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The current state of domestic water consumption and the feasibility of implementing a rainwater harvesting system in the coastal zone of the Vietnamese Mekong delta: the case study of the Vinh Chau town, Soc Trang province

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Abstract:

The research was conducted to assess the feasibility of the installation of a rainwater harvesting system for households facing difficulties in using tap water and groundwater for domestic purposes in a coastal area of the Vietnamese Mekong delta - the case study of the Vinh Chau town, Soc Trang province. Direct household interviews and literature review were executed to comprehend the current state of domestic water consumption. According to the research results, Vinh Chau was among the towns seeing moderate rainfall in the delta (~ 1,776 mm/year), and rainwater was used frequently by the local people. However, local households did not employ proper harvesting techniques, hence the harvested rainwater did not meet the required quality for domestic use. Additionally, difficulties in using tap water, groundwater, and surface water were notable. The quality of tap water was not suitable for household consumption because of the presence of aluminum, and the price was high relative to the household's income. Salinization of surface and groundwater, as well as degradation in quantity of ground water, made water of acceptable quality scarce. The research results also indicated that the use of rainwater harvested by a proper system demonstrated a higher cost efficiency than that of other water resources. Therefore, the installation of a rainwater harvesting system for water supply should be encouraged in order to provide a safe and efficient alternative water source for domestic use, and to contribute to the relief of domestic water-related issues and pressure on groundwater extraction in the study area.

Keywords: **domestic water use, rainwater, rainwater harvesting system, Vinh Chau town.**

Classification number: **5.2**

Introduction

The Vietnamese Mekong delta (VMD) is one of the regions in the world projected to be seriously affected by climate change (CC), especially in its coastal areas [1-3]. Under conditions of CC, sea-level rise - and the resulting effects of saline intrusion, tide-induced flood, drought, and degradation of water quality - shortages in water for domestic use have become more commonplace in coastal areas of the VMD. According to the prediction of [4], the percentage of the population in the rural area impacted by saline intrusion will increase from 39.5% in 2012 to 41.4, 45.3, and 47.6% in 2020, 2030, and 2050, respectively.

Not only does the VMD face the degradation of groundwater - both in quality and quantity - but it also suffers from surface water pollution. Several water quality indicators revealed that physical, chemical, and biological pollutants exceeded the allowed standard. In the VMD's coastal regions (e.g., Soc Trang, Bac Lieu, Ca Mau, and Kien Giang provinces), groundwater has been exploited for various purposes, leading to significant drops in groundwater tables in recent decades [5]. According to [6], the groundwater table of Tra Vinh and Soc Trang provinces declines on average from 4 to 9 meters in the dry season. Moreover, groundwater exploitation has resulted in land subsidence in the delta. It is estimated that groundwater withdrawal has caused the VMD to sink approximately 18 cm over the past 25 years, with some areas exceeding 30 cm [7].

Conversely, rainwater is abundant in quantity and is of suitable quality for domestic use in the VMD [8]. While

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researching rainwater quality at the College of Environment and Natural Resources (CENRes) and the Institute Research Institute for Climate Change, scientists from Can Tho University indicated that the quality of rainwater is good, meeting the national standard (QCVN 02:2009/BYT) in physio-chemical indicators, except for turbidity and coliforms. Consequently, rainwater can be an acceptable alternative water source if it is properly harvested and treated.

Nevertheless, most people in the rural areas of the VMD have not collected rainwater properly (without first fushing[*] or filtering), and therefore have not met the requirement for domestic water quality [4]. According to the research of [9], 4.3% of the population in the VMD harvested standard rainwater for domestic use in 2012. In short, harvesting and using rainwater should be given more attention in order to meet current water demands, adapt to CC, and mitigate the impacts of groundwater extraction in the VMD's coastal areas [7]. For these reasons, the research was aimed at assessing the feasibility of implementing rainwater harvesting systems in the Vinh Chau town, Soc Trang province, that offer opportunities to use alternative water sources to meet the increasing water demands under the impacts of CC.

