure rainwater, boiled pure rainwater, rainwater flowing through roof, rainwater kept in a stainless tank, and rainwater kept in a stainless tank and boiled. The test results revealed that only the groundwater passes the pH criteria. Note that this is very easy to correct. For substances, it was found that all of the samples pass the criterion. In terms of bacteria, however, only boiled rainwater passed the standard. This indicates that rainwater when boiled is indeed safe for drinking.

Keywords: rainwater, drinkable, drinking water standard

ACKNOWLEDGEMENTS

The authors wish to thank Rajamangala University of Technology Srivijaya, for their financial aid by means of the annual government statement expenditure 2015 (BE 2558). Furthermore, during undertaking this research project the support for all aspects of consulting and assisting was provided by the people at Research and Development Institute, Trang Campus, for which the authors are gratefully indebted.

Special thanks are due to Asst Prof Charoen Maiduang for his help and support for collecting rainfall. In addition, the authors would like to extend their gratitude to officials and students at College of Industrial Technology and Management for their help with respect to collecting and storing the samples.

Lastly, the author is very grateful and appreciative of all of the assistance and support offered from colleagues, researchers, and lecturers of Civil Engineering Division, Faculty of Engineering. Please be noted that this research was completed in March 2016.

TABLE OF CONTENTS

NOTATION AND ABBREVATION

EPA	Environmental protection agency
G1	Rainwater directly collected (pure rainwater)
G2	Rainwater directly collected and boiled
G3	Rainwater flowing through roof and gutter
G4	Rainwater kept in a stainless tank
G5	Rainwater kept in a stainless tank and boiled
G6	Well water (groundwater)
pH	Potential of hydrogen
TIS	Thailand industrial standard
WHO	World health organisation
USP	United state pharmacopie

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Research context

As the world's population rapidly growing, the increasing development of communities for both rural and urban areas is manifested. For example, according to the survey conducted by United States Agency for International Development (USAID, 2012) the population around the world in 2012 was just 7 billion; but, in the next 40 years it would be around 9 billion. It should be stressed that the world's population at 40 years ago was just 2.5 billion. In the case of Thailand, the population in 1910 was 8 million only. In 2010, however, it was greatly increased to 64 million, 8 times a hundred years ago (Prasartkul and Wawattanawong, 2011). These figures confirm that the world's population is certainly increasing all the time. As a result, the need for drinking water is also progressively rising thereby causing the problem around the world. Nonetheless, it has been found that the sources for drinking water are shrinking.

The increasing population has resulted in the expansion of both residential and industry. This of course indirectly affects the invasion of forests in order to occupy an area for living. The consequent is that the naturally adsorbed-water land is also decreased. The increase of industrial factories is worrying people in the sense that the rainwater falling around those areas is so polluted that is undrinkable. Thus, they have no intention whatsoever to store the rainwater for consumption as used to do in the past. It should be noted that this statement is not true all over the world. In facts, some parts of the world are still harvesting the rainwater for something, e.g., feeding grass, planting, and farming. For drinking, however, some are turning to the groundwater. Consequently, land subsidence has been observed around the globe. In addition, a regularly sinkhole resulted from over pumping incident is no surprised to common people anymore. All of these accounts have resulted in the people are more and more paying for drinking water.

The problems concerning drinking water as aforementioned led the authors to investigate and find a solution for seriously making use of rainfall. To achieve that intention, the first step was to collect the rainwater in the South in order to evaluate its quality in terms of drinking water standards. Other tasks were to study the methods and techniques for improving its quality according to the standards. The research concept was based on the assumption that there is huge rainfall in the South each year. In addition, it rains for a very long period during a year. As such, if there is a way to safely store rainfall and make use later on, it would be very beneficial for common people in terms of reducing their expense for drinking water.

1.2 Research objectives

The following objectives were set to achieve the aims of this research project:

1) To study the types and quantity of water usage in households, including water-usage in household, drinking water, and cost for drinking water.
2) To investigate the quality of rainfall by collecting it directly from the sky in order to avoid any contaminations.
3) To investigate techniques for improving the rainfall quality so that the drinking water standard is met.
4) To study techniques and methods for storing the rainfall enough for a community.

1.3 Scopes of research

The time for this project was only one year, with an additional year; thus, it needed to limit the areas for the study. Hence, Nakhon si thammarat and Songkhla were chosen because there are lots of rains during rainfall season.

1.4 Research methods

To achieve the aims of this research the first task was to design a system for collecting the rainwater. The design was based on the assumptions that it should be able to collect the rainwater directly, i.e., the rain water must drop to the system and then to a container straightaway. The intention for this design was to avoid any contaminations that may occur in which they might alter the test results. The water then was cooled in a closed bucket before transporting to a scientific laboratory within 24 hours. Next, the water was immediately tested in accordance with a drinking water standard to assess the quality in order to further analyse the substances found in details.

This research collected the rainwater from two areas: (1) Songkhla and (2) Nakhon si thammarat provinces. Both are located in the South of Thailand. Apart from collecting the rainwater directly, this project also collected the rainwater dropped on roofs having different roof material. In addition, some samples were boiled before sending to the laboratory. Then, the laboratory results for the non-contaminated, roof-contaminated, and boiled rainwater were compared and analysed.

1.5 Expected outcomes

This project expected to know the quality of rainwater collected from different methods in order to decide whether it can be drank or not. The results would be used to prepare an academic article to be published. The intention was to show that the rainwater actually is safe for drinking thereby encouraging people to abandon the habit of spending money on drinking water of which we can get it for free.

1.6 Layout of report

The report begins with chapter 1 introducing the important of this research project. It explains why this research was carried out. Also in the chapter are research objectives, research methods in brief descriptions, and expected outcomes. The following chapter is chapter 2 literature review. This part simply shows the collection of research, studies, and information related to this project. It was used as a guide for conducting the experiment. In addition, its information was later on referred to the test results obtained from this project.

Chapter 3 was prepared in order to give the explanation of the methods employed. Some physical as well as engineering properties of the materials tested are also included. It was prepared in such a way that is as more precise and concise as possible based on the assumptions that it may be used as a reference in the future for whom interested in a similar project. This is followed by chapter 4 results and discussion. All of the test results are shown in this chapter. However, it also explains, for example, why a particular behaviour happens. Also in the chapter is the discussion of the test results. The aim of this section was to propose a new piece of knowledge related to this discipline. Chapter 5 conclusions and recommendations is just the short information summarised from the research project; however, recommendations for further work and studies are also included.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to water resources

It has been commonly known that without food humans may be able to survive for a week or little bit longer; but, without drinking water, they may last for only few days. Such strong statement indicates the very important aspect of drinking water for the human species in terms of survival. According to Tarbuck and Lutgens (2002), of all of the water on earth 97.2 % is being kept in the oceans around the globe. Around 2.15% is in the form of ice sheets and glaciers. This leaves only 0.65% sharing among lakes, streams, underground water, and the atmosphere. Considering these figures there would not be a problem for in the past as the population was relatively scarce. In the present time, however, the world population is almost ten billion thereby lacking of drinking water is not uncommon in some areas. As a result, in some places the cost of drinking water is beyond reach for ordinary people, resulting in the low-standard of living.

This chapter investigates and reviews the studies and research related to this project. It includes rainfall statistics from major cities around the world, usage of rainfalls for drinking and others, rainfall quality, the standards with respect to drinking water, and techniques for rainfall storing. The review could provide useful information for further analysing and comparing with the results obtained for this research.

2.2 Rainfall statistics

The easiest and cheapest drinking water is surface water because it is easy to obtain followed by the groundwater. Nonetheless, when the surface water and groundwater are either not enough or contaminated, sometimes storing rainwater is applied. The rainwater is the result of the evaporation into water vapour. It can be said that, excepted contaminated with polluted air, the rainwater is one of the cleanest water. Figure 2.1 displays how the rainwater is obtained. Nowadays, directly collecting the rainwater by not allowing it to have a contact with medium is increasingly becoming a normal practice for harvesting the rainwater for household usage.

It is vital to have knowledge concerning rainfall statistic in an area one is interested in harvesting rainfall. Table 2.1 displays the total rainfall (mm) during 2002 – 2014 for some areas in Thailand covering all parts of the country, including the South, North, North-East, and Central. The southern provinces selected for displaying are Nakhon si thammarat, Songkhla, and Suratthani, of which are a group of big provinces in terms of area, population, and economy. It should be emphasised herein also that the provinces are the area that this research was concerned. The selected northern, north-eastern, and central provinces comprises Chiangmai and Pitsanulok, Nakhonratchasima and Khonkaen, and Bangkok and Karnchanaburi, respectively. Please be noted that the provinces other than the South were randomly selected for rough comparison only.

The other factor concerning rainfall behaviour that should also be considered is a number of rainy days. This is because it provides a clue concerning the possibility of rainwater harvesting. For instance, if rainfall happens regularly, harvesting is very likely. Table 2.2 shows the number of rainy day during 2002 – 2014 for some areas in Thailand covering all parts of the country, same as already displayed in table 2.1.

Figures 2.2 – 2.5 show the annual rainfall graphs for some parts of Thailand, including the South, North, North-East, and Central, respectively. All of the information for all parts were also plotted and shown in figure 2.6. In the meantime, Figures 2.7 – 2.11 show the number of rainy day graphs for some parts of Thailand, including the South, North, North-East, and Central, respectively. All of the information for all parts were also plotted and shown in figure 2.12.

Considering the annual rainfall amount for the South, it can be seen that Nakhon si thammarat has the highest rainfall, comparing to those two provinces of Songkhla and Suratthani. In other words, this implies that the province is most suitable for rainfall harvesting judged by the facts that it has plenty of rainfall. In addition, it seems Songkhla also has the rainfall as high as Nakhon si thammarat, meaning it is also suitable for making use of rainfall. For Suratthani, however, shows the lowest amount of annual rainfall. Nonetheless, the annually average values are still quite high.

For the other parts – North, North-East, and Central – it is obvious that their rainfalls are very much lower than that of the South. This indicates the less possibility of making use of rainfall when compared to the South. Despite of the facts described, however, it does not mean the rainfall harvesting cannot be done. The method may still be possible if a right method is employed. The data was further analysed by averaging for all parts; it was found that the average rainfalls for the South, North, North-East, and Central are 2209.2, 1295.6, 1203.9, and 1385.9 mm. It can be clearly seen that the South shows the highest potential in terms of rainfall harvesting for household use, followed by the Central, North, and North-East, respectively.

The average number of rainy days for Nakhon si thammarat, Sonkhla, and Suratthani are 168, 161, and 152 days, respectively. It can be observed that this is proportional to the annual rainfall already explained. From these figures it can again be seen that Nakhon si thammarat and Songkhla are the most suitable for harvesting the rainwater for household use as well as drinking. Nonetheless, Suratthani, even though has fewer rainy days it does not mean it is not suitable because the number of rainy days is as high as 152 days, corresponding to raining every 2.4 days. The average number of rainy days for the South, North, North-East, and Central are 160, 119, 110, and 1121 days, respectively, having the same pattern as of the rainfall amount.

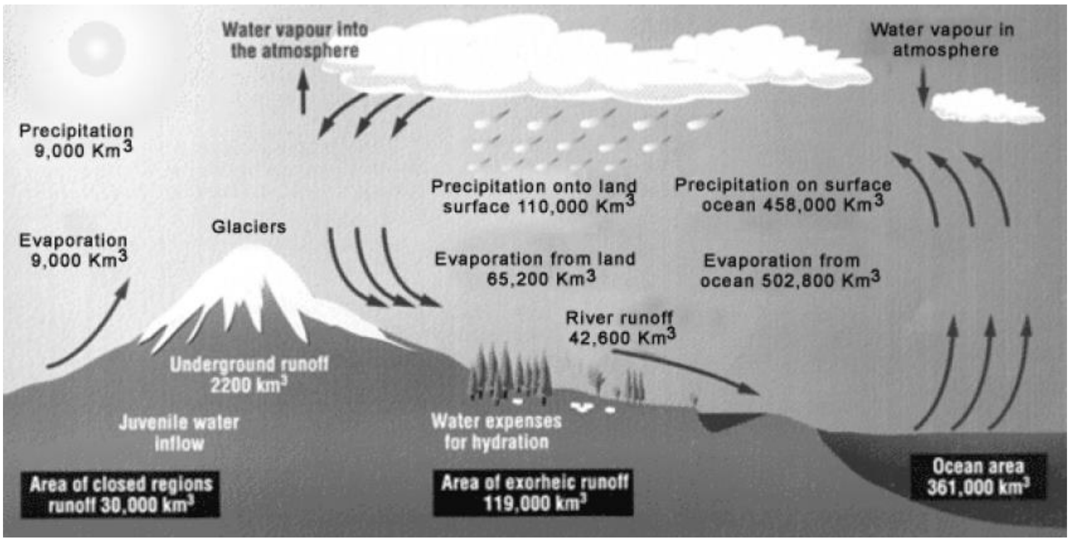

Figure 2. 1 Rainfall cycle (Bhattacharya and Rane, nd)

Table 2. 1 Total rainfall (mm) during 2002 – 2014 for some areas in Thailand (modified from National statistical office website)

Location	Total rainfall (mm)													
	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Average
South														
Nakhon si thammarat	2,646.3	2,831.6	1,849.8	2,897.2	2,766.9	2,598.6	3,248.4	2,175.5	2,699.6	4,177.9	2,544.4	2,840.6	2,318.4	2,738.1
Songkhla	1,551.1	2,247.7	1,555.1	3,048.4	1,985.4	1,861.6	2,816.5	2,119.3	2,805.7	2,966.1	2,483.4	2,793.6	1,943.0	2,321.3
Surat thani	1,112.4	1,992.5	1,248.1	1,578.0	1,229.3	1,518.4	1,624.7	1,420.2	1,930.7	1,970.8	1,493.1	1,637.6	1,629.4	1,568.1
North														
Chiangmai	1,612.3	889.6	1,208.9	1,393.4	1,500.0	1,125.3	1,141.0	1,070.2	1,156.0	1,449.5	925.6	1,288.0	1,064.4	1,217.2
Pitsanulok	1,065.8	1,366.1	1,002.0	1,466.8	1,220.9	1,513.4	1,642.4	1,338.5	1,348.5	1,368.6	1,853.6	1,203.7	1,470.8	1,373.9
Nort-East														
Nakhon ratchasima	1,013.5	933.0	980.0	1,380.4	991.8	1,177.8	1,375.6	1,212.5	1,386.2	1,208.6	1,028.5	1,306.0	976.7	1,151.6
Khonkaen	1,352.6	1,402.6	1,467.4	1,221.8	936.5	1,201.5	1,378.9	1,780.6	1,039.9	1,230.1	1,377.1	1,000.0	943.0	1,256.3
Central														
Bangkok	1,362.5	1,372.0	1,160.4	1,651.4	1,598.7	1,684.2	1,902.4	2,272.0	2,023.7	2,240.2	1,656.9	1,772.9	1,130.1	1,679.0
Karnchanaburi	992.2	1,184.5	882.1	1,164.2	1,045.8	1,091.7	1,324.8	1,329.2	1,120.4	1,067.0	1,091.3	1,088.9	824.4	1,092.8

Table 2. 2 r Number of rainfall in a year for some areas in Thailand (modified from National statistical office website)

Location	Number of rainy day													
	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Average
South														
Nakhon si thammarat	152	170	163	148	191	178	174	159	171	195	145	168	164	168
Songkhla	166	153	128	135	176	165	173	153	170	176	156	196	146	161
Surat thani	140	155	144	150	161	162	147	145	150	173	142	154	148	152
North														
Chiangmai	123	96	111	122	117	101	147	121	112	144	116	134	112	120
Pitsanulok	128	126	96	103	108	124	126	115	118	116	138	115	112	117
Nort-East														
Nakhon ratchasima	111	102	88	116	107	106	123	103	126	126	105	121	99	110
Khonkaen	121	105	103	93	103	108	101	121	103	110	131	97	118	109
Central														
Bangkok	122	108	102	124	125	139	156	139	142	161	133	148	128	133
Karnchanaburi	114	104	93	114	113	110	125	109	99	109	115	111	103	109

