A Sustainability Assessment of the Rainwater Harvesting System for Drinking Water Supply: A Case Study of Cukhe Village, Hanoi, Vietnam

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Abstract

In Cukhe, a village located in the outskirts of Hanoi, Vietnam, people suffer from a shortage of high-quality water due to an arsenic contaminated supply water resource. We installed catchments, filters and settled tanks in the existing rainwater harvesting facility to improve water quality, and ten portable rainwater tanks to provide good-quality drinking water to the poor households and kindergartens in the dry season. The triple bottom line considerations, as well as the environmental, economic, and social impacts of the rainwater harvesting (RWH) systems are examined. RWH is a sustainable method to obtain good-quality drinking water at low cost and with little energy expenditure. Education of the system also encourages that continuation of the system and expansion can lead into economic prosperity, as the safe drinking water can be sold to the community. Hence, RWH is a unique proposal as sustainable drinking supply water for improving the lives and health of residents in Cukhe and other sites where water supply sources are contaminated.

Keywords: Drinking water, Rainwater harvesting, Water supply

1. Introduction

A sufficient, clean drinking water supply is essential to life. Millions of people throughout the world still do not have access to this basic necessity.

Cukhe is a typical village of the Red River Delta region, nearby Hanoi, where the local residents did not have access to a safe water supply, because the local water supply sources are contaminated. The river, groundwater and aquifers are contaminated with human waste and arsenic. Therefore, there is a need to promote alternative water supply options to the traditional water sources. We found that rainwater harvesting (RWH) is a suitable method to provide sustainable water to the local residents. The reasons are that: First, RWH was one of the most popular traditional methods in villages of Vietnam. Second, Vietnam has a high annual precipitation. The annual precipitation in the area is 1,682 mm, which is 1.7 times more than the global average (973 mm) [1]. In 2010 and 2011, we, a team from Seoul National University visited Cukhe and made the demo to help the residents. During the project, we installed ten RWH systems, for two kindergartens and eight poor households. Two cases of RWH systems were installed: 1) canvas catchment and plastic tank, 2) roof and stainless tank. We would like to share our method of installing RWH systems as well as the triple bottom line consideration of the RWH systems.

2. Materials and Methods

2.1. The Status of Water Sources

To investigate the current status of water sources in the village, 45 random households were interviewed about their water sources with the same questions. The questionnaire covered the use of water supplies and the reliability of rainwater. In addition, we examined the structure and implementation of the water supply system for each household.

2.2. Water Quality Analysis

The water quality from various sources was tested and compared. For the test, samples were taken from three well and rainwater storage tanks at three sites. A 2100P Portable Turbidimeter (HACH, Loveland, CO, USA) was used to test turbidity and a pH meter was used to test pH, temperature and electrical conductivity (EC). The water quality of the representative samples was analysed at the Vietnam Institute of Environmental Technology upon completion of the research trip. The water quality analysis considered 17 heavy metals (As, Be, Ca, Cd, Co, Cr, Cu, Fe, Mg, Mn, Mo, Ni, Pb, Sb, Se, Ti, and Zn), six negative ions (F^-, Cl^-, NO_2^-, NO_3^-, PO_4^{3-}, and SO_4^{2-}) and the amount of total suspended solids.
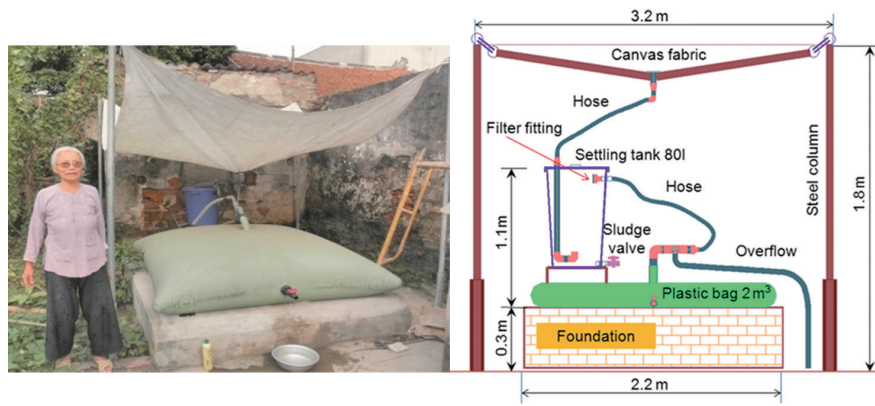
Fig. 1. Rainwater harvesting system using canvas catchment and plastic tank.
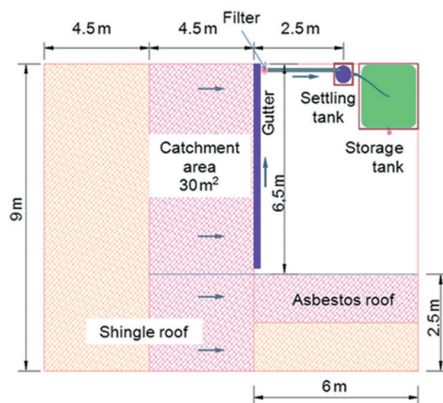