Materials and methods

Data collection

Secondary data: monthly rainfall data over the period between 2010 and 2015, the current state of utilization and extraction of domestic water in the Vinh Chau town collected from the Vinh Chau census data, reports from the Department of Natural Resources and Environment in the Soc Trang province, and scientific articles on water resources in the Soc Trang province and the Vinh Chau town (e.g., [10, 11]).

Primary data: the current state of the use of tap water, groundwater, surface water, and rainwater for domestic activities was collected from interviews with 35 households in the Hoa Dong commune, Vinh Chau town. The criteria for selecting the study area and interviewees are listed in Table 1. The map of the study area is illustrated in Fig. 1.

[*]The action of flushing initial runoff water. In this phase, rainwater could be significantly polluted by contaminants on the roof.

Table 1. The criteria to select studied area and interviewees.

No.	Contents	Criteria	Households
1	Location	Commune and households that: • Are located far from the center of the Vinh Chau town • Have difficulties in domestic water use	
2	Water resources for domestic use	• Groundwater • Tap water • Surface water • Rainwater	35
3	Economic conditions	• Belong to various social groups (low, fair, and high)	

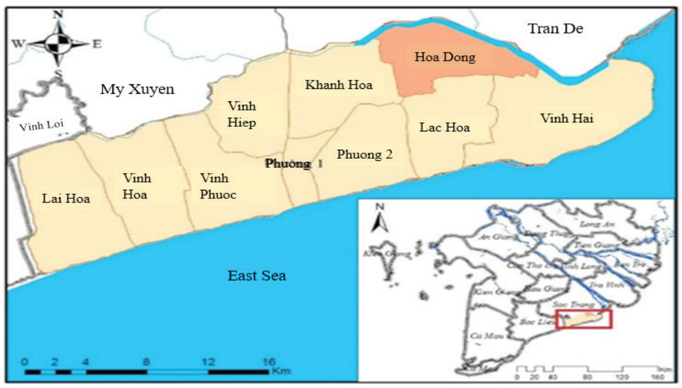

Fig. 1. Studied area in the Hoa Dong commune, Vinh Chau town, Soc Trang province.

Analytical methods

Rainfall data were gathered and plotted on a graph to reflect general trends. The reports were cited for a general evaluation of the current state of water resources for domestic use in the Vinh Chau town.

Primary data were coded and analyzed by descriptive statistics via the Microsoft Excel software to conduct the analysis and assessment of the current situation, needs, and difficulties in the use of water and economic efficiency of the rainwater harvesting system. Calculated figures were indicated in average and percentage values or graphs and tables.

The rainwater harvesting system

Rainwater harvesting systems for domestic water supply were piloted in two households in the Hoa Dong commune, Vinh Chau town, Soc Trang province, and the criteria to select these two households are listed in Table 2. Selected households had representative characteristics of roof and water usage patterns in the study area; therefore, results from the pilot systems were representative for the entire study area.

Table 2. The criteria to select the two household case studies.

No.	Contents	Criteria
1	Location	In areas facing qualitative and quantitative difficulties in domestic water use.
2	Conditions of roof	According to [8], suitable roofs for rainwater collection were made from: Corrugated iron Tile New thatched-roof (a thatched roof over one year old was not suitable for rainwater catchment for drinking)
3	Willingness	Willing to support the research team in installing the systems and providing the necessary information.

Research of the rainwater quality of [8] revealed that the main indicators for not meeting the water quality standard when rainwater flows over rooftops were turbidity and microorganisms. Therefore, the rainwater harvesting system was designed to treat collected rainwater by a physical mechanism. This design is based on the guideline document of CENRes and the Research Institute for Climate Change, Can Tho University [8], including (Fig. 2A): gutter(s) (1), primary filter(s) (2), a first flush (3), primary container(s) (4), a filter (5), and secondary container(s) (6). Harvested rainwater flows through these parts respectively.