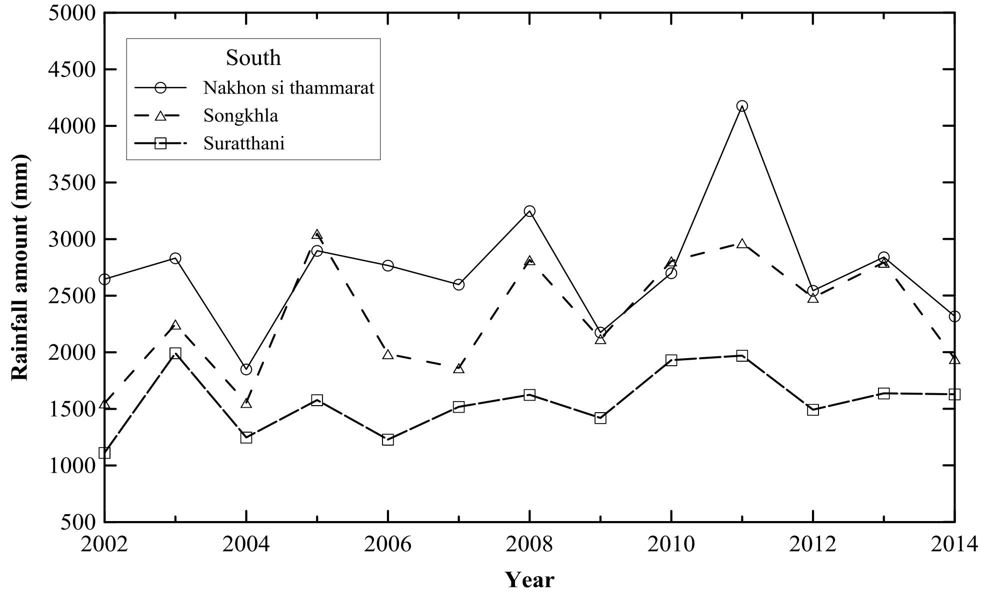

Figure 2. 2 Annual rainfall amounts from 2002 to 2014 for some southern provinces of Thailand

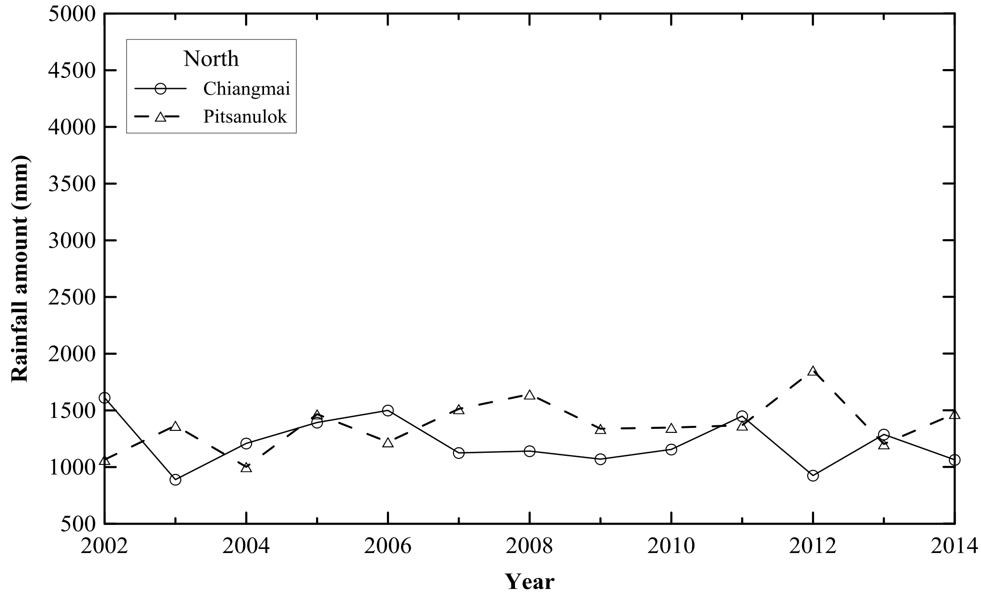

Figure 2. 3 Annual rainfall amounts from 2002 to 2014 for some northern provinces of Thailand

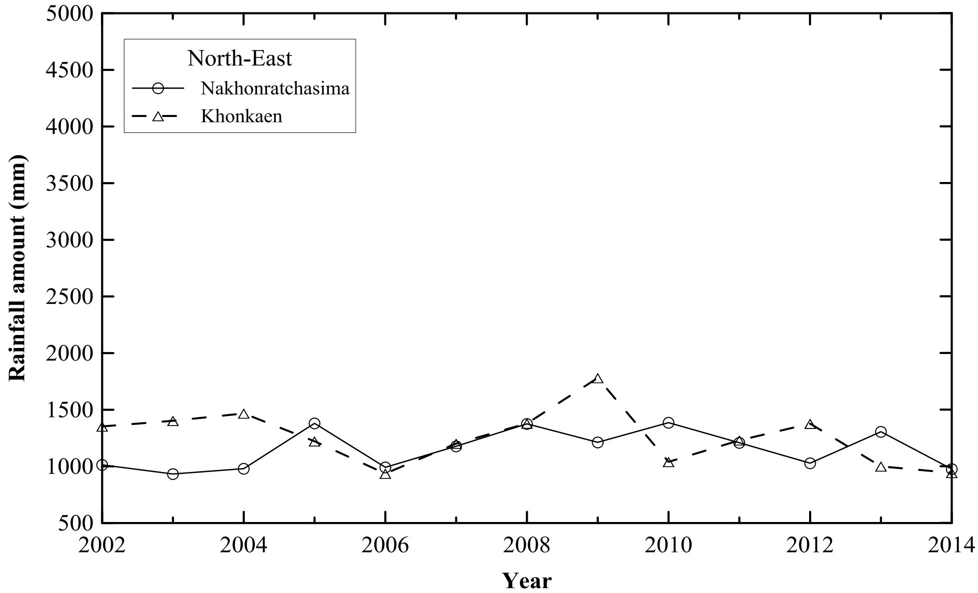

Figure 2. 4 Annual rainfall amounts from 2002 to 2014 for some north-eastern provinces of Thailand

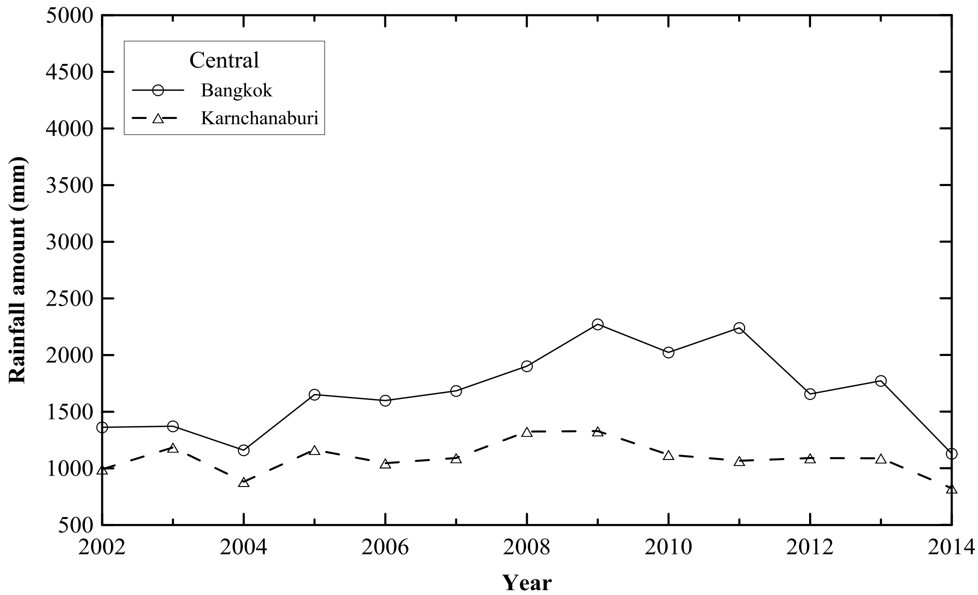

Figure 2. 5 Annual rainfall amounts from 2002 to 2014 for some central provinces of Thailand

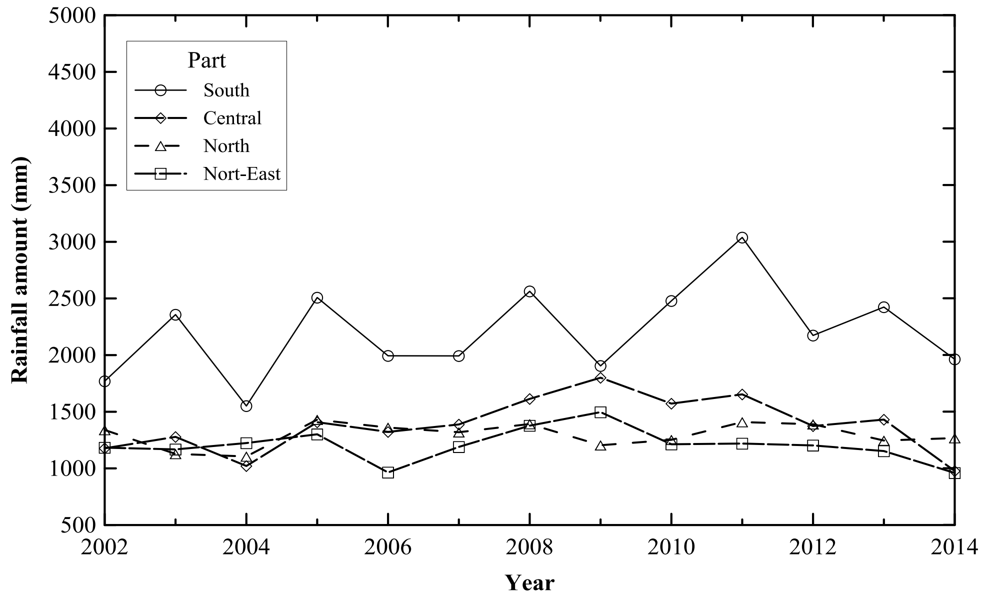

Figure 2. 6 Annual rainfall amounts for the South, Central, North, and North-East of Thailand

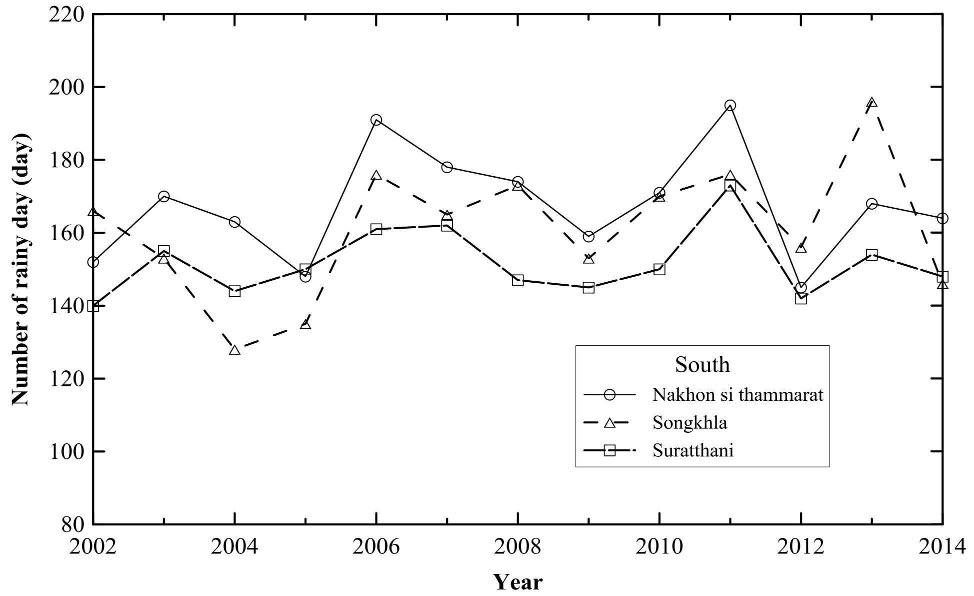

Figure 2. 7 Number of rainy days from 2002 to 2014 for some southern provinces of Thailand

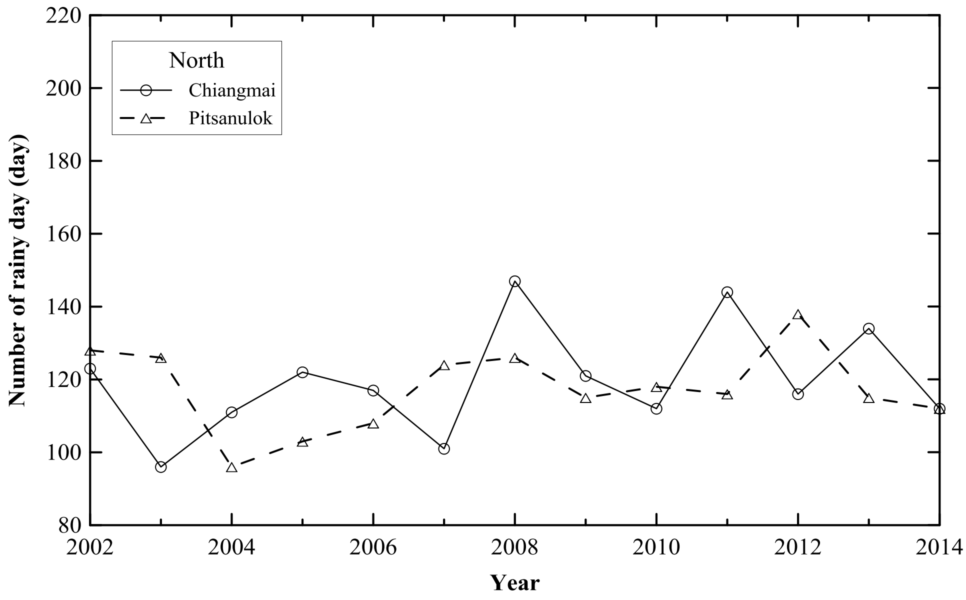

Figure 2. 8 Number of rainy days from 2002 to 2014 for some northern provinces of Thailand

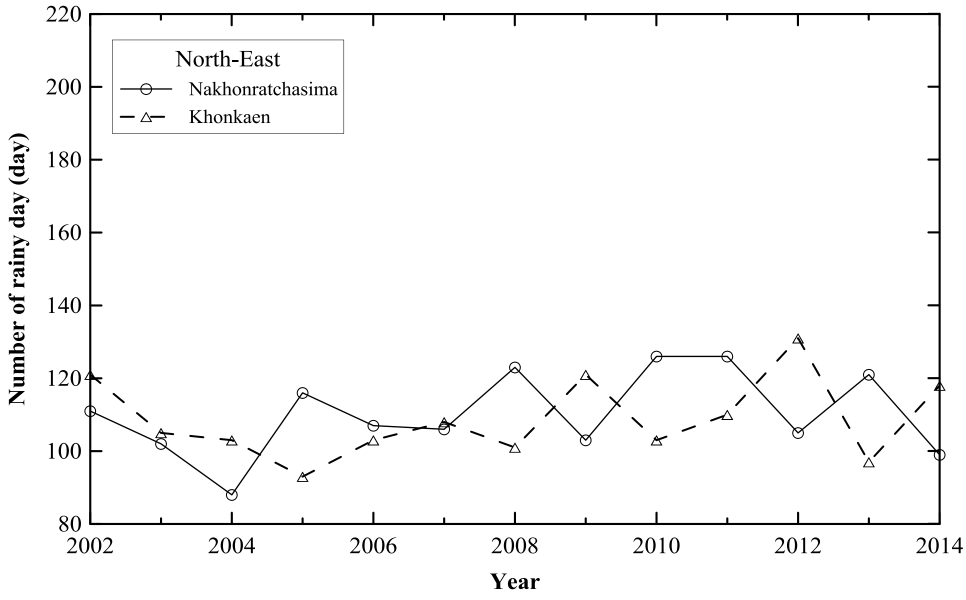

Figure 2. 9 Number of rainy days from 2002 to 2014 for some north-eastern provinces of Thailand

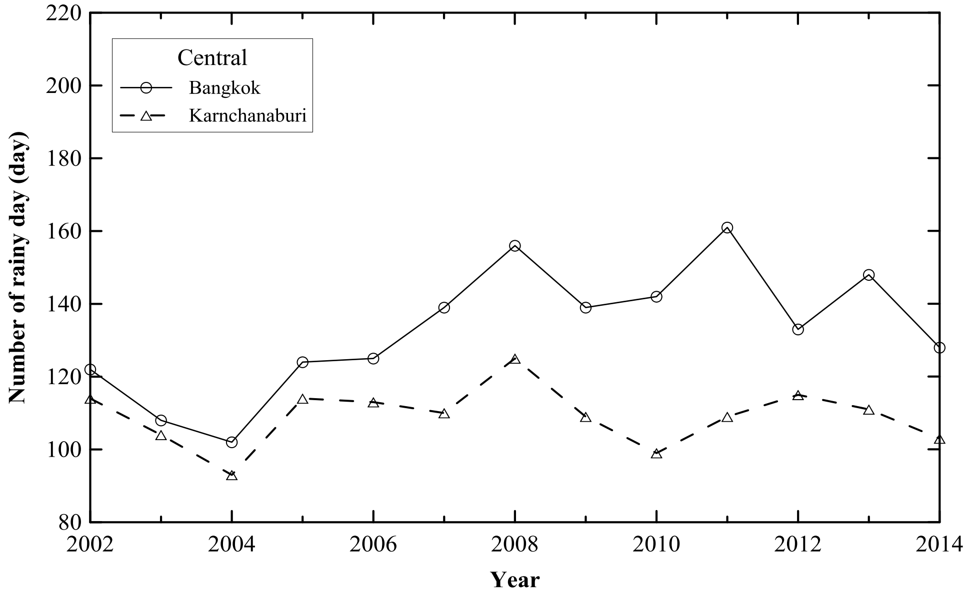

Figure 2. 10 Number of rainy days from 2002 to 2014 for some central provinces of Thailand