Fig. 2. Rainwater harvesting system using roof and local stainless tank.

2.3. Installation of Portable Rainwater Harvesting Facility

Ten portable RWH systems with 2-ton capacity were installed in the village. There were two cases of RWH system installation using two types of catchments and two types of tanks. The RWH system is simple for everyone to install, operate and maintain. RWH is a relatively inexpensive, effective and sustainable method of supplying clean water.

2.3.1. Case 1: using canvas catchment and plastic tank

Rainwater is harvested from the catchment which is a 3-m wide by 3-m long tarpaulin made of 300 gm^{-2} polyethylene. The water flows into an 80-L settling bottle. Filtered, settled water is passed into a 2 m^3 plastic foldable storage tank (Fig. 1). The total price of this system is inexpensive US $225.

With the canvas catchment, households which do not have a good roof could install the RWH system easily. The canvas catchment is a smooth, clean surface with a high run-off coefficient. The area of the catchment is 9 m^2, it is expected to be large enough to collect sufficient water for a household. It is not expensive, light and easy to install and clean. The disadvantage is that it could be broken because of exposure to the sun. It should be replaced each year or used in local material. The storage tank is made from foldable fabric materials that are light, flexible and could be installed and moved easily. By using a tank constructed

from fabric, we were able to reduce the unit cost of the total system. However, if it is exposed to the sun, the stored water would develop a foul odour. To prevent this problem, the storage tank should be covered.

2.3.2. Case 2: using roof and local stainless tank

Rainwater is harvested from the roof of the household. The run-off will be distributed through a gutter and a 0.5 mm mesh filter into the settling bottle. Filtered, settled water is passed into a 2 m^3 stainless storage tank (Fig. 2). The total price of this system is US $380.

The roof of the household is utilized to collect rainwater. The storage tank is made of local stainless material that is durable, strong and hygienic. The volume of the storage tank is 2 m^3. It is effective in maintaining stored water quality. However, the price of the stainless tank is relatively high.

3. Results and Discussion

3.1. The Status of Water Sources

Table 1 shows the opinions of the local residents about water sources. The current water sources are river water, groundwater and rainwater. Based on the results of the interviews, rainwater

Fig. 3. Water sources in Cukhe village: (a) surface water, (b) groundwater system, and (c) rainwater system.

and groundwater are the main sources used in daily living. Rainwater is the most trusted source and groundwater is the most untrusted source for drinking. The reason why people do not trust groundwater is that arsenic pollution of groundwater has been recognized in the area. Therefore, if the performance of the RWH systems is successful and efficient, and the local community becomes truly aware of its benefits, the concept and use of RWH will spread rapidly, even without the help of any external forces.