The primary filter removes litter and leaves from the rooftop and gutter. In the first flush (Fig. 2B), rainwater that is polluted with ambient air and rooftop contaminants is retained in the storage chamber equipped with a floating ball inside. If the chamber is filled with water, the floating ball rises to lock the chamber and diverts rainwater from entering the primary container.

The filter (Fig. 2C) is a plastic barrel of 460 mm in diameter, including a 100 mm layer of gravel, a 200 mm layer of sand, a 200 mm layer of charcoal, and a 100 mm

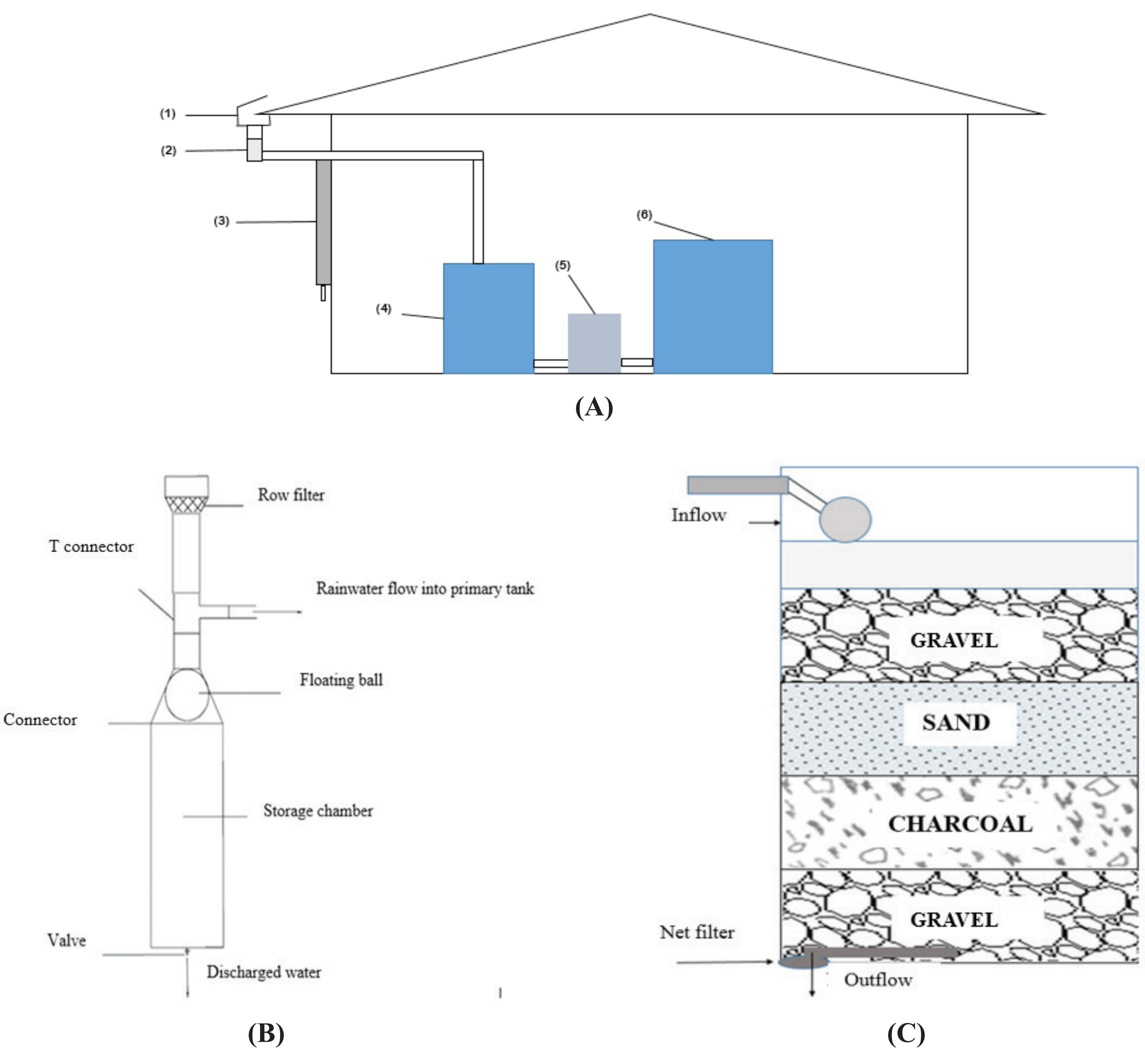

Fig. 2. The rainwater harvesting system (A), the first flush (B), and the filter (C).

