Rainwater for drinking in Vietnam: barriers and strategies

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ABSTRACT

For many decades in Vietnam, rainwater harvesting has been widely used as a nature-based solution in rural areas, aiming at good-quality drinking water with low cost and little energy. Recently, rainwater for drinking has attracted much attention from the Vietnam government. Furthermore, despite its efforts, the outcomes are not as expected due to local barriers. This paper reviewed rainwater for drinking demonstration projects in some specific areas of Vietnam, with identification of the technical, economic, and social barriers, further suggesting possible overcome strategies. A lesson learnt from this study would be the principle of promoting rainwater for drinking in developing countries, looking forward to sustainability.

Key words | barriers, drinking rainwater, rainwater harvesting, strategies, water supply

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INTRODUCTION

A sufficient and clean drinking water supply is essential for life and is set as one of the targets in Sustainable Development Goal 6 (SDG6: Ensure availability and sustainable management of water and sanitation for all) (UNDP 2015). Regardless, the world has been suffering from water shortage. The World Health Organization has reported that 783 million people lack enough water to simply meet their basic needs (WHO/UNICEF 2013). The drinking water supply problems are related to the water demand, water pollution, and emerging pollutants. In developing countries, including Vietnam in particular, drinking water problems are more common due to high population growth, rapid

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urbanization, degradation of water quality, and overexploitation of water resources.

To date, the urban water supply has significantly depended on the centralized system using surface and groundwater, with negligible rainwater. However, the conventional centralized water supply is facing many issues, such as limited water resources (both quality and quantity), because of contaminated surface/groundwater, drought, and salinization (Semra *et al.* 2011; Agusa *et al.* 2014; Wilbers *et al.* 2014; Gugliotta *et al.* 2017). Moreover, the construction and operation of centralized water supply networks require too much cost, time, and effort.

In contrast, in recent years, decentralized rainwater harvesting (RWH) has attracted much attention as a nature-based solution of safe drinking water supply to solve the Sustainable Development Goals (SDGs) in Vietnam (Semra *et al.* 2011; Nguyen *et al.* 2013; Nguyen & Han 2014, 2017a, 2017b; Dao *et al.* 2017). Many researchers have reported that rainwater quality in this region is good and can be supplied as drinking water. Vietnam receives a relatively high yearly precipitation of around 1,800 mm. Although much effort has been put into the potential of implementing RWH in Vietnam, the outcomes were not as expected. Efforts have been stopped at research, and there are not many implemented RWH systems in practice, so far. In fact, rainwater has seldom been considered as a drinking water source, although it has been practiced for many decades in rural Vietnam as a traditional water supply method. There may have been barriers to implementing RWH, which should be overcome by innovative strategies and successful case studies. Most of the current studies focus on the quality, design, and evaluation of RWH. Almost no studies reported why these efforts did not bear the expected results and how to overcome this.

During 2008–2017, we visited villages in both the Red River Delta and the Mekong Delta regions, which are the two largest deltas in Vietnam, and surveyed and carried out rainwater for drinking (RFD) projects for the residents who are facing water problems. We would like to share our practice of promoting RFD in Vietnam. This paper reviewed existing RFD systems in some specific areas of Vietnam, with identification of the barriers (i.e., technical, economic, and social aspects), and further suggested possible strategies to overcome them. The lesson learnt would be a principle for enhancement of RFD, looking forward to the SDGs.

RESEARCH METHODOLOGY

Literature review and survey

Reported RFD systems in Vietnam were reviewed. Based on the findings of these reports and studies, the barriers to implementing RFD in Vietnam were examined. The barriers to RFD in Vietnam have also been identified based on a practical field experiment during the implementation of the demo projects which were made by the authors from 2008 to 2017. We surveyed and examined the structure, implementation, and status of existing RFD systems for households and public schools in Red River Delta villages (Lai Xa, Ha Noi; Cu Khe, Ha Noi, Kim Bang, and Ha Nam (2008–2016)) and the Mekong Delta (Ben Tre (in 2017)) (Figure 1). In both two surveyed delta regions, people are suffering from water shortages for many reasons, including arsenic contamination of groundwater (Red River Delta), salinization (Mekong Delta), and lack of a centralized and distributed water supply system. More than 100 households were interviewed about their experience, opinion, challenges, and suggestions on using rainwater. The questionnaires covered the reliability of the rainwater quality and quantity, the difficulty of installing, operating, and maintaining RFD systems both in technical and economic terms. Furthermore, rainwater quality was also checked by both field and experimental tests during the survey.