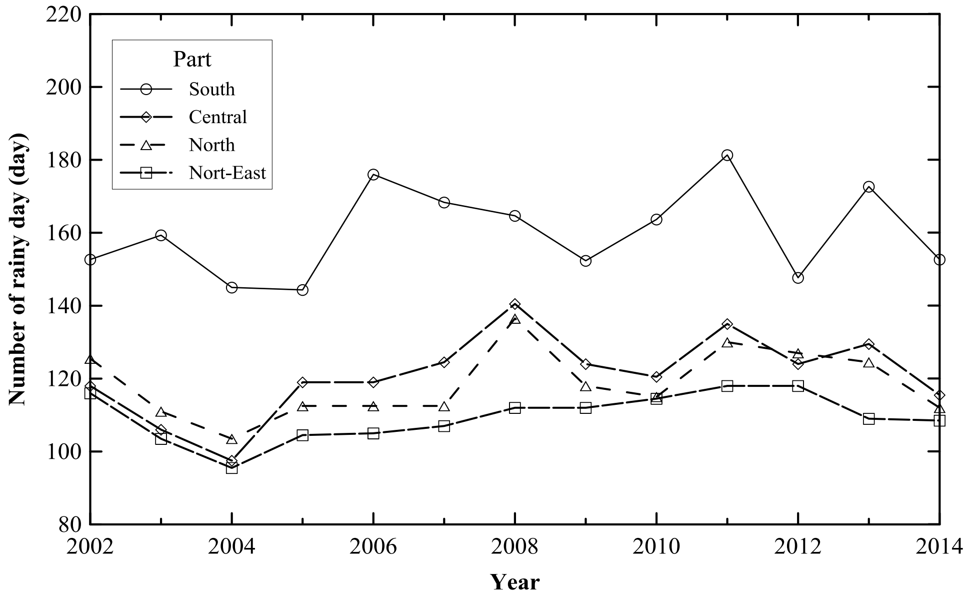

Figure 2. 11 Number of rainy days from 2002 to 2014 for the South, Central, North, and North-East of Thailand

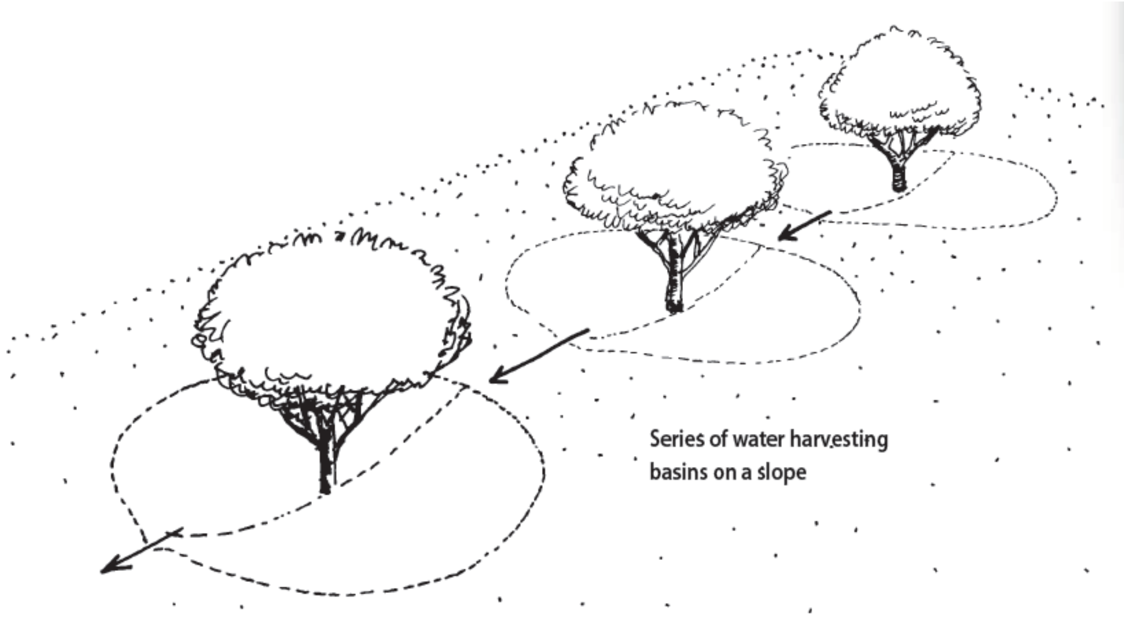

Figure 2. 12 Example of rainwater harvesting for landscaping work

2.3 Rainfall harvesting and its usage

According to City of Tucson (2013), the term rainfall (or rainwater) harvesting is activities involving capturing, diverting, and storing of rainwater for some kinds of irrigation and other uses. It should be noted that in its context the rainwater harvesting is mainly concerned with landscape irrigation. In this research, however, it wanted to deal with drinking water. It also should be noted that harvesting the rainwater for irrigation is much less stringent than for drinking water does. Figure 2.12 illustrates the example of an easy method for rainwater harvest for being used in irrigation.

As the population is rapidly growing the residing area is progressively lowering due to climate change. This results in the fewer areas for storing water for drinking and other uses. Actually, humans have utilised the rainwater for a long time. Nonetheless, they somehow avoid consuming it based on believing that the rainwater is contaminated. The statement may be true in some areas; but, may be absolutely wrong in other areas. It should not be forgotten, however, that the industrial development has caused pollutions around the world.

It has been widely acknowledged that the world population is progressively rising. Since 1950 the global population is doubled to six billion in 1999. In addition, it has been speculated that the global population would peak in 2050 to 8.9 billion. Considering these figures with natural resources, it may be concluded that in the future there would be problems concerning drinking water. Actually, many parts of the world have faced the problem for years, especially some countries in Africa, Asia, South America, and Australia. It is therefore essential to harvest rainfall for household use because it is totally free and abundant.

GDRC (nd.) gives some advantages of rainwater harvesting, as shown below:

- Rainwater harvesting could be employed parallel to other means of water sources and utility systems thereby reducing pressure on other sources of water.
- Harvesting the rainwater could provide a water supply buffer for employing of emergency of breakdown of public water supply systems, particularly during major natural disasters.
- Storing rainwater could benefit urban areas by reducing or softening flooding during thunder storms and heavy rainfalls.
- Rainwater harvesting normally requires low technologies and equipment. People may utilise whatever they have got to catch the rainwater for later use.

The roman probably was the first who systematically harvest and utilise rainwater for household use. There have been some clues indicating that the roman villas were designed and built to have the storages for rainwater to be used as drinking as well as domestic purposes. In the meantime, Egypt was the first country in Africa who also had some kinds of utilising rainwater dated back at least 2000 years; some of them are still in operation. In Asia, there were evidences related to rainwater harvest in Thailand almost 2000 years ago (GDRC, nd.). In Africa and Asia, rainwater was commonly harvested trough eaves of roof or via simple gutters into jars, pots, and small containers.

GDRC has explained that a rainwater harvesting system basically comprises three main parts: (1) the collection system, (2) the conveyance system, and (3) the storage system. As already described, collection systems and vary from quite simple types built within a household to much bigger systems, depending on several factors such as the size of a house, area for collecting the rainwater, and available storing area.

Since the beginning of human kind there have been many rainwater harvesting systems developed, some of the systems are illustrated and explained below.

1) Simple roof water collection systems

This system is mainly suitable for a single household, as can be seen in figure 2.13. It seems the amount of rainwater collected by this method is not significant; but, if lots of household employ the system impacts could be made. From the figure there are three main components: (1) roof water collection system, normally roof itself, (2) piping systems leading the water to, (3) storage system. Additional systems have been included into the system. For instance, a filter system may be inserted between the piping and storage systems in order to make the rainwater cleaner.

2) Larger systems for public premises

For public premises that water usage is a big issue, the overall system may be complicated due to not only the water to be consumed but also the frequency of the usage. The piping system from the top to the ground must be designed in order to not only conveying the rainwater but also easy to maintain. Underground storages are common for this system as they must be large enough for more people. Some water treatment systems are also necessary. Figure 2.14 shows an example of the larger system.

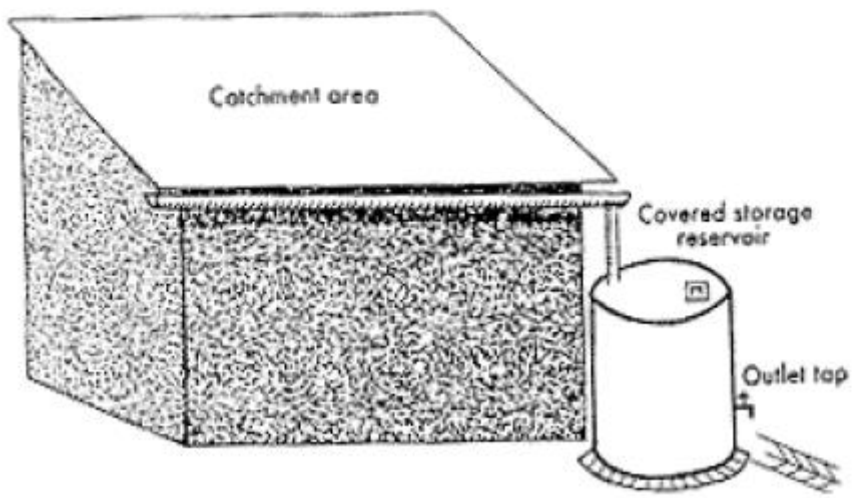

Figure 2. 13 Example of a roof catchment system (GDRC, nd.)

Figure 2. 14 Rainwater collecting system at Kokugikan sumo wrestling arena in Tokyo (GDRC, nd.)

3) Roof water collection for high-rise buildings

Generally, this system must be designed during the design of a building. This is because constructing the water collection system after the completion of building may be too expensive.

4) Land surface catchment

The catchment of rainwater at land surface is simple as the name implies. Figure 2.15 displays the components for this method, comprising land area, piping system, and storage system. The catchment area may have to designed and landscaped to have a proper slope for the flowing of rainwater. A filter system must also be included to separate some garbage and leaves and prevent them to get into the storage.

5) Collection of storm water in urbanised catchments

Collecting rainwater in urban areas is more complicated. Actually, the collection itself is not difficult. In facts, there are several methods and techniques available. The problem is, however, the cleanliness of the catchment system. This may be solved by employing a group of people who are solely responsible for taking care of the system to ensure the rainwater collected is safe for consume.

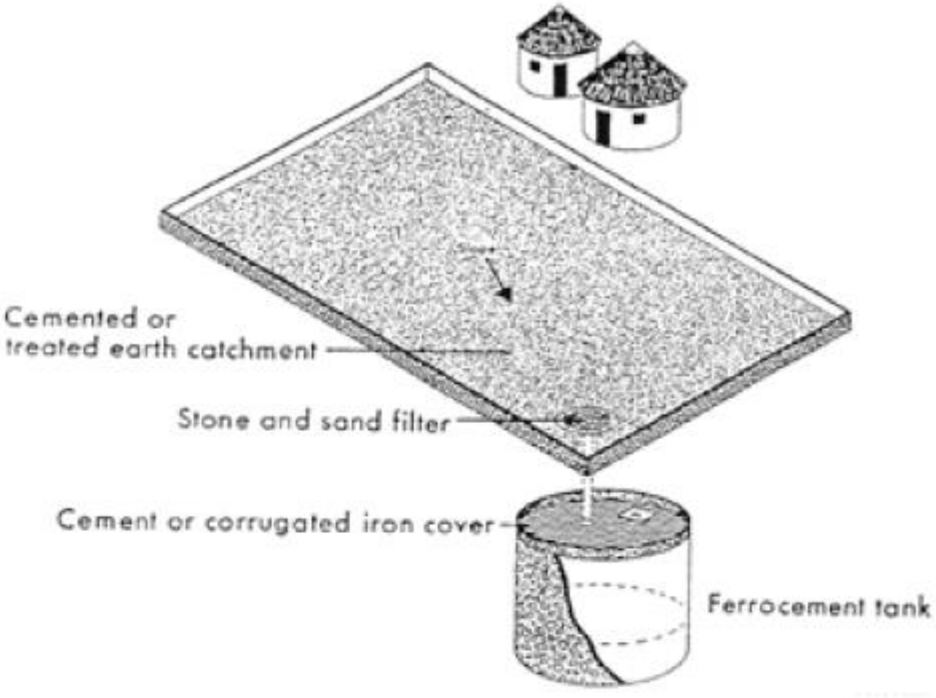

Figure 2. 15 Example of a ground catchment system (GDRC, nd.)

2.4 Quality of rainwater

In Thailand, there have not been many studies concerning the quality of rainwater because the Thais are increasingly becoming used to with buying drinking water. Artificial rain was first operated in Thailand around 1989. It should be noted that sometimes it is called cloud seeding. The principles of the cloud seeding that triggers the artificial rainfall can be found in Bollay, et. al., (nd.).

Since the beginning of the operation there were concerns with respect to the quality of artificial rain, mainly on the basis of water consumption. As such, there were experiments to investigate the quality of the artificial rain at the locations of Muang Lopburi, Takfa Nakhonsawan, and Pasak Dam, as shown in tables 2.3, 2.4, and 2.5 respectively. A total of 114 natural rainwater samples and 204 artificial rainwater smples were collected during 8 August 2005 to 24 July 2006. Then, each sample was experimented concerning 19 parameters according to the drinking water standard set by WHO, as already shown in the tables 2.3 to 2.5. Please be noted that the natural rainwater was collected on the days that the artificial rain operation was not carried out, while the artificial rain was solely collected on the days the operation carried out.

Table 2. 3 Quality of artificial rain obtained from Muang, Lopburi (Office of the permanent secretary, Ministry of Agriculture and Cooperatives)

Chemical properties	Maximum value		Average value[3]		Result[4]	Criteria for drinking water[5]	Maximum allowable criteria
	Artificial rain	Natural rain	Artificial rain	Natural rain			
pH	6.54-7.76	6.60-7.86	7.24	7.38	OK	6.5 - 8.5	✓
Acidity[1]	0.30	0.35	0.17	0.20	OK	-	-
Alkalinity[2]	0.40	0.30	0.15	0.11	OK	-	-
Sulphate[2]	26.00	12.00	7.01	2.13	Not OK	400/250	✓
Chloride[2]	1.70	2.00	0.51	0.42	OK	250	✓
Hardness[2]	0.25	0.15	0.09	0.06	Not OK	500	✓
Ammonia[2]	1.620	1.230	0.221	0.343	OK	-	-
Nitrite[2]	1.770	0.120	0.101	0.033	OK	-	-
Nitrate[2]	10.800	4.700	1.950	1.321	OK	10	✓
Calcium[2]	3.7100	1.0660	1.0333	0.5882	Not OK	-	-
Chromium[2]	nd	nd	nd	nd	OK	0.05	✓
Copper[2]	0.0392	0.0488	0.0065	0.0229	Not OK	1.0	✓
Iron[2]	0.0300	0.0300	0.0075	0.0165	OK	0.3	✓
Lead[2]	0.0740	0.0536	0.0130	0.0037	OK	0.05/0.01	✓
Cadmium[2]	0.0294	0.0316	0.0137	0.0191	Not OK	0.005/0.003	×
Zinc[2]	0.1240	0.0982	0.0385	0.0324	OK	5.0	✓
Manganese[2]	0.1050	0.0780	0.0228	0.0222	OK	0.1	✓
Magnesium[2]	0.1700	0.1500	0.0382	0.0264	OK	-	-
Mercury[2]	0.0010	0.0012	0.0002	0.0002	OK	0.001	✓

Notes: [1] Max. – min. from rainwater samples

[2] Unit of mg/l (pH has no unit)

[3] Average values for rainwater samples

[4] T-test at thereliability of 95%

[5] According to the standard set by WHO, 1984; TIS, 2006 according to the announcement by the Ministry of Industry

✓ OK × Not OK - No standard set

nd: non detectable

Table 2. 4 Quality of artificial rain obtained from Takfa, Nakhonsawan (Office of the permanent secretary, Ministry of Agriculture and Cooperatives)

Chemical properties	Maximum value		Average value[3]		Result[4]	Criteria for drinking water[5]	Maximum allowable criteria
	Artificial rain	Natural rain	Artificial rain	Natural rain			
pH	5.80-7.69	6.09-7.75	7.03	7.27	OK	6.5 - 8.5	✓
Acidity[1]	0.30	0.35	0.15	0.20	OK	-	-
Alkalinity[2]	0.30	0.20	0.11	0.09	OK	-	-
Sulphate[2]	32.00	12.00	9.05	3.33	Not OK	400/250	✓
Chloride[2]	1.20	1.50	0.01	0.02	OK	250	✓
Hardness[2]	0.10	0.10	0.05	0.06	OK	500	✓
Ammonia[2]	0.670	0.727	0.197	0.251	OK	-	-
Nitrite[2]	0.117	0.055	0.010	0.022	OK	-	-
Nitrate[2]	3.500	3.700	1.115	1.026	OK	10	✓
Calcium[2]	0.8912	1.4976	0.3679	0.5462	OK	-	-
Chromium[2]	nd	nd	nd	nd	OK	0.05	✓
Copper[2]	0.0182	0.0388	0.0049	0.0145	Not OK	1.0	✓
Iron[2]	0.0300	0.0200	0.0256	0.0022	Not OK	0.3	✓
Lead[2]	0.0650	0.0646	0.0172	0.0066	OK	0.05/0.01	✓
Cadmium[2]	0.0274	0.0274	0.0124	0.0127	OK	0.005/0.003	×
Zinc[2]	0.0714	0.1272	0.0318	0.0488	OK	5.0	✓
Manganese[2]	0.1300	0.1710	0.0304	0.0060	OK	0.1	✓
Magnesium[2]	0.1000	0.0500	0.0224	0.0067	Not OK	-	-
Mercury[2]	0.0007	0.0037	0.0001	0.0005	OK	0.001	✓

