Doctor of Philosophy

A Strategy to Promote Sustainable Drinking Water in Vietnam by Rainwater Harvesting

By

Dao Anh Dung

Advisor: Prof. Mooyoung Han

A dissertation submitted in partial fulfillment of the requirements for the degree

Doctor of Philosophy

Department of Civil and Environmental Engineering

Seoul National University

Abstract

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Dao Anh Dung

Department of Civil and Environmental Engineering

The Graduate School

Seoul National University

Currently, drinking water problems in Vietnam are more common due to high population growth, rapid urbanization, degradation of water quality and over exploitation of water resources. To date, the water supply system highly depends on centralized system by using the surface and groundwater; with a negligibility of rainwater. However, the conventional centralized water supply is facing many issues i.e. limited water resources (both quality and quantity) because of e.g. contaminated surface/ground water, drought, and salinization.

For many decades in Vietnam, rainwater harvesting (with a relatively high yearly precipitation of around 1.680 mm) has been widely used as a nature-based solution in rural areas. But recently, rainwater for

drinking has been gained much attention from the Vietnam Government. Therefore, this study implemented the demo RWH system in Vietnam to identify the technical, economical, and social barriers, and suggesting proper strategies to overcome and promoting RWH spread widely for Vietnam Government.

Technical barriers are lack of the design guideline and manual, professional skill and established market for rainwater harvesting. While, economic barriers are that it's too expensive to install and maintain and that is not profit generating system. Social barriers are lack of (a) knowledge of rainwater and rainwater harvesting system, (b) communication amongst the users and stakeholders, and (c) high expectation about the tap water installation.

In order to overcome the technical, economic and social barriers, four demo RWH systems for school at rural area in Vietnam have been installed and monitored for several years. Through these demo systems, the sustainability of the RWH was proved. Technically, the rainwater quality meets the Viettnam drinking water standard – QCVN 01-2009. Water can be supplied during the dry season. The maintenance fee can be collected by reducing the water purchasing fee. The science group in school can be involved in the routine maintenance of the RWH system.

All the village people should be involved in the activity of the rainwater education and promotion.

New strategies to promote sustainable drinking water in Vietnam is suggested. Firstly, community RWH should be established and operated with self-monitoring and operation. Secondly, technical design guidelines and training to improve rainwater quality as well as operation and maintenance manual should be provided. Thirdly, encourage the private sector or enterprise to implement RWH for community by the incentive strategy. In addition, a market for rainwater harvesting equipment should be established. Fourthly, to promote RWH system widely, the communication can be implemented in the school through the student and teacher activities such as education, training, contest, event etc. These activities bring large positive impacts to the villagers and communities. Finally, Vietnam Government should support research activities and implement laws and regulations to promote RWH by providing financial incentives, and to encourage people to harvest rainwater for various purposes.

Keyword: Barriers; Community-based rainwater harvesting; Drinking water supply; Rainwater harvesting design; Strategies; Sustainability.

Acknowledgement

I would like to express my gratitude to my Advisor, Professor 한 무영 , for his support, encouragement, and help me to complete my graduate studies. My thanks also go Professor Van Thinh Nguyen, Professor 최정 권 , Professor 김미경 , Professor Viet Anh Nguyen for reading drafts of my dissertation and giving many correction and useful comment that improved my presentation and contents of this dissertation.

I also would like to thank my laboratory members, junior and friend who help me to do our research, Dr Kim Tchung-il, Ms. Bui Thi Thuy, Ms. Chung Jooho, Ms. Lee hakyung, Mr. Le Trong Bang, Ms. Park Jin, Ms. Malwina, Ms. Tian zhenrong, Ms Yunn, Ms, Hayeon, Ms. Esther, Ms Rose', Ms Haerim, Mr. Yonghwan, Ms. Gippuem Dr. Duc Canh Nguyen and my Vietnamese friends in Department of Civil and Engineering. Without their cooperation I could not gotten the great result for my research.

My last and most heartfelt appreciation must go to my beloved wife, my sons, my parents, and other relatives for their great supports during my study period.

Dao Anh Dung

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Nomenclature

ADB - Asia Development Bank

RWH – Rainwater Harvesting

RWHD – Rainwater Harvesting for Drinking

RWM – Rainwater Management

SDGs - Sustainable Development Goals

UNEP – Union Nation Environmental Program

QCVN- Vietnam water standard

BYT – Ministry of Health

RUR – Rainwater Usage Ratio

TC – Total Coliform

NGOs - Nongovernmental Organizations

O&M – Operation and Maintenance

CHAPTER I. INTRODUCTION

1.1. Background

Developing countries in Asia suffers from water scarcity which have caused by the increase of urbanization and climate change. A study which is conducted by Asia Development Bank (ADB) in 2011 noted that freshwater resources in Asia are already facing severe threats, with the situation expected to worsen in the future. About 60% of the world population live in Asia area, and Asian regions need a clean water supply system for not only in rural areas but also for the fast-growing cities where rapid urbanization is occurring. It is estimated that about one in five people (700 million) do not have access to the safe drinking water; 22 out of 32 Indian cities face daily water shortages. In Kathmandu, the capital of Nepal, many residents are accustomed to waiting in the queues for hours to get drinking water from their ancient city's stone well. The UN estimates that the population of Asia will grow by 700 million people between 2010 and 2025. According to the Water Operational Plan 2011-2020 for Asia which was developed by the Asian Development Bank (ADB) (ADB 2011) reported the growing populations, rapid urbanization, the increase of water pollution, and competing for demand for water left not many water resources for Asian countries. As its critical state, i.e., the gap between demand and supply is widening, and water supply competition is increasing between the water users, including farmers, energy producers, households, and businesses. Around 70% of Asia's water is used to irrigate the crops, but much of it is used for inefficient ways, while many water-stressed countries lose the large volumes of treated water through the leakage from urban water supply systems. Asia's supply of water to meet future needs is rapidly decreasing. Located in the Southeastern part of Asia, the total population of Vietnam is over 86 million and the estimation of GDP per capita is about $3100. Like many other countries, Vietnam is already facing water shortages problems, due to the many reasons like the government's inability to establish a centralized water supply system and the contaminated of water resources. The lack of physical infrastructure and financial capacity, there is low utilization of the supply along with an uneven distribution of rainfall resulting in water shortages throughout the country. Although Vietnam has improved its water supply situation compare to the past few decades, many rural parts of the countryside people have not experienced significant improvement. Only 39% of the rural population has access to safe water and sanitation (based on the water project). The rural community has changed their ways to use water from shallow wells to groundwater pumped from private tube wells. In the Northern region of Vietnam around Hanoi, there is ab evidence of arsenic contamination in the drinking water. About 7 million people living in the Northern region have a severe risk of arsenic poisoning, elevated levels of arsenic cancer, and neurological and skin cancer problems (Berg, M. et al., 2001). Besides, due to rapid economic development in Vietnam, river water quality has been affected along with an increased concentration of various toxins in the river. The surface water in the rivers is locally polluted by organic pollutants such as oil waste and solids. Also, pollution from untreated wastewater released by industries and agriculture activities have severe results on river contamination. The Ministry of Natural Resources and Environment stated that almost 80% of the diseases in Vietnam are caused by polluted water (Hoang, D.T et al., 2008).

In recent years, rainwater harvesting (RWH) is gaining interest as a safe drinking water supply option to solve Sustainable Development Goals (SDGs). If water is collected safely from catchment systems at atop buildings, there will be no additional cost, and the quality source of drinking water will not require other energy use and an exacerbation of territorial conflicts between the countries(Julius et al. 2013, Mwenge Kahinda et al. 2007, UNEP 2009, Amin et al. 2009, Song et al. 2009, Tabatabaee et al. 2010). As of its many other publications had reported, the low quality of rainwater is not because of its component, but either an inadequate design, poor maintenance of equipment (Dobrowsky et al. 2014), or an incorrect sampling method from the rainwater tanks. The only contaminants are the particles and microorganisms, which originally come from the atmosphere (Kaushik et al. 2012), bird droppings, or the roof catchment (Ahmed et al. 2012), which requires minimum treatment before use as drinking water.

Rain harvesting is a reliable solution for the problems arising water restriction, and it has both direct and indirect roles in achieving the goals of human well-being mentioned in Millennium Development Goals (Salas et al., 2009). For example, it RWH released a burden of children and women from the collection of water. The RWH gave them to have more free time for themselves (Zhu et al., 2015). Even with the situation of the dry year, rain harvesting can meet the basic need of humans (drinking, cooking, and limited hygiene). Therefore, rain harvesting has an important role in water security and social benefits. From an environmental perspective, rain harvesting is a sustainable approach because it has little impact on the water cycle although it can reduce groundwater and surface water in some contexts (Zhu et al., 2015). Rain harvesting has some beneficial effects on the economic aspect. For example, the benefits of rain harvesting can be seen in three aspects (Zhu et al., 2015). The first element is saving labor for collecting water so that they have more time for earning money by others works. Second, it saves money paying for pipe water supply. Third, it can increase production of the crop by enhancing water for irrigation.

In Vietnam, rainwater harvesting is one of the most popular traditional methods in villages. However, after the centralized water supply systems have been developed, rainwater is almost neglected. Vietnam is located in a tropical region which has high annual rainfall. According to the report of the Ministry of Resource and Environment of Vietnam, the annual rainfall is about 1680 mm per year, which is much higher than the world and Asia's average. Many researchers reported that rainwater quality in Vietnam is good and can be supplied as drinking water (D.A.T Dinh et al. 2012; C.L Tran 2002). The amount of rainwater is quite high (Nguyen and H.H Huong 2009; X.D.Nguyen and V.O Tran 2010).

Although RWM is gaining interest as a resilient and sustainable water management approach, the lack of scientific and engineering knowledge such as uncertainty of water quality and quantity, a risk of public acceptance, and the limit of economic and social often prohibit the use of rainwater. Sempra et al. 2011 reported that both statistics and focus group interviews suggest that a storage capacity is a major limitation in rainwater harvesting and about one-third of the sampled households said the running out of rainwater during the six- month of a dry season. Nguyen et al. 2015 indicated a typical lack of awareness and knowledge in RWH and utilization among urban residents, professionals, and policymakers in Vietnam. Along with urbanization, the conventional centralized water supply has been focused, the technology of RWH is generally forgotten and neglected. As a result of poor recognition of rainwater as an important resource and its benefits, there are no policies, regulations, and guidelines related to RWH so far in Vietnam.

1.2. Necessity

Currently, drinking water problems in Vietnam are more common due to high population growth, rapid urbanization, degradation of water quality and over exploitation of water resources. To date, water supply system highly depends on centralized system by using the surface and groundwater; with a negligibility of rainwater. However, the conventional centralized water supply is facing many issues i.e. limited water resources (both quality and quantity) because of e.g. contaminated surface/ground water, drought, and salinization. Moreover, the construction and operation of centralizes water supply networks require too much cost, time and effort.

For many decades in Vietnam, rainwater harvesting (with a relatively high yearly precipitation of around 1.680 mm) has been widely used as a nature-based solution in rural areas, aiming at good-quality of drinking water with the low cost and little energy. Recently, rainwater for drinking has been gained much attention from the Vietnam Government. However, despite its efforts, the outcomes are not as expected due to local barriers. Therefore, this study implemented the demo RWH system in Vietnam during the period from 2010 to 2018 to identify the technical, economical, and social barriers, and suggesting proper strategies to overcome and promoting RWH spread widely for Vietnam Government.

1.3. Object of the dissertation

The overall intention of this research is to promote the use of rainwater as a sustainable water source for drinking and make the strategy suggestion better for the implementation of the sustainable drinking water for Vietnam government.

1. To identify barriers of rainwater harvesting in Vietnam.
2. To determine the solution to overcome the barriers by an installation of demo RWH system for drinking in the rural community.
3. To suggest a strategy for the promotion of sustainable drinking water by rainwater harvesting including technical, social, economic aspects.

1.5. The structure of the dissertation

This dissertation consists of a total of six chapters which summarize in Figure 1. Chapter 1 introduces an overview of the study including study objective, the dissertation structure with a general description of the water supply situation in Vietnam. Chapter 2 summarizes a collection of basic literature review which describes the status of water supply and RWH in Vietnam. Chapter 3 contains a strategy to overcome barriers for rainwater harvesting as drinking water through a survey in Vietnam. Chapter 4 provides a demo project to overcome barriers of technical and economic aspects.

Chapter 5 summarizes suggestions to promote sustainable water supply with the use of RWH. Chapter 6 contains a conclusion of this study with recommendations. The structure of this study is shown in Figure1.

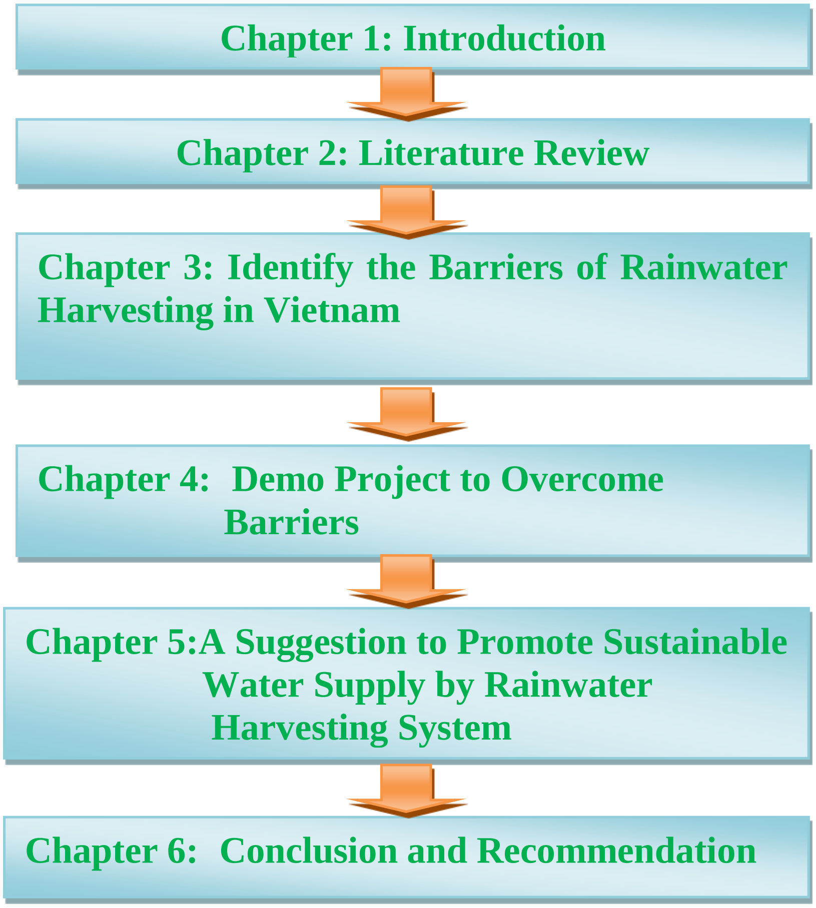


Figure1. Structure of this dissertation

CHAPTER 2: LITERATURE REVIEW

2.1. Water supply system in Vietnam

According to the data of the National Target Programme for Rural Water Supply and Sanitation in Phase 3 (2011 – 2015), by 2015, a total rural population's use of clean water was increased from 4,880,000 to 8,630,000 in comparison with the end of 2005. The rate of the rural population who has access to clean water increased from 62% to 80%, but it is only 5% of total and the average risen just 3.6% in a year. The rate of rural people's use of domestic water meets Vietnamese water standard (QCVN, 02/ 2009) but the BYT standard is 40% which is 10 % less than it is initially planned.

The current total water resource is about 4.5 million m3 which holds the water supply rate of 60% from the surface water and 40% from the groundwater. Both surface and groundwater resources are starting depleted and polluted due to the untreated wastewater from urban and industrial areas, as well as the salinity. The pollution of hazardous substances is made of arsenic contamination, ammonium compounds, pesticides or industrial chemicals, etc. The water sources are getting more and more polluted, and the traditional technologies do not allow to remove all special pollutants like persistent organic substances, heavy metals, dissolved hazardous ions and, etc.

Therefore, water source protection, upgrade of water treatment plants and reform of water supply system management should be carried out.

There are still many models of management exist which are not professional such as the model of community People Committees, community, and collective management. A capacity of staff and operators are still weak. Many communities did not issue regulations on an operation, maintenance of centralized water supply schemes. Management mechanism, an especially financial mechanism is not appropriate, leading to a situation in which sustainable activities of the works is not ensured. People did not pay attention to the water treatment, supervision, and control of water quality system. People's responsibilities in water management and user guideline, system protection as well as the monitoring of water supply schemes are not high enough. In many places, centralized water supply systems keep good water quality, but the connection of a water distribution network system is still low. Many household uses only piped water for cooking purposes, and do not use other unsanitary water sources for their domestic purposes. There are many rural water supply schemes exist, but most of the time, it does not operate well or effectively (Figure 2). Also, the waste of water investment and its impacts affected people's lives negatively and reduced any expectation and altitudes of water use due to its low service of water supply and sanitation.

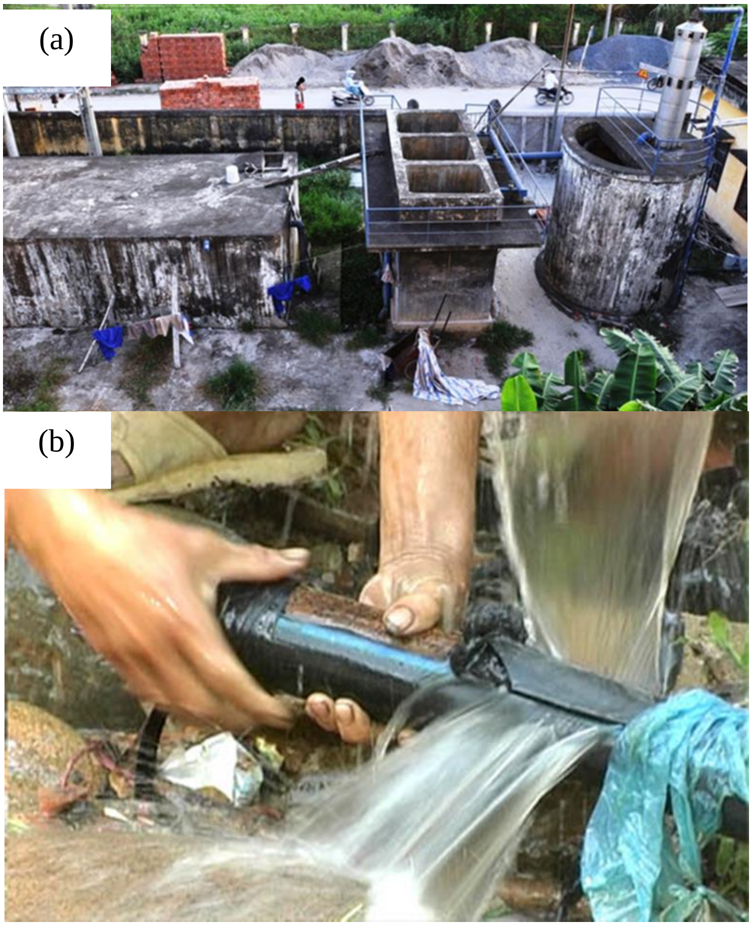


Figure 2. Weakness of rural water supply system

a) Low operation & Maintenance

b) Lack professional worker

2.2. History of rainwater harvesting systems

“Is there anything that thou hast seen under the heavens that is better than water “Solomon said to Queen of Sheba (Budge, E.A.W. 1932) and rainwater harvesting is the process of collecting, storing and using as a primary or supplementary water source (Brian Latham& Dr. Eric Schiller 1984). This process has been applied for a lot of areas in the world: EUROPE from the sixth century onwards; began to used in ATLANTIC since 1628; EAST ASIA from ancient time etc….(Brian Latham& Dr. Eric Schiller 1984)

In terms of water harvesting and management, immense wisdom has existed in various countries since ancient times. Technologies, such as Qanats, where artificial underground water channeling systems were installed under 305 m from the Earth's surface, bring a continuous stream of water to the Earth's surface for agricultural and domestic uses. The Persians used Qanats for more than 3,000 years (Mohsen et al. 2013). This technique later spread to northern African countries such as Egypt. Similar techniques were used in other countries, such as Foggara in Libya, Tunisia, and Algeria and Khettara in Morocco (Hydria 2009, UNESCO).

Despite their arid and semiarid weather, at most 10% of these areas receiving more than 300 mm of rainfall annually (FAO 2000), these techniques ensured sufficient water supply throughout the year. Thus, regardless of the rainfall quantity, RW can be harvested, and it can contribute partially and/or fully serve water demand with proper management. Archeological evidence proves the use of RW even 4,000 years ago, and the concept of RWH in China may date back 6,000 years. Ruins of cisterns built in 2000 B.C. to store runoff from hillsides for agricultural and domestic purposes are still standing in Israel (Texas 2005). The world's first RW gauge known as Chuk-u-gi was invented in A.D. 1441 during the Joseon Dynasty in

Korea by King Sejong the Great. As a result, despite some destruction in the past, rainfall records have been remained for 250 years(Han and Park 2009). In Vietnam, rainwater was started to be collected from long time ago and it was used for drinking and cooking. Rain water is collected from rooftop and conveyed to the jar or brick tank via the bamboo gutter (Figure 3)

These systems have been continued for centuries due to their compatibility with local lifestyles, institutional patterns, and social systems (Mbilinyi et al. 2005). To develop sustainable RWH strategies, it is important to take into account and learn from the knowledge which has been already shared among local people, and developed based on this knowledge.

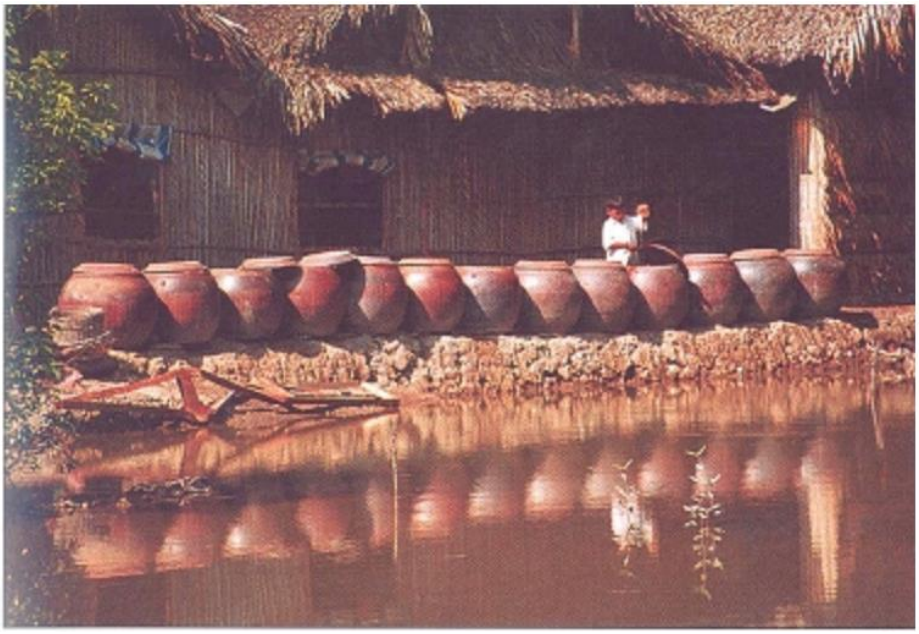


Figure 3. Ancient rainwater harvesting system in Vietnam

2.3 Rainwater harvesting roles

RWH has been suggested as a main component in the new water paradigm, which is an idea meant to help reverse the current trend in extreme weather effects due to climate change. The new water paradigm develops, utilizes, and supports overland RWH and conservation of RW in watersheds so that ecosystems can produce good enough quality water for human and wildlife needs; purify polluted water; reduce the risk of natural disasters such as floods, droughts, and fires; stabilize the climate; strengthen biodiversity; and become a component of economically sustainable development programs (Kravis et al. 2008). Thus, the necessity to promote in situ and ex situ RWH interventions arises. In situ interventions include soil management strategies that enhance rainfall infiltration and reduce surface runoff, whereas ex situ interventions include RWH capture areas such as rooftops, road surfaces, rock catchments into external water storage areas such as storage tanks, and ponds (UNEP 2009). RWH interventions have been successful implemented in upgrading societies~~developing countries~~, such as Gansu in China, and the Slovak Republic, which have experienced drought, flood, low annual precipitation, poor agricultural production, and poor domestic water supply (Zhu 2008, Kravcik et al.2012).

Furthermore, RWH can play both direct and indirect roles to achieve a number of the Millennium Development Goals (MDG), especially in areas related to basic human needs and health (UNEP 2009). For instance, improved agricultural production can end poverty and hunger; increased water availability can improve gender equality; better domestic water supply and sanitation practices can improve the health of children; and enhanced ecosystem productivity, freshwater provisions, and GW recharging can improve environmental sustainability.

In the 2014 World Water Week, a group of scientists and experts made a declaration in United Nations General Assembly to add a Hunger Goal as a target on sustainable and resilient RW management. This is to increase food production of over 50% in the yield of food per unit of RW through the adoption of sustainable watershed management practices at all scales (RWH declaration 2014).

Additionally, the potentiality of sustainable domestic RWH projects was shown through recent case studies in Tanzania, Ethiopia, and Vietnam (Nguyen et al. 2013, Mwamila et al. 2016, Temesgen et al. 2015). Furthermore, UN-Habitat (2005) has compiled a list of successful case studies of RWH for both domestic and agricultural purposes, which can serve as guides for future projects.

2.4. Rainwater harvesting for drinking

2.4.1 Pretreatment methods

Coarse screen, first flush tank, and storage system design strategies are proposed to tactically offer pretreatment services in RWH practices. Moreover, the tanks are recommended to be located above ground or at least 50 feet (15.24 m) away from animal stables if they are underground (Texas 2005).