Demonstration project

During the project, we installed potable RWH systems for poor households and public schools in the surveyed areas. The existing RWH systems were checked and the installed technologies were developed year by year. After almost ten years of implementing RWH, many pragmatic findings and innovative technologies were applied and improved as natural-based solutions to develop sustainable rainwater for the drinking water supply system in Vietnam (Figure 2). A typical RWH system generally consists of three main parts: (1) pre-storage (rooftop catchment, gutter, downpipe, and screen) which aims to collect, transfer, and pre-treatment of rainwater to

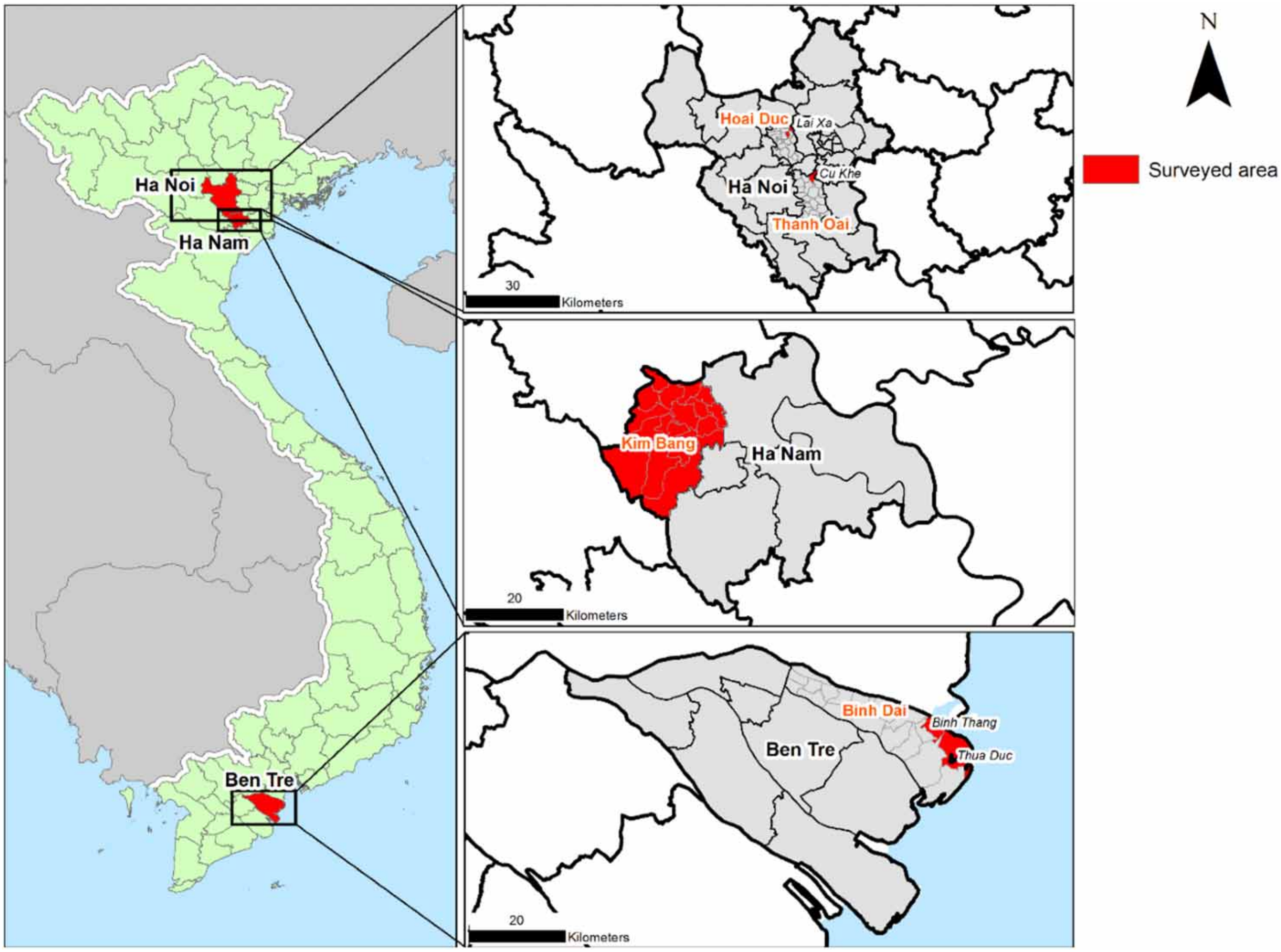

Figure 1 | Location of surveyed regions. Ha Noi (Lai Xa and Cu Khe): altitude of 10 m, latitude of 21° 01′ 28″ north, and longitude of 105° 50′ 28″ east; Ha Nam (Kim Bang): altitude of 6 m, latitude of 20° 35′ 60″ north and longitude of 105° 51′ east; and Ben Tre: altitude of 10 m, latitude of 10° 14′ 29″ north, and longitude of 106° 22′ 33″ east. (Adopted from http://dateandtime.info, accessed on 30th May, 2019.).