Notes: [1] Max. – min. from rainwater samples

[2] Unit of mg/l (pH has no unit)

[3] Average values for rainwater samples

[4] T-test at thereliability of 95%

[5] According to the standard set by WHO, 1984; TIS, 2006 according to the announcement by the Ministry of Industry

✓ OK × Not OK - No standard set

nd: non detectable

Table 2. 5 Quality of artificial rain obtained from Pasak Dam (Office of the permanent secretary, Ministry of Agriculture and Cooperatives)

Chemical properties	Maximum value		Average value[3]		Result[4]	Criteria for drinking water[5]	Maximum allowable criteria
	Artificial rain	Natural rain	Artificial rain	Natural rain			
pH	5.29-7.60	6.18-7.73	6.93	7.20	OK	6.5 - 8.5	✓
Acidity[1]	0.30	0.30	0.15	0.16	OK	-	–
Alkalinity[2]	1.50	0.30	0.23	0.15	OK	-	–
Sulphate[2]	23.00	8.00	7.32	2.76	Not OK	400/250	✓
Chloride[2]	2.70	1.90	0.76	0.32	Not OK	250	✓
Hardness[2]	0.15	0.10	0.07	0.05	OK	500	✓
Ammonia[2]	1.390	0.744	0.261	0.333	OK	-	–
Nitrite[2]	0.067	0.199	0.007	0.030	OK	-	–
Nitrate[2]	6.300	5.700	0.786	0.960	OK	10	✓
Calcium[2]	3.1420	1.7380	0.803	0.574	OK	-	–
Chromium[2]	nd	nd	nd	nd	OK	0.05	✓
Copper[2]	0.0500	0.0530	0.0106	0.0217	OK	1.0	✓
Iron[2]	0.0990	0.0498	0.0197	0.0054	Not OK	0.3	✓
Lead[2]	0.0552	0.0510	0.0174	0.0067	OK	0.05/0.01	✓
Cadmium[2]	0.0298	0.0292	0.0064	0.0193	Not OK	0.005/0.003	✗
Zinc[2]	0.1846	0.2280	0.0532	0.0582	OK	5.0	✓
Manganese[2]	0.0590	0.0880	0.0252	0.0446	Not OK	0.1	✓
Magnesium[2]	0.1200	0.1900	0.0433	0.0400	OK	-	–
Mercury[2]	0.0011	0.0007	0.0004	0.0003	OK	0.001	✓

Notes: [1] Max. – min. from rainwater samples

[2] Unit of mg/l (pH has no unit)

[3] Average values for rainwater samples

[4] T-test at thereliability of 95%

[5] According to the standard set by WHO, 1984; TIS, 2006 according to the announcement by the Ministry of Industry

✓ OK ✗ Not OK - No standard set

nd: non detectable

From the results obtained from the water analyses, it was found that both the majority of the artificial rain and natural rain have contaminations lower than those set by WHO. In other words, there was no significant difference between the two typs of water. Nonetheless, it was observed that both water types have cadmium that is higher than the standard, meaning they are not suitable for drinking. It should be noted that, however, this contamination had nothing to do with the artificial rainfall operation. On the contrary, the contamination was created by human activities.

2.5 Standards for drinking water

Generally, all of the drinking water, including rainwater, groundwater, filtered-water, and commercial water are not totally free of any substances. It should be noted that the substances found in water may be or may not be harmful for humans. Some may cause very serious illness; others may be consumed as much as one could without any consequences. As such, there have been studies attempting to set out a criterion with respect to the quality of drinking water.

Edstorm (2003) has recommended that to ensure the quality of drinking water the following steps should be carried out:

1) Meet Environmental Protection Agency (EPA) standards. This means that drinking water should be interpreted as water meeting the EPA’s Primary Drinking Water Standards for human consumption.
2) One should set limits and tests for any contaminants of concern to his/her facilities.
3) Study and learn from limits and tests from other agencies.
4) Monitor the producing and purifying processes.

Another useful standard should be looked at is United State Pharmacopie (USP) specifications. This is about the standards for animals’ drinking water. It should be bearing in mind that the animal is also a creature as humans. Thus, water that an animal can drink is probably good for humans as well. Table 2.6 displays the standards for drinking water set by the EPA and USP. It basically displays containments that might be found in water and their corresponding limits as drinking water.

Table 2. 6 Water quality standards (mg/l unless other units given) (Edstrom, 2003)

Contaminant	EPA Standards (as of 10/96)			USP 23 (as of 11/96)		Animal Drinking Water
	Primary MCL (1)	MCLG (2)	Secondary MCL (3)	Purified Water	WFI	
Organic Contaminants						
Adipate (diethylhexyl)	0.4	0.4		*	*	*
Alachor	0.002	zero		*	*	*
Aldicarb	0.007	0.007		*	*	*
Aldicarb sulfone	0.007	0.007		*	*	*
Aldicarb sulfoxide	0.007	0.007		*	*	*
Atrazine	0.003	0.003		*	*	*
Benzene	0.005	zero		*	*	*
Benzo(a)pyrene (PAH)	0.0002	zero		*	*	*
Carbofuran	0.04	0.04		*	*	*
Carbon Tetrachloride	0.005	zero		*	*	*
Chlordane	0.002	zero		*	*	*
2,4-D	0.07	0.07		*	*	*
Dibromochloropropane (DBCP)	0.0002	zero		*	*	*
p-Dichlorobenzene	0.075	0.075		*	*	*
o-, m-Dichlorobenzene	0.6	0.6		*	*	*
1,2-Dichloroethane	0.005	zero		*	*	*
1,1-Dichloroethyene	0.007	0.007		*	*	*
cis-1,2-Dichloroethylene	0.07	0.07		*	*	*
trans-1,2-Dichloroethylene	0.1	0.1		*	*	*
1,2-Dichloropropane	0.005	zero		*	*	*
Di(2-ethylhexyl)phthalate (PAE)	0.006	zero		*	*	*
Dinoseb	0.007	0.007		*	*	*
Diquat	0.02	0.02		*	*	*
Endothall	0.1	0.1		*	*	*
Endrin	0.002	0.002		*	*	*
Ethylbenzene	0.7	0.7		*	*	*
Ethylene dibromide	0.00005	zero		*	*	*
Glyphosate	0.7	0.7		*	*	*
Heptachlor	0.0004	zero		*	*	*
Heptachlor epoxide	0.0002	zero		*	*	*
Hexachlorobenzene	0.001	zero		*	*	*
Hexachlorocyclopentadiene	0.05	0.05		*	*	*
Lindane	0.0002	0.0002		*	*	*
Methoxychlor	0.04	0.04		*	*	*
Monochlorobenzene	0.1	0.1		*	*	*
Oxamyl (Vydate)	0.2	0.2		*	*	*
Pentachlorophenol	0.001	zero		*	*	*
Picloram	0.5	0.5		*	*	*
Polychlorinated biphenyls (PCBs)	0.0005	zero		*	*	*
Simazine	0.004	0.004		*	*	*
Styrene	0.1	0.1		*	*	*
Tetrachloroethylene	0.005	zero		*	*	*
Toluene	1.0	1.0		*	*	*
Toxaphene	0.003	zero		*	*	*
2,4,5-TP Silvex	0.05	0.05		*	*	*
Trichlorobenzene (1,2,4-)	0.07	0.07		*	*	*
1,1,1-Trichloroethane	0.2	0.2		*	*	*
1,1,2-Trichloroethane	0.005	0.003		*	*	*
Trichloroethylene	0.005	zero		*	*	*
Vinyl chloride	0.002	zero		*	*	*
Xylenes	10	10		*	*	*
Total trihalomethanes	0.10	zero		*	*	*
Total Organic Carbon (TOC)				0.05	0.05	*

Table 2.6 (continued)

Contaminant	EPA Standards (as of 10/96)			USP 23 (as of 11/96)		Animal Drinking Water
	Primary MCL (1)	MCLG (2)	Secondary MCL (3)	Purified Water	WFI	
Inorganic Contaminants						
Antimony	0.006	0.006		*	*	*
Arsenic	0.05	-		*	*	*
Asbestos	7 MFL	7 MFL		*	*	*
Barium	2	2		*	*	*
Beryllium	0.004	0.004		*	*	*
Cadmium	0.005	0.005		*	*	*
Chromium	0.1	0.1		*	*	*
Copper	1.3	1.3	1.0	*	*	*
Cyanide	0.2	0.2		*	*	*
Fluoride	4.0	4	2.0	*	*	*
Lead	0.015	zero		*	*	*
Mercury	0.002	0.002		*	*	*
Nickel	0.1	0.1		*	*	*
Nitrate (as N)	10.0	10.0		*	*	*
Nitrite (as N)	1.0	1.0		*	*	*
Selenium	0.05	0.05		*	*	*
Thallium	0.002	0.0005		*	*	*
Aluminum			0.05 to 0.2			
Chloride			250	(4)	(4)	
Iron			0.3			
Manganese			0.05			
pH			6.5-8.5	5.7-7.0	5.7-7.0	6.5-8.5 (brass) 2.5-8.5 (ss/plastic)
Silver			0.1			
Sulfates			250	(4)	(4)	
Total dissolved solids (TDS)			500	(4)	(4)	
Zinc			5.0			
Ammonia				(4)	(4)	
Calcium				(4)	(4)	
Heavy Metals				(4)	(4)	
Conductivity				4.7-5.8 µS/cm (depending on pH)	4.7-5.8 µS/cm (depending on pH)	
Radionuclides						
Gross alpha particle activity	15 pCi/L	++		*	*	*
Beta particle and photon activity	4 mrem/yr	++		*	*	*
Radium 226 and 228 (total)	5 pCi/L	++		*	*	*
Microbiological Contaminants						
Coliforms (total)	<1/100 mL	zero		*	*	*
Giardia lamblia	TT	zero				TT
Heterotrophic Plate Count	TT	NA		100 cfu/mL**	10 cfu/100 mL**	100 cfu/mL **
Legionella	TT	zero				
Pseudomonas sp.						1 cfu/mL**
Pyrogens					0.25 EU/mL	
Turbidity	0.5-1.0 NTU	NA				*
Viruses	TT	zero				TT

Notes:

(1) National Primary Drinking Water Standards Maximum Contaminant Levels are federally enforceable.

(2) Maximum Contaminant Level Goals are not enforceable.

(3) National Secondary Drinking Water Standards are not federally enforceable. These limits are for contaminants that may affect the aesthetic qualities of water.

(4) These wet chemistry tests were replaced by a conductivity standard per UPS 23 Fifth Supplement effective 11/15/96.

* Assume same as EPA Primary Drinking Water Standard MCLs

** Action Guidelines, not enforceable limits, limits set on a case-by-case basis.

TT Treatment technique is specified, not the measured concentration

++ No final MCLG, but zero proposed in 1991

In the USA there are several standards concerning the drinking water. For example, EPA (2009) has provided the regulations with respect to the primary drinking water, as shown in table 2.7. The table comprises contaminant and its unit, potential health effects from long-term exposure above the maximum contaminant level (MCL), common sources of contaminant in drinking water, and public health goal. It should be noted that it is regulations, not a law. In other words, different areas may apply these regulations differently.

Table 2. 7 Primary drinking water regulations set by the United States Environmental Protection Agency (EPA, 2009)

	Contaminant	MCL or TT[1] (mg/L)[2]	Potential health effects from long-term[3] exposure above the MCL	Common sources of contaminant in drinking water	Public Health Goal (mg/L)[2]
OC	Acrylamide	TT[4]	Nervous system or blood problems; increased risk of cancer	Added to water during sewage/ wastewater treatment	zero
OC	Alachlor	0.002	Eye, liver, kidney or spleen problems; anemia; increased risk of cancer	Runoff from herbicide used on row crops	zero
R	Alpha/photon emitters	15 picocuries per Liter (pCi/L)	Increased risk of cancer	Erosion of natural deposits of certain minerals that are radioactive and may emit a form of radiation known as alpha radiation	zero
IOC	Antimony	0.006	Increase in blood cholesterol; decrease in blood sugar	Discharge from petroleum refineries; fire retardants; ceramics; electronics; solder	0.006
IOC	Arsenic	0.010	Skin damage or problems with circulatory systems, and may have increased risk of getting cancer	Erosion of natural deposits; runoff from orchards; runoff from glass & electronics production wastes	0
IOC	Asbestos (fibers >10 micrometers)	7 million fibers per Liter (MFL)	Increased risk of developing benign intestinal polyps	Decay of asbestos cement in water mains; erosion of natural deposits	7 MFL
OC	Atrazine	0.003	Cardiovascular system or reproductive problems	Runoff from herbicide used on row crops	0.003
IOC	Barium	2	Increase in blood pressure	Discharge of drilling wastes; discharge from metal refineries; erosion of natural deposits	2
OC	Benzene	0.005	Anemia; decrease in blood platelets; increased risk of cancer	Discharge from factories; leaching from gas storage tanks and landfills	zero
OC	Benzo(a)pyrene (PAHs)	0.0002	Reproductive difficulties; increased risk of cancer	Leaching from linings of water storage tanks and distribution lines	zero
IOC	Beryllium	0.004	Intestinal lesions	Discharge from metal refineries and coal-burning factories; discharge from electrical, aerospace, and defense industries	0.004
R	Beta photon emitters	4 millirems per year	Increased risk of cancer	Decay of natural and man-made deposits of certain minerals that are radioactive and may emit forms of radiation known as photons and beta radiation	zero
DBP	Bromate	0.010	Increased risk of cancer	Byproduct of drinking water disinfection	zero
IOC	Cadmium	0.005	Kidney damage	Corrosion of galvanized pipes; erosion of natural deposits; discharge from metal refineries; runoff from waste batteries and paints	0.005
OC	Carbofuran	0.04	Problems with blood, nervous system, or reproductive system	Leaching of soil fumigant used on rice and alfalfa	0.04
OC	Carbon tetrachloride	0.005	Liver problems; increased risk of cancer	Discharge from chemical plants and other industrial activities	zero
D	Chloramines (as Cl_2)	MRDL=4.0[1]	Eye/nose irritation; stomach discomfort; anemia	Water additive used to control microbes	MRDLG=4[1]
OC	Chlordane	0.002	Liver or nervous system problems; increased risk of cancer	Residue of banned termiticide	zero
D	Chlorine (as Cl_2)	MRDL=4.0[1]	Eye/nose irritation; stomach discomfort	Water additive used to control microbes	MRDLG=4[1]
D	Chlorine dioxide (as ClO_2)	MRDL=0.8[1]	Anemia; infants, young children, and fetuses of pregnant women: nervous system effects	Water additive used to control microbes	MRDLG=0.8[1]
DBP	Chlorite	1.0	Anemia; infants, young children, and fetuses of pregnant women: nervous system effects	Byproduct of drinking water disinfection	0.8
OC	Chlorobenzene	0.1	Liver or kidney problems	Discharge from chemical and agricultural chemical factories	0.1
IOC	Chromium (total)	0.1	Allergic dermatitis	Discharge from steel and pulp mills; erosion of natural deposits	0.1
IOC	Copper	TT[5]; Action Level = 1.3	Short-term exposure: Gastrointestinal distress. Long-term exposure: Liver or kidney damage. People with Wilson's Disease should consult their personal doctor if the amount of copper in their water exceeds the action level	Corrosion of household plumbing systems; erosion of natural deposits	1.3
M	*Cryptosporidium*	TT[7]	Short-term exposure: Gastrointestinal illness (e.g., diarrhea, vomiting, cramps)	Human and animal fecal waste	zero

LEGEND

D	Disinfectant	IOC	Inorganic Chemical	OC	Organic Chemical
DBP	Disinfection Byproduct	M	Microorganism	R	Radionuclides

Table 2.7 (Continued)