2.4.1.1 Coarse screen

To capture leaf litter and debris, a coarse screen may be placed along the gutter or in the downspout, contributing to reduce particle quantity into the first flush tank (Texas 2005, Worm and Hattum 2006, Martinson and Thomas 2007). The coarse screen needs frequent monitoring to prevent clogging. Having only screens/filters may be insufficient to improve RW quality significantly (Amin et al. 2013).

2.4.1.2 First flush tank

The purpose of a first flush tank is to divert the initial rainfall. Previous researchers have proved that the first flush tank can wash out most of the contaminants, both physicochemical and microbiological parameters, that are adhered to the roof (Texas 2005, Doyle 2008, Amin and Alazba 2011, Gikas and Tsihrintzis 2012, Amin et al. 2013). Several factors affect to determine the effective size of the first flush tank volume including the slope and smoothness of the collection surface, intensity of the rain event, length of time between events which increases the amount of accumulated contaminants, and the nature of the contaminants themselves (Texas 2005). Based on field observations and laboratory experiments, Coombes (2015) discovered that a first flush device designed to capture the first 0.25 mm of roof runoff can remove 11% – 94% of dissolved solids and 62% – 97% of suspended solids from the first flush runoff into a RW tank, limiting the inflow of chemicals and metals. Generally, it seems that the quantity of a contaminant (dissolved and suspended material) will be halved with each additional millimeter of diverted first flush (Martinson and Thomas 2005, Thomas and Martinson 2007). An additional recommendation is to divert water if rainfall follows at least three dry days.

2.4.1.3 Role of sedimentation

RW tank design considerations can also improve stored RW quality. This is because of enhanced sedimentation and biofilm development due to retention time, longer flow paths, and presence of internal walls/baffles (Amin et al. 2013). Han and Mun (2007) investigated the effect of retention time, distance between inlet and outlet, and water supply (access) level. They recommended that an adequate distance between the inlet and outlet would increase removal efficiency of particles because they will settle as the water moves along the flow path. Han and Mun also showed that higher retention

times reduce the amount of significant 17 particles. Hence, they recommended to extend a retention time for more than 24 hours. Additionally, these researchers showed that accessing water at top layers reduces particle concentrations, due to settling effect which refers to the fact that particles tend to accumulate at levels close to the bottom. Amin et al. (2013) also found this to be true. Coombes et al. (2006) found that there
was an accumulation of lead and iron in samples taken from the sludge at the bottom of tanks, supporting their assumption that contaminants settle at the bottom of tanks.

A calm inlet into the storage tank should be used to ensure minimum/no suspension of already settled particles, and the RW should be drawn from the layer near the water surface in the tank by using a floating suction device to avoid settled contaminants removal (Figure 4).

2.4.1.4 Role of biofilm

On the tank's inner wall and bottom surfaces, biofilm grows and adsorbs heavy metals, organics, and pathogens from the water (Amin and Alazba 2011). A study on biofilm development and performance in RW storage tanks concluded that a larger surface area to volume ratio improves microbiological quality (Kim et al. 2011). Moreover, Kim et al. (2012) studied the impact of using common construction materials (concrete, clay, and PVC) for RW tanks on biofilm development and attachment. They showed that clay and PVC were good for the initial attachment of biofilm, but concrete provided a better support on a long-term basis. Due to its highest degree of roughness, concrete widens surface area, so it provides a favorable site for colonization. Moreover, in an elemental analysis using high resolution ICP-MS, Coombes et al. (2006) saw an accumulation of metals including lead, zinc, copper, manganese, chromium, mercury, and arsenic in biofilms. Coombes (2015) further suggested that RW storages are bioreactors with biofilms at the water surface micro layer, on internal walls and at the bottom as sludge. He recommended that stored RW should not be drawn from the bottom 100 mm of the RW tank to maximize the quality of water by avoiding sludge disturbances. In addition, frequent cleaning of the RW storage tanks is not recommended to guarantee the existence and good performance of biofilm. Furthermore, the pump inlet should be located above the potential biofilm growth area. Figure 4 illustrates technical innovations in RW storage tank design to enhance particle removal.

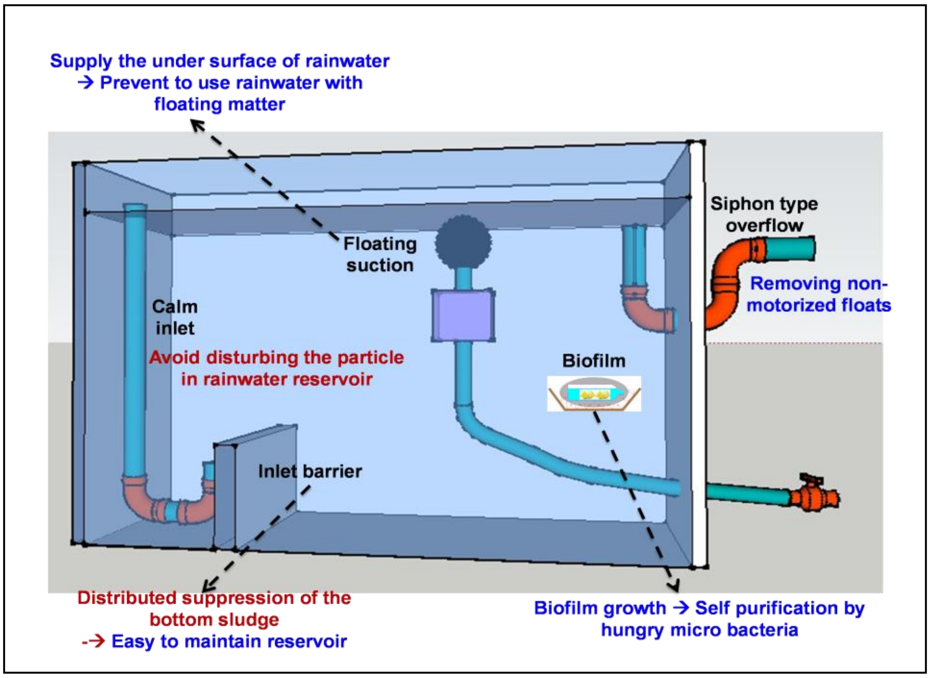


Figure 4: Technical innovation in particle removal from rainwater
(Credit: Prof. M.Y. Han)

2.4.2 Post treatment methods in the world

Household water treatment may be applied to RW to assure of the user's health and safety better. These treatments may include chemical disinfection; membrane, porous ceramic, or composite filters; granular media filters; solar disinfection (SODIS); UV light technologies; thermal technologies; and coagulation, precipitation, and/or sedimentation (WHO 2008). Each of these may have sustainability challenges considering treatment efficiency, technology cost, ease of use, time consumption, energy demand, and supply chain (Sobsey et al. 2008). SODIS and point-of-use chlorination have been suggested as low cost disinfection techniques for stored RW (WHO 2008). Precautions are required for chlorination of RW harvested from asphalt shingles and green rooftops due to high concentrations of dissolved organic carbon, which could lead to high concentrations of disinfection by-products (Mendez et al. 2011). The performance of SODIS was evaluated based on criteria including PET bottle condition and handling, sunlight exposure time, sunlight magnitude (temperature and radiation effects), turbidity level and pH of the RW, backing surface effect, and microbial regrowth (Amin and Han 2009a, b). A solar collector enhanced the efficiency of SODIS in microbial inactivation up to 30% (as a result of concentrated effects of sunlight radiation and synergistic effects of thermal and optical inactivation), ensuring complete disinfection in not only strong (irradiance range 650 – 1000 W/m2) but also moderate (350 – 700 W/m2) weather conditions. In addition, reflective surfaces were better than absorptive and simple surfaces. Furthermore, acidic condition of RW with turbidity levels less than 20 NTU showed better results. Food product use, such as lemon and vinegar as catalysts, enhanced the performance of SODIS and resulted in complete disinfection of RW even under weak weather conditions (100 – 400 W/m2) with solar collectors (Amin and Han 2011). In their review of SODIS technology mechanisms, application, and adoption, McGuigan et al. (2012) acknowledged that SODIS is effective against almost all waterborne microbial pathogens, and it can reduce household finances by reducing fuel, morbidity, and illness-related costs. Therefore, RWH can provide drinkable water enough using cost effective technology, as illustrated in Figure 5.

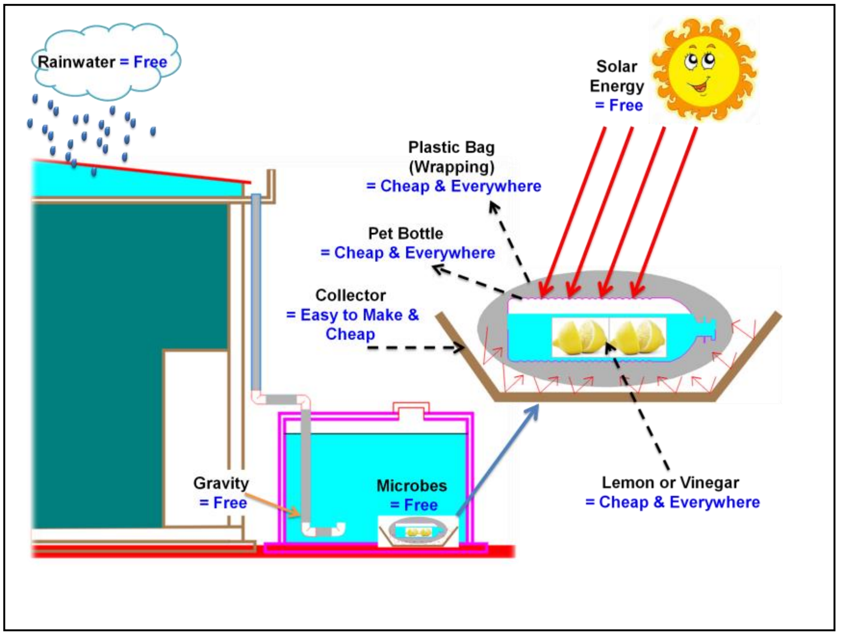


Figure 5: Rainwater harvesting with affordable technical innovations for enhanced water quality (Credit: Prof. M.Y. Han)

In Texas (USA), they suggest to use some filtration technologies relatively effective to remove the microbes that could be present in harvesting system like microfiltration membrane, ultrafiltration and nanofiltration membrane. Cartridge filter should be installed to make sure that large particles do not enter membrane unit (Kathleen Hartness White et al, 2007). Another technology, filtration adsorption disinfection (FAD) was introduced in EU (Vincenzo Naddeo et al, 2013) to treat rainwater for drinking. It includes the pre-filtration membrane cartridge, adsorption GAC, microfiltration at 0.5 µm and UV disinfection. This technology provides an absolute barrier for pathogens and several contaminants, and reduces turbidity.

2.5. Rainwater harvesting in Vietnam

Vietnam is a tropical country, with a total area of 329,841 Km^2 and a population of nearly 86 million, of which 75% are in the rural area. Population growth rate is 1.6 % in 2015, the average income per capita was 1050 US$, The annual average rainfall is approximately 1680mm and it is separated into 7 regions with rainfall vary from 1100 mm to 2500 mm, Figure 6 (Tran et al, 2007- Vietnam Climate and Meteorology general book). The above factors and others affect and vary the way and habit of harvesting rain water in different areas and to certain degree among different ethnics in the country. While water is abundant in many parts of Viet Nam, safe drinking water is scarce. In fact, the majority of rural Vietnamese farmers have a long tradition of harvesting rainwater by using various types of catchments systems as well as various storage facilities, with a summary as follows:

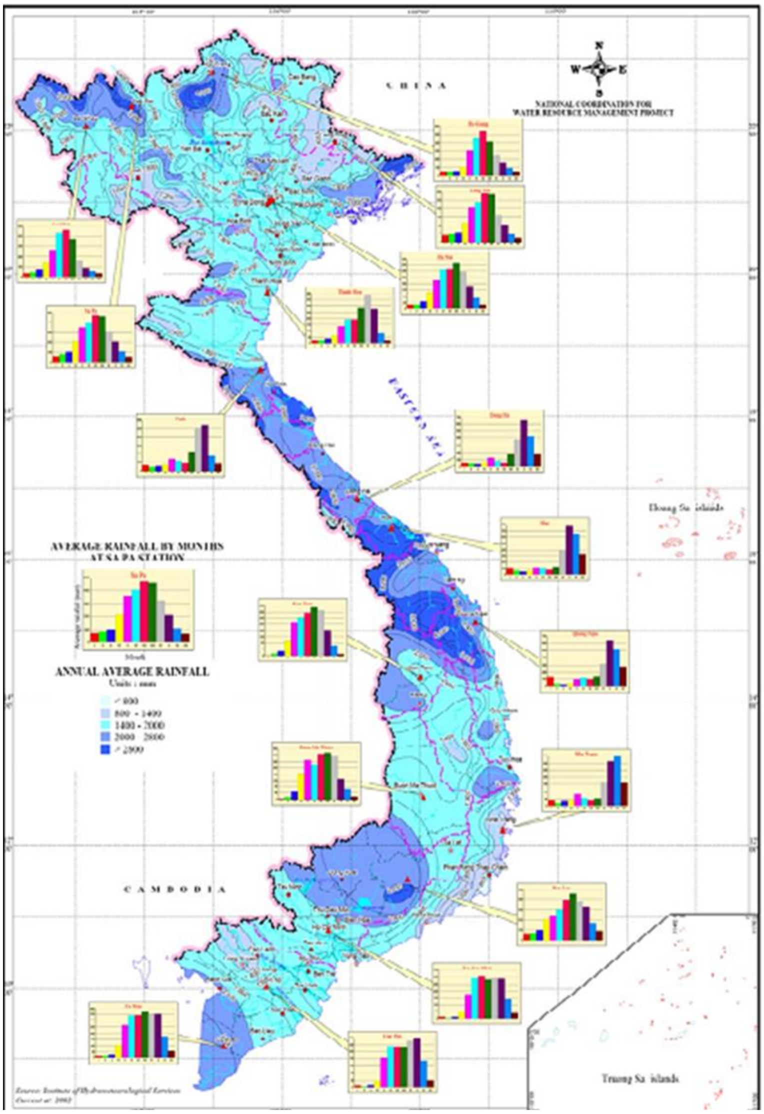


Figure 6. Map of average annual rainfall in Vietnam (mm)

Types of catchment systems: traditionally, Vietnamese farmers have used the areca tree for catchment area (Fig. 7), put an earthen jar near the trunk of the areca tree and bind a dry areca leave as gutter to lead rain water from top of the tree to flow down on the trunk to the jar. This is still continued in some rural areas in the country nowadays. The rain water is mainly used for direct drinking as the farmers feel “sweet” and “refreshed”. But they can catch a small amount of rain water only in summer.

Previously, brick house, brick ground and tile roof were dreams of most farmers, and only rich farmers and landlords could afford. Hence, the use of roof tile and concrete roof as catchment area of rain water was limited. This situation is changing rapidly, so the potential for rainwater systems in many parts of the country is increasing. Poor farmers in remote rural part of the country can still use the thatch roof or ‘|rain coat”| to catch rain in storage containers. - In some places, the farmers dig a small hole in the cemented or paved ground to collect the rainwater. They clean the ground surface. Then, before it rains, the collected rain water is taken to containers – jar or tank.

Figure 7. Collect rainwater from areca

Types of containers: Brick tank: this kind of facility is mainly used by the farmers in the North and Central parts of Vietnam, especially in the Northern Delta area. The capacity of the tank normally ranges from 2 to 10 m^2. In saline and coastal area, people tend to build tanks with higher capacity. The farmers in the Southern provinces have no experience in building & using brick tanks. - Earthen jars are commonly used throughout rural areas from North to South, with storage capacity from 200 to 500 litters. - There are also other types of household containers made of ferro – cement, plastic and composite materials but they are not typical types commonly used by farmers.

The treatment method for drinking is the boiling, and long time ago, farmers sometimes just took water out of a storage and drank.

Nowadays, RWH systems in Vietnam are still installed at rural areas and the potential cost benefit of RWH as a method for the government to supply water in Vietnam varies from location to location. RWH is regarded as the only solution in some locations in Vietnam, such as highland areas in Vietnam's North East and North West regions and some coastal delta areas affected by saltwater intrusion. As a more data about the problem of arsenic in the Mekong Delta is accumulated, RWH can be proved as a cost effective and sustainable solution for the government to promote rainwater harvesting as the complimentary source of potable and chemically safe water for direct human consumption.

There was nothing uncovered to indicate that water companies so far perceive any competition from the rainwater harvesting sector. Rainwater will never be the major water source and be always a smaller volume of high quality water. Water companies have more concerned about the largely unregulated groundwater drilling industry, not the suppliers of RWH technologies.

According to the Department of the Water Resources Management of MONRE, there is so far no official policy related to rainwater harvesting and storage. Everyone is free to practice RWH. Government's the most sensitive issues around RWH is mosquito breeding, especially the mosquito that spreads dengue fever. The Department of Preventative Medicine & Environmental Health, working through their network of Commune Health Centers and Village Health Workers, disseminates information to promote strategies to mitigate mosquito breeding along with other messages about the safe use of the water and the way to maintain good household and environmental sanitation and hygiene.

Domestic RWH encourages the control of rural household water supply. Storing water during the wet season from the well or rainwater in a dedicated storage facility will help household cope with extended dry seasons. At the same time, if there is an insufficient storage and collection to be used in dry seasons, then the household has no way to deal with the problem. Solutions are, therefore, to increase storage and collection capacity at the individual household level and put more attention enhance portability of RW

The 2002 National Health Survey and the National Living standards survey estimate that between 10 to 20 percent of the rural population use rainwater as their primary source of clean drinking water. The greatest concentration of RWH is found in Red River Delta and Mekong delta, particularly in areas where surface and groundwater is unavailable, non-potable due to presence of fluoride an/or arsenic, or impacts of saltwater intrusion.

The general perception amongst the users of RWH technologies surveyed was that rainwater is of high quality and should be reserved for hygienic purposes, specifically for drinking and cooking. However, not all respondents held this view. Some indicated that there may be dangerous contaminants either on a roof's survey or in the atmosphere that could contain the water. Such negative perceptions are likely to be more predominant in areas close to urban and industrial locations or which had never collected or used rainwater. Three national surveys have been completed that provides the estimated percentage of consumers that use RWH by ecological region.

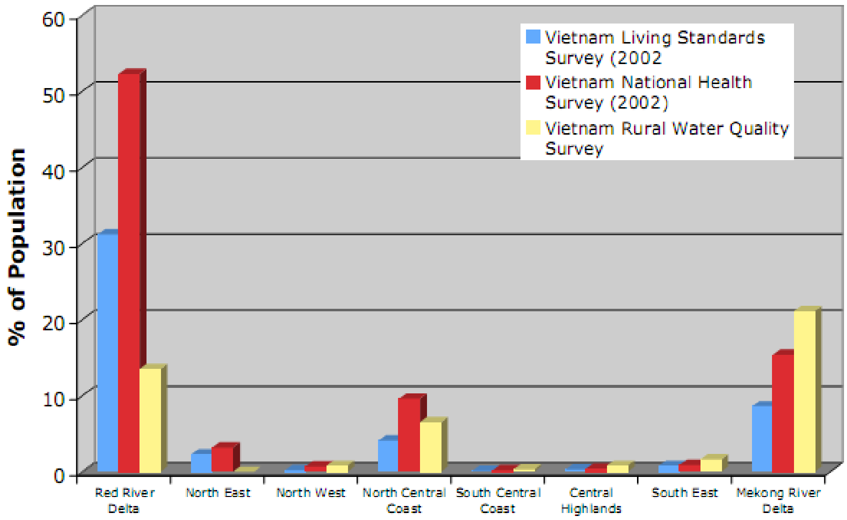


Figure 8. Percentage of household using RWH by ecological region based on Government survey: Vietnam living standards survey (2002), Vietnam national health survey (2002) and Vietnam rural water quality survey (2006)

The Rural Water Supply & Sanitation Sector Review (Soussan et al., 2004) provided a summary of the 2002 Vietnam Household Living Standards Survey results for rainwater harvesting. Data from the provinces where more than three percent of the population uses rainwater is summarized here. Nowadays, use of RWH system is reducing because the government focuses to use ground or surface water for water treatment and distribution system at rural area.

2.6. Summary

Currently, Vietnam government does not have any policy to promote rainwater harvesting and they focus to build the small centralized water supply system for rural area using ground or surface water. However, RWH has been continuously used as the traditional water supply system at Vietnam rural areas since ancient times. Therefore, in situ and ex situ RWH interventions should be employed based on existing indigenous knowledge available within a society.

Nowadays, many countries in the world have laws and policies that collect rainwater as an environmental-friendly and sustainable solution, which increases the groundwater quantity for the future. In order to promote RWH widely in Vietnam, the useful solutions adjusted to Vietnamese local condition should be studied base on the RWH demonstration system, research document to evidential the benefit of the RWH thought the economic, social and technical aspect. Based on these result, it can not only be a suggestion to the government to make the strategy, policy or RWH law, but also an incentive to individual sector to implement RWH system.

CHAPTER 3: IDENTIFY THE BARRIER FOR RAINWATER HARVESTING IN VIETNAM

3.1. Background

Drinking water crisis is one of the most significant problems in developing countries. In Vietnam, surface water is polluted by the consequences of rapid growth of the population and the rapid pace of industrialization. In addition, arsenic contamination of groundwater is a huge threat to public health in Vietnam. Furthermore, piped water supplies reach only about 60% of urban households and 10% of rural households (World Health Organization, 2015). Bottled water is a preferred option, but it is expensive and the bottled water does not guarantee the volume of water for human consumption.

Installing Rainwater harvesting (RWH) systems can be a potential alternative water source to these areas suffering from water shortage. An Installed RWHS collects rainwater from the roof and stores it in an appropriate tank for use as drinking water. The use of an RWHS, along with proper treatment and monitoring, can supply drinking water with good quality and quantity (World Health Organization, 2004). Considering the annual average rainfall in Vietnam which is normally around 1680 mm/year from May to September, the installation of RWHSs can contribute to a fundamental solution to the drinking water problem.

In this chapter, we conducted a survey to find out how the local residents, living in the areas where there is no public tap water supply, feel about drinking rainwater. Also, the stakeholders in the areas where RWH system demonstration project was held were interviewed to assess the degree of their satisfaction and to measure their general perception of rainwater harvesting. Through the survey, barriers of RWH were identified. And strategies to overcome a number of barriers and to spread RWH in Vietnam were explored.

3.2. Materials and methods

3.2.1 Study area

In this study, residents ‘awareness survey was conducted in the areas where rainwater utilization facilities are needed. Henceforth, we organized a demonstration project called ʹRainwater for Drinking ‘and carried out a satisfaction survey. The targeted areas are KimBang and Cuhke located in Hanoi, Vietnam.

KimBang is located 40 km from main street area in Hanoi. Here, arsenic levels in the groundwater of Kim Bang is severe and the water distribution systems does not extensively operate. In 2015, thereby, the ʹRainwater for drinking demonstration project’ was performed. Before the project started, KimBang middle school, which was the targeted area, purchased bottled water for students so that they could consume the bottled water at any time during the school day and supplied groundwater for daily activities.

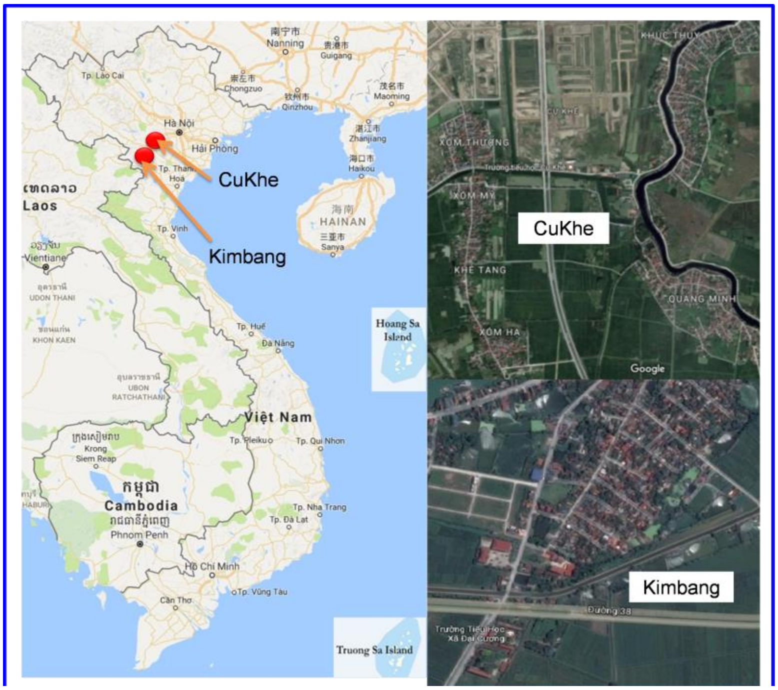


Figure 9: Rainwater survey site

After installing RWH system, the cost of bottled water purchased by the school could be saved to be used for tuition fees which account for 13% of the total tuition. In July 2015, two 8 m3 of stainless steel tanks were connected, therefore a total of 16 m3 of rainwater facilities was installed. Household water filters were used for rainwater treatment, and the quality of the water supplied to residents met standards for drinking water in Vietnam.

Cu Khe is located approximately 15 km from the main street area in Hanoi. The area is situated along the river; however, the untreated sewage discharge from Hanoi is the main source of water pollution. Not only that, groundwater is contaminated with arsenic, making it difficult to supply clean drinking water. In July 2014, a 12m3 and 10m3 of rainwater utilization facilities was installed in kindergarten and elementary schools, respectively, through the project implemented. The two schools collected the stored rainwater in 20L water bottles and distributed them to all students in every classroom. The rainwater quality test results fulfilled all the water quality standards of drinking water in Vietnam and the results showed that water collected in rainwater tanks is suitable for drinking.