storage tank; (2) storage and accessories (rainwater tank, calm-inlet, drain, overflow pipe, ventilation, and manhole) where rainwater can be stored for use and stored rainwater quality can be improved during storing; and (3) point of use treatment (tap, filter, disinfection, or boiling) to ensure rainwater quality by removing any sediment and microorganisms before using as drinkable water (Figures 2). Rainwater samples were collected periodically (monthly or every two to three months) from a tap directly connected to the storage to measure stored rainwater quality, and the other tap after treatment. The following parameters were analyzed for each sample of rainwater collected: pH, turbidity, nitrate, nitrite, heavy metals (arsenic, iron, nickel, lead, and zinc), *Escherichia coli*, and total coliforms. All analyses were carried out following Standard Methods (APHA 1995). Turbidity and pH were measured using a turbidity meter (HACH 2100Q, USA) and a pH meter (HM-31P, UK), respectively. Heavy metals (except As), nitrate, and nitrite were determined in accordance with a UV spectrophotometer (HS-3300, HUMAS) (as shown in the Appendix, Table A1). In our study, arsenic was detected by an arsine generator and adsorber assembly under preparation of acetate buffer (428 mL 0.2 M $NaC_2H_3O_2$, and 72 mL 0.2 M CH_3COOH), silver diethyldithiocarbamate solution (1 mL morpholine in 70 mL $CHCl_3$ with addition of 0.30 g $AsSCSN(C_2H_5)_2$), standard arsenic solution (0.1734 g $NaAsO_2$ in 1,000 mL water), and standard arsenate solution (0.416 g Na_2HAsO_4. $7H_2O$ in 1,000 mL water). Total coliform (TC) and *E. coli* were detected according to the TCVN 6187-2: multiple tube (MPN) method. In addition, Difco™ Lauryl Tryptose Broth (Becton, Dickinson and Company) was

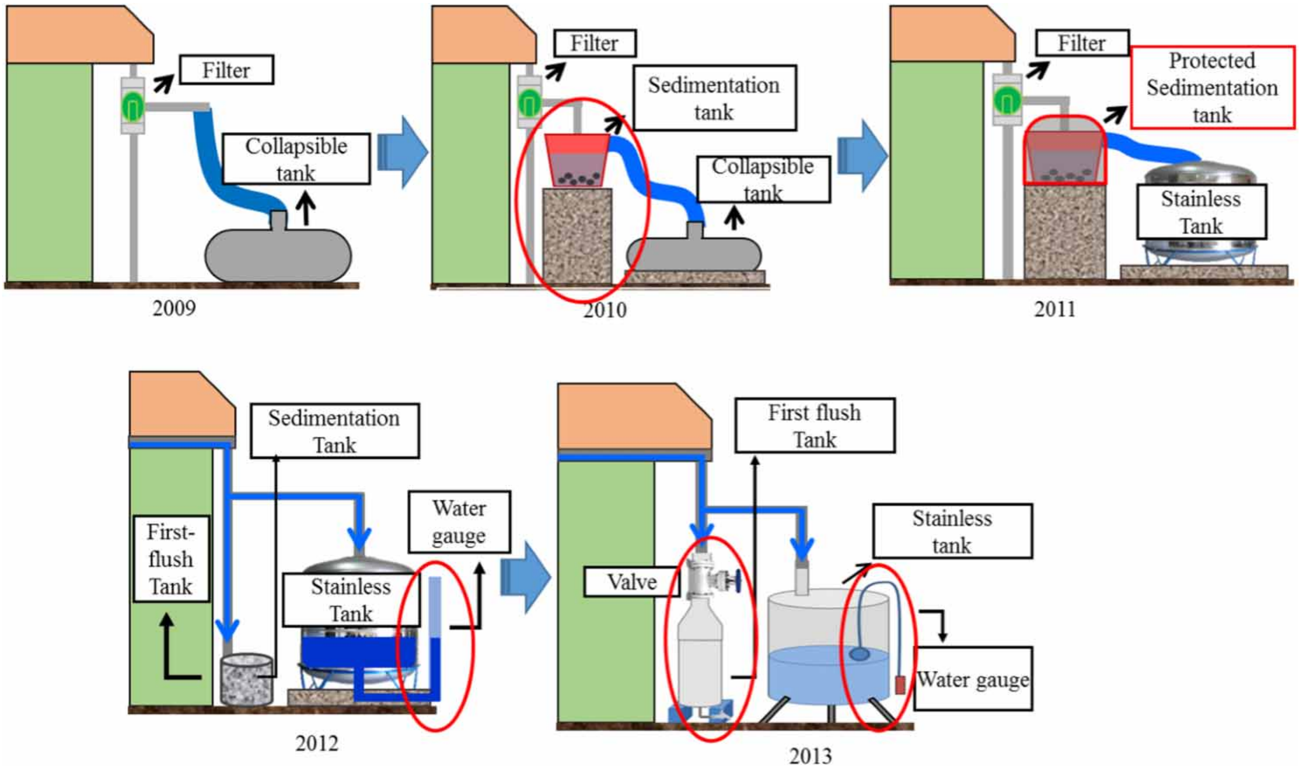

Figure 2 | Improvement of RWH system in households during 2009–2013 in Vietnam.

applied for the presumptive phase, and Difco™ Brilliant Green Bile Broth (Becton Dickinson) was used for the confirmation phase of TC and *E. coli*. The final concentrations are expressed as the number of colony-forming units (CFU) per milliliter of the original sample. The detection limit of the MPN method is 0 CFU/100 mL.

BARRIERS TO RWH IN VIETNAM

Technical barrier

Poor water quality

Rooftop catchments are normally contaminated with wind-blown dust and dirt and the falling leaves can affect rainwater quality. In addition, bacterial contamination through bird droppings and dead animals can also be a main cause of poor rainwater quality. Due to the lack of engineering and scientific knowledge, such components to remove those contaminants are not used in the existing practices of RWH in Vietnam, resulting in bad collected rainwater quality. The bottom of the storage tanks containing a sludge layer could become a good environment for mosquitoes or insect growth.