layer of gravel. When rainwater flows through spaces between these filtering materials, suspended solids and microorganisms in rainwater are filtered out.

The harvested rainwater can be used for domestic purposes requiring high water quality. It is encouraged that harvested rainwater should be boiled for drinking purposes. Households should harvest rainwater after the first four to six rains of the rainy season. In terms of management, operation, and maintenance, hygiene of the parts and rainwater quality should be checked regularly. The rooftop and gutter require cleaning before the rainy season as well as regular checks during the harvesting season to ensure that rainwater quality is not affected. Additionally, the primary filter, pipes, and the first flush also need to be checked to ensure proper water circulation. The filtering material in the filter should be washed before harvesting by letting sufficient water go through it; these material should be renewed every six months to two years. Containers should be closed and washed when they are not in use to ensure the quality of rainwater. Moreover, users should take water by the tap to avoid infection.

Fig. 3. The 2 pilot rainwater harvesting system in Hoa Dong commune, Vinh Chau town.

According to [8], values of indicators in the rainwater such as turbidity, suspended solids, total coliform, and E. coli were significantly reduced after the water was filtered through the system. Harvested rainwater could be used for domestic activities such as food preparation, dishwashing, or other activities requiring high water quality [8]. Therefore, this research focused on assessing the system's economic efficiency and ability to meet the water demands as well as the satisfaction of households. The assessment was based on interviews with 35 households about the installation and consumptive cost of groundwater and tap water and the actual installation cost of the rainwater harvesting system. The pilot rainwater harvesting systems are illustrated in Fig. 3.

Results and discussion

Rainfall and rainwater quality in the Vinh Chau town

Vinh Chau, a coastal town in the Soc Trang province, has a tropical monsoon climate with two distinct seasons - a rainy season from May to November and a dry season from December to April. Vinh Chau is among the towns in the VMD that experience a moderate amount of rainfall. The annual rainfall from 2010 to 2015 was 1,776 mm/year [12]. The monthly average rainfall in the 2010-2015 period is illustrated in Fig. 4.

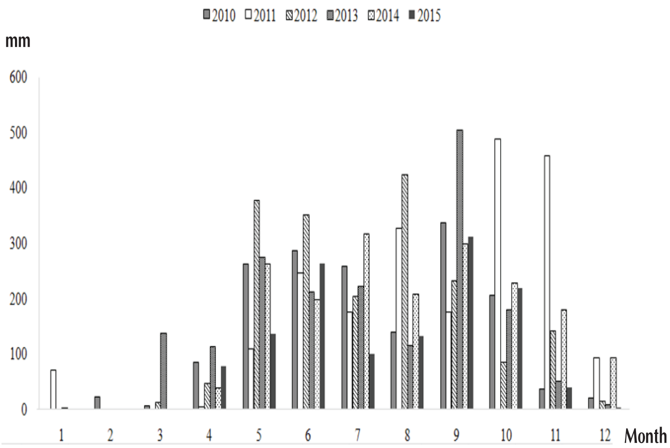

Fig. 4. Monthly average rainfall in the Vinh Chau town from 2010 to 2015.