3.2.2 Survey

To get a general view of water usage, a survey was conducted on 350 residents of KimBang and Cukhe districts where safely managed drinking water services are in poor condition. The survey was carried out for 5 years, from 2010 to 2014. Furthermore, in order to figure out the level of citizens' overall satisfaction with the rainwater supply system, similarly, the other survey was conducted on 200 students from KimBang middle school and elementary school for 3 years from 2014 to 2016. The survey respondents were students, parents, and teachers.

The survey was performed 1:1 so that the researcher in charge of the research survey can accurately measure and understand the level of the respondents' satisfaction based on the questionnaire. The response time of the survey was about 20 minutes.

Table 1. Rainwater harvesting survey process

	Year	Respondents			Survey methods
		Number	Site	Description	
General survey for water use	2010	100	Cukhe	People have experienced to use rainwater due to unavailable tap-water	Personal Interview with paper survey
	2011	50	Cukhe		
	2012	50	KimBang		
	2013	50	KimBang		
	2014	100	Cukhe		
Total	5yr	350			
	Year	Respondents			Survey methods
		Number	Site	description	
Satisfaction survey for rainwater use	2014	50	Cukhe	Student, teacher, student parent, and communities related with RWH system installed at school	Personal Interview with paper survey
	2015	100	KimBang and Cukhe		
	2016	50	KimBang		
Total	3 yr	200			

There are two types of survey questionnaire. One of them was designed before RWH system installed and the other was completed after installing the system.

Table 2 Lists the questions before installing RWH system and other questions after installation are listed in table 3.

1	Basic question
1.1	How many members in your family?
1.2	How about member old in your family?
1.3	Where your income sources come from?
1.4	How much money your family earns per month?
1.5	How about education level in your family?
2	Water supply status
2.1	What kind of the water do you use for domestic? a.Tap water; b. shallow well; c. bottled water; d. tube well; e. Rainwater; f. surface water
2.2	What kind of the treatment method do you use? a. Boiling; b. drink directly c. Sand filter; d. filtration machine
2.3	Why do you select this water source to use? a. Cheap price; b. near house; c. clean and safety; d. everybody using
2.4	What kind of the water source do you want to replace the current water source? a.Tap water; b. shallow well; c. bottled water; d. tube well; e. Rainwater; f. surface water
2.5	Why do you want to replace? a. Cheap price; b. near house; c. clean and safety; d. everybody using
2.6	What kind of the water source do you use for drinking and cooking? a.Tap water; b. shallow well; c. bottled water; d. tube well; e. Rainwater; f. surface water
2.7	Do you attend any train course about clean water treatment?
2.8	Evaluate water source
2.8.1	How do you think about tube well water? a. Very dirty; b. dirty; c, normal; d. clean; e. very clean
2.8.2	How do you think about rainwater? Very dirty; b. dirty; c, normal; d. clean; e. very clean
2.8.3	How do you think about bottled water? Very dirty; b. dirty; c, normal; d. clean; e. very clean
2.8.4	How do you think about tab water? Very dirty; b. dirty; c, normal; d. clean; e. very clean How do you think about tap water after filtration? Very dirty; b. dirty; c, normal; d. clean; e. very clean

3	Rainwater understanding
3.1	Do you install rainwater harvesting?
3.2	Which is purpose you want to use rainwater?
	a. Drinking and cooking ; b showing; c. washing; d. toilet
3.3.	How many times do you clean rainwater tank?
	a. 2-3 times/year; b. over 4 times/year; c. 1time/year; d. 2years/time e. over 3 year/time
3.4	Do you collect rainwater at the first 10 minute?
3.5	Do you install first flush?
3.6	How often do you clean the rooftop?
3.7	How do you use rainwater for drinking?
	a. Boiling; b. filtration machine; c. drink directly;
	b. d. don't know
3.8	How to install rainwater harvesting?
	a.design guideline; b. Experience; c. Worker; d. don't know

Table 3. Questionnaires after installing RWH system

1	Basic question
1.1	How many members in your family?
1.2	How about member old in your family?
1.3	Where your income sources come from?
1.4	How much money your family earns per month?
1.5	How about education level in your family?
2	Water supply status
2.1	What kind of the water do you use for domestic?
	a.Tap water; b. shallow well; c. bottled water; d. tube well; e. Rainwater; f. surface water
2.2	What kind of the treatment method do you use?
	b. Boiling; b. drink directly c. Sand filter; d. filtration machine
2.3	Why do you select this water source to use?
	b. Cheap price; b. near house; c. clean and safety; d. everybody using
2.4	What kind of the water source do you want to replace the current water source?
	a.Tap water; b. shallow well; c. bottled water; d. tube well; e. Rainwater; f. surface water
2.5	Why do you want to replace?
	b. Cheap price; b. near house; c. clean and safety; d. everybody using

2.6	What kind of the water source do you use for drinking and cooking? a.Tap water; b. shallow well; c. bottled water; d. tube well; e. Rainwater; f. surface water	
2.7	Do you attend any train course about clean water treatment?	
2.8	Evaluate water source	
2.8.1	How do you think about tube well water? b. Very dirty; b. dirty; c, normal; d. clean; e. very clean	
2.8.2	How do you think about rainwater? Very dirty; b. dirty; c, normal; d. clean; e. very clean	
2.8.3	How do you think about bottled water? Very dirty; b. dirty; c, normal; d. clean; e. very clean	
2.8.4	How do you think about tab water? Very dirty; b. dirty; c, normal; d. clean; e. very clean How do you think about tap water after filtration? Very dirty; b. dirty; c, normal; d. clean; e. very clean	
3	Rainwater understanding	
3.1	Do you install rainwater harvesting?	
3.2	Which is purpose you want to use rainwater? b. Drinking and cooking ; b showing; c. washing; d. toilet	
3.3.	How many times do you clean rainwater tank? b. 2-3 times/year; b. over 4 times/year; c. 1time/year; d. 2years/time e. over 3 year/time	
3.4	Do you collect rainwater at the first 10 minute?	
3.5	Do you install first flush?	
3.6	How often do you clean the rooftop?	
3.7	How do you use rainwater for drinking? c. Boiling; b. filtration machine; c. drink directly; d. d. don't know	
3.8	How to install rainwater harvesting? a. design guideline; b. Experience; c. Worker; b. d. don't know	
4	People's attitude for RWH system in school	
4.1	Do you drink rainwater in school?	
4.2	How satisfied do you think for rainwater quality after filter? a. Very un-satisfied; b. un-satisfied; c. normal; d. satisfied; e. Strongly satisfied	
4.3	How satisfied do you think for rainwater quantity? a. Very un-satisfied; b. un-satisfied; c. normal; d. satisfied; e. Strongly satisfied	
4.4	Are you satisfaction with operation of the system?	

a. Very un-satisfied; b. un-satisfied; c. normal; d. satisfied;
e. Strongly satisfied

4.5 RWH system is a sustainable solution to solve the water crisis situation in Vietnam. How do you think about it?

a. Very un-satisfied; b. un-satisfied; c. normal; d. satisfied;
e. Strongly satisfied

4.6 RWH system is still good? How do you think?

a. Very un-satisfied; b. un-satisfied; c. normal; d. satisfied;
e. Strongly satisfied

4.7 How do you expectation if RWH is promoted spread?

a. Don not want; b. not expectation; c. consider;
d. expectation; e. strongly expectation.

4.8 How do you think who should be support to install RWH?

a. Government; b. private sector or research center;
c. Local people.

3.2.3 Statistical analysis

The analysis of the survey results was completed using SPSS23.0 statistical package. Likewise, the reliability analysis and validation of the surveys was performed.

3.3. Results and discussion

3.3.1 Survey analysis

3.3.1.1 Statistical characteristic:

The strongest and arguably most important trend throughout the interview and survey was the opinion, expressed by all villagers.

Table 4. Demographic result at KimBang and Cukhe

Age of the respondents	18-30	30-40	40-50	50-60	> 60	Total
Ratio	7%	8%	19%	42%	24%	100%
Number	25	27	68	146	84	350
Education level	Elementary	Middle	High	College	University	
Ratio	5%	61%	21%	6%	6%	100%
Number	19	214	73	22	22	350
Number of family member	1- 2	3-4	5	6	> 6	
Ratio	14%	47%	18%	15%	6%	100%
Number	49	165	64	52	20	350
Income source	Farmer	Breeding farm	Business	Officer	Company staff	
Ratio	74%	10%	1%	6%	9%	100%
Number	260	36	3	21	30	350

Table 5. Demographic result at KimBang & Cukhe after RWH installed

Age of the respondents	18-30	30-40	40-50	50-60	> 60	Total
Ratio	8%	38%	33%	13%	7%	100%
Number	16	76	66	27	15	200
Education level	Elementary	Middle	High	College	University	
Ratio	12%	45%	19%	14%	10%	100%
Number	19	214	73	22	22	2000
Number of family member	1- 2	3-4	5	6	> 6	
Ratio	2%	49%	52%	14%	10%	100%
Number	4	97	52	29	18	200

Income source	Farmer	Breeding farm	Business	Officer	Company staff	
Ratio	40%	15%	22%		13%	100%
Number	260	36	3		30	200

The target areas are not equipped with the appropriate water supply system, so 67% of the area use groundwater, 22% use rainwater, and 9% use river water as domestic water. Moreover, the target areas rarely used tap water and bottled water (Figure. 10). About 70% of the respondents indicated that they did not have enough knowledge to decide on which water resources they should use, so they practiced traditional methods or followed the way in which the community obtain water (Figure. 11).

Up to 95% of the respondents drink boiled rainwater. Hence, the local residents normally collect rainwater for drinking and groundwater is the source for their daily living. Based on the survey result, the result indicates that people in the targeted areas are familiar with capturing and collecting rainwater to use.

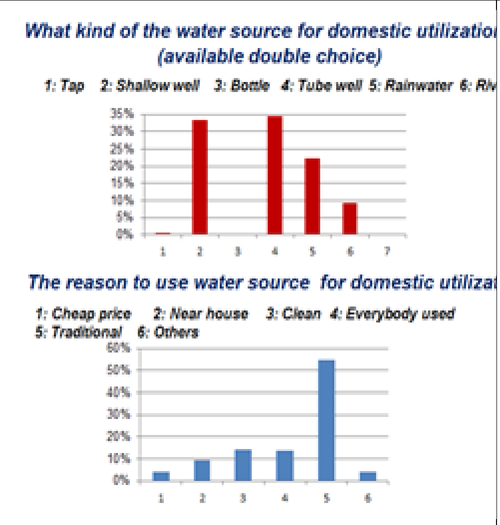


Figure10. Present water resource and reason to choose their water resource for domestic use

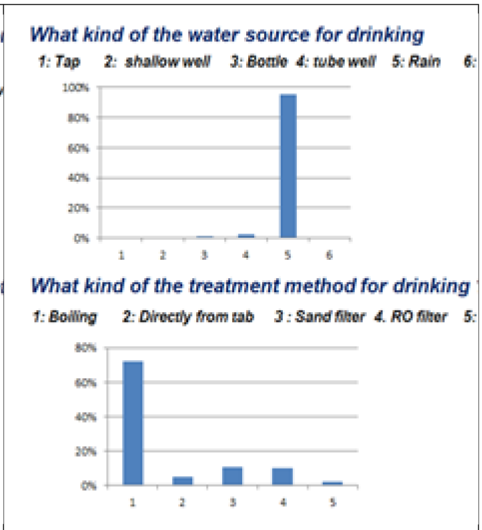


Figure11. Present water resource for drinking and treatment methods

94% of the respondents anticipated on receiving tap water due to the water quality. However, it requires a lot of time and money to get water supply infrastructure within the area. To deal with this difficulty, an efficient solution is to promote rainwater harvesting system which helps the local residents to access to safe drinking water without time and high cost consuming.

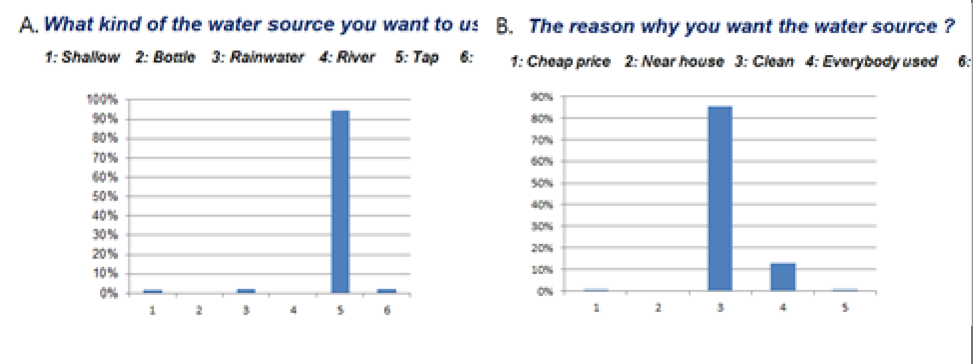


Figure. 12. Preferred water resources and reason

3.3.1.2. Satisfaction for individual RWH system

As shown in Figure 13, a large number of respondents are using rainwater as drinking water in their households. According to the survey results, the assessment of the satisfaction levels of the residents with drinking rainwater was individually compared with water quality, quantity and accessibility. About 20% of the respondents were not satisfied with the water quality, while 30% were satisfied, and the rest of 48% did not show 'likes and dislikes on rainwater quality' clearly (Figure. 13A).

In terms of quantity, 7% of the respondents were unsatisfied, 61% were satisfied, and 32% did not show 'likes and dislikes on rainwater quantity' (Figure. 13B). Furthermore, about 60% were satisfied with accessibility, 40% were normal, and no one wasn't satisfied with it. As a result, the survey reveals that the residents are mostly satisfied with its accessibility and quantity while the survey evaluation of the rainwater quality shows somewhat high unsatisfactory levels.

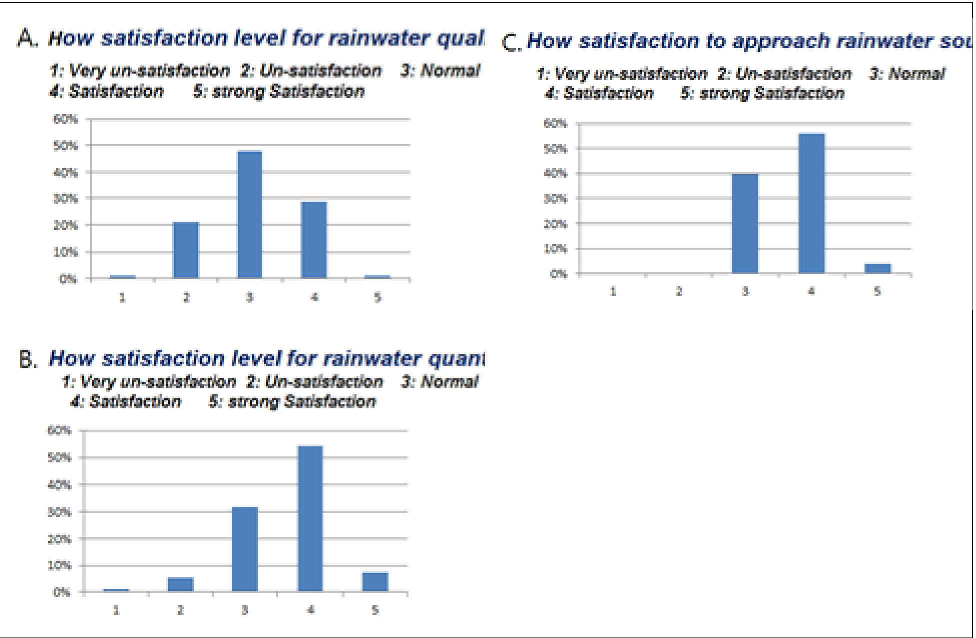


Figure 13. Satisfaction for individual RWH system

RWH systems that were installed in each local house were installed by workers without any guideline, who don't have any personal experience. Furthermore, education and training programs related to RWH system construction did not offer to local workers. A practical guideline or criteria to achieve the standards of management, tank storage, and cleaning is not integrated in each household. And because of the undefined criteria, the water quality results of each RWH system from local households are determined depending on the tank's management and maintenance method. All those factors considered, the main reason for dissatisfaction with drinking rainwater and rainwater quality by the respondents is primarily expected.

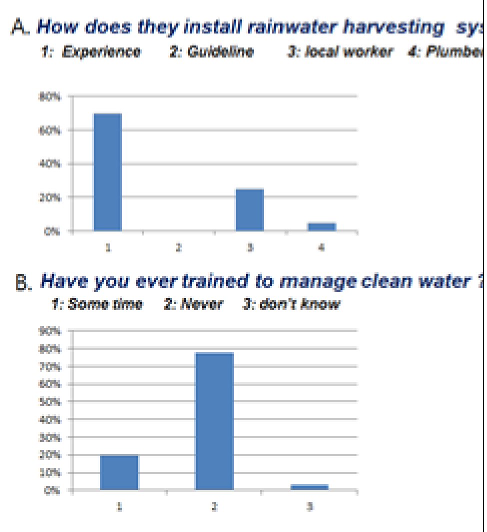


Figure 14. Installation of individual RWH system

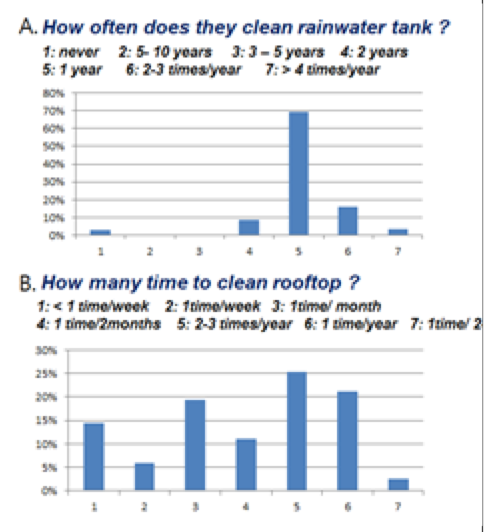


Figure 15. Maintenance of individual RWH system

3.3.1.3 Satisfaction for RWH system installed in school

As a part of "Rainwater for Drinking" project, the RWH system had been installed and have been operating in three province (four sites), KimBang and Cukhe kindergartens, elementary school, and middle school. The local people in these sites are exposed to unsafe drinking water such as groundwater. Here, since the rainwater harvesting facilities had been widely used in the places, the person in charge of the project conducted a facility's satisfaction survey to effectively measure it based on students, parents, teachers and local residents. 90% of the respondents showed high level of satisfaction in terms of odor, water quality, and quantity. In particular, compared to 20% of the respondents 'dissatisfaction with water quality in the individual facilities, the respondents ‘dissatisfaction for RHW system installed in the institutions is reduced to 6%. Hence, well designed and managed RWH system by experts is expected to increase the users’ satisfactory in using rainwater as drinking water.

3.3.2 Barriers on rainwater use for drinking

Based on the results of the survey and the experience of installing and operating the rainwater harvesting system at the school, the characteristic barriers to using rainwater as drinking water were identified within each perspective such as technical, economic and social.

3.3.2.1 Technical barrier

The first main issue related to rainwater harvesting system application occurs with managing the system. If there is no system administrator who is responsible for managing, overseeing and maintaining the system, the maintenance work associated with facility management cannot be ensured. It cannot be identified when there is a problem with the internal structure as well as the exterior of the visible system, which may be a limitation in providing clean and stable rainwater quality.

The second problem is the lack of guidelines for the design and maintenance of rainwater harvesting system. As shown in the survey results (Figure. 7 and Figure. 8), the level of user’s satisfaction with the system can be changeable depending on how the system is designed and managed. In addition, when applying community based RWH system such as school, there is no guideline, so it can be reluctant to adopt it actively. Therefore, in order to provide stable and clean drinking water, specific requirements processing for system management should be tailored first and the guideline based on them are necessary to be set.

The third problem is the technician shortage and the absence of training program sources and materials which offer the system installation guidelines. Systems are relatively simple in design and construction and are generally installed by ordinary individuals or non-trained installers who are not professional engineers. They do not fully understand the system, so they cannot guarantee that the system was completely and accurately installed. By examining the affecting factors, the main limitation of these factors are defined because of the absence of technicians.

3.3.2.2 Economical barriers

When an individual intends to use a rainwater harvesting system, the individual must bear installation full costs and maintenance of the system. Local people being affected by the problem of poverty and low income in rural areas where the public water systems are not there to reach the people feel the burden of constructing rainwater harvesting system by themselves. In addition, installation and maintenance costs are also incurred in the community-based RWH system. Needless to say, the Vietnam government has the responsibility to ensure accessibility to clean and safe drinking water. For that reason, government-level support programs should be prepared to apply the rainwater harvesting system. And technical measures are needed to reduce maintenance costs such as the development of appropriate filters.

3.3.2.3 Social barriers

Since Vietnamese have traditionally used rainwater, they are familiar with using rainwater as a drinking resource. However, the introduction of the public water systems for drinking is highly preferred by the people because the reliability of the water systems is higher for water quality. Therefore, it is necessary to recognize the reality that it is difficult to introduce the waterworks system quickly and educate residents about the necessity of introduction of rainwater harvesting system. As a result, it is needed to create examples of successful rainwater utilization facilities and actively promote them in order to ensure that rainwater supplies can provide clean drinking water.

CHAPTER 4: DEMO PROJECT TO OVERCOME BARRIERS

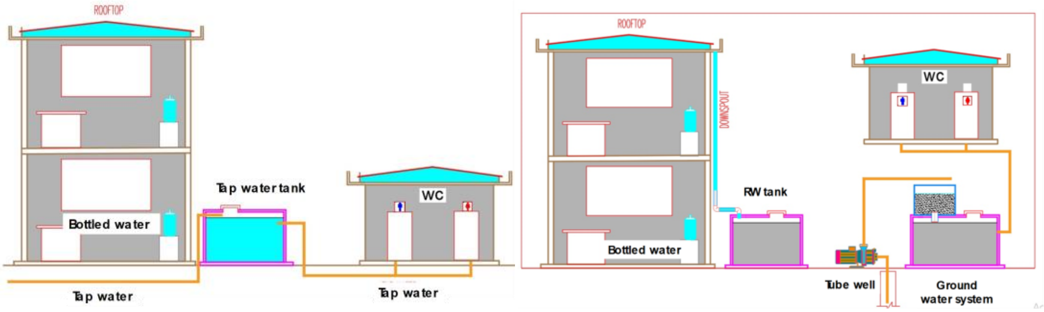
4.1. Introduction

A safe and affordable drinking water supply, which is one of the targets in Sustainable Development Goals 6 (SDG6), is essential for life. However, millions of people around the world still do not have access to this necessity. In rural areas in particular, drinking water problems are more common due to the government's inability to establish centralized water supplies, and the lack of a low cost and sustainable water treatment approach.

Community-based rainwater harvesting (CB-RWH) is recommended as a promising solution to the drinking-water challenges in developing countries (Kim et al., 2016). RWH has been considered to be a sustainable method to obtain good-quality drinking water at a low cost and with little energy expenditure (Nguyen et al., 2013, Ahmed et al., 2011, Helmreich and Horn, 2009). CB-RWH is considered to be adequate for most rural areas, as centralized water supply systems are often unaffordable given the remote locations and lack of financial resources (Peter-Varbanets et al., 2009). Therefore, installation demo RWH for community-based is a good way to find the solution to overcome barriers, which are obstructing the rainwater utilization.

4.1.1. Water supply and drinking water for community-based at Vietnam rural areas

Normally, the community-based at Vietnam rural areas is supplied clean and drinking water follows two options depend on the region condition. Option 1, which have local water treatment plant (LWTP), tap water is supplied to flush toilet or handwashing, sometime it is used for cooking and drinking such as People's Committee campus, health care center. But normally, drinking water for community-based is supplied by a local bottled water company (Ficgure 16a). Option 2, which does not have (LWTP), the tube well will be constructed to exploit groundwater, treated and supply for toilet flushing. In this case, drinking water is provided by local bottle water or rainwater, especially at kindergarten, rainwater is collected for cooking and drinking (Ficgure 16b).



(a) (b)

Fig. 16. Water supply and drinking water for community-based
(a) Water supply system by tap water
(b) Water supply system without tap water

However, local bottled water quality does not strictly manage yet leading to a lot of bottled water brands still exist the toxics in drinking water such as lead, arsenic, nitrate compounds or microorganism. Most of the local bottled water companies exploit groundwater to produce drinking water but the treatment process does not guarantee the hygienic condition like the bottle disinfection process or the treatment technology is not suitable to remove the toxic in groundwater, etc… (figure 17). In addition, exploitation groundwater is not a sustainable solution and it also affects environmental by wastewater, which is drained during the drinking water production process. Therefore, reduction of bottled water for drinking at community-based should be considered and change by the sustainable solutions. At some community-based such as kindergarten, health care center, rainwater harvesting is installed to reduce the bottled water utilization but this system is simple and lacks the treatment technology.

Fig.17. Local bottled water manufacture

4.1.2. Exiting rainwater harvesting community- based

Currently, most of the rainwater system in the community-based is the rainwater drainage system and it was designed in according the Vietnam Plumbing code, Hanoi 2000. Rainwater collecting system includes the rooftop, gutter, piping system and ditch (figure 18). The typical building roof has two types, one is the steel roof frame and other is flat concrete as shown in Figure 20. The steel roof frame of the rooftop is very popular.