Lack of water in dry season

Vietnam is located in the tropical monsoon climate zone with a high annual rainfall and a great seasonal variability. This is a typical disadvantage in terms of sustainable water sources, with an excessive amount in the rainy season and extreme scarcity in the dry season. In fact, RWH at the domestic scale, which is often constrained by the small sizes of catchment roofs and storage tanks, cannot provide enough reliable water for all uses throughout the year. As a result, most of the sampled households reported running out of rainwater during the six-month dry season. Semra *et al.* (2011) also reported that storage capacity is the major limitation in rainwater harvesting and about one-third of the households in Mekong Delta region lack water in the dry season.

Lack of detailed local rainfall data

Analysis of RWH system performance with sufficient capacity is addressed as the key to supplementary sustainable rainwater. Collecting rainfall data is necessary and important for modeling associated with analyzing RWH performance, because it directly influences the performance as well as the size of the rainwater tank, which represents costs, benefits, and operation of the system. It was reported that analysis using monthly average rainfall data overestimates the required rainwater tank size and using daily rainfall data is expected to produce more realistic outcomes (Nguyen & Han 2017a). However, in many remote areas, especially in developing countries like Vietnam, proper rainfall data may not be available.

Economic barrier

Initial investment cost

The main challenge of RWH is the initial investment cost. About 40% of sampled households reported that they cannot afford the initial cost of RWH as a one-time payment even though they know that it is better to have a RWH system. The initial cost of typical RWH for a household (2 m^3 of storage tank) is about 200–400 USD (Nguyen *et al.* 2013), which is around four to eight times as high as monthly per capita income. Although many RWH facilities are supported free of charge through donation and voluntary work, most facilities contain low quality water due to the limit of donations and the facilities not being maintained properly.

Social barrier

Awareness of local residents

Poor social awareness regarding rainwater can be found in urban areas. As Vietnam is undergoing rapid urbanization, centralized water systems are being well applied through exploiting ground and surface water (Kim *et al.* 2016) and most urban residents acknowledged their negative thoughts on rainwater, especially on rainwater quality. The main reasons are due to (1) previous failures implying RWH is a bad experience and (2) concerning the bad quality of rainwater caused by air pollution. In many systems, treated rainwater evidenced its safety for drinking (Dao *et al.* 2017), although people are still afraid of utilizing rainwater in their daily life. In rural areas, it is traditional for households to utilize water from dug wells and crude rainwater harvesting systems and people demonstrated a positive mind on rainwater. In our surveys, about 81% of sampled residents acknowledged their trust in rainwater because rainwater is the only choice of water supply in rural areas and has been practiced for a long time without problems.

Lack of knowledge and institutional/legal aspects

Rainwater harvesting has been considered as an essential source for (domestic) water supply. The Vietnamese Law of Water Resources (2012) encouraged harvesting and using rainwater (Article 4, Article 39, Article 41, Article 54, VLWR 2012). However, there is limited guidance under the law regarding detailed instructions on using rainwater. For example, there is only guidance on rainwater monitored by the Ministry of Natural Resources and Environment (MONRE) focusing on rainwater quality (Circular 32/2011/TT-BTNMT) without mentioning the purpose of using rainwater (MONRE 2011). The use of rainwater for domestic water supply should involve instructions from the Ministry of Health (regarding rainwater quality standard) and Ministry of Construction (regarding rainwater harvesting). Furthermore, there is a common lack of awareness and knowledge in RWH and utilization among urban residents, professionals, and policy-makers in Vietnam. Along with urbanization, the conventional centralized water supply has been focused on, and the technology of RWH is generally forgotten and neglected.

STRATEGIES TO OVERCOME THE BARRIERS TO RWH IN VIETNAM

Innovation in technical aspect

Technologies to improve the water quality

In this project, a series of technical innovations have been made to improve the stored rainwater quality using filter, sedimentation tank, first flush, calm-inlet, and swing pipe, as shown in Figure 3. The design, installation, and