Limited data about rainwater quality was available for the Vinh Chau town, therefore, we used available data from another province in the VMD with a similar climate but more activities affecting rainwater quality (transportation and industry) - the Can Tho city. The research into rainwater quality conducted by CENRes and the Research Institute for Climate Change from 2011 to 2013 revealed that rainwater in the Can Tho city was of rather good and stable quality. Moreover, the quality of directly harvested rainwater nearly met the QCVN 02:2009/BYT standard for domestic use (except for turbidity and coliforms indicators) [8] (Table 3). The research of [8] demonstrates analyzed results of rainwater quality. A significant proportion of respondents believed that the rainwater quality was good while a small number doubted the rainwater quality (Fig. 5). This led to the conclusion that the conditions of rainfall and rainwater quality in the Vinh Chau town were suitable for domestic use if rainwater was harvested properly.

Table 3. Rainwater quality indicators in Can Tho.

Indicators	Unit	Results	Rainwater quality compared with	
			Drinking water (QCVN 01/2009-BYT)	*Domestic water (QCVN 02/2009-BYT)*
pH		6.26	Meet	Meet
Turbidity	NTU	2.86	Not meet	Meet
TDS	mg/l	3.94	Meet	
SS	mg/l	2.11		
Microorganism				
Coliforms	MPN/100 ml	39	Not meet	Meet
E. coli	MPN/100 ml	0	Meet	Meet
Nitrate (NO_3^-)	mg/l	0.08	Meet	Meet
Nitrite (NO_2^-)	mg/l	0.01	Meet	Meet
Ammonia(NH_4^+)	mg/l	0.1	Meet	Meet
Heavy metal: As, Cr, Cu, Cd, Al, Hg, Ni, Mn	mg/l	Not found	Meet	Meet
Heavy metal: Pb, Fe, Zn	mg/l	Very low concentration	Meet	Meet
Total organic substance: Benzene, PAH	µg/l	Not found	Meet	Meet
Radioactive substance	pCi/l	Not found	Meet	Meet

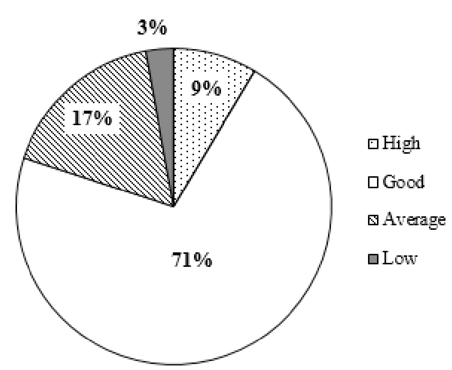

Fig. 5. Rainwater quality assessment.

Current state of domestic water consumption

Tap water (83%), rainwater (94%), groundwater (29%), and surface water (3%) are the main water sources for local domestic activities (Fig. 6). Most households use two or more water sources to ensure that there is sufficient water for their needs and to reduce water consumption expenditures, mostly coming from tap water. On average, there are about four to five members of each household in the Hoa Dong commune with daily water consumption of approximately 117 liters/person/day. More than half of the respondents said their domestic water demands have increased over the past five years. In the next five years, the majority believe their water demands will remain stable while 17% expect them to increase for various reasons. These reasons include, among others, more family members, warmer weather, and more convenient use of tap water (Fig. 7). The findings strengthen the need to find a sustainable source of water to meet the increasing household water demand, particularly in the context of the degradation of groundwater and salinity intrusion.

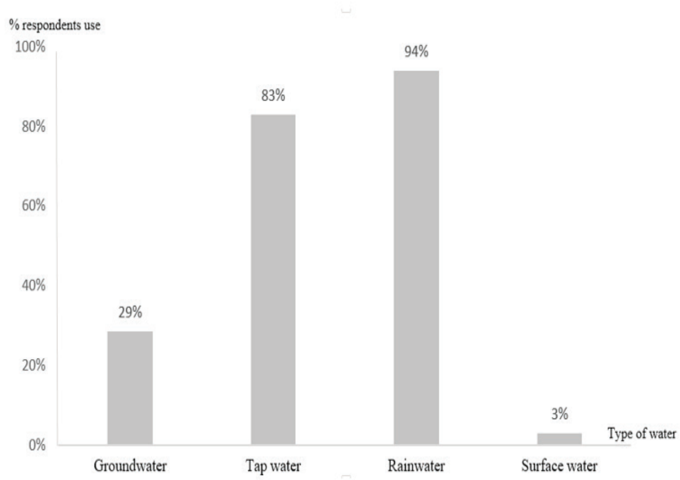

Fig. 6. Water sources for domestic water use.