Fig.18. Rainwater collecting system at community-based

(a) (b)

Fig.19. Rooftop style for community-based
(a) Steel frame rooftop; (b) Flat concrete rooftop

The gutter system was built on the concrete roof and along the roof perimeter with 0,2 – 0,5 m width and height. The downspout is installed along to the gutter and it is designed to depend on the rooftop area and rain intensity at the local site (Figure 20). Rainwater is collected from rooftop to the gutter and through downspout system then flow out to the ditch before diving out to the drainage network of the village or region. This is the typical rainwater collecting system at community-based but it is not an application for all building, especially for the lacking clean water areas. At this area, the rainwater harvesting system is installed to collect rain water for cooking such as kindergarten, health care center or primary school (Figure 21).

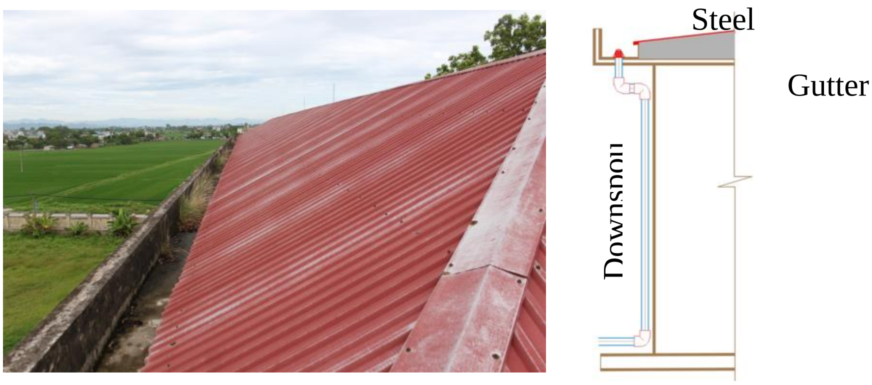


Fig. 20. Gutter and piping system

4.1.3. The barrier for rainwater harvesting at community-based

The barriers to implementing RWH at community-based are also important issue including the technical, economic and social aspect. As well as the villager, almost office lack the acknowledge to understand the role of the rainwater and feasibility of the rainwater harvesting system. The main barriers have been found the base on investigating, survey and gathered from literature reviews (chapter 3) and it was compiled in Table 6.

Fig.21. Rainwater harvesting system at kindergarten

Table 6. Main barriers to implement rainwater harvesting in Vietnam

Perspective	**Main barriers**
Technical	Lack design RWH system guidance and O&M manual Lack the professional plumber Doesn't know treatment technologies Low O &M skill
Economic	Huge budget to install RWH system It is not profitable system
Social	Lack knowledge water source and rainwater harvesting Lack communicate No evident to show the feasibility of rainwater harvesting system Doesn't have liability to manage rainwater system

To overcome the barrier to implement rainwater harvesting system for drinking at community-based, a demo project at local area is a solution to demonstrate the feasibility of the RWH to the community, which are facing the shortage and contaminated water sources. The project and the approaches applied for ensuring technical, economic and to overcome barriers are explained further in the following section.

4.2 Cukhe Kindergarten and elementary school (period of Aug 2014-Sept)

4.2.1. Site information

The Cukhe is the rural areas in the Red River Delta, Vietnam (Fig 22). It is located 15 km southwest of Hanoi. Despite the adjacency to Hanoi, Cukhe does not benefit from a centralized water supply. The Nhue River, which flows alongside these side, is severely polluted by wastewater from Hanoi (Do et al. 2014). In addition, elevated arsenic levels have been found in groundwater of the Red River Delta (Berg et al. 2001).). It was found that groundwater in the Hong River Delta area is contaminated by Arsenic (Fig 23) and the tube wells of Cukhe have the warning “As > 0.05 mg/L,” indicating that arsenic concentrations exceed the Vietnamese drinking water standard of 0.01 mg/L (QCVN 01-1:2018/BYT). The average annual rainfall is 1680 (Lang weather station) mm and over 90% of rainfall occurs from April to October (WMO

2012). During the dry season, from November to March, average monthly rainfall is less than 50 mm.

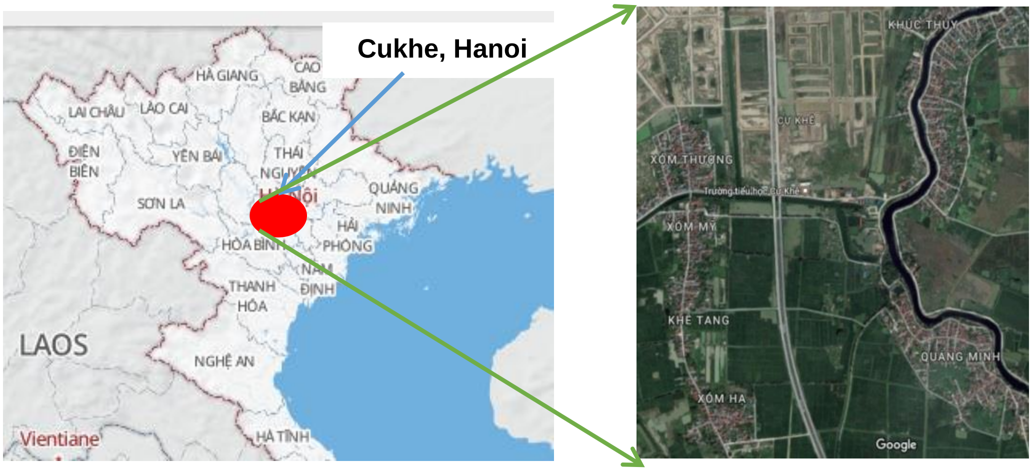


Fig.22. Location of Cukhe Kindergarten

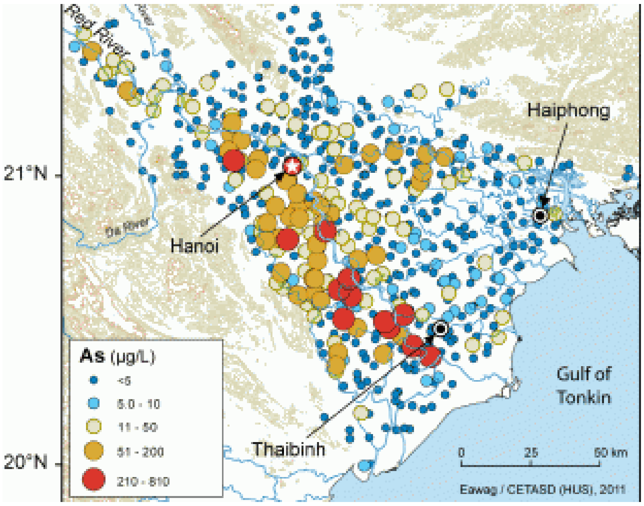


Fig.23 Arsenic contamination map at Hong River Delta area

(Lenny H. E. Winkel 2010)

4.2.2. Information of demo system

There is an urgent need for the kindergarten and elementary school to supply clean water for cooking and drinking for the children. SNU and NUCE decided to build a rainwater harvesting system from the donation of Lotte Department Company as their CSR activity. The design and construction of 12 m^3 rainwater system was made during July-August 2014.

4.2.2.1 Cukhe Kindergarten D1:

The number of the children and teachers of this kindergarten are 450 and 30, respectively. The water supply status of this kindergarten is diverse. Rainwater collected from existing rainwater harvesting system is used for cooking, groundwater is used for toilet flushing, purchased bottled water is used for drinking. The required cooking water is 5m^3/month. In the school, the required quantity of drinking water is 0.3 Liter/day/person (Fig.24)

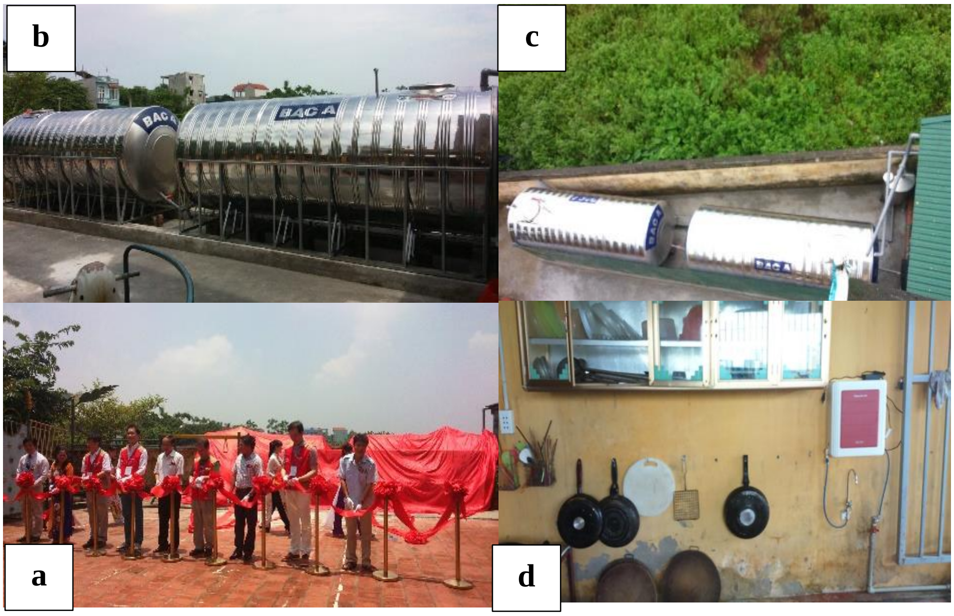


Fig.24. Photos of Cuhke Kindergarten rainwater harvesting system

a) Ceremony b) Side view c) Top view d) Treatment

4.2.2.2 Cukhe elementary school D2

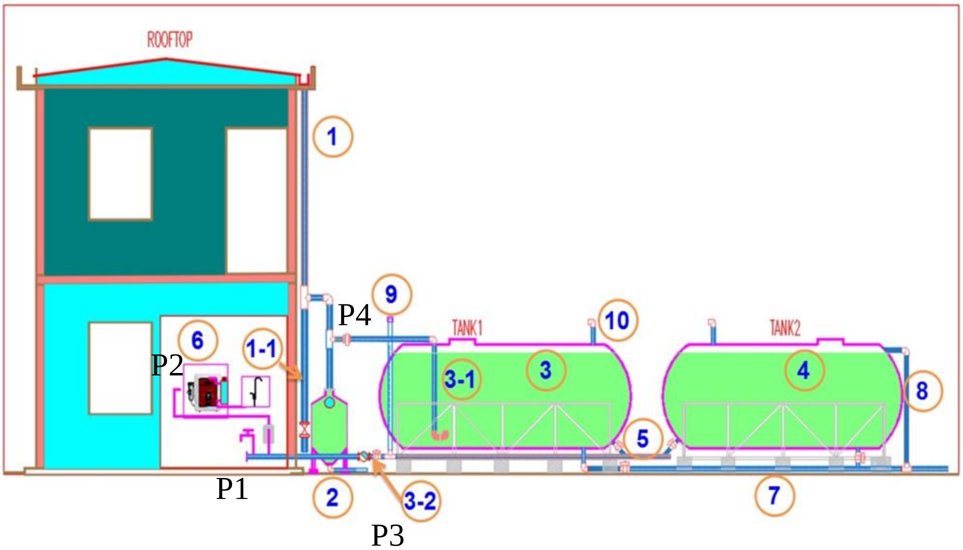
The number of the student and teachers of this elementary school are 320 and 25, respectively. The water supply status of elementary school is similar with kindergarten. Rainwater collected from existing rainwater harvesting system to make drinking water for teacher after boiling, groundwater is used for toilet flushing, purchased bottled water is used for drinking. The required cooking water is $3m^3$/month (Fig.25)

Fig.25. Photos of Cuhke elementary school rainwater harvesting system

a) Front view b) Over view c) Treatment system

4.2.3. Rainwater Harvesting system information

The schematic diagram of the rainwater harvesting system is as in Fig 26 for both of the Cukhe schools The rainwater is collected from the rooftop (area: 450 m^2 and 300 m^2 for kindergarten and elementary school), go through downpipe equipped with first flush diverter. There is first flush tank with the capacity of 200 liters. The water fills the tank 1 (6ooo liter) using a calm inlet and conveying to the tank 2 by piping syste. Both tanks are equipped with ventilation and drain pipe. The stored water is delivered to treatment system before sent to the classroom water bottle. The treatment system consists of micro filter and UV filter. The water usage is monitored by water flow meter. The water quality is sampled for water quality testing periodically (every 1 month) which is sent to Institute of Environmental Science and Engineering agency, National University of Civil Engineering.



Fi.g26. The schematic diagram of Cukhe Kindergarten rainwater harvesting system

1) Downspout; 1-1) Diverter pipe. 2) First-flush 3) Sediment ation tank, 3-1) Calm-inlet

3-2) Water meter ; 4) Storage tank 5) Connection pipe 6) Filtration system; 7) Drain
8) Over flow ; 9) Water level.
P1: Sample point from storage tank P2: Sample point after treatment
P3 : Water consumption checking P4: Water level

4.2.4. Maintenance and Operation

Treated rainwater is supplied to each classroom in a 20 liter plastic bottle by the school manager from 09:00-10:00. Student in charge come and receive the 20 liter bottle to their classroom.

4.2.4.1. *Water quality monitoring*

Cukhe kindergarten:

The water quantity is monitored from the flow meter and monthly data are summarized as in Fig.27. The drinking water for the student in the school is 0.3 L follow the Vietnam standard, but normally they drink around 0.35 L/person/day. After the RWH system installed, the average supply of drinking water per each student is 0.4~0.45 L/day/person which is higher than the official requirement.

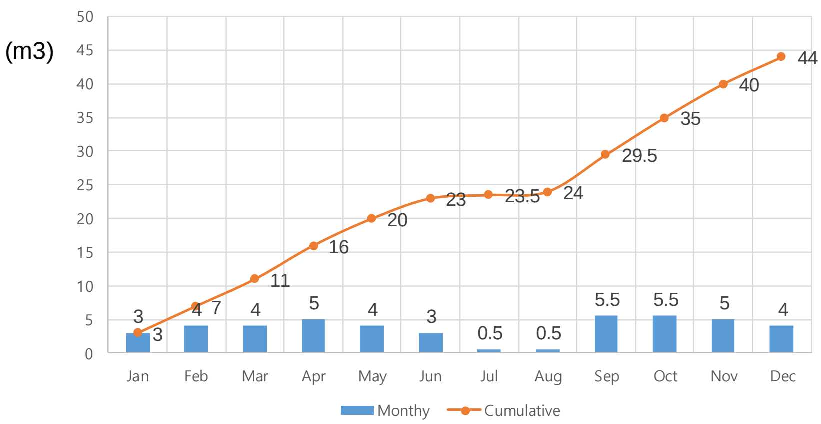


Fig. 27. Monthly water usage and cumulative water consumption

Cukhe elementary school:

The water quantity is monitored from the flow meter and monthly data are summarized as in Fig.28. The drinking water for the student in the school is 0.3 L follow the Vietnam standard, but normally they drink around 0.4-0.5 L/person/day. After the RWH system installed, the average supply of drinking water per each student is 0.5~0.6 L/day/person which is higher than the official requirement.

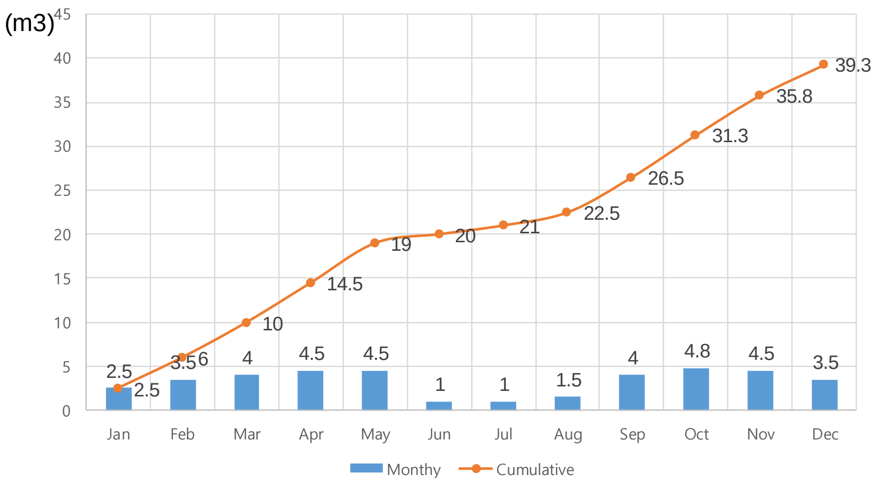


Fig. 28. Monthly water usage and cumulative water consumption at Cukhe elementary school

4.2.4.2.Water quality monitoring

The water quality monitoring is done for 24 items. The water quality was sampled follow two periods, the first from February 2015 – January 2016 and second from September 2018 – May 2019. From 2017 until 2018, the school will check by themselves according to the requirement from Government, normally 2 times/year for water quality checking. The result is summarized as in Table 7,8 for Cukhe Kindergarten(D1) and Table 9,10 for Cukhe elementary school (D2).

Table 7 : Water quality at storage tank P1 of Kindergarten

N0	**Parameters**	**Unit**	*Cu khe Kindergarten P1*											
			10-Aug	10-Sep	10-Oct	10-Nov	10-Dec	10-Jan	10-Feb	10-Mar	10-Apr	10-May	10-Jun	10-Jul
1	*pH*	-	6.9	7.2	6.8	6.4	7.3	7.8	7.5	7.4	7.2	7.7	7.6	7.5
2	*TDS*	*mg/L*	46.5	44.2	44.2	44.2	44.2	44.2	44.2	44.2	44.2	44.2	44.2	44.2
3	Odor	-	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing
4	Turbidity	*NTU*	**2**	**1.58**	**3.2**	**4.05**	**3.55**	**2.25**	**3.16**	**4.5**	**4.75**	**2.68**	**3.21**	**3.8**
5	PO_4^{3-}_P	*mg/L*	0.06	0.08	0.05	0.1	0.086	0.073	0.045	0.065	0.058	0.055	0.092	0.088
6	*TDS*	*µS/cm*	7.59	8.9	7.8	8.5	9.9	10.5	8.6	8.3	9.7	10.4	9.2	8.3
7	NO_2^-_N	*mg/L*	0.22	0.16	0.18	0.24	0.28	0.15	0.21	0.26	0.18	0.15	0.22	0.17
8	NO_3^-_N	*mg/L*	0.17	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
9	NH_4^+_N	*mg/L*	0.03	0.05	0.045	0.055	0.074	0.032	0.026	0.044	0.067	0.032	0.045	0.065
10	*Hardness*	$mgCaCO_3/L$	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
11	*As*	*mg/L*	<0,001	<0,001	<0,001	<0,001	<0,001	<0,001	<0,001	<0,001	<0,001	<0,001	<0,001	<0,001
12	*Fe*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
13	*Cd*		<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
14	*Ni*		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
15	*Mn*		<0.001	<0,0002	<0,0002	<0,0002	<0,0002	<0,0002	<0,0002	<0,0002	<0,0002	<0,0002	<0,0002	<0,0002
16	*Hg*		<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
17	*Se*		<0.001	0,001	0,001	0,001	0,001	0,001	0,001	0,001	0,001	0,001	0,001	0,001
18	*Pb*		<01001	<0,001	<0,001	<0,001	<0,001	<0,001	<0,001	<0,001	<0,001	<0,001	<0,001	<0,001
19	*Zn*		0.432	0.419	0.234	0.411	0.346	0.237	0.356	0.322	0.256	0.432	0.345	0.401
20	SO_4^{2-}		<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
21	Coliform	*MPN/100mL*	**150**	**180**	**160**	**220**	**190**	**240**	**120**	**350**	**160**	**180**	**215**	**160**
22	E.coli	*MPN/100mL*	**250**	**300**	**180**	**220**	**160**	**210**	**245**	**168**	**340**	**280**	**160**	**180**
23	Pecmaganat	mg/l	1.55	1.8	1.43	2	2.15	1.6	1.65	1.84	1.35	1.64	1.55	1.6
24	Cl^-	mg/l	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

Table 8 : Water quality after treatment system P2 of Kindergarten

N0	**Parameters**	**Unit**	*Cu khe Kindergarten P2*											
			10-Aug	10-Sep	10-Oct	10-Nov	10-Dec	10-Jan	10-Feb	10-Mar	10-Apr	10-May	10-Jun	10-Jul
1	*pH*	-	6.9	7.2	6.8	6.4	7.3	7.8	7.5	7.4	7.2	7.7	7.6	7.5
2	*TDS*	*mg/L*	46.5	44.2	44.2	44.2	44.2	44.2	44.2	44.2	44.2	44.2	44.2	44.2
3	Odor	-	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing
4	Turbidity	*NTU*	**0.8**	**1.15**	**1.35**	**0.75**	**1.34**	**1.25**	**1.34**	**1.21**	**1.85**	**1.19**	**1.18**	**1.16**
5	PO_4^{3-}_P	*mg/L*	0.06	0.08	0.05	0.1	0.086	0.073	0.045	0.065	0.058	0.055	0.092	0.088
6	*TDS*	*µS/cm*	7.59	8.9	7.8	8.5	9.9	10.5	8.6	8.3	9.7	10.4	9.2	8.3
7	NO_2^-_N	*mg/L*	0.22	0.16	0.18	0.24	0.28	0.15	0.21	0.26	0.18	0.15	0.22	0.17
8	NO_3^-_N	*mg/L*	0.17	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
9	NH_4^+_N	*mg/L*	0.03	0.05	0.045	0.055	0.074	0.032	0.026	0.044	0.067	0.032	0.045	0.065
10	*Hardness*	$mgCaCO_3/L$	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
11	*As*	*mg/L*	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
12	*Fe*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
13	*Cd*		<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
14	*Ni*		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
15	*Mn*		<0.001	<0,0002	<0,0002	<0,0002	<0,0002	<0,0002	<0,0002	<0,0002	<0,0002	<0,0002	<0,0002	<0,0002
16	*Hg*		<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
17	*Se*		<0.001	<0.001	<0.001	<0.002	<0.003	<0.004	<0.005	<0.006	<0.007	<0.008	<0.009	<0.010
18	*Pb*		<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
19	*Zn*		0.333	0.365	0.41	0.233	0.412	0.236	0.322	0.347	0.356	0.443	0.401	0.389
20	SO_4^{2-}		<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
21	Coliform	*MPN/100mL*	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**
22	E.coli	*MPN/100mL*	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**
23	Pecmaganat	mg/l	0.85	0.9	1.1	1.3	1.45	1.09	1.43	1.32	0.98	0.86	0.68	0.66
24	Cl^-	mg/l	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

Most of the heavy metal parameters meets the drinking water standard of Vietnam except the microorganism but it is guarantee according the standard after treated.

Table 9 : Water quality at storage tank P1 of Elementary school

N0	Parameters	Unit	Cu khe elementary school P1											
			10-Aug	10-Sep	10-Oct	10-Nov	10-Dec	10-Jan	10-Feb	10-Mar	10-Apr	10-May	10-Jun	10-Jul
1	pH	-	6.8	6.5	7.2	7.6	7.4	6.9	6.5	6.5	7,1	6.5	6,9	7.4
2	TDS	mg/L	48.8	45	47.8	45.6	47.7	50	55	46	73	56	47	68
3	Odor	-	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing
4	Turbidity	NTU	2.4	2.3	3.2	2.2	3.55	1.8	3.3	4	3.2	2.5	2.8	2
5	PO_4^{3-}_P	mg/L	0.04	0.06	0.05	0.07	0.05	0.032	0.045	0.05	0.058	0.043	0.056	0.08
6	TDS	µS/cm	7.55	8.9	8.1	9.3	9.9	10.5	8.8	8.4	7.9	10.2	9.3	8.3
7	NO_2^-_N	mg/L	0.24	0.12	0.25	0.24	0.32	0.24	0.21	0.18	0.18	0.15	0.22	0.17
8	NO_3^-_N	mg/L	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
9	NH_4^+_N	mg/L	0.02	0.04	0.045	0.05	0.06	0.032	0.04	0.053	0.06	0.034	0.045	0.055
10	Hardness	$mgCaCO_3/L$	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
11	As	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
12	Fe		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
13	Cd		<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
14	Ni		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
15	Mn		<0.001	<0,0002	<0,0002	<0,0002	<0,0002	<0,0002	<0,0002	<0,0002	<0,0002	<0,0002	<0,0002	<0,0002
16	Hg		<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
17	Se		<0.001	<0.001	<0.001	<0.002	<0.003	<0.004	<0.005	<0.006	<0.007	<0.008	<0.009	<0.010
18	Pb		<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
19	Zn		0.323	0.342	0.474	0.357	0.401	0.345	0.234	0.493	0.346	0.453	0.341	0.41
20	SO_4^{2-}		<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
21	Coliform	MPN/100mL	160	120	150	180	140	156	240	255	226	188	156	250
22	E.coli	MPN/100mL	140	145	120	110	108	134	128	135	154	111	120	147
23	Pecmaganat	mg/l	1.24	1.26	1.43	1.79	1.34	1.6	1.46	1.34	1.44	1.28	1.55	1.39
24	Cl^-	mg/l	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

Table 10 : Water quality at storage tank P2 of Elementary school

N0	Parameters	Unit	Cu khe elementary school P2											
			10-Aug	10-Sep	10-Oct	10-Nov	10-Dec	10-Jan	10-Feb	10-Mar	10-Apr	10-May	10-Jun	10-Jul
1	pH	-	6.8	6.5	7.2	7.6	7.4	6.9	6.5	6.5	7,1	6.5	6,9	7.4
2	TDS	mg/L	48.8	45	47.8	45.6	47.7	50	55	46	73	56	47	68
3	Odor	-	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing
4	Turbidity	NTU	1.23	1.13	1.2	1.34	0.98	0.84	1.12	1.32	1.16	0.95	0.76	1.18
5	PO_4^{3-}_P	mg/L	0.06	0.08	0.05	0.1	0.086	0.073	0.045	0.065	0.058	0.055	0.092	0.088
6	TDS	µS/cm	7.59	8.9	7.8	8.5	9.9	10.5	8.6	8.3	9.7	10.4	9.2	8.3
7	NO_2^-_N	mg/L	0.22	0.16	0.18	0.24	0.28	0.15	0.21	0.26	0.18	0.15	0.22	0.17
8	NO_3^-_N	mg/L	0.17	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
9	NH_4^+_N	mg/L	0.03	0.05	0.045	0.055	0.074	0.032	0.026	0.044	0.067	0.032	0.045	0.065
10	Hardness	$mgCaCO_3/L$	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
11	As	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
12	Fe		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
13	Cd		<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
14	Ni		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
15	Mn		<0.001	<0,0002	<0,0002	<0,0002	<0,0002	<0,0002	<0,0002	<0,0002	<0,0002	<0,0002	<0,0002	<0,0002
16	Hg		<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
17	Se		<0.001	<0.001	<0.001	<0.002	<0.003	<0.004	<0.005	<0.006	<0.007	<0.008	<0.009	<0.010
18	Pb		<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
19	Zn		0,423	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002
20	SO_4^{2-}		<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
21	Coliform	MPN/100mL	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing
22	E.coli	MPN/100mL	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing
23	Pecmaganat	mg/l	0.83	0.76	0.9	0.95	1.2	1.15	0.89	1.3	1.1	0.98	0.68	0.78
24	Cl^-	mg/l	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

Most of the heavy metal parameters meets the drinking water standard of Vietnam except the microorganism but it is guarantee according the standard after treated.