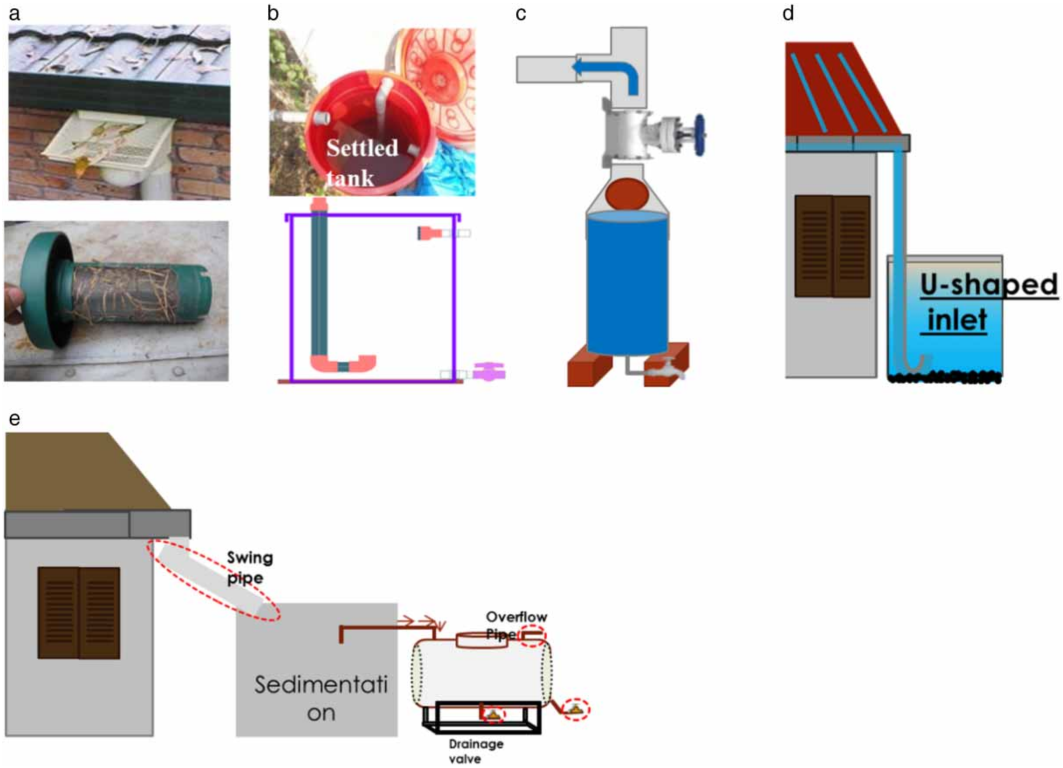

Figure 3 | Technologies to improve rainwater quality: (a) filter; (b) sedimentation; (c) first flush; (d) calm-inlet; (e) swing pipe.

maintenance of these innovative components are applied with simplicity and ease.

Filter: Due to poor management on catchment, a filter is necessary to remove debris that gathers in the catchment area and to lead to high quality water. Filters can be leaf screens, which are usually ¼-inch mesh screens in wire frames that fit at the point of drainpipe installation. The filter can be easily removed and cleaned without needing to dismantle the filter body from the downpipe.

Sedimentation and calm-inlet: Most domestic rainwater cisterns are small and subject to the problem of sediment resuspension when inflowing water falls from an elevated inlet. Disturbance of the water surface by the inflow resuspends settled particles and thus decreases the quality of the stored water. A U-shaped inlet design, referred to as a calm-inlet, reduces the potential energy of inflow and thus maintains a stable condition for the stored water and prevents the resuspension of sediment.

First flush and swing pipe: Although a filter or gutter screen can keep large debris out of a RWH system, a first-flush diverter keeps most of the dust and dirt contaminants out of the untreated water storage tank. There are two such simple systems. One is a 'swing pipe' which is based on a simple manually operated arrangement, whereby the downpipe is moved away from the tank inlet and replaced once the first flush water has been disposed of. In another simple and automatic system, a separate vertical pipe is fixed to the down pipe with a floating ball as a valve provided below the 'T' junction. After the first rain is washed out through the first flush pipe, the ball is floated at the top of the first flush downpipe allowing the water to enter the downpipe and reach the storage tank.

Storage tank: It is shown that the storage tank improves rainwater quality by neutralizing pH, settling particles, and precipitating heavy metals (Despins *et al.* 2009). We found that water quality slightly depended on the material of the storage tank; in which a stainless steel tank seemingly results in better quality than a plastic bag. Stored and treated rainwater quality from the various installed systems was tested and compared with the Vietnam and WHO drinking water guidelines. As shown in Table 1, all chemical and physical parameters for stored rainwater quality were

Table 1 | Quality of stored and treated rainwater samples

Variables	Vietnam standard	WHO	Stored rainwater	Treated rainwater
pH	6.5–8.5	–	6.3–8.1	6.3–7.4
Turbidity (NTU)	2	–	0.05–1.63	0.05–1.3
Nitrite (mg/L)	3	3	0–2.31	0–0.35
Nitrate (mg/L)	50	50	0–8.6	0–2.0
As (mg/L)	0.01	0.01	<0.005	0–0.005
Iron (mg/L)	0.3	–	0.02–0.084	<0.05
Lead (mg/L)	0.01	0.01	<0.001	0–0.001
Zinc (mg/L)	3	–	0–1.5	<0.05
Nickel (mg/L)	0.02	0.07	<0.001	0–0.001
Total coliform (MPN/100 mL)	0	0	0–78,000	0
E. coli (MPN/100 mL)	0	0	0–3,200	0

found to be far less than the standards listed in the MOH (2018) and WHO Drinking Water Guidelines (2017). Rainwater has the potential of microbiological contamination due to pollutants from bird and animal feces, dust and leaves but it can be safely disinfected by simple point of use treatment as results show in Table 1. Nguyen *et al.* (2013) and Han & Nguyen (2018) also reported similar results and proved that RWH can safely be used for drinking with a point of use treatment system.

Rainwater quality results were summarized from the periodical tests conducted during the demonstration project.