3.1.1. River water

Twenty years ago, local residents used to go to the Nhue River to swim or wash clothes. They sometimes took surface water to empty into the jars or small tanks and used the aluminium alum to settle particles. They then used such clean water to cook. They are unable to do so nowadays because the river is seriously polluted by the wastewater of Hanoi city (Fig. 3).

The concentration of biochemical oxygen demand and

Table 1a. Interview result about the water status in Cukhe

	River water	Ground water	Rain water	Centralized	Others
Purpose (%)					
Drinking	0	51	-	-	-
Washing	-	-	49	-	-
Treatment (%)					
Boiling	0	99	-	-	-
Others (solar & none)	-	32	32	-	-
Trust (%)	0	1	68	22	9

Table 1b. Interview result about the water status in Cukhe

Understanding about rainwater (%)	
Quality	
Clean	19
Not clean	81
For drinking	
Possible	95
Impossible	5
Current utilization	
Yes	61
No	39

chemical oxygen demand were 41 and 54.83 mg/L in 2003, respectively [2]. Other parameter concentrations are also higher than the standard for drinking water such as: nickel (Ni), chromium (Cr), lead (Pb), copper (Cu), zinc (Zn), cadmium (Cd) are 1.24–7.74, 1.51–6.45, 0.28–1.97, 1.66–2.31, 25.19–77.94, 0.06-0.14 µg/L, respectively [2].

3.1.2. Groundwater

Groundwater is the main water source in Cukhe village. Most of the households own a depth well (Fig. 3). The depth of wells is approximately 34–40 m and wells were made by manual drill equipment. Households use electric pumps to take the groundwater and treat it by a simple filter system. A groundwater system includes a perforated pipe, slow sand filter and a storage tank. Filters consist of a sand layer; gravel layer and an activated carbon layer housed on the storage tank in a concrete structure with average dimensions of about 100 cm in width, 200 cm in length, and 85 cm in height. The filter is cleaned monthly by the residents, and all filter layers are replaced with new layers twice a year. However, the filter used by the lower socioeconomic class is different. It comprises a tin can of 47 cm radius and 45 cm height filled with sand and an activated carbon layer. This filter is expected to have the disadvantages of having less filter material and being more difficult to recover. Pumped up groundwater is stored in the storage tank after being filtered by an installed filter, after which it is potable. The filter efficiency for the groundwater system affects the water quality, and thus periodic cleansing and changing of the filter is an important attribute. However, the lower socioeconomic class, who have suffered from diseases due to the use of groundwater without the periodic cleansing and changing of filters, do not trust the potable use of groundwater.

Normally, groundwater is used for washing and showing. However, it is also used for drinking and cooking during the dry season. The cost to exploit the ground water only includes the cost for an electrical pump, and it accounts for 10% of the household's total electrical cost. Nevertheless, groundwater is also polluted by arsenic. The arsenic concentration is greater than Vietnams' standard of eight to ten times [3]. This is a huge problem for local residents, especially poor households.

3.1.3. Rainwater

Rainwater was the most trusted potable water. According to the survey results, there were 49% of all households using rainwater for cooking and drinking. The rest did not use the rain water because they did not have enough money to build both the ground water and RWH system, especially the poor households. During the investigation period, many local residents thought

that rainwater was not clean (81% of interviewees). There were some problems with the existing RWH system in Cukhe village as there was no catchment management and filtration in the system. Therefore, a sludge layer at the bottom of the storage tank always exists and it could potentially become a good environment for mosquitoes or insect growth. This accounts for the water quality in the rainwater storing tank.

3.2. Quality of Water Sources

The results are shown in Table 2 and are compared with the World Health Organization (WHO) drinking water guideline [4]. Groundwater had a very high concentration of heavy metals (arsenic) and NO_2, and was far from meeting the potable water quality standard. In fact, groundwater is the main source for drinking. Thus, it is very dangerous for the health of residents. Meanwhile, the rainwater is far less than that listed in the WHO drinking water guideline. Therefore, encouraging the collection of rainwater of a certain quality is unnecessary.