4.2.5. Lessons learnt

Technically:

- Separate the storage tank to reduce the suspended solid
- Simple device to remove the contaminated on the rooftop of the fir st rain by using diverter pipe
- Simple water level and calm inlet
- RWH treatment technology solution to produce drinking water

Economically:

- Reduce the water fee for student by using rainwater
- The method to encourage private sector to donate for rainwater a ctivities

Socially:

- The role of the private sector or organization to promote RWH system
- The ability of the school to communicate RWH system

- The method to implement RWH system for researcher team
- Role of the teacher, student parents and commune authorities to promote RWH.

4.3.2. Daicuong elementary(D3) and middle (D4) school

4.3.1. Site information

Daicuong Middle and Elementary are located at the Hanam province, south direction of Hanoi city, along Day river. (Fig 29). The water supply situation of the school to weak, exactly no centralization water supply system at this site. They exploited groundwater to use after simple treatment system by using slow sand filter. But they just used groundwater for toilet flushing because the groundwater contaminated be Arsenic and Ammonia (Fig.30). The average annual rainfall which is obtained nearby PhuLy Weather station is 1550mm/year

Fig.29. Location of Daicuong commune and schools

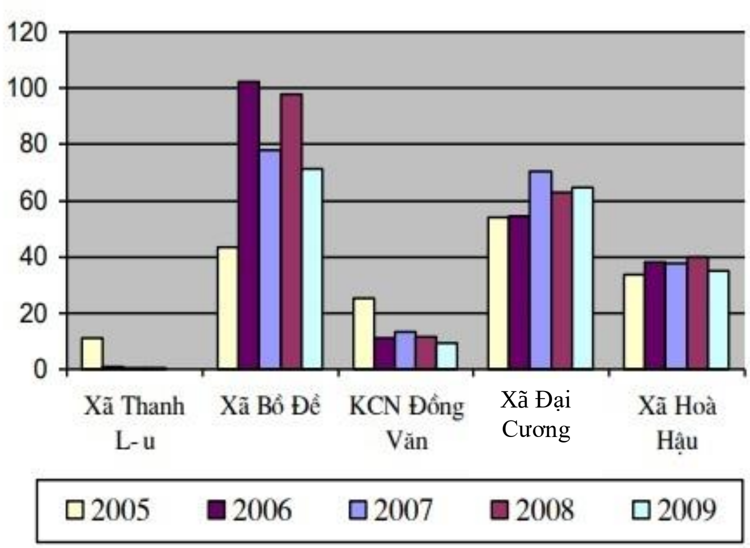


Fig.30. Ammonia contamination map at Hong River Delta area

(Hanam environmental report, 2015)

4.3.2. Information of demo system at Daicuong elementary school (D3) and middle school (D4)

Daicuong elementary school:

Total people of school is 500 persons including student 47 and teacher 30 (Fig.31). Because of the contaminated water source situation, the bottled water is used for drinking at elementary school. The required drinking water is 5 m^3/month and the drinking water quantity standard for student is 0.3 L/student/day (TCVN 4513: water supply and drain for building).

Daicuong middle school:

Total people of school is 420 persons including student (400) and teacher (20). Drinking water source situation is similar with the elementary school and bottled water is used for drinking at Daicuong middle school. The required drinking water is 5,5 - 6 m^3/month and the drinking water quantity standard for student is 0.3 L/student/day (TCVN 4513: water supply and drain for building). In the fact, student can drink much more than 0.5 L/day but school limited at 0.4 – 0.45 L/student/day because drinking water fee limitation.

There is an urgent need for school to supply clean water for drinking for the children. SNU and NUCE decided to build a rainwater harvesting system from KOICA organization. The design and construction of 16 m^3 rainwater system was made during August-September 2015. The opening ceremony was done on September 5, 2015 . (Fig 32)

Fig 31. Photos of Daicuong elementary school rainwater harvesting system
a) Side view b) In front view

Fig 32. Photos of Daicuong middle school rainwater harvesting system
a) Back view b) Treatment system c) Ceremony d) In front view

4.3.3. Rainwater Harvesting system information

The schematic diagram of the rainwater harvesting system is as in Fig 33. The rainwater is collected from the rooftop (area: 450 m2), go through downpipe equipped with first flush diverter. There is first flush tank with the capacity of 200 liter. The water fills the tank 1 (6ooo liter) using a calm inlet. Tank 2 is connected by a pipe. Both tanks are equipped with ventilation and drain pipe. The stored water is delivered to treatment system before sent to the classroom water bottle. The treatment system consists of micro filter and UV filter. The water usage is monitored by water flow meter. The water quality is sampled for water quality testing periodically (every 1 month) which is sent to Institute of Environmental Science and Engineering agency, National University of Civil Engineering.

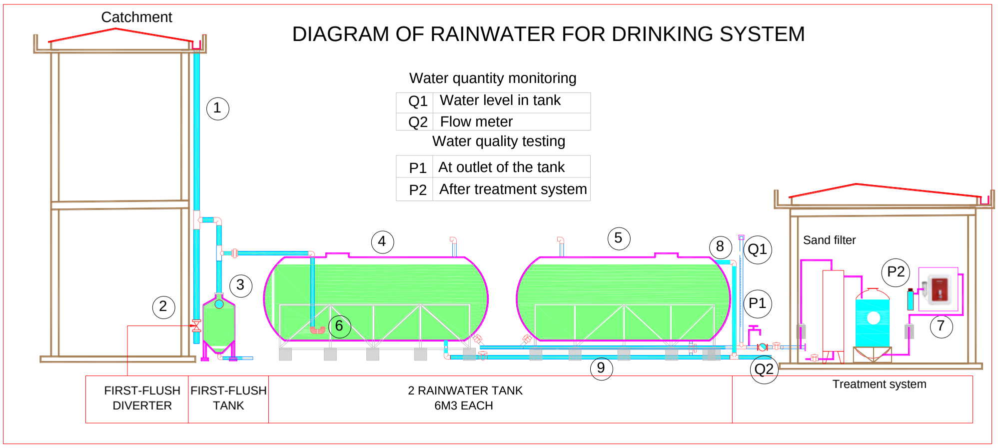


Fig.33. The schematic diagram of RWH system for Daicuong element and middle school

1.Downspout; 2 Diverter pipe. 3) First-flush 4) Sedimentation tank, 5) Storage tank, 6) Calm-inlet. 7) Filtration system, 8) over flow, 9) drain,

P1: Sample point from storage tank P2: Sample point after treatment

Q2 : Water consumption checking Q1: Water level checking

4.3.4. Maintenance and Operation

Treated Rainwater is supplied to each classroom in a 20 liter plastic bottle by the school manager from 09:00-10:00. Student in charge come and receive the 20 liter bottle to their classroom.

4.3.4.1 Water quantity monitoring

<u>Daicuong elementary school</u>

The water quantity is monitored from the flow meter and monthly data are summarized as in Fig 34. The drinking water for the student in the school is 0.3 L follow the Vietnam standard. After the RWH system installed, the average supply of drinking water per each student is 0.45~0.5 L/day/person which is higher than the official requirement.

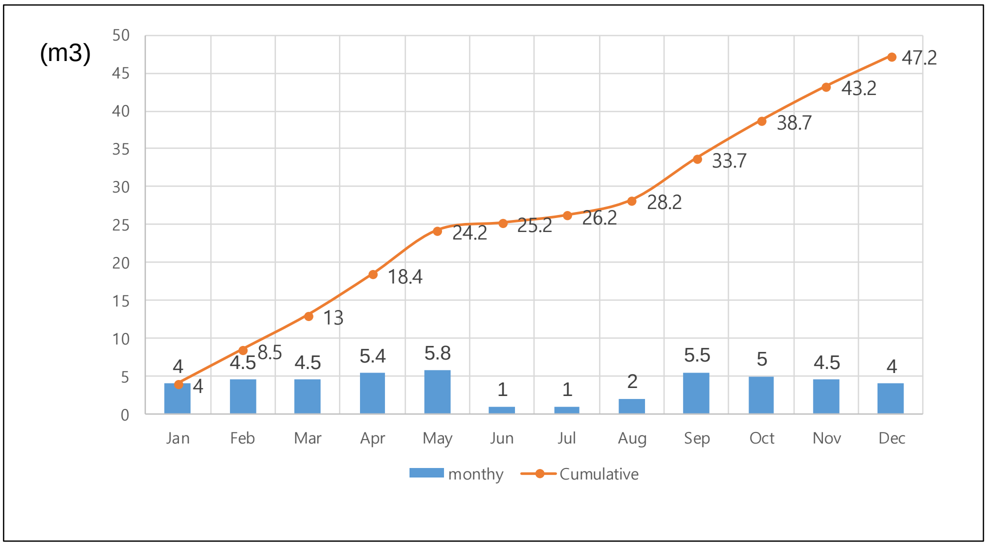


Fig. 34. Monthly water usage and cumulative water consumption of Daicuong elementary school

Daicuong middle school

At the Daicuong school, the student has a lot of the activities, so they drink much water than element try's student. After the RWH system installed, the average supply of drinking water per each student is 0.5~0.6 L/day/person which is higher than the official requirement. The water quantity is monitored from the flow meter and monthly data are summarized as in Fig 35.

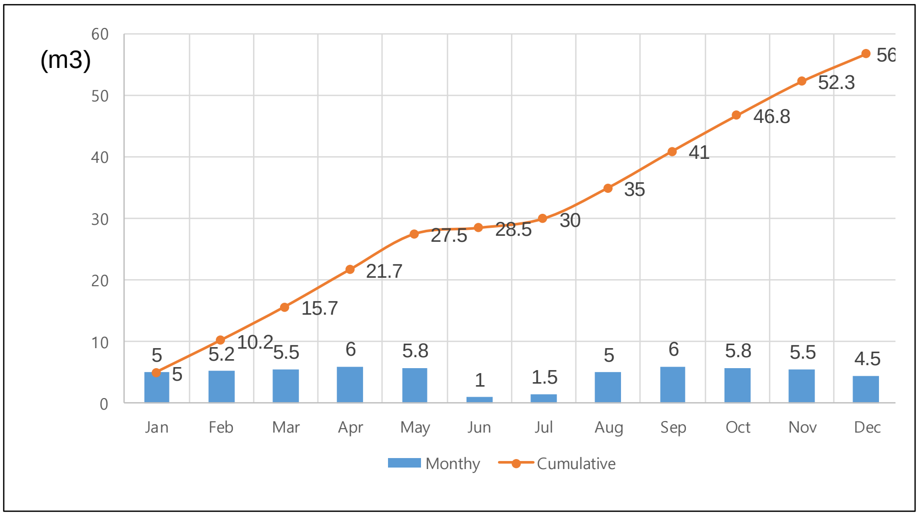


Fig. 35. Monthly water usage and cumulative water consumption of Daicuong middle school

4.2.4.2.Water quality monitoring

The water quality monitoring is done for 24 items. The water quality was sampled follow two periods, the first from February 2015 – January 2016 and second from September 2018 – May 2019. From 2017 until 2018, the school will check by themselves according to the requirement from Government, normally 2 times/year for water quality checking. The result is summarized as in Table 11,12 for D3 and Table 13,14 for D4

Table 11 : Water quality at storage tank P1, Daicuong elementary school

N0	Parameters	Unit	*Daicuong elementary school P1*											
			5-Oct	5-Nov	5-Dec	5-Jan	5-Feb	5-Mar	5-Apr	5-May	5-Jun	5-Jul	5-Aug	5-Sep
1	*pH*	-	6.5	7.2	7.6	6.9	7.35	7.7	7.4	6.8	7,1	6.8	6.5	7.3
2	*TDS*	mg/L	55	58	59	46	49	50	52	60	47	58	68	52
3	Odor	-	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing
4	Turbidity	NTU	**2.8**	**3.1**	**2.9**	**3.5**	**3.9**	**4**	**2.5**	**4.5**	**3.6**	**3.8**	**4**	**3.3**
5	$PO_4^{3-}\_P$	mg/L	0.032	0.045	0.023	0.06	0.05	0.054	0.036	0.057	0.056	0.034	0.064	0.056
6	*TDS*	µS/cm	8.8	8.45	9.34	9.5	8.6	8.8	10.5	9.8	8.7	10.1	8.9	7.5
7	$NO_2^-\_N$	mg/L	0.34	0.45	0.42	0.28	0.27	0.25	0.29	0.18	0.21	0.15	0.19	0.21
8	$NO_3^-\_N$	mg/L	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
9	$NH_4^+\_N$	mg/L	0.07	0.06	0.045	0.056	0.06	0.048	0.034	0.045	0.043	0.037	0.046	0.034
10	*Hardness*	$mgCaCO_3/L$	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
11	*As*	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
12	*Fe*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
13	*Cd*		<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
14	*Ni*		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
15	*Mn*		<0.001	<0,0002	<0,0002	<0,0002	<0,0002	<0,0002	<0,0002	<0,0002	<0,0002	<0,0002	<0,0002	<0,0002
16	*Hg*		<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
17	*Se*		<0.001	<0.001	<0.001	<0.002	<0.003	<0.004	<0.005	<0.006	<0.007	<0.008	<0.009	<0.010
18	*Pb*		<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
19	*Zn*		0.35	0.342	0.474	0.357	0.401	0.345	0.234	0.493	0.346	0.453	0.341	0.41
20	SO_4^{2-}		<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
21	Coliform	MPN/100mL	**260**	**280**	**310**	**340**	**290**	**256**	**185**	**255**	**278**	**230**	**190**	**205**
22	E.coli	MPN/100mL	**160**	**155**	**132**	**146**	**180**	**156**	**139**	**135**	**147**	**120**	**158**	**134**
23	Pecmaganat	mg/l	1.12	1.15	1.24	1.18	1.55	1.94	1.34	1.56	1.68	1.78	1.53	1.67
24	Cl^-	mg/l	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

Table 12: Water quality after treatment P2, Daicuong elementary school

N0	Parameters	Unit	*Daicuong elementary school P2*											
			5-Oct	5-Nov	5-Dec	5-Jan	5-Feb	5-Mar	5-Apr	5-May	5-Jun	5-Jul	5-Aug	5-Sep
1	*pH*	-	6.5	7.2	7.6	6.9	7.35	7.7	7.4	6.8	7,1	6.8	6.5	7.3
2	*TDS*	mg/L	55	58	59	46	49	50	52	60	47	58	68	52
3	Odor	-	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing	Nothing
4	Turbidity	NTU	**1.01**	**1.15**	**1.21**	**1.16**	**1.24**	**0.96**	**0.94**	**0.87**	**0.88**	**1.13**	**1.56**	**1.32**
5	$PO_4^{3-}\_P$	mg/L	0.03	0.05	0.08	0.042	0.067	0.053	0.045	0.065	0.043	0.025	0.057	0.083
6	*TDS*	µS/cm	8.56	8.84	7.65	8.5	8.56	9.55	9.65	8.75	7.94	9.45	9.2	8.55
7	$NO_2^-\_N$	mg/L	0.21	0.14	0.175	0.222	0.187	0.24	0.21	0.14	0.18	0.16	0.2	0.19
8	$NO_3^-\_N$	mg/L	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
9	$NH_4^+\_N$	mg/L	0.02	0.035	0.04	0.052	0.046	0.024	0.036	0.056	0.06	0.078	0.055	0.05
10	*Hardness*	$mgCaCO_3/L$	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
11	*As*	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
12	*Fe*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
13	*Cd*		<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
14	*Ni*		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
15	*Mn*		<0.001	<0,0002	<0,0002	<0,0002	<0,0002	<0,0002	<0,0002	<0,0002	<0,0002	<0,0002	<0,0002	<0,0002
16	*Hg*		<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
17	*Se*		<0.001	<0.001	<0.001	<0.002	<0.003	<0.004	<0.005	<0.006	<0.007	<0.008	<0.009	<0.010
18	*Pb*		<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
19	*Zn*		<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
20	SO_4^{2-}		<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
21	Coliform	MPN/100mL	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**
22	E.coli	MPN/100mL	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**
23	Pecmaganat	mg/l	0.76	0.74	0.81	0.88	1.15	1.28	0.94	0.96	1.18	1.13	1.19	0.99
24	Cl^-	mg/l	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

Most of the heavy metal parameters meets the drinking water standard of Vietnam except the

Table 13: Water quality at storage tank P1, Daicuong middle school

N0	Parameters	Unit	Daicuong Middle school P1											
			5-Oct	5-Nov	5-Dec	5-Jan	5-Feb	5-Mar	5-Apr	5-May	5-Jun	5-Jul	5-Aug	5-Sep
1	*pH*	-	*6.5*	*7.2*	*7.6*	*6.9*	*7.35*	*7.7*	*7.4*	*6.8*	*7,1*	*6.8*	*6.5*	*7.3*
2	*TDS*	*mg/L*	*55*	*58*	*59*	*46*	*49*	*50*	*52*	*60*	*47*	*58*	*68*	*52*
3	Odor	-	*Nothing*	*Nothing*	*Nothing*	*Nothing*	*Nothing*	*Nothing*	*Nothing*	*Nothing*	*Nothing*	*Nothing*	*Nothing*	*Nothing*
4	Turbidity	*NTU*	***2.6***	***3.8***	***3.5***	***3.2***	***2.9***	***4.3***	***4.6***	***3.5***	***3.2***	***4.3***	***4***	***4.5***
5	PO_4^{3-}_P	*mg/L*	0.034	*0.025*	*0.037*	*0.042*	*0.046*	*0.043*	*0.032*	*0.035*	*0.025*	*0.036*	*0.054*	*0.059*
6	*TDS*	*µS/cm*	*9.8*	*9.5*	*10.5*	*10.8*	*8.9*	*9.4*	*9.5*	*9.8*	*10.8*	*10.1*	*10.5*	*9.9*
7	NO_2^-_N	*mg/L*	*0.26*	*0.28*	*0.34*	*0.42*	*0.37*	*0.35*	*0.41*	*0.24*	*0.26*	*0.18*	*0.22*	*0.26*
8	NO_3^-_N	*mg/L*	<1	*<1*	*<1*	*<1*	*<1*	*<1*	*<1*	*<1*	*<1*	*<1*	*<1*	*<1*
9	NH_4^+_N	*mg/L*	0.065	*0.045*	*0.043*	*0.057*	*0.034*	*0.036*	*0.063*	*0.045*	*0.055*	*0.047*	*0.036*	*0.042*
10	*Hardness*	*$mgCaCO_3/L$*	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
11	*As*	*mg/L*	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
12	*Fe*		*<0.1*	*<0.1*	*<0.1*	*<0.1*	*<0.1*	*<0.1*	*<0.1*	*<0.1*	*<0.1*	*<0.1*	*<0.1*	*<0.1*
13	*Cd*		*<0.0002*	*<0.0002*	*<0.0002*	*<0.0002*	*<0.0002*	*<0.0002*	*<0.0002*	*<0.0002*	*<0.0002*	*<0.0002*	*<0.0002*	*<0.0002*
14	*Ni*		*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*
15	*Mn*		*<0.001*	*<0,0002*	*<0,0002*	*<0,0002*	*<0,0002*	*<0,0002*	*<0,0002*	*<0,0002*	*<0,0002*	*<0,0002*	*<0,0002*	*<0,0002*
16	*Hg*		*<0.002*	*<0.002*	*<0.002*	*<0.002*	*<0.002*	*<0.002*	*<0.002*	*<0.002*	*<0.002*	*<0.002*	*<0.002*	*<0.002*
17	*Se*		*<0.001*	*<0.001*	*<0.001*	*<0.002*	*<0.003*	*<0.004*	*<0.005*	*<0.006*	*<0.007*	*<0.008*	*<0.009*	*<0.010*
18	*Pb*		*<0.002*	*<0.002*	*<0.002*	*<0.002*	*<0.002*	*<0.002*	*<0.002*	*<0.002*	*<0.002*	*<0.002*	*<0.002*	*<0.002*
19	*Zn*		0.35	*0.342*	*0.474*	*0.357*	*0.401*	*0.345*	*0.234*	*0.493*	*0.346*	*0.453*	*0.341*	*0.41*
20	SO_4^{2-}		*<0.03*	*<0.03*	*<0.03*	*<0.03*	*<0.03*	*<0.03*	*<0.03*	*<0.03*	*<0.03*	*<0.03*	*<0.03*	*<0.03*
21	Coliform	*MPN/100mL*	**300**	**350**	**360**	**290**	**305**	**306**	**385**	**402**	**309**	**410**	**395**	**450**
22	E.coli	*MPN/100mL*	**205**	**220**	**185**	**198**	**220**	**169**	**216**	**234**	**197**	**185**	**201**	**180**
23	Pecmaganat	mg/l	1.14	*1.21*	*1.16*	*126*	*1.45*	*1.36*	*1.35*	*1.56*	*1.22*	*1.24*	*1.55*	*1.68*
24	Cl^-	mg/l	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

Table 14: Water quality after treatment P2, Daicuong middle school

N0	Parameters	Unit	Daicuong Middle school P2											
			5-Oct	5-Nov	5-Dec	5-Jan	5-Feb	5-Mar	5-Apr	5-May	5-Jun	5-Jul	5-Aug	5-Sep
1	*pH*	-	*6.5*	*7.2*	*7.6*	*6.9*	*7.35*	*7.7*	*7.4*	*6.8*	*7,1*	*6.8*	*6.5*	*7.3*
2	*TDS*	*mg/L*	*55*	*58*	*59*	*46*	*49*	*50*	*52*	*60*	*47*	*58*	*68*	*52*
3	Odor	-	*Nothing*	*Nothing*	*Nothing*	*Nothing*	*Nothing*	*Nothing*	*Nothing*	*Nothing*	*Nothing*	*Nothing*	*Nothing*	*Nothing*
4	Turbidity	*NTU*	***0.98***	***1.1***	***0.95***	***1.21***	***1.26***	***1.15***	***1.25***	***0.88***	***0.94***	***0.96***	***1.15***	***1.15***
5	PO_4^{3-}_P	*mg/L*	0.025	*0.045*	*0.064*	*0.042*	*0.078*	*0.059*	*0.045*	*0.032*	*0.046*	*0.028*	*0.043*	*0.058*
6	*TDS*	*µS/cm*	*9.8*	*9.5*	*10.5*	*10.8*	*8.9*	*9.4*	*9.5*	*9.8*	*10.8*	*10.1*	*10.5*	*9.9*
7	NO_2^-_N	*mg/L*	*0.16*	*0.22*	*0.18*	*0.25*	*0.14*	*0.24*	*0.26*	*0.18*	*0.15*	*0.23*	*0.2*	*0.16*
8	NO_3^-_N	*mg/L*	<1	*<1*	*<1*	*<1*	*<1*	*<1*	*<1*	*<1*	*<1*	*<1*	*<1*	*<1*
9	NH_4^+_N	*mg/L*	0.023	*0.034*	*0.018*	*0.045*	*0.026*	*0.018*	*0.028*	*0.045*	*0.036*	*0.027*	*0.035*	*0.043*
10	*Hardness*	*$mgCaCO_3/L$*	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
11	*As*	*mg/L*	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
12	*Fe*		*<0.1*	*<0.1*	*<0.1*	*<0.1*	*<0.1*	*<0.1*	*<0.1*	*<0.1*	*<0.1*	*<0.1*	*<0.1*	*<0.1*
13	*Cd*		*<0.0002*	*<0.0002*	*<0.0002*	*<0.0002*	*<0.0002*	*<0.0002*	*<0.0002*	*<0.0002*	*<0.0002*	*<0.0002*	*<0.0002*	*<0.0002*
14	*Ni*		*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*
15	*Mn*		*<0.001*	*<0,0002*	*<0,0002*	*<0,0002*	*<0,0002*	*<0,0002*	*<0,0002*	*<0,0002*	*<0,0002*	*<0,0002*	*<0,0002*	*<0,0002*
16	*Hg*		*<0.002*	*<0.002*	*<0.002*	*<0.002*	*<0.002*	*<0.002*	*<0.002*	*<0.002*	*<0.002*	*<0.002*	*<0.002*	*<0.002*
17	*Se*		*<0.001*	*<0.001*	*<0.001*	*<0.002*	*<0.003*	*<0.004*	*<0.005*	*<0.006*	*<0.007*	*<0.008*	*<0.009*	*<0.010*
18	*Pb*		*<0.002*	*<0.002*	*<0.002*	*<0.002*	*<0.002*	*<0.002*	*<0.002*	*<0.002*	*<0.002*	*<0.002*	*<0.002*	*<0.002*
19	*Zn*		<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
20	SO_4^{2-}		*<0.03*	*<0.03*	*<0.03*	*<0.03*	*<0.03*	*<0.03*	*<0.03*	*<0.03*	*<0.03*	*<0.03*	*<0.03*	*<0.03*
21	Coliform	*MPN/100mL*	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**
22	E.coli	*MPN/100mL*	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**	**Nothing**
23	Pecmaganat	mg/l	0.57	*0.74*	*0.83*	*0.46*	*0.54*	*0.88*	*0.94*	*0.85*	*0.97*	*0.85*	*1.12*	*1.18*
24	Cl^-	mg/l	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

Most of the heavy metal parameters meets the drinking water standard of Vietnam except the microorganism but it is guarantee according the standard after treated.