Design of dual water supply system to overcome the lack of rainwater in the dry season

Due to the seasonal rainfall which often causes a lack of water in the dry season, a dual water supply system can be developed to obtain 100% self-sufficiency (Nguyen & Han 2014). Rainwater can become the best source of drinking water. The uncertainty about the quantity of rainwater can be solved by using contaminated groundwater for non-drinking purposes as a supplement water. Nguyen & Han (2014) recommended that rainwater should be supplied for drinking purposes only in January–April and October–December but should be supplied for all purposes in May–September at household scale in Vietnam, while groundwater should be supplied for non-drinking purposes as a supplement water supply in January–April and October–December.

Where proper local data are lacking, there are two possible solutions: using the monthly rainwater data model and gathering local data by installing a simple rainfall gauge (Han & Nguyen 2018). The monthly rainfall data model can be used to generate pseudo daily rainfall for better predicting the performance of a RWH system, which is quite similar to that of using the actual daily rainfall data (Nguyen & Han 2017a). Another suggestion was to install a simple rainfall gauge and work with a science student group to monitor rainfall each day and keep the records via a website.

Innovations in economy

Using available local material and labor

For rainwater harvesting systems, rain and available rooftop catchments are free of cost. The storage tank is usually the major cost of the system (almost 90% of the total cost). Therefore, it is essential that careful design provides optimal storage capacity while keeping the cost as low as possible. Costs also can be reduced by using the available local material and labor. This also allowed those concerned to gain a good working knowledge of the system – how it works, operates, and needs to be maintained.

Increase affordability by sharing the cost

Communities can increase the affordability in investing in a RWH system by involving cooperative social responsibility (CCSR). The donation of a company using CSR or creating shared value (CSV) is suggested to share the initial cost for a win-win situation (Kim *et al.* 2016). The cost is not only supported from the donation, but also the communities should be involved at all stages, including finance and labor. Beneficiary contributions can be in the form of funds, labor, and materials. A community may contribute only a fraction of the cost by way of funds, but much more in-kind, for example, by giving sand, water, or bricks. Some roof-top RWH techniques involve a substantial amount of unskilled labor such as earth moving and fetching of local materials. The willingness of a community to contribute labor in such a case is a substantial contribution which affects the cost of the project. It also has a positive impact on building community ownership of rooftop RWH systems.

A sustainable rainwater management plan is an important tool to consider for the utilization of rainwater in the present and in the future. This plan should take into account cost and benefit analysis, and risk assessment. Based on the facts, the local authority may decide to take a fee based on the total cost (including installation and maintenance fee). The local government should invest in supporting poor households in mountainous areas, on islands, rural areas, and the city, with a rainwater reserve and filter system. In addition, a model of one company–one community (1C-1C) can be applied to obtain the implementation of rainwater harvesting as community based. Households and owners who have certified the installation and operation of rainwater management equipment will be entitled to a reduction of taxes, water bills, and other expenses.

Saving money from saving rainwater

Although initial investment is necessary to set up a RWH system, saving costs paid for tap or bottle water is a good reason to use rainwater free of charge. The assessment of the affordability of roof-top RWH systems for the target beneficiaries will increase their willingness to pay the costs and demonstrate the market opportunity for local business, and allow projects to develop any private sector financing options. For example, in the case of Cukhe kindergarten, a 12 m^3 RWH system was installed to supply drinking water for all the students at the school (Dao *et al.* 2017). The cost of the rainwater harvesting system is 4,000 USD. Before installing the RWH system, the school needed to buy bottled water to supply drinking water. The school can save 11 m^3 of bottled water per month by using rainwater, which is equivalent to 500 USD. In other words, they can save 4,000 USD in 16 months which is the construction cost of the rainwater harvesting system (Figure 4 and Table 2).