	Contaminant	MCL or TT[1] (mg/L)[2]	Potential health effects from long-term[3] exposure above the MCL	Common sources of contaminant in drinking water	Public Health Goal (mg/L)[2]
IOC	Cyanide (as free cyanide)	0.2	Nerve damage or thyroid problems	Discharge from steel/metal factories; discharge from plastic and fertilizer factories	0.2
OC	2,4-D	0.07	Kidney, liver, or adrenal gland problems	Runoff from herbicide used on row crops	0.07
OC	Dalapon	0.2	Minor kidney changes	Runoff from herbicide used on rights of way	0.2
OC	1,2-Dibromo-3-chloropropane (DBCP)	0.0002	Reproductive difficulties; increased risk of cancer	Runoff/leaching from soil fumigant used on soybeans, cotton, pineapples, and orchards	zero
OC	o-Dichlorobenzene	0.6	Liver, kidney, or circulatory system problems	Discharge from industrial chemical factories	0.6
OC	p-Dichlorobenzene	0.075	Anemia; liver, kidney or spleen damage; changes in blood	Discharge from industrial chemical factories	0.075
OC	1,2-Dichloroethane	0.005	Increased risk of cancer	Discharge from industrial chemical factories	zero
OC	1,1-Dichloroethylene	0.007	Liver problems	Discharge from industrial chemical factories	0.007
OC	cis-1,2-Dichloroethylene	0.07	Liver problems	Discharge from industrial chemical factories	0.07
OC	trans-1,2-Dichloroethylene	0.1	Liver problems	Discharge from industrial chemical factories	0.1
OC	Dichloromethane	0.005	Liver problems; increased risk of cancer	Discharge from drug and chemical factories	zero
OC	1,2-Dichloropropane	0.005	Increased risk of cancer	Discharge from industrial chemical factories	zero
OC	Di(2-ethylhexyl) adipate	0.4	Weight loss, liver problems, or possible reproductive difficulties	Discharge from chemical factories	0.4
OC	Di(2-ethylhexyl) phthalate	0.006	Reproductive difficulties; liver problems; increased risk of cancer	Discharge from rubber and chemical factories	zero
OC	Dinoseb	0.007	Reproductive difficulties	Runoff from herbicide used on soybeans and vegetables	0.007
OC	Dioxin (2,3,7,8-TCDD)	0.00000003	Reproductive difficulties; increased risk of cancer	Emissions from waste incineration and other combustion; discharge from chemical factories	zero
OC	Diquat	0.02	Cataracts	Runoff from herbicide use	0.02
OC	Endothall	0.1	Stomach and intestinal problems	Runoff from herbicide use	0.1
OC	Endrin	0.002	Liver problems	Residue of banned insecticide	0.002
OC	Epichlorohydrin	TT[8]	Increased cancer risk; stomach problems	Discharge from industrial chemical factories; an impurity of some water treatment chemicals	zero
OC	Ethylbenzene	0.7	Liver or kidney problems	Discharge from petroleum refineries	0.7
OC	Ethylene dibromide	0.00005	Problems with liver, stomach, reproductive system, or kidneys; increased risk of cancer	Discharge from petroleum refineries	zero
M	Fecal coliform and *E. coli*	MCL[4]	Fecal coliforms and *E. coli* are bacteria whose presence indicates that the water may be contaminated with human or animal wastes. Microbes in these wastes may cause short term effects, such as diarrhea, cramps, nausea, headaches, or other symptoms. They may pose a special health risk for infants, young children, and people with severely compromised immune systems.	Human and animal fecal waste	zero[6]
IOC	Fluoride	4.0	Bone disease (pain and tenderness of the bones); children may get mottled teeth	Water additive which promotes strong teeth; erosion of natural deposits; discharge from fertilizer and aluminum factories	4.0
M	*Giardia lamblia*	TT[7]	Short-term exposure: Gastrointestinal illness (e.g., diarrhea, vomiting, cramps)	Human and animal fecal waste	zero
OC	Glyphosate	0.7	Kidney problems; reproductive difficulties	Runoff from herbicide use	0.7
DBP	Haloacetic acids (HAA5)	0.060	Increased risk of cancer	Byproduct of drinking water disinfection	n/a[6]
OC	Heptachlor	0.0004	Liver damage; increased risk of cancer	Residue of banned termiticide	zero
OC	Heptachlor epoxide	0.0002	Liver damage; increased risk of cancer	Breakdown of heptachlor	zero
M	Heterotrophic plate count (HPC)	TT[7]	HPC has no health effects; it is an analytic method used to measure the variety of bacteria that are common in water. The lower the concentration of bacteria in drinking water, the better maintained the water system is.	HPC measures a range of bacteria that are naturally present in the environment	n/a

LEGEND

D	Disinfectant	IOC	Inorganic Chemical	OC	Organic Chemical
DBP	Disinfection Byproduct	M	Microorganism	R	Radionuclides

Table 2.7 (Continued)

	Contaminant	MCL or TT[1] (mg/L)[2]	Potential health effects from long-term[3] exposure above the MCL	Common sources of contaminant in drinking water	Public Health Goal (mg/L)[2]
OC	Hexachlorobenzene	0.001	Liver or kidney problems; reproductive difficulties; increased risk of cancer	Discharge from metal refineries and agricultural chemical factories	zero
OC	Hexachlorocyclopentadiene	0.05	Kidney or stomach problems	Discharge from chemical factories	0.05
IOC	Lead	TT5; Action Level=0.015	Infants and children: Delays in physical or or mental development; children could show slight deficits in attention span and learning abilities; Adults: Kidney problems; high blood pressure	Corrosion of household plumbing systems; erosion of natural deposits	zero
M	*Legionella*	TT7	Legionnaire's Disease, a type of pneumonia	Found naturally in water; multiplies in heating systems	zero
OC	Lindane	0.0002	Liver or kidney problems	Runoff/leaching from insecticide used on cattle, lumber, gardens	0.0002
IOC	Mercury (inorganic)	0.002	Kidney damage	Erosion of natural deposits; discharge from refineries and factories; runoff from landfills and croplands	0.002
OC	Methoxychlor	0.04	Reproductive difficulties	Runoff/leaching from insecticide used on fruits, vegetables, alfalfa, livestock	0.04
IOC	Nitrate (measured as Nitrogen)	10	Infants below the age of six months who drink water containing nitrate in excess of the MCL could become seriously ill and, if untreated, may die. Symptoms include shortness of breath and blue-baby syndrome.	Runoff from fertilizer use; leaching from septic tanks, sewage; erosion of natural deposits	10
IOC	Nitrite (measured as Nitrogen)	1	Infants below the age of six months who drink water containing nitrite in excess of the MCL could become seriously ill and, if untreated, may die. Symptoms include shortness of breath and blue-baby syndrome.	Runoff from fertilizer use; leaching from septic tanks, sewage; erosion of natural deposits	1
OC	Oxamyl (Vydate)	0.2	Slight nervous system effects	Runoff/leaching from insecticide used on apples, potatoes, and tomatoes	0.2
OC	Pentachlorophenol	0.001	Liver or kidney problems; increased cancer risk	Discharge from wood-preserving factories	zero
OC	Picloram	0.5	Liver problems	Herbicide runoff	0.5
OC	Polychlorinated biphenyls (PCBs)	0.0005	Skin changes; thymus gland problems; immune deficiencies; reproductive or nervous system difficulties; increased risk of cancer	Runoff from landfills; discharge of waste chemicals	zero
R	Radium 226 and Radium 228 (combined)	5 pCi/L	Increased risk of cancer	Erosion of natural deposits	zero
IOC	Selenium	0.05	Hair or fingernail loss; numbness in fingers or toes; circulatory problems	Discharge from petroleum and metal refineries; erosion of natural deposits; discharge from mines	0.05
OC	Simazine	0.004	Problems with blood	Herbicide runoff	0.004
OC	Styrene	0.1	Liver, kidney, or circulatory system problems	Discharge from rubber and plastic factories; leaching from landfills	0.1
OC	Tetrachloroethylene	0.005	Liver problems; increased risk of cancer	Discharge from factories and dry cleaners	zero
IOC	Thallium	0.002	Hair loss; changes in blood; kidney, intestine, or liver problems	Leaching from ore-processing sites; discharge from electronics, glass, and drug factories	0.0005
OC	Toluene	1	Nervous system, kidney, or liver problems	Discharge from petroleum factories	1
M	Total Coliforms	5.0 percent[8]	Coliforms are bacteria that indicate that other, potentially harmful bacteria may be present. See fecal coliforms and *E. coli*	Naturally present in the environment	zero
DBP	Total Trihalomethanes (TTHMs)	0.080	Liver, kidney or central nervous system problems; increased risk of cancer	Byproduct of drinking water disinfection	n/a[6]
OC	Toxaphene	0.003	Kidney, liver, or thyroid problems; increased risk of cancer	Runoff/leaching from insecticide used on cotton and cattle	zero
OC	2,4,5-TP (Silvex)	0.05	Liver problems	Residue of banned herbicide	0.05
OC	1,2,4-Trichlorobenzene	0.07	Changes in adrenal glands	Discharge from textile finishing factories	0.07
OC	1,1,1-Trichloroethane	0.2	Liver, nervous system, or circulatory problems	Discharge from metal degreasing sites and other factories	0.2
OC	1,1,2-Trichloroethane	0.005	Liver, kidney, or immune system problems	Discharge from industrial chemical factories	0.003
OC	Trichloroethylene	0.005	Liver problems; increased risk of cancer	Discharge from metal degreasing sites and other factories	zero

LEGEND

D	Disinfectant	IOC	Inorganic Chemical	OC	Organic Chemical
DBP	Disinfection Byproduct	M	Microorganism	R	Radionuclides

Table 2.7 (Continued)

Contaminant		MCL or TT[1] (mg/L)[2]	Potential health effects from long-term[3] exposure above the MCL	Common sources of contaminant in drinking water	Public Health Goal (mg/L)[2]
M	Turbidity	TT[7]	Turbidity is a measure of the cloudiness of water. It is used to indicate water quality and filtration effectiveness (e.g., whether disease-causing organisms are present). Higher turbidity levels are often associated with higher levels of disease-causing microorganisms such as viruses, parasites and some bacteria. These organisms can cause short term symptoms such as nausea, cramps, diarrhea, and associated headaches.	Soil runoff	n/a
R	Uranium	30μg/L	Increased risk of cancer, kidney toxicity	Erosion of natural deposits	zero
OC	Vinyl chloride	0.002	Increased risk of cancer	Leaching from PVC pipes; discharge from plastic factories	zero
M	Viruses (enteric)	TT[7]	Short-term exposure: Gastrointestinal illness (e.g., diarrhea, vomiting, cramps)	Human and animal fecal waste	zero
OC	Xylenes (total)	10	Nervous system damage	Discharge from petroleum factories; discharge from chemical factories	10

Table 2. 8 Secondary drinking water regulations set by the United States Environmental Protection Agency (EPA, 2009)

Contaminant	Secondary Maximum Contaminant Level
Aluminum	0.05 to 0.2 mg/L
Chloride	250 mg/L
Color	15 (color units)
Copper	1.0 mg/L
Corrosivity	noncorrosive
Fluoride	2.0 mg/L
Foaming Agents	0.5 mg/L
Iron	0.3 mg/L
Manganese	0.05 mg/L
Odor	3 threshold odor number
pH	6.5-8.5
Silver	0.10 mg/L
Sulfate	250 mg/L
Total Dissolved Solids	500 mg/L
Zinc	5 mg/L

EPA also provides a regulation for secondary drinking water. This regulation is meant to be non-enforceable guidelines regarding contaminants that may cause cosmetic effects (such as skin and tooth discolouration) or aesthetic effects (such as taste, odour, or colour) in drinking water. Note that the EPA recommends that the secondary drinking water regulation is only applied to water systems. Some areas, however, have chosen these as primary drinking water.

In the case of Thailand, the standards concerning drinking water are mainly from the announcements by the ministry of public health. In the case of commercial drinking water such as bottled water, it must also comply with the standards set by the Thai Industrial Standard, ministry of industry. According to TIS 257 – 2549 (TIS, 2006), drinking water is classified into two categories: (1) drinking water in a closed container, and (2) drinking water without any containers. It describes four characteristics that drinking water must comply: (1) general appearance, (2) physical characteristic, (3) chemical characteristic, and (4) toxic substance. In addition, drinking water must also comply with other hygienic conditions, including coliform, E. coli, salmonella etc.

2.6 Techniques for rainfall storing

Rainwater harvesting has been operated very long time ago since the early human history. As they have evolved over time the harvest now is being done for two purposes: for consumption and irrigation. In this section emphasise is made on the rainwater harvesting for consumption because it seems people have paid too much for drinking water that actually should be free.

The problem involved in rainwater harvesting is that rainfall occurs irregularly. We cannot precisely predict when rainfall occurs and how long it might take. When it does come, sometimes the rainfall amount is enormous, but sometimes is very little. It is therefore necessary to have a storage system for collecting the rainfall for future when it dries up.

To store rainwater, Daily and Wilkins (2012) summarised that four components are required:

(1) Collection area – for example, roof area.
(2) Conveyance system – it is used to carry rainwater and may be consisted of gutters and flat roof drainage.
(3) Water storage – may be installed either above or below ground, and may comprise one or more containers.
(4) Filtration – this is employed to keep out debris from the system.

For the conveyance system, there are two types: dry and wet, as shown in figure 2.16. The difference between the two is that for the dry the conveyance has no water in it until there is rainfall; while for the wet there is always water in the system until is replaced by new water. For the storage tank, it features should at least include an inlet for rainwater to enter, overflow pipe that should as large as the inlet, air vent for air to escape while the tank is being filled, as illustrated by figure 2.17.

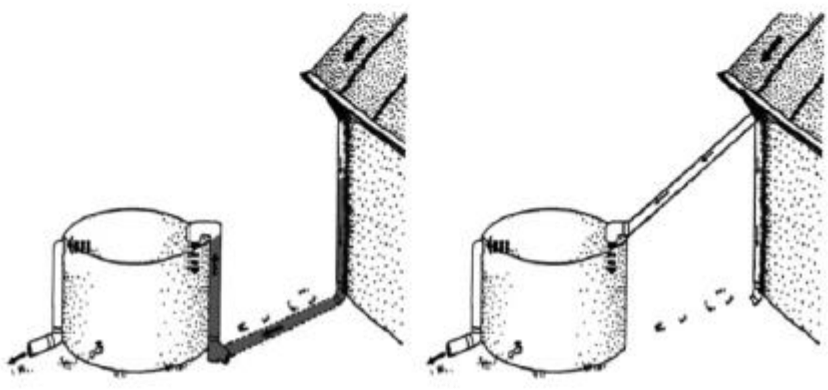

Figure 2. 16 Examples of wet (left) and dry (right) conveyance systems (Daily and Wilkins, 2012)

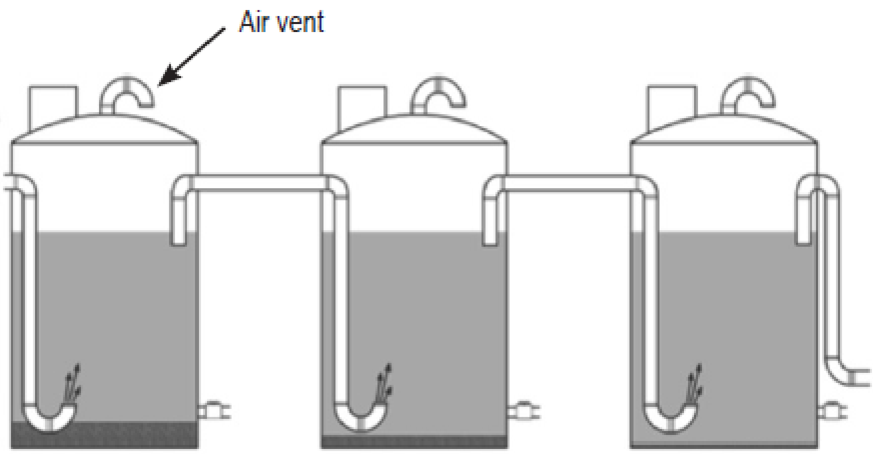

Figure 2. 17 Multiple water tanks connected in a series at the top (Daily and Wilkins, 2012)

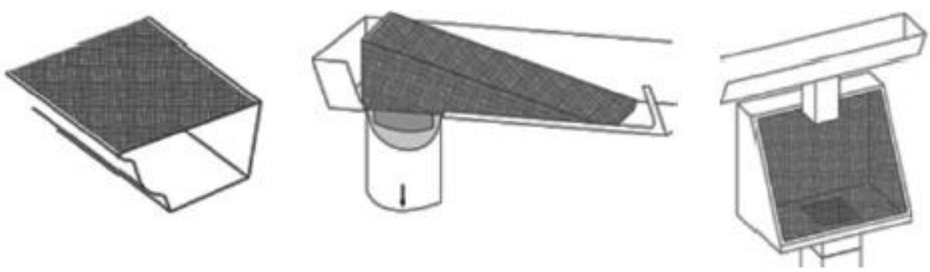

Figure 2. 18 Examples of common gutter and downspout screens (Daily and Wilkins, 2012)

The filtration is essential for the rainwater storage system in that it prevents some dirt to enter the system. This is not only to keep the water clean, but also prevent clogging and sediment build-up. The first component needed for the filtration is common gutter and downspout screen, as shown in figure 2.18. A first flush diverter is also essential. Its duty is to prevent the first flush that is of poor quality to enter storage.

It should be noted that diverters must have a drainage outlet for the poor-quality water to flow out, as shown in figure 2.19 (Daily and Wilkins, 2012).