4.3.5. Lessons learnt

Technically:

- Separate the storage tank to reduce the suspended solid
- Simple device to remove the contaminated on the rooftop of the first r ain by using diverter pipe
- Simple water level and calm inlet
- Extend the lifecycle of the filtration cartridge
- Using the plug flow type to reduce suspended solid in rainwater

Economically:

- Reduce the water fee for student by using rainwater
- The solution to reduce investment cost of the RWH for school

Socially:

- The role of the private sector or organization to promote RWH system
- The ability of the school to communicate RWH syste
- Role of the teacher, student parents and commune authorities to

promote RWH

- Establish rainwater group such as BiTS (Rain, teacher and student) to implement the communication to village, commune and province in further.

4.4. Economic analysis of rainwater harvesting systems for drinking at school in Vietnam

4.4.1. Introduction

The benefit of RWH has been represented mostly by savings public water supply fee and reduction tax of storm water disposal. These approaches are not applicable to rural areas that lack of infrastructure, especially of safe drinking water supply. To evaluate economic sustainability, a key concept is "willingness to pay." If users are willing to pay for the full costs of the system, it indicates that the system is valuable and it will be possible to generate the funds required to sustain and even replicate the system (Whittington et al., 1990). Willingness to pay on water service is derived from user's evaluation on water which is influenced by complex elements such as water quality, their incomes, hygienic education level, and available alternative water sources (World Bank Water Demand Research Team, 1993). Additionally, water usage purposes also have effect on willingness to pay. People usually put much value on drinking purpose than other non-potable purposes like showering, toilet flushing, and laundry. This idea is supported by the phenomenon that people buy of bottled water, which is much expensive than tap water even in countries where tap water quality is considered excellent (Doria et al., 2006). Therefore, cost-benefit of the RWH for drinking will calculate to compare with bottled water in this section.

4.4.2. Material & Method

Economic analysis

The economic analysis has been performed by using the Net Present Value (NPV) model shown in equation,

$$\mathrm{NPV}_T = \sum_{t=0}^{T} \frac{(B_t - C_t)}{(1+i)^t}$$

Where B_t is the benefit and C_t is the cost in the period t and where i is the discount rate. Benefit is assumed the same as willingness to pay on bottled water. Water rate of bottled water is 26.5 USD/kL. Cost information on RWH system installation and maintenance is estimated from the case study shown as Table 10. Costs include: rainwater tank; tank installation and fitting; filter and pump replacement; electricity tariff; labor cost for operating and maintenance. The discount rate of 1.7% which is an average real discount rate of Vietnam from 2000 to 2016 is applied. A social discount rate of 0% is also applied in order to reduce underestimation of the benefit introduced by RRWH (Domènech and Saurí, 2011) and compare the differences formed by the selection of a discount rate. It has been mentioned that rainwater harvesting generates positive environmental and social benefits such as saving water, flood control and mitigating climate change (Herman and Schmida, 1999; Eroksuz and Rahman, 2010; van Roon, 2007; An et al., 2015). Furthermore, the value of water is likely to become more increased in the long term (Domènech and Saurí, 2011).

In the costs, service life of filters relies on raw water quality and water usage. We have changed sediments filter every 3 months and didn't changed other filters until 15 months. More frequent changes of filters are assumed as Table 10. Labor cost is calculated from average income per capita of rural area of Vietnam (70 USD).

20 min/day working time is assumed for operation and maintenance including washing bottles. Supply cost for each component is calculated in equation,

$$\text{Supply cost}\ \left[\frac{\text{USD}}{kL}\right] = \frac{\text{Cost}\ [\frac{\text{USD}}{\text{year}}]}{\text{Q}_{s,ave}\left[\frac{\text{L}}{\text{day}}\right] \times 365\left[\frac{\text{day}}{\text{year}}\right]}$$

Installation cost is converted to yearly cost which makes NPV=0 after 50 years. For UV sterilizer, a half of original service life is assumed because frequent on/off reduce the lamp life span (8,000 hr). Supply cost for using UV sterilizer is calculated in equation,

$$\text{Supply cost}_{\text{UV}}\ \left[\frac{\text{USD}}{\text{kL}}\right] = \frac{Cost[\frac{\text{USD}}{\text{ea}}]}{\text{Life span}\ \left[\frac{\text{hr}}{\text{ea}}\right] \times \text{flowrate}\ \left[\frac{\text{L}}{\text{min}}\right] \times 60\left[\frac{\text{min}}{\text{hr}}\right]}$$

where flowrate 0.5 L/min is applied.

Table 15. Installation and maintenance cost for RWH system

C&B	Period		Item	Cost ($ US Dolla)				Note
				D1	D2	D3	D4	
			Tank capacity (m3)	12	12	16	16	
Cost	Inimial	Design & construction	Design	2,000 ~2,500	2,000 ~2,500	2,000-3000	2,000-3000	CI1
			Tank	1,500-1,800	1,700-1,800	2,000 - 2,2000	2,000 - 2,2000	
			Foudation, piping system, labor etc…	1,000-1,200	1,000-1,200	4,000 - 5,000	4,000 - 5,000	CI2
			Housesing, fence	0	0	3,000 - 4,000	3,000 - 4,000	CI3
			Treatment	800-1,000	800-1,000	3,200 - 3,8000	3,200 - 3,8000	
			Sum	**5,300 - 6,500**	**5,300 - 6,500**	**14,200 - 18,000**	**14,200 - 18,000**	
	Annual	O&M (yearly)	Treatment	120 - 150	120 - 150	240-300	240-300	CM1
			Equipment repair	50-70	50-70	80 -100	80 - 100	CM2
			Routine cleaning	200- 240	200- 240	200- 240	200- 240	CM3
			Sum	**370 - 460**	**370 - 460**	**520 - 640**	**520 - 640**	
		Mornitoring	Water quality testing	250 - 350	250 - 350	250 - 350	250 - 350	CM4
			Water quantity	50-100	50-100	50-100	50-100	
			Sum	**300-450**	**300-450**	**300-450**	**300-450**	
Benefit	Annual		Rainwater consumption	**55**	**42**	**65**	**72**	
			Cost ($ US dolla)	**1,694**	**1,294**	**2,000**	**2,218**	B1, B2

- Initial cost
  - CI 1: Design cost for researcher or expert during the construction process. This item can reduce by technology transfer from abroad to local designer or expert.
  - CI 2 : Cost for construction include foundation, pipping and gutter work.
  - CI 3: Cost to build the treatment house and fence to protect RFD system
  - CI2 and CI3 can reduce cost by sharing work with the owner such as manpower, foundation, labor to do piping installation etc….
- Maintenance cost
  - CM1: Using the multi-barrier to improve rainwater quality in the storage tank and then increase the lifetime of the treatment

system. It will the solution to reduce cost for RFD treatment system.

- CM2: Cleaning the fountain every day. This item should cooperate with the owner to provide their staff to implement.
- CM3: Cost for water quality test. Total 99 parameters should be checked follow QCVN 06-2010, Vietnam standard. But through the water quality data on rainwater, these parameters should reduce to 8 – 10 parameter. It will be checked 2 times per year

➢ Benefit

- B1 : Benefit can get from RWH during summer vacation by selling raw rainwater for local bottled water.
- B2: Provide drinking water for villager during the summer vacation.

4.4.2 Result & discussion

Economic analysis

Figure. 26 shows the NPV considering two interest rates, 0% and 1.7%. The pay-back periods are less than four years in both under 0% and 1.7% discount rate. It is evident that using RWH is more beneficiary than using bottled water after 4 years. Table 4 shows supply cost for each component of RRWH. Total supply cost is 5.05 USD/kL on 1.7% discount rate and 4.27 USD/kL on 0% discount rate. These are less than 1/5 of bottled water cost of 27.9 USD/kL.

Even though people have willingness to pay on bottled water for children, we need to check whether RRWH system is not burden to the household's income. Average monthly income per capita of Vietnam rural area is $70 (1,579,400 VND) (GSO 2012). If each person drinks water 2 liter per day, bottled water charges 2.39% of their income. At the same condition, RWH system charges 0.43% of their income under 1.7% discount rate.

In total supply cost, installation cost charges almost 50% at 1.7% discount rate and 30% at 0% discount rate. Total cost of installing 10 kL RWH system was $4,000 which is not cheap comparing with average cost of other studies. The total cost of installing 10 kL RRWH system was $1,166 (R$ 4,366) in Brazil (Ghisi and Ferreira, 2007), $2,500-$2,800 in Australia (Tam el al., 2010), $ 7,829 (€7,366) in Spain (Domènech and Saurí, 2011). If the installation cost of RWH can be reduced, the pay-back period will be shorter and the water rate will be reduced.

Operation and maintenance (O&M) cost also can be reduced if treatment procedure is simplified. A simpler point of use filtration with a 20-micron sediment filter, a 5-micron sediment filter, an UF membrane, an activated carbon filter, and an ultraviolet sterilizer sufficiently cleared turbidity, total coliforms and E. coli (Jordan et al., 2008) to the level satisfying Vietnam drinking water quality standards. Ceramic filter of $0.6/kL, bio-sand filter of $0.1/kL and SODIS of $0.9/kL (Voigt et al.,2012) are also have been suggested to improve water quality to reduce waterborne disease. But, because these technologies could not remove 100% of total coliform and E. coli, sometimes it could not satisfy VDWQS. For reference, the most common means of treating water, boiling is not cheaper than other system (over $8/kL) considering indirect cost of time spent on preparing for boiling and heating water (Clasen et al., 2008). For community-based, it is difficult to boil rainwater and provide to member because it complicates and require much energy. Therefore, RWH with filtration and UV light disinfection is a suitable option to provide drinking water for community-based.

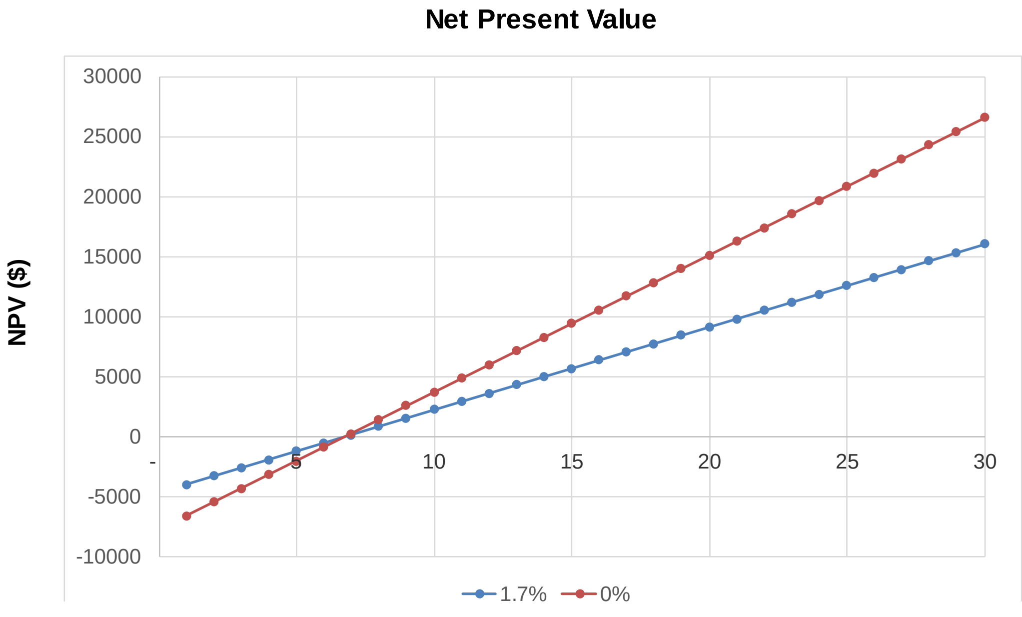


Fig 36. Net Present Value

4.4.4.Summary

Potential of RWH as drinking purpose for community-based was investigated considering qualitative, quantitative and economic aspect based on a RWH system in a rural area of Vietnam. For 24 months, the system has provided drinking water replacing bottled water.

On economic aspect, comparing with bottled water (0.53 USD per 19 L), the pay-back period of the RWH with POU treatment system is less than 4 years. Supply cost was $5.05/kL under 1.7% discount rate. 2 L consumption per day charges 0.43% of average monthly income per capita (70 USD). It could be affordable option even for low income rural areas.

RWH for drinking at school also a suitable option to reduce the drinking water fee for the student, especially for the students, which their parent has low income. At the Cukhe and Daicuong site, 50% drinking water fee for students had been saved. Hence, RWH can play an important role in supply safe drinking water with these advantages.

4.5. Social communication to promote rainwater harvesting system for drinking at school in Vietnam

4.5.1. Introduction

To promote the RWH system installation and to spread out rainwater utilization widely, besides the technical and economic assessment, communicating with residents should be implemented to create awareness about rainwater harvesting system and enhance their views on drinking rainwater. There are many methods and tools for communication and the methods and tools can show different effects depending on stakeholders who live in the community, especially for the clean water and RWH utilization at rural area. Normally, the rural residents lack of knowledge and information on RWH system and they install it via the actual experience reported by older generation without any design and guideline documents. In this case, the effective communication should be defined to prove the feasibility of the rainwater utilization as well as the RWH installation. Unfortunately, stakeholders normally make decisions focused on individual’s social influence. Stakeholders are the individuals interested in RWH systems or they are in groups or institutions concerned with RWH and the system management. They include all those who affect and/or are affected by the policies, decisions, and actions of the system. That means not only direct rainwater users but those affected by their family or neighborhood.

In Vietnam, the Ministry of Health issued the 6847/QĐ-BYT decision on November 13, 2018, to implement the Communication Project on the personal hygiene and rural clean water utilization and sanitation improvement during the period from 2018 until 2025 and the vision 2030.

Accordingly, there are four solutions and a coordination to implement:

+ Policy solutions: Completing, proposing and implementing legal regulations to overcome communication barriers on personal hygiene, environmental sanitation and rural clean water;

+ Agency coordination: Coordinating between the Government agencies such as Ministries, division, labor union and local agencies to implement the Project.

+ Technical solution: Doing research and making book guidelines, and providing communication skills training for individuals.

+ Financial solutions: allocating funds to implement the Communication Project

+ Science and technology solution and international

This is an overall approach to communicate the clean water utilization including rainwater. Based on the solutions, a detailed approach should be in parallel with creating effective communication.

During, 2008-2018, we visited the regions in Red River Delta which is the largest deltas in Vietnam, and surveyed and made the demo RWH projects to help the residents who face severe water scarcity. This paper presents how the RWH communication for the residents in rural areas was implemented.

4.5.2. Materials and methods

Study approach and data gathering

A preliminary survey, using rapid rural appraisal (RRA) as a tool and being based on a review of other previous studies, was conducted to guide the identification of study stakeholders living at the survey sites. The selected two community places having the projects' background on RWH activities were focused as a part of the investigation and the local residents living there were interviewed.

To understand variability in indigenous knowledge among the villagers in the study sites, every member of the target groups including social groups was selected for the sample. The sampled households were drawn from the village registers. According to the result, the sample shown that about 10% of the total villagers were practicing RWH. The sampled people were defined within each category using a random number generator. A total of 400 people participated in the survey. After working on the RRA preliminary analysis, a combined use of different data collection methods was used to provide an improved understanding of the variability of indigenous knowledge related to RWH in the study area.

Participatory rural appraisal (PRA)

In order to make the knowledge acquired by ingenious residents used and to understand social situation relating to RWH, PRA tools should be used

(B.P. Mbilinyi 2005). These include a keen focus on investigation, observation, group activities such as RWH contest, blink-test, discussion and open-ended interviews of key informants. The on–site interview was went through the group discussions at the school, commune and stakeholders who relate to RWH system also participated in the discussions.

Questionnaire for survey

A questionnaire was designed to draw conclusions from qualitative data which is essential to quantify the data by collecting them during the PRA process. The intended respondents were the villagers, teachers, students and local officers. The questionnaires and PRA were designed to gather the following information related to RWH:

(a) Indigenous resident knowledge. The main content focus on the role of rainwater, rainwater satisfaction, RWH practice and human resource.

(b) Experiences of local experts, including extension workers and private organization, on land characteristics and other factors known to be critical for RWH.

Action plan for stakeholder

In the last phase of the study, the action plan for stakeholder was organized such as training, education, workshop, and contest event to prove the feasibility of drinking rainwater and also enhance awareness of the local residents for RWH. The training courses for the teachers and the local officers were implemented three times at the Daicuong school and the organized education for the students was held for the students at Cukhe and Daicuong schools. The contents of these courses were carefully managed and designed based on the relevant people' opinions and the knowledge passed down through the generations by using the RWH system for years at the schools or by accumulating the knowledge from the experts. More than 150 people participated in these courses. By holding the convention in the communities at local level, necessary tasks were performed to present various values involving economic viability of an RWH system at school and people opinions were gathered for them. The participants include the villagers, man powers, local plumbers and several experts from SNU, Hanoi University of Civil Engineering and Kimbang district officers. A RWH contest for the student, which gives an expected from the student was implemented at the Daicuong school and it is a special event in here, even in the Kimbang district, Hanam province. This event attracted many people from commune, even from neighboring regions and district authorities. It is important to note that the participants were drawn from different communes/regions. This was purposely done to get views from a broad geographic scope.

4.5.3. Result and discussion

Training program.

The adequate working knowledge of RWH can be ensured by training for the teachers who are drinking the filtered rainwater from the system at the school. The contents of the training courses include the technical aspects such as rainwater harvesting system installation design and guideline manual, RW treatment technology, RWH quality result of the RWH system and operation and maintenance guideline. During the training courses, the group discussion also organized to consult the methods to promote RWH for drinking by widely spreading over at commune and neighboring regions. Total 4 training courses were organized at Cukhe and Daicuong school with over 110 participants. Besides on the technical aspects, the survey of the recognition of the participants

Fig.37. Training course for teachers at school

about drinking rainwater filtered from RWH system was investigated to estimate the effectiveness of the RWH at school for the residents (Fig.37).

Result of the interview indicated that participants were a high satisfaction with rainwater drinking at school (90%) and their knowledge for RWH technical were also rising (Fig.38). They understand that RWH is a proper water source to reduce groundwater exploitation and help the environment to sustainable. Over 95% of participants expect to apply RWH system to other schools and also spread over the system at other provinces of Vietnam.

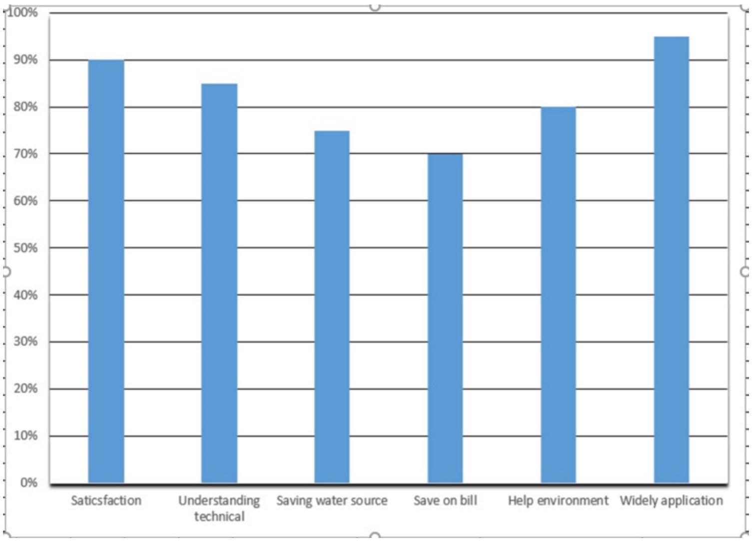


Fig.38. Response to a question on RWH for dinking at school

Education. The school and public education would be a great strategy for raising public awareness about rainwater. Education includes both the formal and informal instruction and training. Formal education refers to teaching in an open classroom at the schools, while informal education involves to hold training sessions including discussions, seminars and activities regarding to RWH on residents, local groups. For example, publishing books, making rainwater contests and holding blind-test rainwater activities for young students were implemented well in Daicuong schools.

In addition, considering being hard to install the RWH systems technically, we also educated the local residents explaining the system easily by distributing a simple instruction manual. The involvement of the local residents can be considered as an implicit capacity building and technology transfer. This was also allowing those concerned to gaining a good working knowledge of the system - how it works, operates and needs to be maintained. It is suggested to create a RWH training and application center in Universities or Institutes. The training center concentrating on the system construction and communication can be able to raise skill levels and awareness of the people to implement RWH system effectively. In Dai Cuong school case, a rainwater communication groups including teachers and students (BiTS) were set up for communicating RWH for drinking under the support for Daicuong middle school and a rainwater research center of National University of Civil

Engineering (NUCE). During the spring semester 2019, a contest was hosted to promote rainwater utilization targeting students. The contest includes two round, primary and final contest. The primary contest has 12 teams attended and then 5 teams were selected for the final contest. Each team had 5 persons and an advisor (teacher) proceeded the contest using the following format such as storytelling, drama, rhetoric, poster presentation. These activities engaged people' interest like more than 400 audiences from the school, villagers, officers and authority officers from Kimbang district and Hanam province (Fig.39)

(a) (b)

Fig. 39. Understanding rainwater contest at Daicuong school
(a) Primary contest (b) Final contest

Based on the BiTS activities and demonstration system at Daicuong schools, Villagers and people from other commune recognized the feasibility of the rainwater for life and their awareness about drinking rainwater was highly raised learnt from the survey results.

Public acceptance interview

To investigate the public acceptance of the RWH for drinking model in Cukhe and Daicuong schools, a total of 400 stakeholders, including teachers, students and their parents who used the RWH system, were interviewed with the same questions to gauge satisfaction. The questionnaires covered the reliability of the rainwater quality and quantity, their satisfaction with the operation, and maintenance of the system. Finally, the economic satisfaction with the RWH projects were examined.

Table 16 shows the opinions of the teachers, students and their parents about the RWH system in Cukhe and Daicuong schools. Through the surveys and the interviews, it presents that community people have a positive perception toward the RWH model. Most of people generally consider that rainwater is relatively easy to filter and safe to drink. Furthermore, people are satisfied with the RWH model because of the economic benefits, which were proved to reduce waste and save money to buy costly bottled water.

The public acceptance and success of RWH model at the Cukhe and Daicuong schools can be widely transferred to their communities and villages, since many of the stakeholders were involved in the RWH model. This may hopefully suggest the promotion and replication potential of RWH to achieve resilient and sustainable drinking water supplies in rural areas in developing countries affected by water shortages, and should be promoted as an important tool to achieve SDG6.

Table 16**.** Stakeholders' opinions about the RWH model at CuKhe and Daicuong schools

	Very disappointed (%)	Disappointed (%)	Normal (%)	Good (%)	Very good (%)
Are you satisfied with the taste of rainwater?	3	1	51	35	9
Are you satisfied with the rainwater quality?	2	4	41	42	11
Do you think the RWH system supplies enough water?	4	6	39	39	12
Do you think the RWH is convenient for use?	3	0	45	41	11
Do you think the system is economic?	2	1	36	35	26

4.6. Conclusion

Rainwater harvesting system for drinking water at school in Cukhe and

Daicuong schools are the good demo system. Base on proper design and management, the technical issue has been solved to construct nice and useful RWH system. During the construction period, the local government manpower was also trained so that he/she can be available to approach with new water treatment option and figure out solutions to maintain safe and fresh water quality in the storage tanks.

After treatment, rainwater satisfied all WHO drinking water guidelines at the tap. Because the distance from filter to tap is short, the possibility of contamination during distribution is unlikely. Therefore, rainwater with a point-of-use treatment system is a viable drinking water option in terms of quality, because it ensures safety at the tap.

On economic aspect, comparing with bottled water (0.53 USD per 19 L), the pay-back period of the RHRW with POU treatment system is less than 4 years. Supply cost was $5.05/kL under 1.7% discount rate. 2 L consumption per day charges 0.43% of average monthly income per capita (70 USD). It could be affordable option even for rural areas living in low income. Offering clean and safe water to children can help them continue saving the money for purchasing the bottled water and improve their lives significantly ensuring to get water through a tap at the school and bring the water to home if they want to.

To generalize the results, further efforts should be made by all stakeholders including government, the private sector, and individuals. Government can devise design and operation guidelines for RWH systems since improper design and operation can make rainwater unsuitable for drinking. The private sector is a key player that could make RWH systems available for the market. Individuals can select the market products and manage their own systems by understanding the sources of contamination.

CHAPTER 5: SUGGESTION TO PROMOTE SUSTAINABLE DRINKING WATER BY RAINWATER HARVESTING SYTEM

5.1. Introduction

RWH has the potential to provide sustainable water supply in Vietnam, if the system is adequately managed. From this study, it suggests that RWH technology is capable of serving sustainable water in a decentralized manner. For this vision to mature, identifying and establishing a roadmap is necessary. This should include means by which adoption can be extended through increased awareness, acceptance, and usage. Hence, the strategy is proposed for sustainability in drinking water using RWH technology.