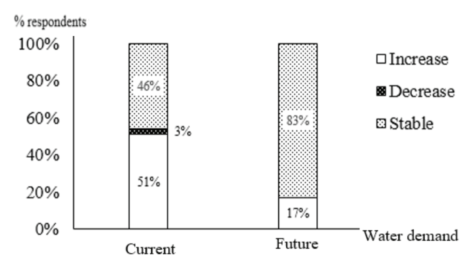

Fig. 7. Current and future water demands.

Households in the Hoa Dong commune face considerable difficulties in the use of domestic water. The market price of tap water is considered high relative to the low income of the local people. However, the quality of the tap water does not meet the proper standards for domestic use - 62% of surveyed households indicate that the aluminum characteristic of the tap water affected their water use. Instead, the households use rainwater for drinking purposes over tap water due to their concerns about health. Local water consumers must measure alum settlement or discharge aluminum water to ensure water quality, causing additional financial cost and wasting time. Moreover, loss of water use entirely occurs frequently in the dry season, leading to a discontinuity in domestic activities. Each water outage lasts five to 30 days, from several hours to all day.

The groundwater in the Hoa Dong commune is not suitable for domestic water consumption because of its salinity. Although the quality remains stable, the quantity of this groundwater resource has declined in recent years [11]. Most households (86%) reported that the flow rate of the pumped water was much lower than it was five years ago, especially in the dry season. These problems cause difficulties for households as they must increase the pumping time, use supporting equipment, and buy fresh water - causing a rise in living expenses.

Surface water in almost all canals in the Vinh Chau town are polluted by saline intrusion, alum affection, and wastewater from domestic activities, livestock farming, and aquaculture [11]. Although the quality of surface water does not meet the standard for domestic use, households in remote areas that are not served by the water supply system - especially the poor - continue to use surface water. They usually use it directly or simply take an aluminum settlement treatment, which is considered not safe for health.

In the study area, most households use rainwater as another domestic water source during the rainy season and store it for drinking purposes during the dry season. There are several reasons that households use rainwater, such as cost savings (82% of respondents), relative good quality (76% of respondents), high rainfall (45% of respondents), and not having any other water resources (3% of respondents). In general, the principal reasons for rainwater harvesting are the cost and the quality of rainwater. In contrast to tap water and groundwater, rainwater is a low-cost water resource used in the rainy season to save expenses. As explained above, the quality of rainwater in the study area is relatively good. However, the reasons that households do not use rainwater are the lack of storage facilities, the presence of mosquitoes in the rainwater container, and the lack of necessity because of the ready availability of tap water.

In contrast to the 18% of households who do not experience any difficulties in using rainwater, the majority of households do face such problems for domestic activities. These include an inadequate amount of rainwater to use in the dry season (48%), the time and effort in preparation for consuming (18%), low rainfall (15%), a lack of storage facilities (9%), and the presence of mosquitoes in the tank (3%).

Rainwater is usually harvested from July to November every year. Therefore, most households only use rainwater during the rainy season because of a lack of storage facilities to meet the entire family's water demands year-round. Many households find that it takes much time and effort to harvest rainwater by the traditional techniques as they must wait for heavy rain to collect water or take time to discharge rainwater at the beginning of each rain. Additionally, they must place a sheet on the storage tanks to filter litter and dust, then wait for the suspended solid settlement and transfer the fresh water to another tank for use.

In general, the collecting techniques of local people are simple but they take time and effort. Although the directly collected rainwater is of rather good quality, the rainwater is contaminated in indicators such as turbidity, suspended solids, dissolved solids, and microorganisms after flowing over the roof. The causes of pollution can be dust, moss, cat feces, or bird droppings from the roof or gutter. Most of the interviewed households (74%) said they would like to have a more reliable and effective rainwater harvesting system than the current traditional methods.