A further protection for the quality of water is a strainer basket or screen installed at the tank water inlet, as shown in figure 2.20. Sometimes an overflow outlet is also needed. However, make sure that its outlet is diverted far from a building. Otherwise, the flowing out water may erode surface thereby causing slope stability problem or foundation failure. An example of the strainer basket is illustrated by figure 2.21.

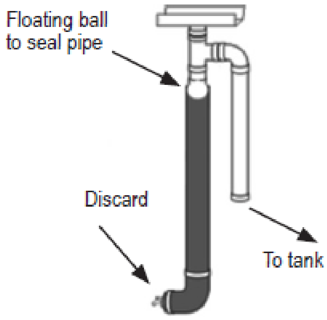

Figure 2. 19 Example of a first flush diverter (Daily and Wilkins, 2012)

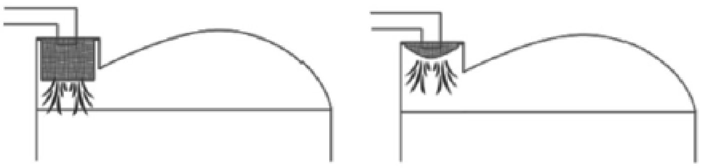

Figure 2. 20 Examples of a strainer basket (left) and screen (right) (Daily and Wilkins, 2012)

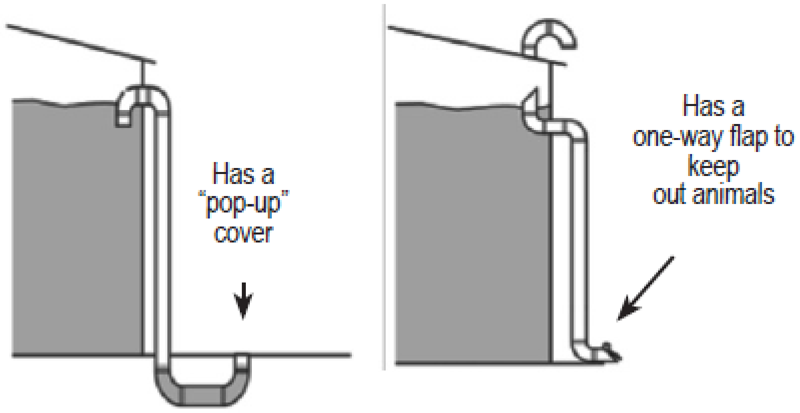

Figure 2. 21 Examples of tank overflow outlets (Daily and Wilkins, 2012)

Another useful component is a tank calming inlet, as shown in figure 2.22. This component simply prevents water flowing in a take too fast thereby stirring the bottom sediment layer. Figure 2.23 shows a complete whole system for collecting rainwater for a house. It should be noted herein that all of the example shown were obtained from abroad – USA, a developed country. They have indeed the living standard much higher than our do. One might argue that the examples should not be applied for Thailand. However, please remember that drinking water is the most important for human kind. As such we must ensure that we have done everything to get drinking water clean enough for humans.

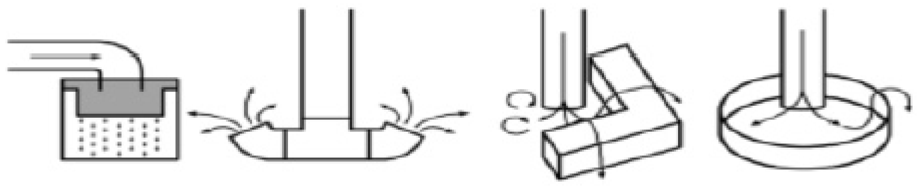

Figure 2. 22 Examples of calming inlets (Daily and Wilkins, 2012)

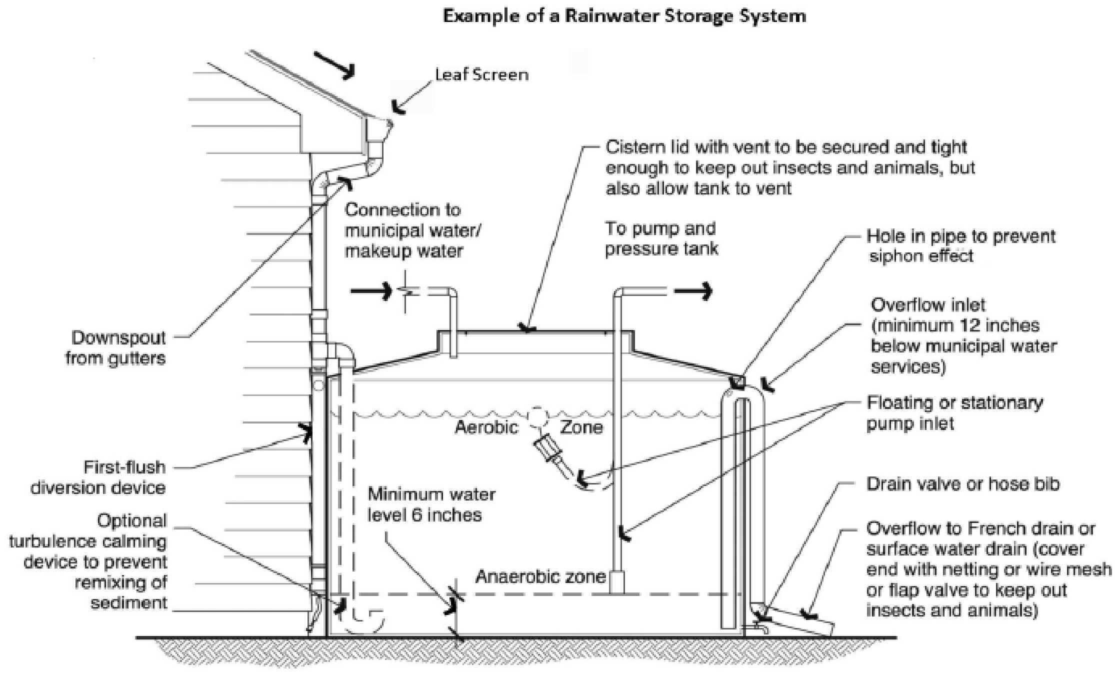

Figure 2. 23 Example of a complete rainwater storage system (Daily and Wilkins, 2012)

CHAPTER 3

MATERIALS, TEST PROGRAMMES, AND METHODS

3.1 Introduction

It has been known that the majority of Thai people have now paid for drinking water. It should be noted that in the market there are several types of drinking water, e.g., bottled drinking water, closed-container water, and delivery drinking water. During this time – 2015-2016 – some bottled drinking water is more expensive than fuelling a car. This may not be acceptable considering there is plenty of rainfall in Thailand, especially in the South. However, to convince people to come back to the rainwater requires convincingly proven clues. This chapter was aimed at describing the methodologies employed for this research to obtain evidences indicating that the rainwater is actually drinkable. In addition, it also gives details with respect to what qualities were tested to prove that a sample of rainwater collected was comply with the standards set by Thai government agencies who are responsible for public health concerning drinking water.

3.2 Methodologies

3.2.1 Introductory remarks

Three steps were employed for this research in order to answer the thesis question: (1) surveying for expense for drinking water, (2) methods for collecting rainwater samples, and, (3) performing quality tests of the rainwater samples according to the drinking water standard. The first step was achieved by creating a questionnaire asking short questions related to drinking water. The second step was designed to collect rainwater as pure as possible. The third step was done by just submitting the rainwater samples to a reliable organisation that is capable of testing and qualifying drinking water.

3.2.2 Expense for drinking water surveying

As this research was concerned that people are spending too much money on drinking water, it was necessary to acknowledge a whole picture with respect to their behaviour regarding the drinking water. A questionnaire was chosen to obtain such information. It should be noted that acquiring that data may be done by many ways, e.g., interview. However, the questionnaire was employed because it was low cost and most convenient considering the research had to be completed in a short time of only one year.

The questionnaire was designed to have three sections, including section 1, general information; section 2, cost for drinking water; and section 3, perception regarding the quality of rainwater. The section 1 basically comprised sex, age, education, marital status, occupation, and income. This section was quite important in that it would later on be used to analyse with other sections. For instance, why the rich decides to buy drinking water, and why the poor prefers to drink the water that could be obtained with no cost. In addition, their education would be very helpful in terms of analysing the results obtained. For example, what is the difference between higher-educated people and lower-educated people in thinking of the quality of rainwater?

The section 2 asked the following questions: (1) type of water currently being drunk, of which comprises the choices of rainwater, tap water, well head, groundwater, and pay for; (2) most purchasing place, of which comprises the choices of convenient store, grocery store, supermarket, drinking water manufacture, and delivery; and (3) cost for drinking water (Baht per week), of which comprises the choices of less than 20, between 20 and 50, between 50 and 100, between 100 and 200, and more than 200. The section 3 simply asked the question have you ever drunk rainwater? It comprises the choices of drinkable, undrinkable, and not sure.

The section 2 was the most important for this questionnaire because it was the main information required for this study. The priority was that we would like to know how much a week people spend for drinking water. In addition, what kind of drinking water was also asked because it would be used together with the section 1 to analyse the results in details. The section 3 was simply asking for the perception with regard to the quality of drinking water. This information would provide something that we could employ to educate people in the further concerning the quality of drinking water.

NB: This questionnaire is part of the research project titled "the potential of rainwater harvesting for house-hold use", of which is funded by Rajamangala University of Technology Srivijaya.

THE POTENTIAL OF RAINWATER HARVESTING FOR HOUSEHOLD USE **ศักยภาพของการเก็บเกี่ยวน้ำฝนเพื่อใช้ในครัวเรือน** COST FOR DRINKING WATER QUESTIONNAIR แบบสอบถาม ค่าใช้จ่ายสำหรับน้ำดื่ม

คำชี้แจง โปรดทำเครื่องหมาย ✓ ลงใน ☐ ให้ตรงตามความเป็นจริง (Instruction: please put ✓ in ☐ according to the truth)

ส่วนที่ 1 ข้อมูลส่วนบุคคลทั่วไป (Section 1 General information)

1. เพศ (Sex) ☐ ชาย (Male) ☐ หญิง (Female)	**2. อายุ, ปี** (Age, years) ☐ < 20 ☐ 20 - 40 ☐ 40 - 60 ☐ > 60
3. ระดับการศึกษา (Education) ☐ ต่ำกว่าปริญญาตรี (Below undergraduate) ☐ ปริญญาตรี (Undergraduate) ☐ สูงกว่าปริญญาตรี (Postgraduate)	**4. สถานภาพสมรส** (Marital status) ☐ โสด (Single) ☐ สมรส (Married) ☐ หม้าย/หย่า/แยกกันอยู่ (Widow, widower/divorced/separated)
5. อาชีพ (Occupation) ☐ ราชการ/รัฐวิสาหกิจ/หน่วยงานราชการ (Government official) ☐ พนักงานหน่วยงานเอกชน (Private-sector employee) ☐ อื่นๆ (ลูกจ้าง, กิจการส่วนตัว, ค้าขายฯ) (Others: general worker, self-employed, seller)	**6. รายได้ บาทต่อเดือน** (Income, Baht/month) ☐ < 15,000 ☐ 15,000 – 30,000 ☐ 30,000 – 50,000 ☐ > 50,000

ส่วนที่ 2 ข้อมูลค่าใช้จ่ายสำหรับน้ำดื่ม (Section 2 Cost for drinking water information)

1. ประเภทน้ำที่ดื่มในปัจจุบัน, เลือกได้มากกว่า 1 ข้อ (Type of water currently being drunk, more than 1 can be chosen) ☐ น้ำฝน (Rainwater) ☐ น้ำประปา (Tap water) ☐ น้ำบ่อ (Well head) ☐ น้ำบาดาล (Groundwater) ☐ ซื้อ (Pay for) หากตอบ *ซื้อ* โปรดตอบข้อต่อไป (If Pay for is chosen, please answer the following)
2. สถานที่ซื้อประจำ, เลือกได้มากกว่า 1 ข้อ (Most purchasing place, more than 1 can be chosen) ☐ ร้านค้าสะดวกซื้อ (Convenient store) ☐ ร้านขายของชำ (Grocery store) ☐ ห้างสรรพสินค้า (Supermarket) ☐ โรงงานผลิตน้ำดื่ม (Drinking water manufacturer) ☐ มาส่งถึงที่ (Delivery)
3. ค่าใช้จ่ายซื้อน้ำดื่ม, บาทต่ออาทิตย์ (Cost for drinking water, Baht per week) ☐ < 20 ☐ 20 - 50 ☐ 50 -100 ☐ 100 - 200 ☐ > 200

ส่วนที่ 3 การรับรู้เกี่ยวกับคุณภาพน้ำฝน (Section 3 Perception regarding the rainwater quality)

1. ท่านเคยดื่มน้ำฝนหรือไม่ (Have you ever drunk rainwater?) ☐ เคย (Yes) ☐ ไม่เคย (No)
2. ท่านคิดว่า น้ำฝนในปัจจุบันดื่มได้หรือไม่ (Do you think rainwater at the moment drinkable?) ☐ ดื่มได้ (Drinkable) ☐ ดื่มไม่ได้ (Undrinkable) ☐ ไม่แน่ใจ (Not sure) หากตอบ *ดื่มไม่ได้* หรือ *ไม่แน่ใจ* โปรดให้เหตุผล (If either undrinkable or not sure is chosen, please give reasons) ....

Figure 3. 1 The questionnaire employed for this research to obtain the information with respect to drinking water

3.2.3 Collecting of rainwater samples

The first task for collecting of rainwater was to design and build a system that could collect the rainwater as pure as possible. The best way, however, is to collect the rainwater directly falling from the sky. However, that method needs space and big area of supporter. It is also should be noted that it would take time to obtain enough amount of rainwater to be able to test its quality. Thus, the system shown in figure 3.2 was design and built for the task. Basically, it comprised a steel frame supporting a zinc sheet built to have a curved surface. At the other end of the zinc sheet connected with a PVC pipe acting as conveyance in order to bring the rainwater into a closed container, as can be seen in figure 3.2. This system was designed based on the assumption that the rainwater collected would have a contamination as least as possible.

After the rainwater had been collected enough, it was transferred to a new plastic bottle having the capacity of about 2 litres, as shown in figure 3.3. In order to be able to evaluate all of the quality tests required for drinking water standards at least 6 litres of rainwater sample was required. Thus, each rainwater sample was required to be filled in at least three bottles. When the bottled rainwater ready, it was immediately wrapped by a black plastic bag. Then, it was immediately put into a closed container filled with ice, as illustrated by figure 3.4. The ice was place in order to keep the temperature of the rainwater sample low so that any bacterium to have a chance to grow. This is because it might alter the quality of the rainwater collected thereby obtaining false results.

The other step that was also important is that the rainwater samples must be transport to a laboratory within 24 hr. As such, if there was rainfall on Saturday rainwater was not collected. This is because it may take 48 hr before the rainwater sample is delivered to the laboratory.

As previously mentioned in Chapter 1, two provinces were selected for collecting rainwater, namely Songkhla and Nakhon si thammarat. This is because the two provinces are big compared to their in terms of both area and population, counterparts in the South. In Songkhal, two districts were chosen, Singkhanakhon and Namom. This was because there were volunteers for collecting rainwater in those areas. In Nakhon si thammarat, Khanom and Pakpanang were chosen because of the same reason given for the case of Songkhal province. Figure 3.5 depicts the rainwater sample being collected in Khanom, Nakhon si thammarat, Egco to be precise.

The other places in Khanom chosen include College of Industrial Technology and Management, Rajamangala University of Technology Srivijaya, located in Thongnian sub-district and Sho intersection that also located in the same area.

Figure 3. 2 The structure used to collect rainwater

Figure 3. 3 Rainwater kept in new plastic bottles

Figure 3. 4 Rainwater samples packed in a container filled with ice

Figure 3. 5 Collecting pure rainwater at Egco, Khanom, Nakhon si thammarat

Table 3.1 displays the rainwater samples that were being collected during 14 November 2014 and 18 December 2015. Notice that a total of 17 rainwater samples were collected. This figure was based on the fact that the cost for quality tests is very expensive. In addition, the budget for this project was limited thereby limiting a number of rainwater samples. Actually, we would like to collect more samples so that the results obtained would be more reliable.

The table comprises number of sample, sample symbol, location of the sample, collecting date, type of rainwater, and designate group. The sample symbol would tell some information such as location, collector, and date collected. In the column of type of rainwater, it can be seen that there are six types of rainwater collected. These included pure rainwater, boiled pure rainwater, roof and gutter rainwater, rainwater passing through roof and kept in a stainless tank, rainwater passing through roof and kept in a stainless tank and boiled, and well water (shown in figure 3.6). For convenience the types of rainwater samples were designate as G1, G2, G3, G4, G5, G6, respectively, as also described in table 3.1.

For the pure rainwater (G1), it was collected by means of the support structure already described. It can be said that its quality was the best compared to the rest. In the case of boiled pure rainwater, just after the collection, it was boiled for at least 10 minutes. Then, it either was transported to the laboratory or kept in a refrigerator for transferring to the laboratory later on. Please be noted that in the case the boiled rainwater was kept in a fridge, it would be transferred as soon as possible.