5.2. Rainwater harvesting promotional strategies in other countries

The successes and failures of other countries can serve as stepping-stones for Vietnam in progressing towards increased RWH technology adoption. Countries like Germany, Japan, Korea, India, Australia, and Thailand have embraced RWH technology in efforts to enhance water availability for domestic and nondomestic uses, to reduce energy demand as well as for environmental sustenance.

Rainwater harvesting regulations in other countries

By March 2015, the cabinet of Japan approved wider usage of RWH in new buildings constructed by state government or administrative agencies (JFS 2015). In USA, in addition to voluntary effort, some states and municipalities are choosing to establish rules related to RWH. Rules, ordinances, building codes, and homeowner association covenants nationwide run the gamut from requiring RWH systems on new construction to prohibiting tanks as an eyesore (Texas 2005). In addition, the city of Seoul in South Korea announced a new regulation in December 2004 to enforce the installation of a RWH system for purposes including flood mitigation and water conservation. By 2010, RW regulations were implemented in 23 local governments (Lee et al 2010, Han et al 2009). In Belgium, national legislation requires all new construction to have RWH systems for the purposes of flushing toilets and external water uses. The purpose of this legislation is twofold: 1) to reduce the demand for treated water and the expansion of the water supply infrastructure; and 2) to collect and use RW instead of surcharging storm water management systems (Brussels 2015). In Australia, five state governments have taken active steps to ensure that newly constructed houses are designed and built with the latest energy and water efficient designs and products, which includes RWH facilities. Germany collects rain taxes for the amount of impervious surface cover on a property that generates runoff to local storm sewers (Rainwaterharvesting.org). In Berlin, the fee charged is currently €1.84/m2/year (Berlin 2010). In India, too, many cities have mandatory rules on RWH application (Rainwaterharvesting.org1).

5.3. Technical aspect suggestion to Vietnam Government

5.3.1. Rainwater harvesting component for community - base

- Conventional rainwater harvesting system

At normal rainwater harvesting site, the kindergarten collected rainwater only to use to prepare children’s lunches (Fig.40). The rainwater harvesting system has been installed on a long-term basis with a number of components such as rain gutters, trash gutters, rainwater piping systems, and screen and storage tank. A rainwater tank is usually built on the ground and has only one chamber with 3 -5 m^3 volumetric, depending on the economic condition of the school. To get the rainwater, the faucet or bucket is used. Also, boiling is the main method for disinfection to kill the bacteria.

This system is very difficult to directly supply drinking water to schools, People's committees, health centers, etc. In this case, the rainwater harvesting system (chapter 4) can provide drinking water to public places in rural areas.

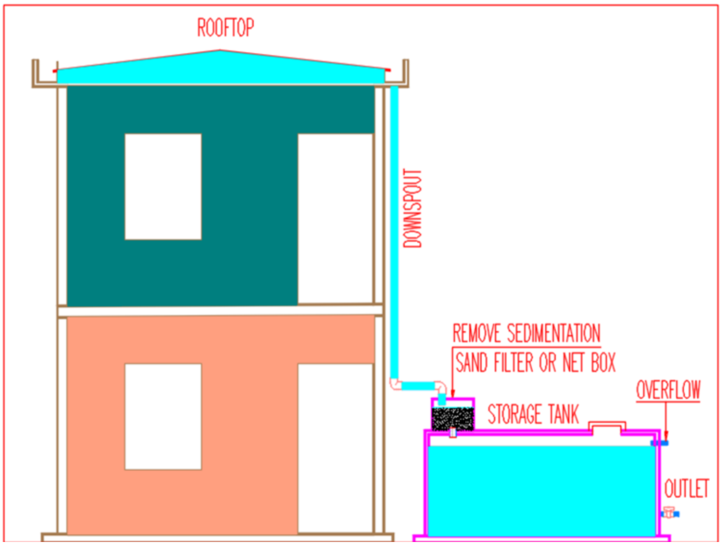


Fig.40. Conventional rainwater harvesting system

- Rainwater harvesting for drinking system (RWHD)

Based on the rainwater project for schools at Cukhe and Daicuong, RWHD system is promoted to apply widespread and the component of the system like as (Fig.41).

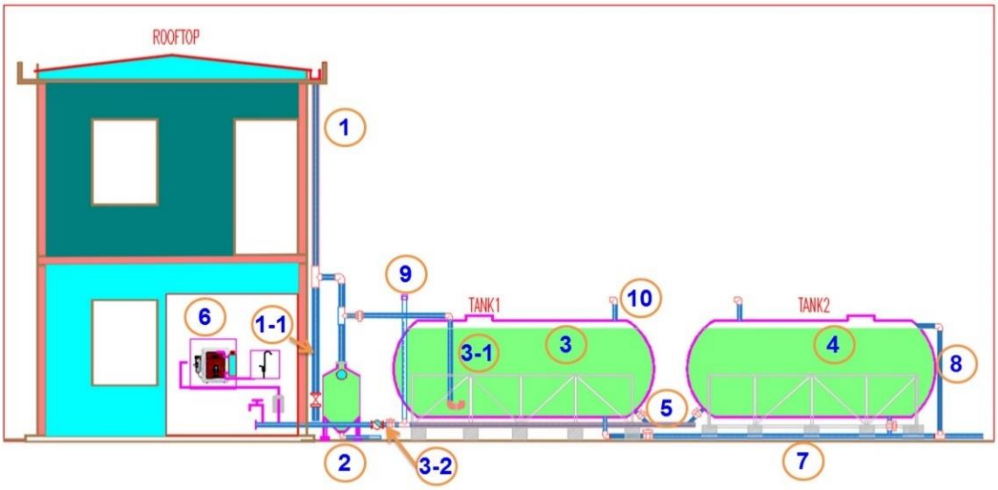


Fig.41. Rainwater harvesting for drinking system at community-bases

Table 17. Rainwater harvesting for drinking components

Symbol	***Component***	***Symbol***	***Component***
1	Gutter and downspout	5	Outlet
1-1	Urgent pipe	6	Filter-system
2	First-flush	7	Drain pipe
3	Settling tank	8	Overflow
3-1	Calm-inlet	9	Water level
3-2	Water meter	10	Ventilation
4	Storage tank		

The RWHD's principle:

Rainwater is collected from the roof to the gutter and the downspouts (1) system and then convey to the first-flush (2) before go to the settling tank (3) via the inlet pipe and calm-inlet device. Rainwater is conveyed continuously from settling to storage tank (4) by connection piping. From storage tank, rainwater continues to be conveyed to the treatment system (6) by pumping before supply drinking water for user. Other items are installed with RWHD system like water meter (3-2) and water level (9) to determines the water consumption per month in a whole year. They are the basic data to manage drinking water demand to guarantee the rainwater quantity for every month. When storage tank is full, rainwater is fall out via over-flow (8) and in the case, the urgent pipe (1-1) is opened to withdraw rainwater directly from catchment to the drainage system. Beside on, the urgent pipe is opened to drain all the dust, debris or leaf from first rain during rainy season of each year (starting on May). Drain pipe (7) is opened when the manager cleans tank, once per year.

5.3.2. Design guideline

5.3.2.1. Gutter and downspout

Currently, the design criteria of rainwater collection systems for public buildings are calculated to drain all rainwater into the sewers system. Most buildings use a part of the top floor as the gutter and convey collected rainwater to the downspouts system. Therefore, to harvest rainwater for RWHD system, a gutter should be installed on the top floor (Figure 31).

Gutter dimension is calculated according to the plumbing code and accordant with the roof area and rainfall condition. Rectangular shape is choosed for gutter because it is easy to be installed on the top floor (Fig.42). Downspouts of RWHS system is designed with 70mm diameter and connected with the urgent pipe (Fig.43). At the end of the urgent pipe, a valve is installed to control rainwater flow when rain falls heavily. Also, a valve drains all the sludge from rooftop when the first rain comes in rainy season of the year. Piping material is the PVC class0 (10 bar) for the pipes.

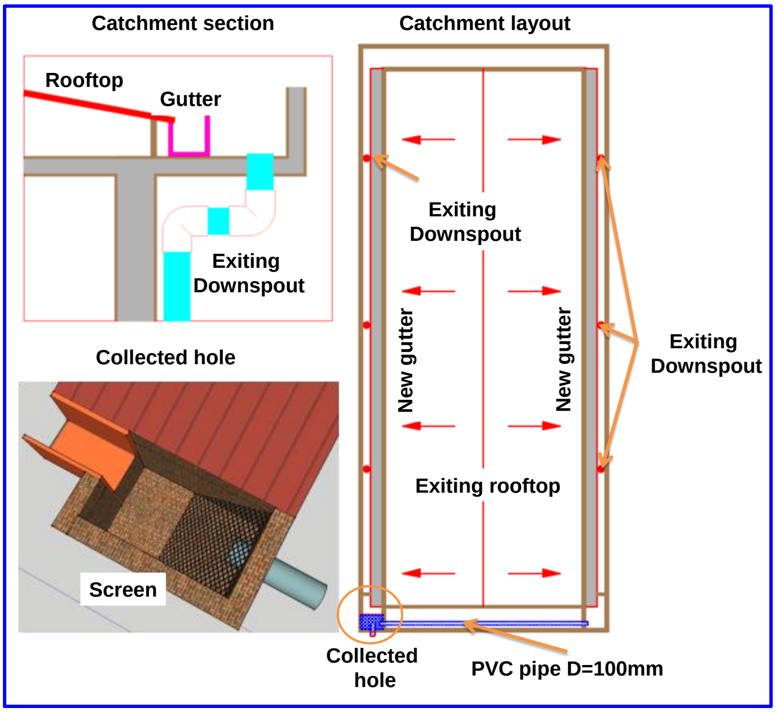


Fig.42. RWH catchment for school or community based

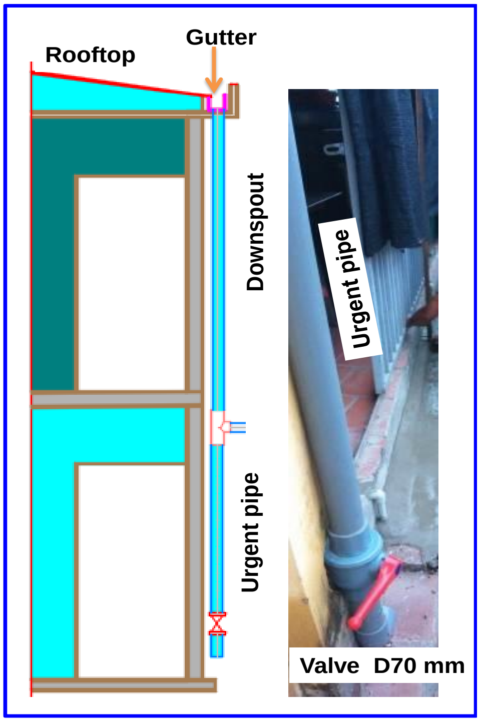


Fig.43. Downspout and urgent valve

5.3.2.2. First-flush

First-flush is installed first, in front of the settling tank. The function of the first-flush is to reduce the sedimentation, debris or leaf from catchment within 10 minutes of the rain. The dimension of the first-flush is calculated based on the exiting RWHD system and at the school with 200 – 500 m^2 catchment, the first-flush is around 250 L volumetric (Fig.44). The component includes the floating ball, managing gate, flange and drain valve. Floating ball is a plastic ball which is a component of the floating valve. Diameter of this ball is 90 – 110 mm (Figure 32). Using stainless steel to make the first flush and to connect with PVC downspout, the PVC flange is connected to first-flush inlet. The managing gate is used to check and change the floating ball in case it is broken or licking. The drain valve is opened after each the rain to drain sedimentation, and debris or contaminants from the rooftop. The valve diameter is 40 mm.

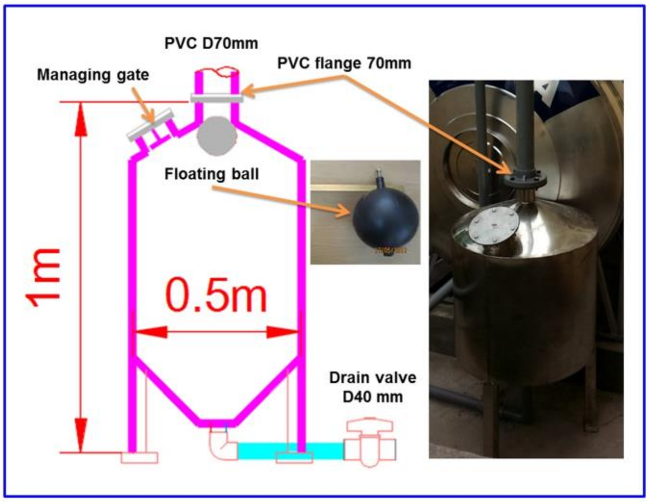


Fig.44. First-flush structure

5.3.2.3. Settling tank and storage tank

The settling tank and the storage tank have the same volume. They are connected by PVC class 1 (12,5 bar) pipe with 50 mm diameter (Figure 45). Rainwater is conveyed to the settling tank via the inlet pipe and calm-inlet device (Figure 46). Calm-inlet device can reduce the sludge mixing situation at the bottom of the settling tank. Also, it reduces the sedimentation transfer to the storage tank during the rain. Structure of calm-inlet includes two connected elbows and forming the U shape. The diameter is around 50 – 60 mm. The ventilation covers the grid to prevent the insect, and the diameter is

25 mm. Diameter of the drain pipe is 40 mm (depend on the factory) and the diameter of the over flow is 50 mm. The material of the piping is the PVC class 0 except the outlet of the storage tank. The outlet pipe is the PPR pipe with 20mm diameter.

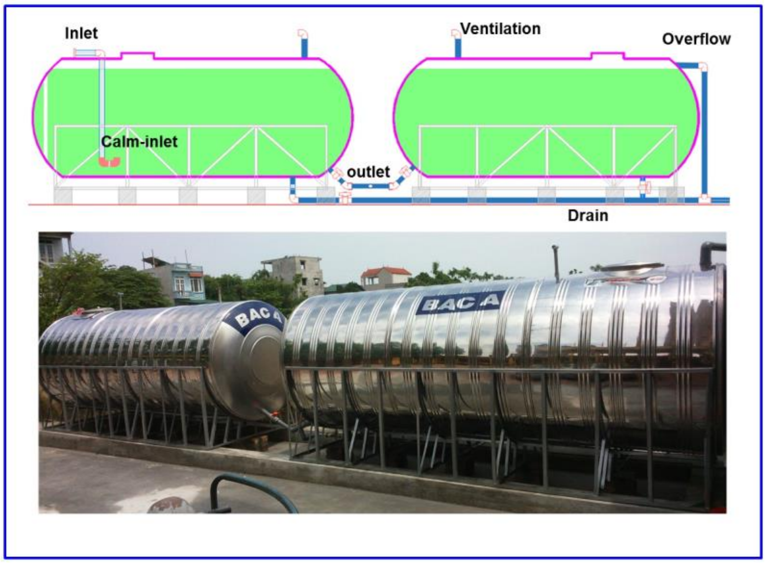


Fig.45. Settling and storage tank

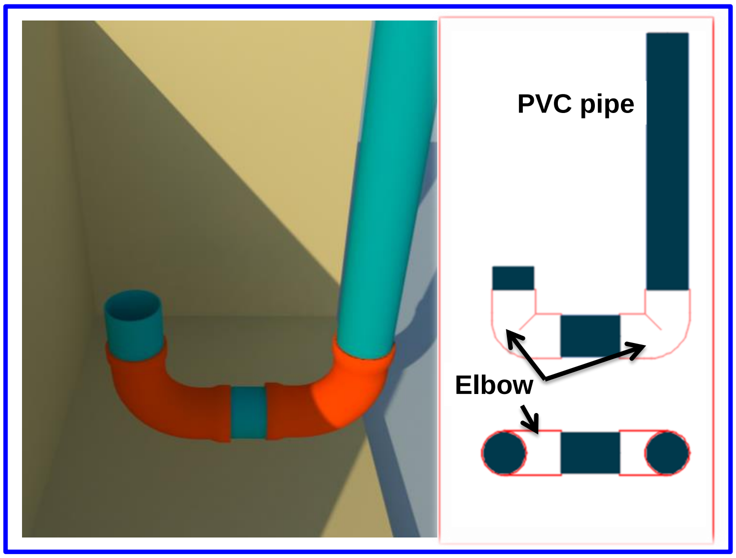


Fig.46. Calm-inlet structure

5.3.2.4. Rainwater treatment system

At present, there are many water treatment technologies for drinking purpose in Vietnam like RO system, membrane MF system and nano-filter system. RO system has been famous since 2005 and Nano filter just sold at Vietnam market from 2014. For rainwater harvesting system, RO system is not a suitable technology because it needs 1,5L rainwater to get 1L drinking water. Therefore, the rainwater quantity is not enough to fill the storage tank volume will be increate and it effect to the investment cost. Via the demonstration project at Cukhe and Kimbang, Nano-filtration system (Fig. 47) is a good option to treat rainwater for drinking. After treatment, all the drinking water parameters are guaranteed with Vietnam drinking water standard. Depend on the pumping capacity, flow rate of system from 200 – 300 L/day. Also, on the drinking demand at school, 1 or 2 system can be installed to supply drinking water for users.

Fig.47. Rainwater treatment system

5.3.2.5. Water meter, water level and drinking water delivery

The water level meter is installed to determine the amount of water left in the tank. Then, based on the data, the user adjust the drinking water demand to guarantee the rainwater consumption for every months of the year. The structure of water level includes a ruler put in the PVC pipe with 20mm diameter. Rainwater is stored in the acrylic pipe and connected to storage tank by PVC pipe. To avoid the algal, grow up inside the acrylic pipe, a mobilization pipe with 25 mm diameter covers the water level. In addition, water meter is installed to control the amount of monthly water usage. Also, it is the basis to determine the water consumption from which water-based solutions are suitable for the rainwater system installation. Water is stored in bottle and delivered to classrooms by student or teachers (Fig.48).

Fig. 48. Water meter & water level

5.3.3. Operation and Maintenance

The RWHD system will be operated when the manager knows much about the operation process as well as the system component like piping, valve system etc. The operation process of the system(Fig.49) :

- Valve (V) V1: frequently closes, and opens when it rains heavily and the first rain of the rainy season.
- V2: always and immediately open when the first-flush is repaired.
- V3: It is opened after the rain to empty first-flush before the next rain come.
- V4,5,6,7: Always and immediately open when a manager cleans settling and storage tank.

Operation process of the each RWHD component is also posted in table 10.

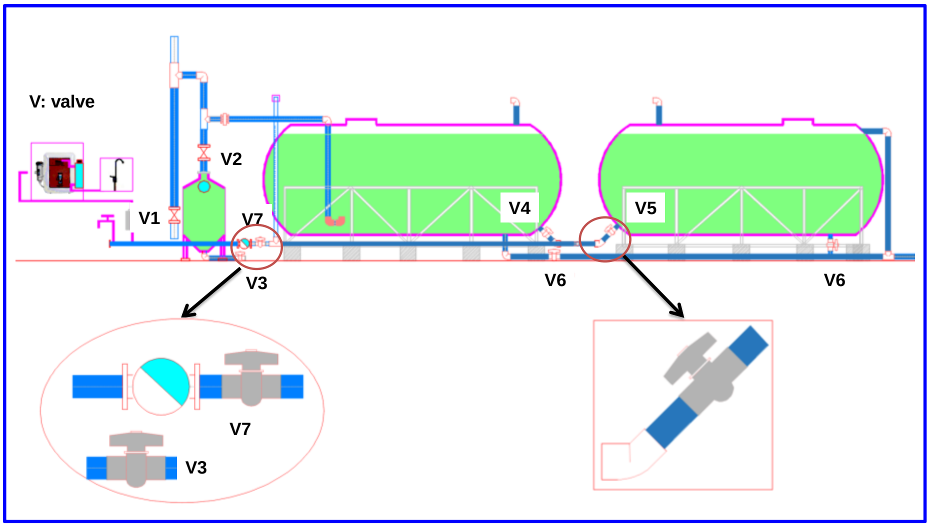


Fig.49. Piping and valve system to operate RWHD system

Table 18. Operation and Maintenance RWH system

Main components	Operation and Maintenance
Gutter & downspout	+ Every 3 months, manager should come to clean leaf on gutter and check the broken point + If gutter is broken, it should be changed to new one or repaired by workers
Urgent pipe	
First-flush	+ After the rain, a manager should open drain valve (V3) to throw all water and sludge in the first-flush tank + Change the floating ball, valve if it is broken
Settling & storage tank	+ Clean settling and storage tank 6 months /time and separate. Before clean should be use much water in the tank. + Immediately change the piping, valve if it is broken
Treatment system	
Pre-treatment	Replaced every 3 months
Filter cartridge	1. Sediment filter: replaced every 6 months 2. Pre carbon filter: replaced every 8 months 3. Nano-membrane: replaced every 8 months 4. Post carbon filter: replaced every 1 year 5. Mineral source: replaced every 2 years
UV sterilizer	UV will be switch on or off according to the operation of the pumping. UV lamp should be changed after 3600 hours
Pumping	Capacity is 200 – 300 L/day and flow rate is 1.8L/minute. Immediately replace pump if it broken
Piping system	Replace and repair if it is licking or broken

5.4. Strategy promotion to implement RWH system

To promote RHW system widespread, the stategy should be suggested to the government step by step to implement for rural, and suburban areas. Especially in the areas where suffer from the polluted water sources or limited clean water, the proposed legislation to the government include the social, economic and policy aspects. Participants include the government agencies, private sector, local communities, and local public places such as schools, people's committees, clinics, etc. (Fig.50).

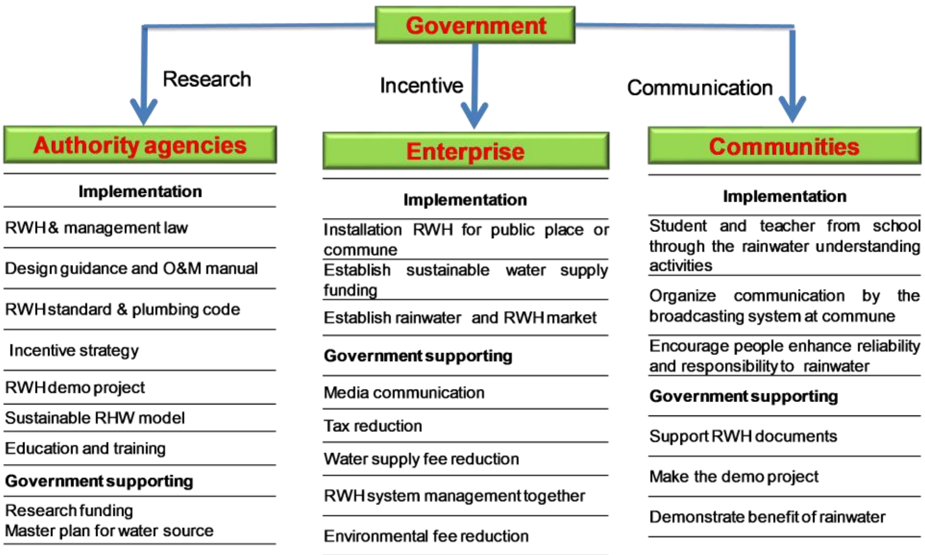


Fig50. Strategy promotion to Government

5.4.1. Authority agency

Authorities, such as specialized research institutes, government agencies, universities, colleges, etc., should be given the responsibility to undertake in-depth research on the subject. To collect rain water, it is important to find effective solutions to widely carry out the installation of rainwater collection system. Steps to carry out the research work include the following steps:

- **Education.**

Education includes both formal and informal instruction and learning. Formal education refers to in-class teaching in schools, vocational colleges and universities. However, informal education involves discussions and seminars about RWH among citizens, local groups, and communities. Both types of education are significant to promote RWH technology. Working with middle schools and high schools, and possibly through class projects, the benefits of RWH can be spread to the minds of young students. Then, they can share the technology with their parents. Some people asked for more information on RWH first learnt the idea from their children.

- **Training**

For those already in the workforce, training courses offered by authority agency can be very useful. The universities have a vast network of engineering and agricultural/cooperative extension services in the country that can/should organize training in RWH. Since their primary role is to disseminate knowledge, this would be an ideal field to provide training.

- **RWH demo project**

It is a good idea to install RWH systems at public facilities such as schools, libraries and community centers even if there is not much of a profit for the installer. Once people see the benefits of RWH, it will spread, and help the installer's business to grow. In some cases, there may be limited funds available for capital expenses and not enough for labor. However, it should not discourage the challenges for RWH business. New businesses have to put a lot of effort to be recognized and to ultimately become successful.

- **Design guidance and O&M manual**

Currently, rainwater management concept in Vietnam is to collect rainwater from catchment like rooftop, parking, and road via the piping system. Then, the rainwater is conveyed to the drainage system of the city or town, etc… However, the concept is changing to the RWH system. However, it is still limited at the scientific area and there are not much advanced research for RWH system. To promote RWH system widely, the design guideline, O&M should be written and suggested to the government to make the RWH standard. Also, it should add plumbing code to apply for construction standard.

- **Incentive strategy**

Due to the rainwater management concept, most of the social components from people, agencies, organizations, the private sector, and the government agencies are not responsible to design RWH system for their buildings. Also, they are not interested to the rainwater management situation. In order to change the perspective of people about RWH system, to encourage the involvement of social sectors to the government program to implement the propaganda. Also, to cooperate with the government agencies to install RWH or support for advance research is crucial. The incentive strategy is also composed to ensure that economic, environmental and social factors are balanced to encourage the private sector to engage in the collection and treatment of rainwater.