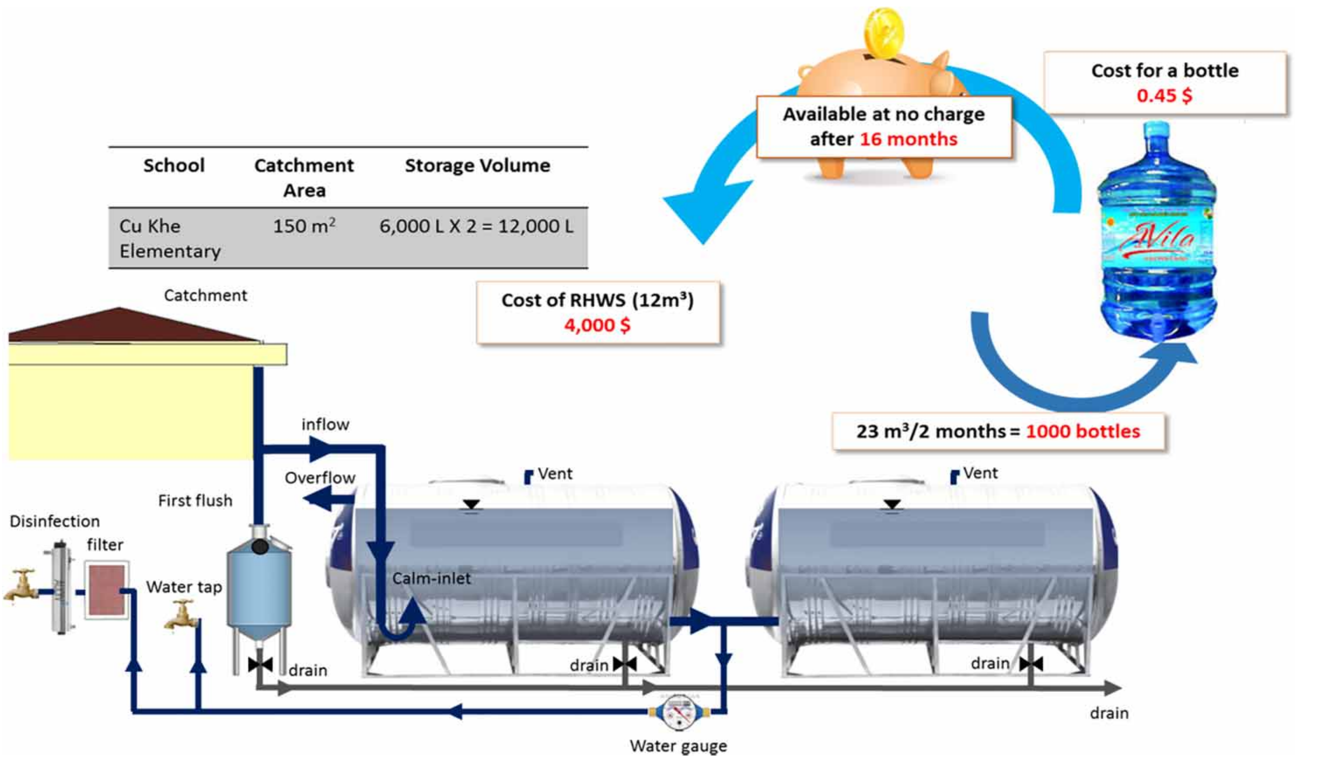

Figure 4 | RWH system in Cukhe kindergarten.

Table 2 | Cost analysis of RWH system

Cost of RWH system (12 m^3)	Monthly rainwater used	Cost of used bottled water (20 L bottle)	Monthly saving
4,000 $	11 m^3	0.45 $/bottle	500 $

Innovations in social

Decorating and changing the awareness

To reduce community negative perception on rainwater, we made the RWH systems look attractive and beautiful by simple drawings. These systems will work as a demonstration to encourage rainwater to be trusted and popular in the local community. In addition, through frequent communication, we tried to provide the local people with the results of scientific analysis of the quality of the rainwater in an effort to enhance their positive perceptions of rainwater.

Education

A great strategy for increasing public awareness on rainwater would be through schools and public education. Education includes both formal and informal instruction and training. Formal education refers to classroom teaching in schools and universities, while informal education involves discussion, seminars, and activities about RWH to residents, local groups, and at community events. For example, publishing books, making a rainwater museum, and holding blind-test rainwater activities for young students have been implemented well in Korea.

Demonstration of facility systems

It is good to install RWH systems in public facilities, especially schools. Students would obtain safe drinking water and more hygienic sanitation. In addition, RWH systems in schools can provide a demonstration model to be applied to other scales, i.e., household, office. Involvement of children in operation and maintenance of system provides them with an extra-curricular activity and develops a long-lasting habit of using and maintaining such plants and developing the self-confidence to use them.

Training program

A good working knowledge of RWH can be increased by training local residents to be involved in how a RWH system works. Provision of technical guidelines and maintenance manuals is useful to educate the local residents. Their involvement can be an effective tool for potential capacity building as well as for technology transfer. This also allows those concerned to gain a good working knowledge of the system (regarding design, installation, operation, and maintenance). It is suggested to create a rainwater tank plant and training center in communities. A training center on system construction and installation will increase the skill of people for further installations and maintaining new systems. Also, people can buy rainwater tanks at an affordable cost from the plant.

Institutional/legal considerations

As mentioned, there is limited guidance in rainwater harvesting in Vietnam, and the use of rainwater is mainly based on traditional experiences which were found to have some limitations (e.g., water contamination). It is necessary to issue a technical guideline for rainwater collection and use as a standard reference to the related parties (investors, decision-makers, household owners, donating companies, and local governments). In the future, the government should provide guidelines, and a building code with incentive programs, e.g., the Ministry of Health, Ministry of Construction, in promoting and supporting rainwater harvesting practices in Vietnam. In addition, financial incentives for rainwater harvesting to private and other sectors through economical tools are also very essential.

CONCLUSION

This paper identifies the barriers to rainwater for drinking in Vietnam in technical, economic, and social terms and suggests possible strategies to overcome these barriers. The barriers have been identified based on literature review and practical field experiment. Rainwater harvesting is simple and easy to access. However, due to a lack of scientific and engineering knowledge, there are some problems in the existing systems in Vietnam, such as poor collected rainwater quality, lack of rainwater in the dry season, and lack of detailed rainfall data. Initial investment requirements for rainwater for drinking system building would be difficult for low-income households. Some biased perceptions exist in society and the lack of knowledge and institutional/legal aspects regarding rainwater harvesting create obstacles to promote it widely.