For the G3 – rainwater passing through roof and gutter – the procedure for transporting the samples was the same as for the G1. In the case of rainwater kept in a stainless tank, G4, there was no record with regard to how long it had been kept. The sample simply was poured into plastic bottles and carried to the laboratory for the quality tests. In the case of G5 – rainwater kept in a stainless tank and boiled – the procedure was the same as for the G1 except the water was boiled before being tested. For G6, water directly collected from a well, the sample was transported to the laboratory straight away.

Figure 3. 6 The water well the sample 2SK221214GW located in Namom, Songkhla

Table 3. 1 Rainwater samples collected for the quality tests according to the drinking water standards

No.	Sample	Location	Date collected	Type of rainwater	Group
1	2SK141114	Namom, SK	14 Nov 2014	Pure rainwater	G1
2	3KN141114	Sho intersection, Khanom, NST	14 Nov 2014	Pure rainwater	G1
3	1KN161114	Thongnian, Khanom, NST	16 Nov 2014	Pure rainwater	G1
4	2SK221214GW	Namom, SK	22 Dec 2014	Well water	G6
5	1SK181114	Singhanakhon, SK	25 Nov 2014	Pure rainwater	G1
6	2KN251114	Egco, Khanom, NST	8 Dec 2014	Pure rainwater	G1
7	2SK081214	Namom, SK	8 Dec 2014	Pure rainwater	G1
8	2SK151214B	Namom, SK	15 Dec 2014	Boiled pure rainwater	G2
9	1SK211214B	Singhanakhon, SK	21 Dec 2014	Boiled pure rainwater	G2
10	2SK221214R	Namom, SK	22 Dec 2014	Roof rainwater	G3
11	1SK070115G	Singhanakhon, SK	7 Jan 2015	Gutter rainwater	G3
12	3KN130115	Sho intersection, Khanom, NST	13 Jan 2015	Pure rainwater	G1
13	1KN130115	Thongnian, Khanom, NST	13 Jan 2015	Pure rainwater	G1
14	2KN130115	Egco, Khanom, NST	13 Jan 2015	Pure rainwater	G1
15	3CM210515T	Singhanakhon, SK	21 May 2015	Rainwater kept in stainless tank	G4
16	3CM210515TB	Singhanakhon, SK	10 May 2015	Boiled rainwater kept in stainless tank	G5
17	1BK181215	Pakpanang, NST	18 Dec 2015	Pure rainwater	G1

Note:

SK = Songkhla

NST = Nakhon si thammarat

3.2.4 Quality tests for rainwater samples

The main drinking water standards chosen to be conducted for this research were from the announcements and notifications by the ministry of public health no. 61 (BE 2524), no. 135 (BE 2534), no. 6 (2553), published in Royal Gazette, Vol. 126 (41) dated 19 March 2009. In addition, all of the tests were carried out by a renowned scientific laboratory, namely Scientific Equipment Centre, Prince of Songkhla University.

According to those standards set by the ministry of public health, 13 parameters were tested and evaluated. These included pH, TS, total hardness, nitrate, chloride, fluoride, iron, lead, arsenic, coliforms, E. coli, S.aureus, Salmonella sp. The details concerning their meaning, unit used, and limited values, can be found the Chapter 4 and also in Appendix A.

CHAPTER 4

TEST RESULTS AND DISCUSSION

4.1 Introduction

There are two folds of the results obtained from this research project, including the behaviour of people with respect to drinking water and the quality of the rainwater samples collected. The former basically was obtained by employing a questionnaire in order to gather the essential information related to this research. The latter, however, was the solely the results obtained from the laboratory concerning the drinking water standards as previously described in Chapter 3.

4.2 Behaviour of people concerning drinking water

4.2.1 Data surveying

The main purpose of this research was to evaluate the quality of rainwater in terms of drinking water, particularly in Songkhla and Nakhon si thammarat. However, to understand the behaviour of people regarding the expense for drinking water, a questionnaire was also employed to obtain such information. One of the most important information needed was the people opinion with respect to the quality of rainwater, i.e., is the rainwater (in Songkhla and Nakhon si thammarat) drikable?

The next information was the amount of money people spend for drinking water (in case they had to pay for). As the rainwater samples for this project were collected in Songkhla and Nakhon si thammarat, the target people who provided the answers were also from those two provinces. The details of the questionnaire used were already given in Chapter 3. The total number of people who answered the questions was 193.

4.2.2 Behaviour of paying for drinking water

Firstly, figure 4.1 display the proportion between male and female that answered the questionnaire. It can be seen that their percentages are very similar, indicating the balance of sex in this study. The ranges of age of answerers were plotted and shown in figure 4.2. It was observed that the age range of 20 – 40 years old takes about 72 % of which is the highest. This is a very good point because it may be said that the people in this age range are mainly working for their family thereby providing accurate answers.

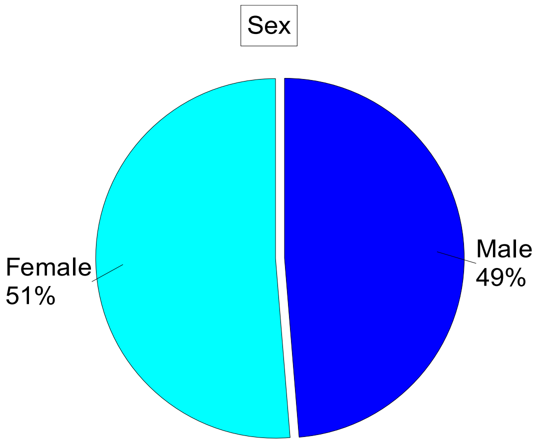

Figure 4. 1 Questionnaire answers according to sex

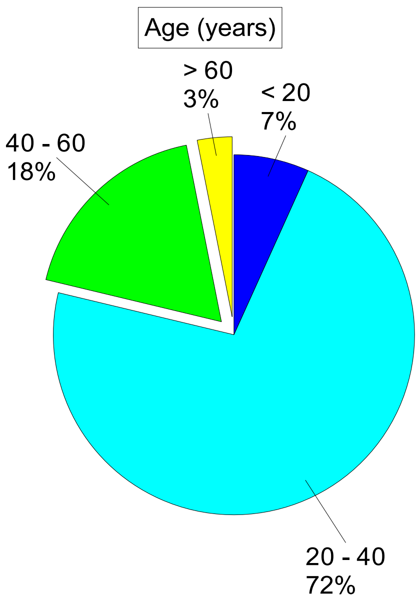

Figure 4. 2 Ranges of age of answers

Figure 4.3 shows the educational levels of the answers in which were categorised as below undergraduate, undergraduate, and postgraduate. According to the figure 65%, 28%, and 7% of answerers had the education levels of undergraduate, below undergraduate, and postgraduate, respectively. In the meantime, figure 4.4 displays one of the most important parameters, the perception with respect to drinking water by means of drinkable or not. It showed that 36% think rainwater can be drunk; while 35% and 29% had the opinions that they are not sure and undrinkable, respectively. These findings indicate a very good sign in that the majority still think rainwater is drinkable. In addition, 35% of the answerers thought that it may be or may be not drinkable. If we could persuade those 35% that rainwater is actually clean enough for humans, there would be the total percentage of about 71% that might turn into drinking rainwater in the future.

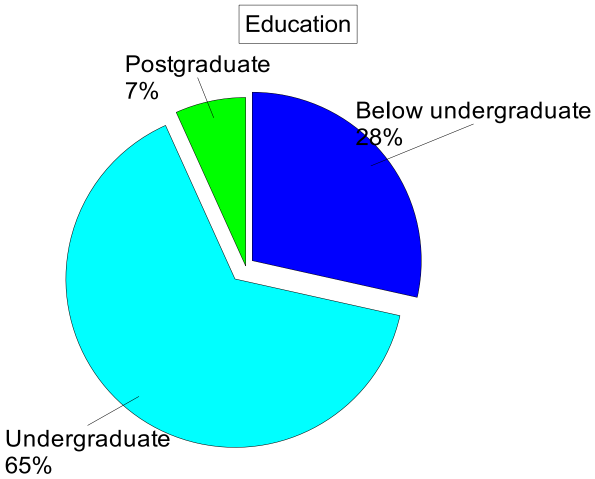

Figure 4. 3 Education levels

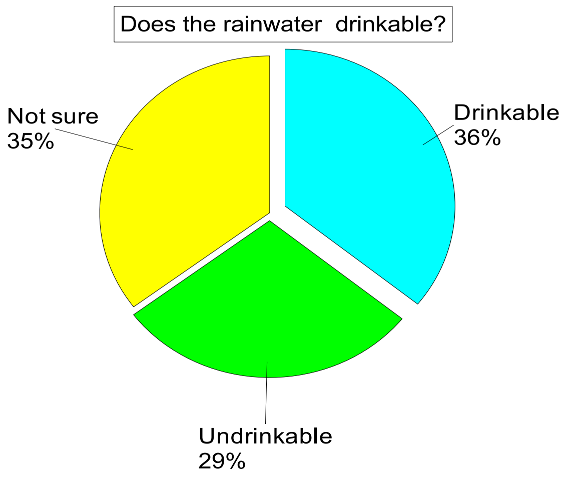

Figure 4. 4 Perception of drinking water in terms of drinkable

Figure 4.5 shows the monthly income of the answerers in which was categorised as less than 15,000, between 15,000 and 30,000, and between 30,000 and 50,000. It can be seen that the majority of the reply has the income less than 15,000 Baht a month. Considering the current economic conditions, that income is quite low. Thus, if they would seek a way to consume rainwater instead of paying for, they could save some money for other usage. This statement may be confirmed when considering the figures 4.6 and 4.7 showing type of drinking water consumed and weekly expense on drinking water, respectively.

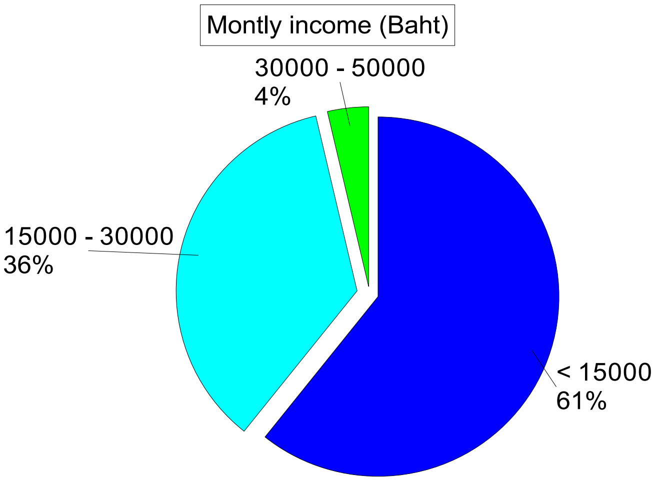

Figure 4. 5 Average income of answers

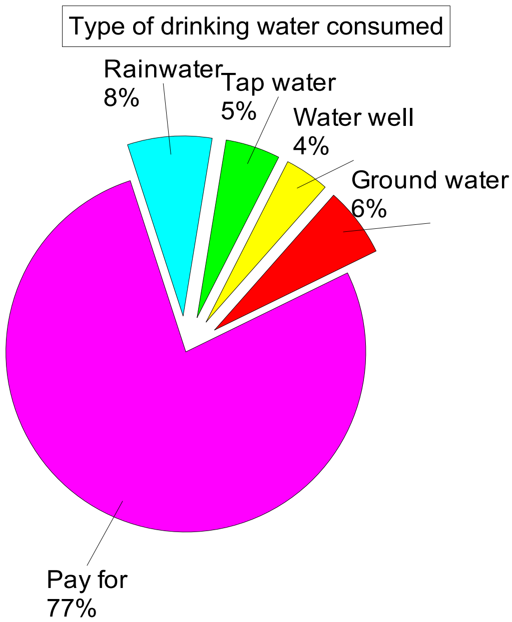

Figure 4. 6 Types of drinking water consumed

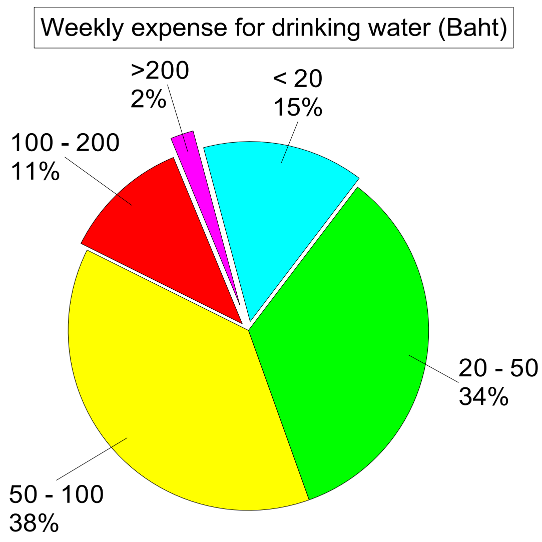

Figure 4. 7 Expense (Baht per week) for drinking water

Table 4. 1 Summary of the rainwater samples classified as groups 1 to 6

No.	Group	Description	Note
1	G1	Rainwater directly collected (pure rainwater)	From NST and SK
2	G2	Rainwater directly collected and boiled	From SK
3	G3	Rainwater flowing through roof and gutter	From SK
4	G4	Rainwater kept in a stainless tank	From SK
5	G5	Rainwater kept in a stainless tank and boiled	From SK
6	G6	Groundwater	From S K

Note: NST = Nakhon si thammarat, SK = Songkhla

4.3 Quality of rainwater samples

The quality tests for all of the six rainwater sample groups (G1 to G6) were carried out in a renowned laboratory belonging to a government university. A total of thirteen criteria were tested in order to be able to certify whether a rainwater sample is drinkable or not. Table 4.1 redisplays all groups of rainwater samples tests, including group, description, and note, in order to make the discussion to be written is easier to grasp. Table 4.2 displays the parameters tested for all of the rainwater samples. It also includes the criteria employed. The quality test results for all of the parameters were summarised and displayed in table 4.3; while table 4.4 shows the overall quality test results with respect to the drinking water standards.

Table 4. 2 Parameters and criteria for the drinking water standards set by the ministry of public health

No.	Parameter	Unit	Instrument/method	Criteria
1	pH	-	pH meter	6.5 - 8.5
2	TS	mg/L	Gravimetric method	<= 500
3	Total hardness expressed as CaCO3	mg/L	Totrimetric method	<= 100
4	Nitrate	mg/L	Photometric method	<= 4
5	Chloride	mg/L	Photometric method	<= 250
6	Fluoride	mg/L	Photometric method	<= 0.7
7	Iron (Fe)	mg/L	ICP-OES	<= 0.3
8	Lead (Pb)	mg/L	ICP-OES	<= 0.05
9	Arsenic (As)	mg/L	ICP-OES	<= 0.05
10	Coliforms	MPN/100 mL	AWWA method	< 2.2
11	E. coli	per 100 mL	AWWA method	Not found
12	S.aureus	per 100 mL	AWWA method	Not found
13	Salmonlla sp.	per 100 mL	AWWA method	Not found

Table 4. 3 Water quality test results for all groups

No.	Parameter	G1	G2	G3	G4	G5	G6
1	pH	6.3	6.2	5.6	5.6	6.0	6.8
2	TS	9.76	6.25	11.25	6.00	9.00	103.50
3	Total hardness expressed as CaCO3	6.98	2.97	3.00	4.04	4.04	22.28
4	Nitrate	0.282	0.200	0.200	0.210	0.200	3.180
5	Chloride	2.73	2.50	1.50	2.50	2.50	9.00
6	Fluoride	0.315	0.250	0.195	0.160	0.150	0.510
7	Iron (Fe)	0.0078	0.0065	0.0020	0.0010	0.0010	0.0020
8	Lead (Pb)	0.0339	0.0270	0.0070	0.0120	0.0080	0.0070
9	Arsenic (As)	0.0335	0.0480	0.0490	0.0340	0.0340	0.0490
10	Coliforms	15.7	1.1	23.0	1.1	1.1	23.0
11	E. coli	Found	Not found	Found	Not found	Not found	Found
12	S.aureus	Not found	Not found	Not found	Not found	Not found	Not found
13	Salmonella sp.	Not found	Not found	Not found	Not found	Not found	Not found

Table 4. 4 Final quality test results with respect to the drinking water standards

No.	Parameter	G1	G2	G3	G4	G5	G6
1	pH	Not Passed	Not Passed	Not Passed	Not Passed	Not Passed	Passed
2	TS	Passed	Passed	Passed	Passed	Passed	Passed
3	Total hardness expressed as CaCO3	Passed	Passed	Passed	Passed	Passed	Passed
4	Nitrate	Passed	Passed	Passed	Passed	Passed	Passed
5	Chloride	Passed	Passed	Passed	Passed	Passed	Passed
6	Fluoride	Passed	Passed	Passed	Passed	Passed	Passed
7	Iron (Fe)	Passed	Passed	Passed	Passed	Passed	Passed
8	Lead (Pb)	Passed	Passed	Passed	Passed	Passed	Passed
9	Arsenic (As)	Passed	Passed	Passed	Passed	Passed	Passed
10	Coliforms	Not passed	Passed	Not passed	Passed	Passed	Not passed
11	E. coli	Not passed	Passed	Not passed	Passed	Passed	Not passed
12	S.aureus	Passed	Passed	Passed	Passed	Passed	Passed
13	Salmonella sp.	Passed	Passed	Passed	Passed	Passed	Passed

From table 4.3, it should be noted herein that the parameters 1 to 10 are in terms of quantity criteria; while the parameters 11 to 13 are solely bacteria criteria. In addition, for the bacteria the result is only either found or not found.