- **Authority agency**

Authorities, such as specialized research institutes, government agencies, universities, colleges, etc., should take a responsibility to undertake in-depth research on the subject. To collect rainwater, find practical solutions to carry out the installation of the rainwater collection system widely. Steps to carry out the research work include the following steps:

- **Education.**

Education includes both formal and informal instruction and learning process. Formal education process refers to classroom teaching in schools, vocational colleges, and universities. While informal education process involves the discussion of and seminars about RWH to citizens, local groups, and at community events. Both types of the learning process are needed to promote RWH technology. Working with middle schools and high schools, and possibly through class projects, the benefits of RWH can be imbibed into the minds of young students, who can apply learned technology at home with their parents.

- **Training**

For those who are already in the workforce, the training courses which were being offered by authority agency could be beneficial. The universities have a vast network of engineering and agricultural/cooperative extension services in the country which can organize the training system of the RWH. Since their primary role is to disseminate knowledge, this would be an ideal field in which to provide training.

- **RWH demo project**

It is a good idea to install RWH systems at public facilities such as schools, libraries, and community centers even if there is not much of a profit for the investor. Once people see the benefits of RWH, there will be enough publicity generated, and would likely help the installer in growing his or her business. In some cases, there may be limited funds available for capital expenses and not enough for labor, but that should not discourage those venturing into the RWH business. New businesses may have to invest many hours of volunteer effort to be recognized and to ultimately become successful.

- **Design guidance and O&M manual**

Currently, rainwater management concept in Vietnam is collecting rainwater from catchments like rooftop, parking, and road via the piping system and convey to the drainage system of the city or town, etc.… However, this concept is changing to the RWH system but it still limited at the scientific area and not much advance research for RWH system. To promote RWH system widely, the design guideline, O&M should be written and suggest to Government to make the RWH standard and adding to plumbing code to apply for construction standard.

- **Incentive strategy**

Due to the rainwater management concept, most of the social components from people, agencies, organizations, the private sector, and Government agencies are not responsible for designing RWH system for their building and they not interested to the rainwater management situation. For the changes of the standpoint of people with the RWH system, it is necessary to encourage the social sectors to involve to the Government program to implement the propaganda and also cooperate with Government agencies to install RWH or support for advanced research. The incentive strategy is also composed to ensure that economic, environmental, and social factors are balanced to encourage the private sector to engage in the collection and treatment of rainwater.

5.4.2. Enterprise or private sector

- **Install rainwater harvesting for public place or community-based**

At community-based in a rural area like school, committee office, etc.., to help people approach the clean water as well as the drinking water, install RWHD system is the reasonable solution with high benefit and short refund. The enterprise or company can cooperate with the community- based, especially the school to install RWHD system and also contact with the local agency or Government agency to make incentive regulation like tax reduction, environmental fee, etc. In addition, the local bottle Water company, the cooperation with school to install RWHD system and in the rainy season the local company can produce drinking water from school RWH facility and especially in the summer within 3 months, the company can use all rainwater to provide bottled water and get benefit from this RWHD system.

- **Availability of Credit.**

The enterprise can make environmental funding and so that they would be comfortable in providing loans to homeowners when needed. Even if architects and engineers design a good RWH system, if a homeowner cannot secure a loan for his home and the RWH system, the project may be a failure. Therefore, it is always a good idea to keep local lenders, and their agents informed about RWH technology, by inviting them to attend seminars and join its demonstrations.

5.4.3. Communities

- **School activities to communicate RWH system**

A school is an excellent place to install RWH system as well as to implement the communication for its system through many activities such as education, training, student contest. Moreover, parents can realize the feasibility of the rainwater utilization through their children and the benefit they get from the RWH system. Besides, the student activities on rainwater is also a proper action to get large attractive from the community such as villager, local officer, resident or even from authority's officer from the district, province.

Therefore, it is always a good idea to keep local lenders, and their agents informed about RWH technology, by inviting them to attend seminars and join its demonstrations.

- **Organize communication by the broadcasting**

To enhance the awareness of people in the community and to know the benefit of rainwater and rainwater harvesting system, the propaganda and guidance from the committee are very important. In Vietnam, every community has a public radio room, and they are often open at 5 pm to communicate about culture, social, farming etc…. So base on this system the committee can talk about rainwater and rainwater education to people, guidance to villager how to install and benefit of RWH like good quality, sustainable source, environment protection, etc.

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CHAPTER 6: CONCLUSION AND RECOMENDATIONS

6.1. Conclusion

Nowadays, water scarcity is a widespread issue in many countries (Jungou Liu, 2015) and Vietnam is also facing it. To solve this problem, Vietnam Government focuses on exploited surface and groundwater. While rainwater is plentiful water sources and rainwater harvesting for domestic has been installed for a long time in Vietnam, it still has gradually declined.

The reason for this situation is the viewpoint of people, even the Government on the role of rainwater. During the implement rainwater harvesting for drinking projects in Vietnam, barriers to development RWH system is identified through technical, economic and social aspects. However, barriers are also solved through the demo RWH system for drinking at school in rural area of Vietnam. Basically, the problem and solution to overcome barriers are shown in Fig.51. Based on demo RWH system and solution, a strategy to promote rainwater for drinking is suggested to Vietnam Government.

For technical barriers, lack design guideline and manual to install RWH system and the standard from authority agencies, professional manpower, etc.

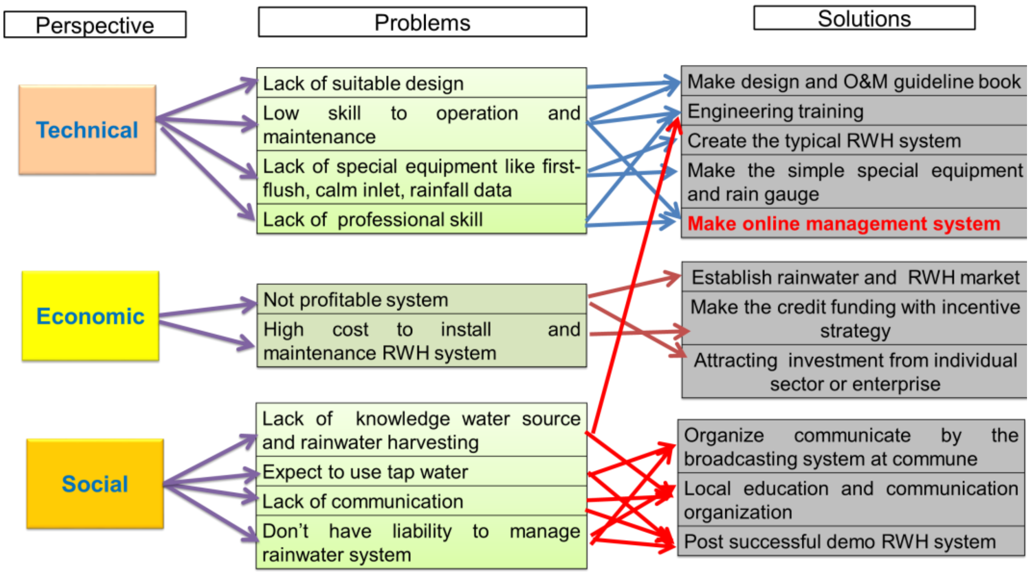

Fig.51. Solution to overcome barrier of rainwater harvesting system

Besides on the socio-economic obstacles such as the installation cost of the RWH system is still high, over 50% cost compare with their income for small capacity, seem like have not seen the benefits system. People's acknowledge on rainwater harvesting system as well as the rainwater quality is limited because lacking communicates to people. These are the main barriers to the widespread installation of rainwater harvesting system in Vietnam

During the 2014 – 2018 period, four demo RWH systems are designed and installed for school at Cuykhe and Daicuong communes. The capacity of these systems is 12 m3 and 16m3 respectively with simple technical include first-diverter, first-flush, calm-inlet, separation storage tank and Nano treatment system. After two years, monitoring; operation and maintenance the result showed that most of the rainwater quality parameters (26 parameters) in the storage tank are meet Vietnam’s drinking water standard (QCVN: 06- 2010, appendix 2) except the microorganism like Coliform and Ecoli. However, it will be met standard after treated by the Nano filtration system. Beside on, the RWH system can increase the drinking water quantity, from 0.3 – 0.4 L/student/day to 0.5 -0.6 L/student/day for a student in the whole year.

For the socio-economic aspect, drinking water fee of student can reduce 45% – 50% after RWH installed and the payback cost is 5 -6 years for RWH system. To promote the installation of RWH systems more widely in the community, it should be installed as schools, health centers, etc….

The communication can implement from the school through the student and teacher activities such as education, training, contest, event, etc. These activities are a large positive impact on the villager and communities.

6.2. Recommendations

Recent years, many areas in Vietnam are facing the shortage of clean water situation like water salinization at Mekong Delta River, ground contaminated at Hong delta river by Arsenic or surface water polluted. For the improvement of the approachability of fresh water, rainwater harvesting is an excellent solution to supplement water supply, especially for drinking and it is a sustainable water source. Rainwater harvesting system will be installing widespread when the people understanding about the role of rainwater as well as to see the benefit of this system with their life. Therefore, the Government should compose a strategy to promote RWH system widespread in communities. A strategy suggestion below can help the Government give the proper orientation to promote RWH widely:

Firstly, community RWH should be established and operated with self-monitoring and operation. Secondly, technical design guidelines improving rainwater quality as well as operation and maintenance manual should be provided. Technical training for owner should be made by expert or engineers. Thirdly, encourage the private sector or enterprise to implement RWH for community by the incentive strategy. In addition, a market for rainwater harvesting equipment should be established. Fourthly, to promote RWH system widely, the communication can be implemented in the school through the student and teacher activities such as education, training, contest, event etc. These activities bring large positive impacts to the villagers and communities.

Finally, Vietnam Government should support research activities to build a design and O&M guideline based on successful demo RWH system of different types, to implement laws and regulations to promote RWH by providing financial incentives, and to encourage people to harvest rainwater for various purposes.

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박사학위논문

빗물 이용으로 베트남의 지속 가능한 식수를 증진시키기 위한 전략

Dao Anh Dung

지도교수: 한 무 영

이 논문을 박사 학위논문으로 제출함

서울대학교 건설환경공학부

초록

빗물 이용으로 베트남의 지속 가능한 식수를 증진시키기 위한 전략

서울대학교 대학원 건설환경공학부

Dao Anh Dung

현재 베트남의 식수 문제는 인구 증가와 급속한 도시화, 수질 악화 및 수자원 과잉개발로 인하여 빈번해지고 있다. 현재까지 급수 시스템은 빗물을 배제하고 지표면과 지하수를 이용한 중앙 집중식 시스템에 매우 의존적이었다. 그러나, 기존의 중앙 집중식 급수는 많은 문제, 즉 오염된 지표수 및 지하수, 가뭄, 염류화로 인하여 제한된 수자원 (양과 질 모두)에 직면 해있다.

베트남에서는 수십 년 동안 빗물 이용(약 1,680 mm 의 상대적으로 높은 연강수량)을 농촌 지역의 자연 기반 솔루션으로 널리 사용해왔다. 그러나 최근에, 베트남 정부로부터 빗물 식수화가 많은 주목을 받았다. 그래서 본 연구는 기술적, 경제적, 사회적 장벽을 파악하기 위해 베트남에서 데모 빗물이용 시스템을 구현하였고, 이를 극복하기 위한 적절한 전략을 제안하였으며 베트남 정부를 위해 빗물 이용이 널리 확산될 수 있도록 촉진하였다.

기술적 장벽에는 빗물 이용을 위한 설계 지침과 매뉴얼, 전문적인 기술 및 확립된 시장의 부족이 있다. 반면에 경제적 장벽은 설치 및 유지 보수가 너무 비싸고 수익 창출 시스템이 아니라는 것이다. 사회적 장벽은

(a) 빗물 및 빗물 이용 시스템에 대한 지식과 (b) 사용자와 이해 관계자간의 의사 소통의 부족, (c) 수돗물 설치에 대한 높은 기대치가 있다.

기술적, 경제적, 사회적 장벽을 극복하기 위해 베트남 농촌 지역의 학교에 4 개의 데모 빗물 이용 시스템이 설치되었고, 수년간 모니터링 되어왔다. 이러한 데모 시스템을 통해 빗물 이용의 지속 가능성이 입증되었다. 기술적으로 빗물의 수질은 베트남 음용수 수질 기준(QCVN 01-2009)에 만족한다. 건기에는 물을 비축할 수 있다. 유지 보수 비용은 물 구매 비용을 줄임으로써 모을 수 있다. 학교의 과학 동아리가 빗물 이용 시스템의 정기적인 유지를 담당한다. 모든 마을 사람들은 빗물 교육 및 홍보 활동에 참여해야 한다.

베트남에서 지속 가능한 식수를 증진하기 위하여 새로운 전략이 제안된다. 첫째, 지역 사회의 빗물 이용은 자체 모니터링과 운영을 통해 설립되고 운용되어야 한다. 둘째, 빗물 수질 향상뿐만 아니라 운영 및 유지 관리 매뉴얼을 위해 기술적인 설계 지침과 훈련이 제공되어야 한다. 셋째, 인센티브 전략을 통해 민간 부문 또는 기업이 지역 사회를 위해 빗물 이용을 시행하도록 장려해야 한다. 또한 빗물 이용 장치 관련 시장이 확립되어야 한다. 넷째, 빗물 이용 시스템을 널리 홍보하기 위해 교육, 훈련, 경연 대회, 행사 등과 같은 학생과 교사의 활동을 통해 학교에서 의사 소통이 이루어져야 한다. 이러한 활동은 마을 주민과 지역 사회에 큰 긍정적인 효과를 가져온다. 마지막으로, 베트남 정부는 재정적인 인센티브를 제공함으로써 빗물 이용을 촉진하고, 사람들이 다양한 목적으로 빗물을 이용할 수 있도록 장려하기 위해 연구 활동을 지원하고 법과 규정을 시행해야 한다.

키워드: 장벽; 지역 사회 기반 빗물 이용; 식수 공급; 빗물 이용 설계; 전략; 지속가능성.

학번: 2008-31109

Appendix 1: List of the domestic water quality parameter and allowable limit

N0	Parameter	Unit	Allowable limit
A group			
	Microorganism		
1.	Coliform	CFU/100 mL	<>
2.	E.Coli or fecal Conform	CFU/100 mL	<>
	Inorganic		
3.	Arsenic (As)(*)	mg/L	0.01
4.	Clo^{-}(**)	mg/L	From 0,2 - 1,0
5.	Turbidity	NTU	2
6.	Color	TCU	15
7.	Odor	-	Nothing
8.	pH	-	From 6,0-8,5
B group			
	Microorganism		
9.	(Staphylococcus aureus)	CFU/ 100mL	<>
10.	(Ps. Aeruginosa)	CFU/ 100mL	<>
	Inorganic		

11.	Amoni (NH_3 và NH_4^+)	mg/L	0,3
12.	Antimon (Sb)	mg/L	0,02
13.	Bari (Bs)	mg/L	0,7
14	Bor and Borat and axit Boric (B)	mg/L	0,3
15.	Cadmi (Cd)	mg/L	0,003
16.	(Plumbum) (Pb)	mg/L	0,01
17.	pecmanganat	mg/L	2
18.	Chloride (Cl^-)(***)	mg/L	250 (hoặc 300)
19.	Chromi (Cr)	mg/L	0,05
20.	Cuprum) (Cu)	mg/L	1
21.	Hardness CaCO3	mg/L	300
22.	Fluor (F)	mg/L	1,5
23.	(Zincum) (Zn)	mg/L	2
24.	Mangan (Mn)	mg/L	0,1
25.	Natri (Na)	mg/L	200
26.	(Aluminium) (Al)	mg/L	0.2
27.	Nickel (Ni)	mg/L	0,07
28.	Nitrat (NO_3^-)	mg/L	2
29.	Nitrit (NO_2^-)	mg/L	0,05
30.	Ferrum (Fe)	mg/L	0,3
31.	Seleni (Se)	mg/L	0,01

32.	Sunphat	mg/L	250
33.	Sunfua	mg/L	0,05
34.	(Hydrargyrum) (Hg)	mg/L	0,001
35.	Total suspended solid (TDS)	mg/L	1000
36.	Xyanua (CN)	mg/L	0,05
	Organic		
	a Alkan group		
37.	1,1,1 -Tricloroetan	µg/L	2000
38.	1,2 - Dicloroetan	µg/L	30
39.	1,2 - Dicloroeten	µg/L	50
40.	Cacbontetraclorua	µg/L	2
41.	Diclorometan	µg/L	20
42.	Tetracloroeten	µg/L	40
43.	Tricloroeten	µg/L	20
44.	Vinyl clorua	µg/L	0,3
	b. Hydrocacbua thơm		
45.	Benzen	µg/L	10
46.	Etylbenzen	µg/L	300
47.	Phenol và dẫn xuất của Phenol	µg/L	1
48.	Styren	µg/L	20

49.	Toluen	µg/L	l 700
50.	Xylen	µg/L	500
	c. Benzen Clo group		
51.	1,2 - Diclorobenzen	µg/L	1000
52.	Monoclorobenzen	µg/L	300
53	Triclorobenzen	µg/L	20
	d. Organic compound		
54.	Acrylamide	µg/L	0,5
55.	Epiclohydrin	µg/L	0,4
56.	Hexacloro butadien	µg/L	0,6
57.	1,2 - Dibromo - 3 Cloropropan	µg/L	1
58.	1,2 - Dicloropropan	µg/L	40
59.	1,3 - Dichloropropen	µg/L	20
60.	2,4-D	µg/L	30
61.	2,4 - DB	µg/L	90
62	Alachlor	µg/L	20
63.	Aldicarb	µg/L	10
64.	Atrazine and chloro-s- triazine	µg/L	100
65.	Carbofuran	µg/L	5
66.	Chlorpyrifos	µg/L	30

67.	Clodane	µg/L	0,2
68.	Clorotoluron	µg/L	30
69.	Cyanazine	µg/L	0,6
70.	DDT	µg/L	1
71.	Dichloprop	µg/L	100
72.	Fenoprop	µg/L	9
73.	Hydroxyatrazine	µg/L	200
74.	Isoproturon	µg/L	9
75.	MCPA	µg/L	2
76.	Mecoprop	µg/L	10
77.	Methoxychlor	µg/L	20
78.	Molinate	µg/L	
79.	Pendimetalin	µg/L	20
80.	Permethrin Mg/t	µg/L	20
81.	Propanil Uq/L	µg/L	20
82.	Simazine	µg/L	2
83.	Trifuralin	µg/L	20
	Disinfection chemical production		
84.	2,4,6 - Triclorophenol	µg/L	200
85.	Bromat	µg/L	10

86.	Bromodichloromethane	µg/L	60
87.	Bromoform	µg/L	100
88.	Chloroform	µg/L	300
89.	Dibromoacetonitrile	µg/L	70
90.	Dibromochloromethane	µg/L	100
91.	Dichloroacetonitrlle	µg/L	20
92.	Dichloroacetic acid	µg/L	50
93.	Formaldehyde	µg/L	900
94.	Monochloramine	µg/L	3,0
95.	Monochloroacetic acid	µg/L	20
96.	Trichloroacetic acid	µg/L	200
97.	Trichloroaxetonitril	µg/L	1
	Radiation		
98.	Total radioactivity α	Bg/L	0,1
99.	Total radioactivity β	Bg/L	1,0

Note:- *(*) application for groundwater exploitation only*

- *(**) application for treated water, which use Chloride for disinfection*

- *(**) application for coastal and island*

- *(***) No unit.*

The water supply treatment plant should take sampling and analysis all parameter of the group A and B following cases:

+ Before operation and supply water to distribution network

+ After rebuild or expand the water supply treatment plant

+ If the environmental accident, which affect to the clean water quality.

+ If the rick from the production process affect to the water quality.

+ All parameter will analysis after each 3 years.

I. First test				
Parameter	**Sampling**	**Standard**	**Analysis method**	**Parameter category**
1. E. coli or fecal coliform	1 x 250 ml	0	TCVN 6187-1:2009 (ISO 9308-1:2000, With Cor 1:2007)	A
2. Total oliform	1 x 250 ml	If bacteria >1 and < 2 then do the second test	TCVN 6187-1:2009 (ISO 9308-1:2000, With Cor 1:2007)	A
3. Streptococci feacal	1 x 250 ml	If bacteria >2 then cannot use the water	ISO 7899-2:2000	A

4. Pseudomonas aeruginosa	1 x 250 ml		ISO 16266:2006	A
5. Scope of the Sulfite anaerobic bacteria	1 x 50 ml		TCVN 6191-2:1996 (ISO 6461-2:1986)	A

Appendix 2: Survey and investigation on rainwater harvesting

SURVEY AND INVESTIGATION ON WATER AND RAINWATER UTILIZATION IN SCHOOL (BEFORE RWH INSTALLATION)

Name :...Trần Van Hao...

Age:...40...

Address:...Dai Cuong commune, Kim Bang, Ha Nam

Occupation:...Farmer...

1	Basic question
1.1	How many members in your family? 5
1.2	How about member old in your family? 8 - 45
1.3	Where your income sources come from? Via field
1.4	How much money your family earns per month? 7.600.000 VND
1.5	How about education level in your family? high school
2	**Water supply status**
2.1	What kind of the water do you use for domestic? a.Tap water; b. shallow well; c. bottled water; d. tube well; e. Rainwater; f. surface water
2.2	What kind of the treatment method do you use? a. Boiling; b. drink directly; c. Sand filter; d. filtration machine
2.3	Why do you select this water source to use? a. Cheap price; b. near house; c. clean and safety; d. everybody using
2.4	What kind of the water source do you want to replace the current water source? a. Tap water; b. shallow well; c. bottled water; d. tube well; e. Rainwater; f. surface water
2.5	Why do you want to replace? a. Cheap price; b. near house; c. clean and safety; d. everybody using
2.6	What kind of the water source do you use for drinking and cooking? a. Tap water; b. shallow well; c. bottled water; d. tube well; e. Rainwater; f. surface water
2.7	Do you attend any train course about clean water treatment? No
2.8	Evaluate water source
2.8.1	How do you think about tube well water? a. Very dirty; b. dirty; c. normal; d. clean; e. very clean
2.8.2	How do you think about rainwater?

	Very dirty; b. dirty; c, normal; d. clean; e. very clean
2.8.3	How do you think about bottled water?
	Very dirty; b. dirty; c, normal; d. clean; e. very clean
2.8.4	How do you think about tab water?
	Very dirty; b. dirty; c. normal; d. clean; e. very clean
	How do you think about tap water after filtration?
	Very dirty; b. dirty; c, normal; d. clean; e. very clean
3	Rainwater understanding
3.1	Do you install rainwater harvesting? Yes
3.2	Which is purpose you want to use rainwater?
	a. Drinking and cooking ; b showing; c. washing; d. toilet
3.3.	How many times do you clean rainwater tank?
	a. 2-3 times/year b. over 4 times/year; c. 1time/year;
	d. 2years/time e. over 3 year/time
3.4	Do you collect rainwater at the first 10 minute? No
3.5	Do you install first flush? No
3.6	How often do you clean the rooftop? 6 months
3.7	How do you use rainwater for drinking?
	a. Boiling; b. filtration machine; c. drink directly;
	b. d. don't know
3.8	How to install rainwater harvesting?
	a. design guideline; b. Experience; c. Worker;
	b. d. don't know

SURVEY AND INVESTIGATION ON WATER AND RAINWATER UTILIZATION IN SCHOOL (AFTER RWH INSTALLATION)

Name :...Tran Van Hao...

Age:...40...

Address:...Dai cuong Commune, Kim Bg Hanam

Occupation:...Farmer...

1	Basic question
1.1	How many members in your family? 5
1.2	How about member old in your family? 8 - 45
1.3	Where your income sources come from? Rice field
1.4	How much money your family earns per month? 8,000,000
1.5	How about education level in your family? High school
2	Rainwater understanding
2.1	Do you install rainwater harvesting? Yes
2.2	Which is purpose you want to use rainwater? b. Drinking and cooking ; b showing; c. washing; d. toilet
2.3.	How many times do you clean rainwater tank? b. 2-3 times/year; b. over 4 times/year; c. 1time/year; d. 2years/time e. over 3 year/time
2.4	Do you collect rainwater at the first 10 minute? Yes
2.5	Do you install first flush? No
2.6	How often do you clean the rooftop?
2.7	How do you use rainwater for drinking? c. Boiling; b. filtration machine; c. drink directly; d. d. don't know
2.8	How to install rainwater harvesting? c. design guideline; b. Experience; c. Worker; d. d. don't know
3	People satisfaction for RWH system in school
3.1	Do you drink rainwater in school? Yes
3.2	How satisfied do you think for rainwater quality after filter? a. Very un-satisfied; b. un-satisfied; c. normal; d. satisfied; e. Strongly satisfied
3.3	How satisfied do you think for rainwater quantity? a. Very un-satisfied; b. un-satisfied; c. normal; d. satisfied; e. Strongly satisfied
3.4	Are you satisfaction with operation of the system? a. Very un-satisfied; b. un-satisfied; c. normal; d. satisfied; e. Strongly satisfied

3.5 RWH system is a sustainable solution to solve the water crisis situation in Vietnam. How do you think about it?

a. Very un-satisfied; b. un-satisfied; c. normal; d. satisfied;
e. Strongly satisfied

3.6 RWH system is still good? How do you think?

a. Very un-satisfied; b. un-satisfied; c. normal; d. satisfied;
e. Strongly satisfied

3.7 How do you expectation if RWH is promoted spread?

a. Don not want; b. not expectation; c. consider;
d. expectation; e. strongly expectation.

3.8 How do you think who should be support to install RWH?

a. Government; b. private sector or research center;
c. Local people.