The efficiency of the rainwater harvesting system

The economic efficiency of rainwater use is higher than that of tap water and groundwater in certain aspects because of the low installation cost and the lack of consumptive cost (Table 4). The cost for installing groundwater wells, including drilling wells and pumping facilities, ranges from 400,000 VND to 6,000,000 VND (depending on the time of installation and depth). Conversely, this cost for tap water ranges from 200,000 VND to 2,000,000 VND (depending on the time of installation and incentive policies). The investment cost for a rainwater harvesting system is 310,000 VND for the first flush and the filter and 2,000,000 VND for the storage tank (plastic, 2 m^3). The monthly consumptive cost of tap water is between 10,000 VND and 200,000 VND (over 5,000 VND/m^3) and the monthly consumptive cost for groundwater is from 40,000 VND to 200,000 VND. However, there is no cost at all when using rainwater. These figures illustrate that if households implement a rainwater harvesting system, they can save on water consumptive expenses. However, the use of rainwater is seasonal and depends on the weather. If households wish to use rainwater year-round, they must ensure sufficient storage capacity to meet the demand. However, large reservoirs occupy a significant amount of space and come with high investment costs. Therefore, there should be consideration of tank volume for economic efficiency.

Table 4. Installation and use cost of the three water resources.

Water sources	Installation cost (VND)	Use cost (VND/month)
Groundwater	400,000-6,000,000	40,000-200,000
Tap water	200,000-2,000,000	10,000-200,000
Rainwater	2,310,000	0

The pilot households are located in the area with saline-affected groundwater. Therefore, tap water is their main water resource. However, the acidic nature of tap water also causes many difficulties for domestic activities. The total water demand of the households is approximately 127.75 m^3/year and the total amount of rainwater collected meeting the demand for use is approximately 90 m^3/year. In short, a rainwater harvesting system can meet 70% of a household's water demand. According to the research results, this system provides convenience and safety for rainwater use. Moreover, the first flush and the filter method help households avoid wasting time and effort in collecting rainwater as with the traditional methods. After it is filtered through the system, rainwater can be used directly. The system provides an alternative water source to households, decreasing the demand for and the cost of using tap water and groundwater. Because the first flush and the final water container are close in proximity, dust or litter contamination is minimized. Harvested rainwater using this system results in a better quality than with traditional rainwater harvesting techniques.

Conclusions and recommendation

The Vinh Chau town experiences moderate rainfall in the VMD (about 1,776 mm/year) and relatively good rainwater quality, suitable for harvesting for domestic purposes. In the study area, difficulties in the use of tap water, groundwater, and surface water are remarkable. The quality of tap water is not suitable for household consumption because of the aluminum effect and the price is high relative to the typical household's income. Salinization of surface water and ground water and degradation in quantity of groundwater also pose difficulties for the local people. Rainwater is also used for domestic activities, especially for drinking water purposes. However, local households do not employ harvesting techniques properly, hence the harvested rainwater does not meet the required quality for domestic use purposes.

This rainwater harvesting system is proposed to be widely installed in other areas with similar socioeconomic development and physical settings due to its safety and economic efficiency. This system helps households save time, money, and efforts in harvesting the rainwater. Moreover, it can remove contaminants and microorganisms, thereby significantly improving the quality of harvested rainwater. Therefore, the installation of this system offers an alternative water source for local households facing difficulties in accessing other water sources - tap water and groundwater in particular - and for households in the coastal area facing salinization of groundwater in general. A larger pilot study in different areas in the VMD should be conducted to provide higher validity on the outcomes, water quality, consumption, and cost comparison. In the short term, more research is needed on rainwater harvesting methods in areas that are threatened; in the longer term, the goal is to provide access to fresh water resources for domestic use and contribute to the relief of domestic water-related issues and pressure on groundwater extraction.

The authors declare that there is no conflict of interest regarding the publication of this article.

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