This paper suggests technical, economic, and social innovations to overcome the barriers of rainwater for drinking in Vietnam. A series of technical innovations has been made to improve the stored rainwater quality using filter, sedimentation tank, first flush, calm-inlet, and swing pipe. A dual water supply system consisting of rainwater and groundwater is proposed to obtain 100% self-sufficiency. The detailed rainfall data can be gathered easily by a simple flow meter and rain gauge or applying a rainfall data model. To increase affordability, a CSR donation or CSV is suggested to share the initial cost for a win-win situation. Costs also can be reduced by using the available local material and labor. By using rainwater, people can save money by not buying bottled water. Making attractive and beautiful rainwater for drinking systems, school education and public education, training and working together help quickly increase public awareness about rainwater for drinking.

The findings from this study can help to promote rainwater for drinking in Vietnam as a sustainable water supply, to overcome the current water problems in the conventional water supply method such as a rapid urban population growth, and contamination of water sources. Similar analysis can be applied to promote rainwater harvesting in other countries and to achieve the Sustainable Development Goals.

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REFERENCES

Agusa, T., Trang, P. T. K., Lan, V. M., Anh, D. H., Tanabe, S., Viet, P. H. & Berg, M. 2014 Human exposure to arsenic from drinking water in Vietnam. *Science of the Total Environment* **488–489**, 562–569.

American Public Health Association (APHA), American Water Works Association (AWWA), Water Environment Federation (WEF) 1995 *Standard Methods for the Examination of Water and Wastewater*. American Public Health Association, Washington, DC, USA.

Dao, A. D., Nguyen, D. C. & Han, M. Y. 2017 Design and operation of a rainwater for drinking (RFD) project in a rural area: case study at Cukhe Elementary School, Vietnam. *Journal of Water Sanitation and Hygiene for Development* **7** (4), 651–658.

Despins, C., Farahbakhsh, K. & Leidl, C. 2009 Assessment of rainwater quality from rainwater harvesting systems in Ontario, Canada. *Journal of Water Supply: Research and Technology-Aqua* **58** (2), 117–134.

Gugliotta, M., Saito, Y., Nguyen, V. L., Ta, T. K. O., Nakashima, R., Tamura, T., Uehara, K., Katsuki, K. & Yamamoto, S. 2017 Process regime, salinity, morphological, and sedimentary trends along the fluvial to marine transition zone of the mixed-energy Mekong River delta, Vietnam. *Continental Shelf Research* **147**, 7–26.

Han, M. & Nguyen, D. C. 2018 *Hydrological Design of Multipurpose Micro-Catchment Rainwater Management*. IWA Publishing, London, UK.

Kim, Y., Han, M., Kabubi, J., Sohn, H. G. & Nguyen, D. C. 2016 Community-based rainwater harvesting (CB-RWH) to supply drinking water in developing countries: lessons learned from case studies in Africa and Asia. *Water Science & Technology: Water Supply* **16** (4), 1110–1121.

MOH 2018 *QCVN 01-1: 2018/BYT: National Technical Regulation on Drinking Water Quality*. MOH, Hanoi, Vietnam.

MONRE 2011 *Circular 32/2011/TT-BTNMT: Regulations Technical Process Rain Water Quality Monitoring*. Ministry of Natural Resources and Environment, Hanoi, Vietnam.

Nguyen, D. C. & Han, M. Y. 2014 Design of dual water supply system using rainwater and groundwater at arsenic contaminated area in Vietnam. *Journal of Water Supply: Research and Technology-Aqua* **63** (7), 578–585.

Nguyen, D. C. & Han, M. Y. 2017a Proposal of simple and reasonable method for design of rainwater harvesting system from limited rainfall data. *Resources, Conservation and Recycling* **126**, 219–227.

Nguyen, D. C. & Han, M. Y. 2017b Rainfall-storage-utilization-discharge model for flood mitigation and water conservation. *Water Science and Technology: Water Supply* **18** (4), 1252–1260.

Nguyen, D. C., Dao, A. D., Kim, T. I. & Han, M. 2013 A sustainability assessment of the rainwater harvesting system for drinking water supply: a case study of Cukhe Village, Hanoi, Vietnam. *Environmental Engineering Research* **18** (2), 109–114.

Semra, O., Mark, A. E., Joe, B., Pham, N. K., Vo, T. H. & Mark, S. 2011 Rainwater harvesting practices and attitudes in the Mekong Delta of Vietnam. *Journal of Water, Sanitation and Hygiene for Development* **1** (3), 171–177.

UNDP 2015 *Sustainable Development Goals – SDG6: Clean Water and Sanitation*. United Nations Development Programme, New York, USA.

VLWR 2012 *The Vietnamese Law of Water Resources*. Vietnam National Assembly, Hanoi, Vietnam.

WHO 2017 *Guidelines for Drinking-Water Quality*, 4th edn, incorporating the 1st addendum. World Health Organization, Geneva, Switzerland.

WHO/UNICEF 2013 *Progress on Sanitation and Drinking Water*. World Health Organization, Geneva, Switzerland. and United Nations Childrens Fund, New York, USA.

Wilbers, G. J., Becker, M., Nga, L. T., Sebesvari, Z. & Renaud, F. G. 2014 Spatial and temporal variability of surface water pollution in the Mekong Delta, Vietnam. *Science of the Total Environment* **485–486**, 653–665.

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