3.3. Triple Bottom Line Consideration for Sustainable Water Supply

Of utmost importance during the installation was the delivery of a sustainable water supply system. This approach was taken and the installation addresses environmental, social and economic concerns.

3.3.1. Environmental

The RWH systems have minimal environmental impact. The entire design is environmentally sustainable and self-sufficient as it does not rely on electricity or producing unwanted emissions or waste. The design is well suited for the Cukhe village climate. The RWH system relies purely on rainwater and reduces the stress on groundwater use and the surrounding underground water table.

A brief overview of the materials used and the installation procedure for each component is given:

1) Catchment: Since we built the RWH system at existing houses the original roof was used for catchment. The roofing materials include galvanised iron and tile. For houses which do not

Fig. 4. Calm-inlet (a) and filter (b).

have a good roof, we use canvas catchment as an alternative. A smooth, clean surface with a high run-off coefficient is needed for the roofing material. The roof was made of galvanized iron sheeting that is ideal for RWH.

2) Gutters: Plastic and iron gutters were installed to capture rainwater running from the catchment. They were fitted on pre-installed brackets that were customized to complement the slope of the roof in order to minimize possible overrunning and to improve catchment efficiency. The gutters were connected to the filter and settling tank using PVC pipes, and were sloped toward the pipes to facilitate good drainage.

3) Filter: Due to the lack of catchment management, a filter is necessary to remove debris that gathers in the catchment area and to ensure high quality water. We installed a 3P Filter Collector made by 3P Technik Filtersysteme GmbH, Germany [5] before the settling tank. The filter involves simple installation and maintenance, which is an important criterion when considering suitable filters because the system will subsequently be used by laypersons that do not have strong technical knowledge. In particular, the filter can be easily removed and cleaned without needing to dismount the filter body from the downpipe.

4) Settling tank: 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. This problem can be prevented by modifying the inlet design so that water flows 'calmly' into the cistern (Fig. 4). A U-shaped inlet design, referred to as a calm inlet, reduces the potential energy

Table 2. Quality of water samples and WHO drinking water guideline

Parameter	Alley 14-Khucthuy		Kindergarten		Quangtrung alley	WHO
	Groundwater	Rainwater	Groundwater	Rainwater	Groundwater	
Temperature (°C)	17.9	19.3	21.8	19.5	18.1	-
pH	7.09	6.89	7.07	7.5	6.48	-
Turbidity (NTU)	0.97	2.75	1	1.96	17.7	5
EC (µS/cm)	596	99.5	720	98.5	592	-
As (mg/L)	0.042	0	0.03	0	0.035	0.01
Cu (mg/L)	0.005	0.012	0.004	0.008	0.003	1
Fe (mg/L)	0.055	0.035	0.016	0.028	1.758	-
Ni (mg/L)	0.002	0	0.002	0	0.002	0.02
Pb (mg/L)	0.005	0.005	0.006	0.003	0.004	0.01
Zn (mg/L)	0.003	0.124	0.011	0.07	0.003	3
NO_2 (mg/L)	12.511	1.93	27.644	0.177	0.333	3
NO_3 (mg/L)	0.029	0	0.078	3.725	7.347	50

WHO: World Health Organization, NTU: nephelometric turbidity unit, EC: electrical conductivity.

of inflow and thus maintains a stable condition for the stored water and prevents the resuspension of sediment.

5) Storage tank: Two types of storage tanks were installed: plastic tank and local stainless tank. The volume of a storage tank is 2 m³ when the storage tank is full. Assuming the daily potable water demand is 1 L per people for drinking and 10 L per household for cooking (consisting of 5 people), it is estimated that one unit of the RWH system can supply about 130 days of potable water to each household. Considering that the dry season in Vietnam is from November to April, this RWH system, which is easy to install and effective in maintaining stored water quality, is expected to relieve the potable water shortage during the dry season. Both of the tanks are simple, easy to install and maintain, and effective in maintaining stored water quality.