Considering table 4.3 in detail, it was found that the pH values for all of the rainwater samples are about 5.6 to 6.8, while the criteria is between 6.5 and 8.5. Note that the pH stands for potential of hydrogen and the unit measured ranges from 0 to 14, and the middle value is 7. If a pH value is found to be lower the middle value, it means that sample is acidic. On the contrary, a value is higher, it is said to be alkaline. In the case of water having high acid, it may corrode metallic materials. It should be noted that even though water has the pH higher than 8.5, it does not affect the health of a person whatsoever. However, it may cause the water to have a bitter taste and clog a water pipe system. There are several methods to improve water to have the pH according to the drinking water standards. For example, one easy method is to add some chemicals such as calcium carbonate or a mixture of magnesium oxide and calcite (Water System Council, 2007).

In terms of TS, it was observed that the groups G1 to G5 have quite low quantity. This, however, was predictable because all of the samples were rainwater thereby should not have any substance. However, in the case of G6, it was found that its value is as much as ten folds higher than those found in the groups G1 to G5. It should be noted that, however, its value was still quite lower the standards. In the case of G6 having TS quite high may be because it was the water obtained from water well. Thus, during the water flowing to meet a water table, it may also erode and bring some substance along the way. In the case of total hardness, it was observed that all groups have the values that are quite lower than those set by the standards.

Figure 4.8 displays nitrate that were found for the entire rainwater sample groups G1 to G6. It was found that for the groups G1 to G5 the values are about 0.2 mg/litre; while it was about 3.2 mg/litre for G6. This suggests that for G6, the water may have eroded and brought some nitrate underground. Figures 4.9 to 4.13 show the quantity of chloride, fluoride, iron, lead, and arsenic, respectively. It was found that, from the figures, all of the quantities obtained from the quality tests are in accordance with the drinking water standards.

Figure 4.14 displays the quality test result with respect to the coliforms quantity found, it can be seen that the groups G1, G3, G6 are not within the standard acceptance; but, the groups G2, G4, and G5 passed the criteria. These results clearly indicate that boiling water could destroy the coliforms a level is safe for humans to drink.

It should be noted that coliforms are a kind of bacteria. If found, it indicates that the water is somewhat contaminated. There are several types of coliforms. Ones that found in water normally are harmless. However, some coliforms such as Bacteriologic and Protozoic pathogens may trigger typhoid, dysentery, cholera, and sudden diarrhoea (Treyens, 2009). It should also be noted that destroying the coliforms can be easily done by the addition of chlorine.

For E. coli, it was found that the groups G1, G3, and G6 are not pass the criteria. However, the groups G2, G4, and G5, passed the test. Similarly to those observed for the coliform amount, this result showed that boiling water can destroy the E. coli. Note that E. coli stands for Escherichia coli of which are a kind of bacteria. It can be found everywhere, such as general place, food, and in intestine of both humans and animals.

There are several types of E. coli; most of them are harmless to us. However, some type may cause diarrhoea, urocystitis, respiratory infections, and pneumonia.

For the cases of the quantities S.aureus and Salmonella sp., the test results showed that all groups pass the criteria. Note that S.aureus stands for Staphylococcus aureus. It is a local bacteria mostly found on skins an in sinus. In case it is found in food, food poisoning may occur. For Salmonella, a bacteria, the contamination may cause the same symptoms as caused by S.aureus. Overall, if the pH criteria ignored, it was found that the groups G2, G4, and G5 pass the drinking water standards; while for the groups G1, G3, and G6 do not pass the criteria.

From the test results observed and discussed, it may be concluded that rainwater if properly harvest and boiled is totally safe for drinking. Thus, it is therefore a good practice to tell and encourage people to drink for free, no need to pay for drinking water anymore. However, it must inform them that the rainwater should be kept properly. And, before drinking, it must be boiled. This would result in the money would be left more in people pocket thereby easing them little more in terms of household economy. From the test results, the authors strongly believe that boiled rainwater is much safer to drink than commercial drinking water locally produced.

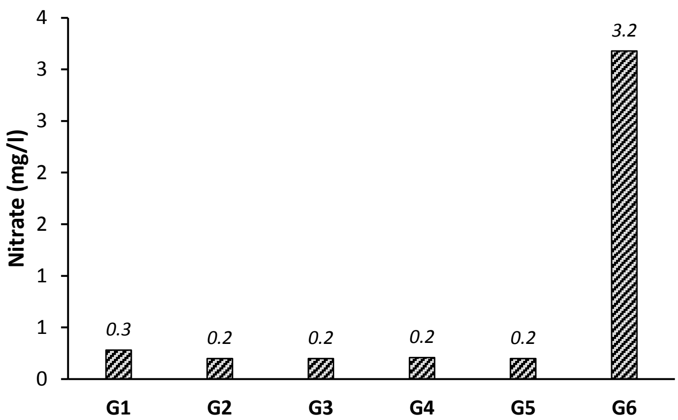

Figure 4. 8 Nitrate for all groups

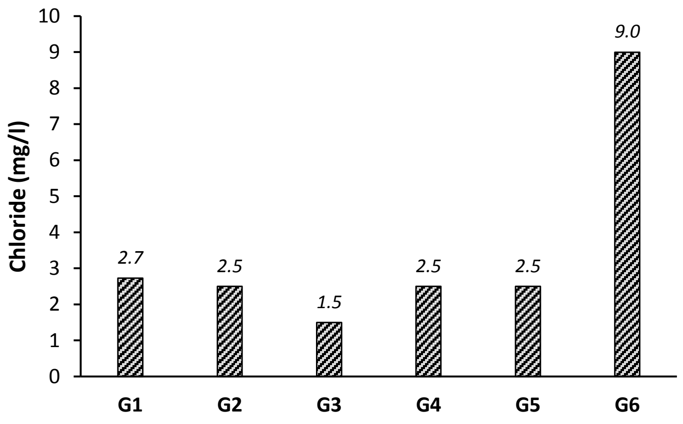

Figure 4. 9 Chloride for all groups

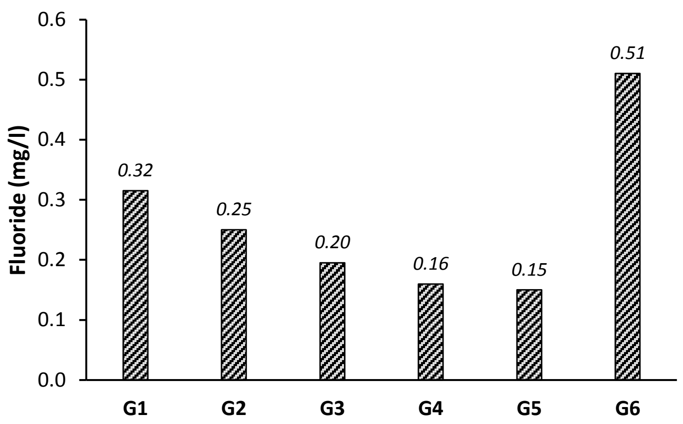

Figure 4. 10 Fluoride for all groups

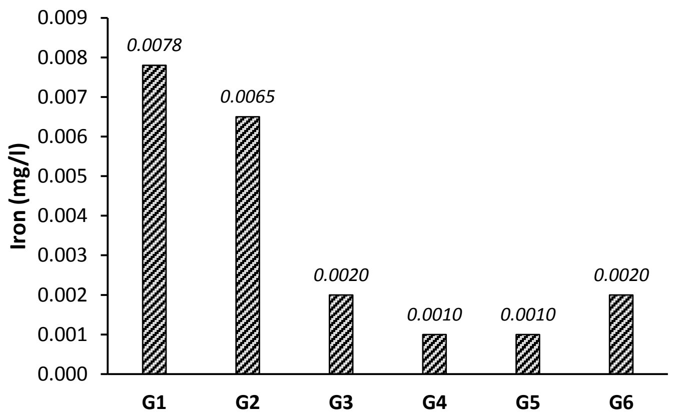

Figure 4. 11 Iron for all groups

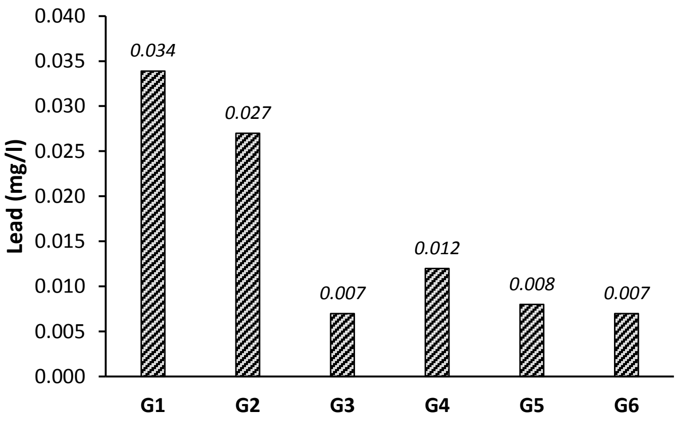

Figure 4. 12 Lead for all groups

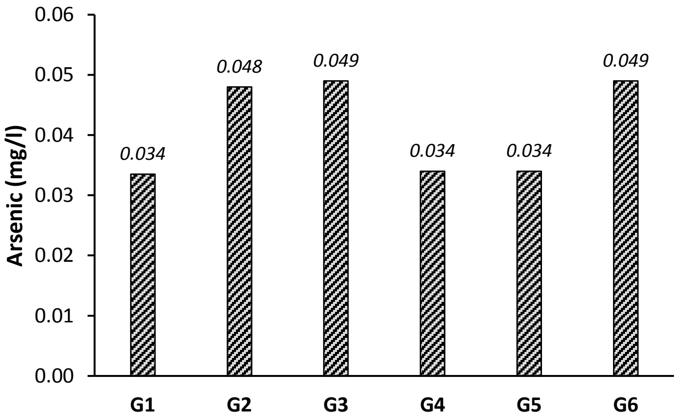

Figure 4. 13 Arsenic for all groups

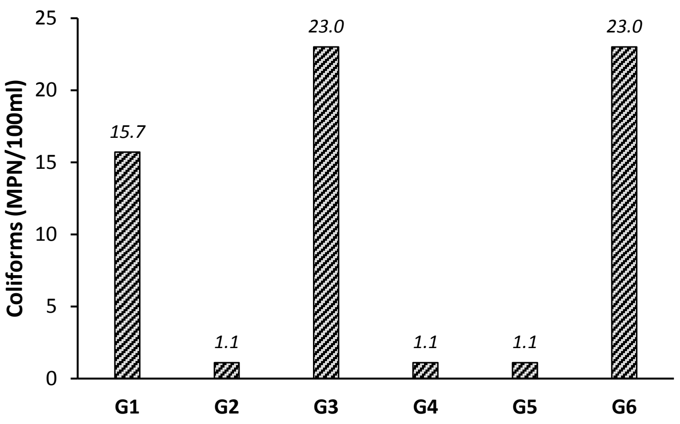

Figure 4. 14 Coliforms for all groups

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In the past, drinking water sources were mainly from rainwater, well water, and ground water. Note that the rainwater was probably the drinking water most consumed. As there have been industries being developed all around the world, there is believe in that the rainwater is contaminated as a result of industrial development. This statement may be somewhat correct in the case rainwater drops in areas that have several heavy industries. In the case of Thailand, this situation occurs at very few areas, e.g., some provinces in the East, inner Bangkok, and around industrial estates accommodating heavy industries.

This research project proposed a proper method for collecting rainwater for quality tests with respect to the drinking water standards set by the ministry of public health. The main purpose was to show that rainwater actually is drinkable. Nakhon si thammarat and Songkhla provinces were chosen as the areas to collect rainwater because they are big provinces in terms of both area and population. In addition, both provinces have quite a lot of annual rainfall. Furthermore, each year rainfall occurs in both very frequently meaning that people have a long period of harvesting rainfall.

To cover all aspects of rainwater there were six types collected, including rainwater directly collected from the sky with some help from a support structure (G1), G1 and boiled (G2), rainwater that flowing through roof and gutter (G3), rainwater being kept in a stainless tank (G4), G4 and boiled (G5), and groundwater (G6).

The quality test results show that the rainwater if harvested, stored properly and boiled is safe to drink. From the intensive testing programmes carried out by this research the authors strongly believe that rainwater is much safer than commercial drinking water locally produced. If people turn to drink more rainwater they would have more money left in their pocket thereby easing them economically. It should be noted that, however, rainfall does not occur every single day. Thus, we have to find methods and containers for properly storing them during rainy season in order to have enough rainwater throughout a year.

5.2 Recommendation for Future Work

Even though the results obtained from this study show a very good promising outcome; but, we recommend more work to be investigated to cover all aspects of rainwater harvesting, as shown below:

(1) As there are several types of roof top being employed, the quality of rainwater flowing through different medium should be further studied.

(2) The rainwater was sent to the laboratory within 25 hr, according to the test standards, however, it would be very interesting to keep the rainwater longer that that before being tested. This is because rainwater when collected is not drunk straight away.

(3) Instead of boiling to get rid of bacterium, one should study by adding some chemical to observe the result. This is because in some situations boiling may not application.

5.3 Output of This Research

Some parts of this research were orally presented and published at the 21st National Convention on Civil Engineering, to be held in Songkhla during 28 – 30 June 2016.

REFERENCES

กรมควบคุมมลพิษ. (2547). คู่มือการตรวจสอบคุณภาพสิ่งแวดล้อมอย่างง่าย, 164 p.

ปราโมทย์ ปราสาทกุล และ ปัทมา ว่าพัฒนวงศ์ (2554). จุดเปลี่ยนประชากรประเทศไทย, ประชากรและสังคม, 1 – 22.

พิมพัฒน์ สิมะวัฒนะ. (2550). การศึกษาสมบัติของน้ำฝนที่รองรับจากหลังคาที่ทำด้วยวัสดุต่างๆ ของบ้านในเขตอำเภอเมือง จังหวัดอุบลราชธานี, มหาวิทยาลัยราชภัฏอุบลราชธานี.

สำนักงานเกษตรเมืองเลย. (ไม่ปรากฏปีที่ตีพิมพ์เผยแพร่). เก็บน้ำฝนอย่างไรให้ดื่มได้, บทความ สาระน่ารู้, จ.เลย.

สำนักงานสถิติแห่งชาติเว็บไซต์ http://www.nso.go.th/

สำนักงานปลัดกระทรวงเกษตรและสหกรณ์ (Office of the Permanent Secretary) (nd.). คุณภาพน้ำฝนจากการปฏิบัติการฝนหลวง, กระทรวงเกษตรและสหกรณ์.

Bhattacharya, A., and Rane, O.N. (nd.). Harvesting rainwater: Catch water where it falls!, Centre for Civil Society, 422 – 439.

City of Tucson (2013). Harvesting rainwater: Guide to water-efficient landscaping, City of Tucson Water Public Information & Conservation Office, 35 p.

Daily, C., and Wilkins, C. (2012). Basic components of a rainwater storage system, College of Agriculture and Sciences, The University of Arizona.

Edstrom. (2003). Drinking water quality standards, Edstorm Industries, Wisconsin.

EPA. (2009). National primary drinking water regulations, EPA 816-F-09-004, United States Environmental Protection Agency.

GDRC (nd). Rainfall harvesting and utilization.

Sabota, C. (2009). Rainwater harvesting for irrigation water, Alabama Cooperative, Alabama A&M and Auburn Universities.

Tarbuck, E.J., and Lutgens, F.K. (2002). Earth: an introduction to physical geology, Prentice Hall, New Jersey, 670 p.

Texas Water Development. (1997). Texas guide to rainwater harvesting, 2nd Edn., Texas Water Development Board in Cooperation with the Center for Maximum Potential Building Systems, Austin, Texas.

TIS 257- 2549. (2006). Drinking water, Thai Industrial Standard, Ministry of Industry.

Treyens, C. (2009). Bacterial and Private Wells: Information Every Well Owner Should Know, National Ground Water Association, pp. 19 – 22.

USAID (2014). 2014 World population data sheet, Population Reference Bureau, United States Agency for International Development, Washington.

Wateraid. (anon.) Rainwater harvesting, Scotland.

Water Systems Council, (2007). Information for You about pH in Drinking Water, U.S. Environmental Protection Agency, pp. 1 – 2.

APPENDIX A

WATER QUAILITY TEST RESULTS

APPENDIX B

PAPER TO BE PUBLISED IN

21ST NATIONAL CONVENTION ON CIVIL ENGINEERING

BP HOTEL, SONGKHLA, 28 – 30 JUNE 2016

(PAPER ACCEPTED)