3.3.2. Economic

The costs associated with implementing the proposed system will be significant. It is therefore recommended that the system be implemented progressively in stages to reduce the economic strain on the households.

The costs of the RWH system are US $225 and US $380 for the cases 1 and 2, respectively (Table 3). This cost is relatively high compared with the income of the household in the village. However, it could be decreased considerably by using local available material and it is cheaper than other systems. Moreover, the extra cost will eventually get paid off through water savings. Assuming a minimum catchment area of 9 m², the expected annual volume of rainwater collected is 13.6 m³, taking into account a run-off coefficient (0.9) and the rainfall in the area. Considering no rainwater, there is only bottled water which meets the drinking water quality. Therefore, households can save a large amount of money by using RWH.

Ultimately the design, once fully operational, will require minimal maintenance and provide a self-sufficient sustainable source of water. Costs were reduced by using the residents and volunteers instead of hired labour. This will also allow those concerned to gain a good working knowledge of the system—how it works, operates and needs to be maintained.

3.3.3. Social

The project was of significant benefit to not only the residents and children of eight households and two kindergartens but the local community as well. Access to clean drinking water is the most importance issue concerning the health of the Cukhe people. By providing a clean, reliable, sustainable source of water, as the project will, many health problems will decrease by provid-

ing a better quality of life for those people.

Rather, we consider this project as a starting point for increasing public awareness about RWH and spreading the practice so that rainwater harvesting can become a popular alternative method for obtaining water in the Cukhe village. Besides technically building the rainwater harvesting systems, we also educated the local residents in using the system properly by distributing a simple instruction manual. In addition, through frequent communications, we attempted to provide the locals with results of scientific analysis regarding the quality of the rainwater in efforts to reduce their negative perception of rainwater. We organized several special events such as organizing a festival day of culture exchange (Korean-Vietnamese) to promote interaction with the local community in order to increase public awareness about rainwater harvesting and we were able to forge links with the community; several residents even voluntarily participated in the installation process. The involvement of the local residents can be considered as an implicit capacity building and technology transfer to spread RWH wider. Lastly, we chose to install the system at poor households. We found that, rainwater is very important for the poor households and thus they perform very well. Therefore, these good study cases can help the concept of rainwater harvesting would be disseminated more quickly.

4. Conclusions

Cukhe is a typical village of the Red River Delta region where residents are affected by using arsenic contaminated groundwater. Filtered groundwater is of relatively good quality, but is not the only source used as drinking water because of the concern of pollution by heavy metals, especially arsenic. On the other hand, rainwater, which is a very trusted water source, was confirmed as not containing heavy metals, thus satisfying the WHO quality standard for drinking water.

A research team from Seoul National University installed filters and settled tanks with a calm inlet, which are simple components that can be installed by anyone, in the existing RWH system in Cukhe. This is expected to have a positive effect on water quality over the long term. In addition, the team installed ten portable rainwater tanks for eight poor households and two kindergartens. The tanks are easily set up and transported, which will assist in obtaining good-quality drinking water regardless of the season and location.

The findings from this RWH study can be further applied to other villages in Vietnam as a safe water supply option, especially when the other water sources are contaminated or too expensive to afford. Lastly, RWH is the best technology available for obtaining good-quality drinking water at low cost and with low energy requirements.

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Table 3. Price of rainwater harvesting system components

Component	Price (US $)	
	Case 1	Case 2
Stainless tank (2 m³)		300
Plastic foldable tank (2 m³)	180	
Canvas catchment (9 m²)	20	
Plastic settling tank (80 L)	15	15
3P filer (1 unit)		50
PVC pipe	10	15
Total	225	380

PVC: polyvinyl chloride.

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