Austin Journal of Hydrology

Open Access

Austin Publishing Group

Research Article

Rainwater Harvesting: An Alternative Source of Safe Drinking Water in Bangladesh

Md. Manzurul Islam[1]*, Chou FNF[2], Jyoti Prakash Maity[3] and Kabir MR[4]

[1]APS to Economic Advisor to the Hon'ble Prime Minister, Prime Minister's Office, Dhaka, Bangladesh

[2]Department of Hydraulic and Ocean Engineering, National Cheng Kung University, Taiwan

[3]Department of Earth and Environmental Sciences, National Chung Cheng University, 168 University Road, Ming-Shung, Chiayi County 62102, Taiwan

[4]Department of Civil Engineering, University of Asia Pacific, Dhaka, Bangladesh

***Corresponding author:** Md. Manzurul Islam, APS to Economic Advisor to the Hon'ble Prime Minister, Prime Minister's Office, Dhaka, Bangladesh, Tel: +880-2-9124746; Email: manzurul73@gmail.com

Received: September 08, 2014; **Accepted:** November 13, 2014; **Published:** November 18, 2014

Abstract

Groundwater has been reported to be contaminated by the Arsenic (As) since 1993, which was highly hazardous for human health and for food safety as well. The groundwater of 61 districts has been heavily contaminated by As. Thus, about 38,000 cases of *arsenicosis* were identified in Bangladesh. A lot of research works had been carried out to reduce the As-concentration at the acceptable limit. A lot of As removal technologies and options are available in Bangladesh. Almost all of those have technical and economic constraints to use by rural uneducated and poor people.

To overcome the As contaminated health hazards, rainwater harvesting was found to be one of the best remedial measures for the rural people of Bangladesh. A Yield Before Spillage (YBS) model using spreadsheet was developed for the study to optimize the rainwater storage tanks according to different numbers of family members ranging three to seven. It was found from the simulated results that different capacities tanks would be able to supply the required water demands of those different family members. The stored water could be used for drinking, cooking and dishwashing of a family throughout the year. The study found that the method to be very much potential.

Keywords: Rainwater harvesting; Arsenic mitigation option; Optimum tank volume; YBS

Introduction

Groundwater is available in shallow aquifers in adequate quantity in the flood plains and Bangladesh achieved remarkable successes by providing drinking water at low-cost to the rural population through sinking of shallow tube wells. Unfortunately, As-contamination of shallow tube well water in excess of acceptable limit has become a major public health problem in Bangladesh. As-contamination of this groundwater has been reported from 1993 but in terms of severity, Bangladesh tops the list, followed by India and Vietnam in the world [1]. Hundreds of thousands of people in Bangladesh, daily use drinking water with As-concentrations several times higher than that of the World Health Organization (WHO) recommendation of 0.01 mg/L of water where as 0.05 mg/L for Bangladesh [2]. It was suspected that over 0.2 million people were suffering from As-related diseases, ranging from melanosis to skin cancer and gangrene. An estimated 35-40 million out of 130 million people are potentially at risk of As-poisoning from drinking water source in Bangladesh [3,4]. The lifetime excess risk (per 100,000 people) of mortality from liver, bladder and lung cancers attributed to arsenic in drinking-water were 198.3 for males and 53.8 for females, with an average across-gender lifetime risk of 126.1 [5].

During the last few years a wide range of small scale As removal technologies and options have been developed, field tested and used under action research programs in Bangladesh. Those technologies could be broadly categorized as: (i) oxidation and precipitation, (ii) coagulation and co-precipitation, (iii) sorption techniques and (iv) membrane techniques. The methods are not so easy to use in the rural areas of Bangladesh. Rainwater harvesting is an alternative source of safe drinking water and it is easy to use by the rural uneducated people of Bangladesh. Compared with the As removal methods, the quality of rainwater is better quality, the cost of construction and maintenance are low. Gomes [6] proved that rooftop rainwater harvesting systems for human consumption represent an alternative among individual technologies of water supply. A domestic rainwater harvesting system may be viewed acceptable from a technical (e.g. risk of demand not being met), economic (e.g. most economical tank capacity), or managerial (e.g. acceptable duration of time with empty tank) perspective [7,8] concluded that rainwater usage is economically feasible for most cases; and the higher the rainwater demand, the higher the feasibility. Parra et al. [9] reviewed that rainwater harvesting (RWH) systems can aid not only in meeting water demand partially, but also doing so in a more cost-effective and environmentally friendly manner than other techniques. The acceptance of the rainwater harvesting is better because some NGOs are now trying to establish it in some places of Bangladesh. The rainwater harvesting option can provide the people a maximum safety from As-contamination which is available in the rural area of Bangladesh. Islam [10] investigated that stored rainwater could be used up to four months as safe drinking purposes and if collected and stored properly, it could be used for longer period. If the rural people can store the rainwater at an air tight container, then the people may use it as drinking water for more than four months. It will reduce the risk of contamination. The objective of this study was to determine the capacity of rainwater harvesting tanks which could store rainwater and satisfy the demand throughout a year for a family having different members and it would help to promote the rainwater harvesting system as potential alternative water source to mitigate As-contamination.

Citation: Md. Manzurul Islam, Chou FNF, Maity JP and Kabir MR. Rainwater Harvesting: An Alternative Source of Safe Drinking Water in Bangladesh. Austin J Hydrol. 2014;1(2): 8.

For this study, a Yield Before Spillage model (spreadsheet) was developed for optimal tank size design. The study used to find the optimal sizes of the tank of a family having different family members. 10 years rainfall data (from 1996 to 2005) were analyzed and simulated to find the suitable data (minimum rainfall data) which was used in the simulation to determine the optimum tank capacities. The rainfall data is one of the very important parameters for the study. The rainfall pattern is changing with the climate change and this climate change scenario was also considered to find the suitable rainfall data. The model was simulated using different parameters like: minimum rainfall data, standard catchment area, water demands and storage tanks. Catchment area was considered as standard roof area of rural households. Water demands were considered for drinking, cooking and dishwashing purposes having different numbers of family members. After a lot of simulations, the study revealed the optimum tank sizes which could provide rainwater to a family throughout the year for drinking, cooking and dishwashing purposes.

Materials and Methods

Study area

Jhikargachha is an upazila (subdistrict) of Jessore District in the Division of Khulna, Bangladesh, was selected as study area for this research work. It is located at 23°6′0″N latitude and 89°7′59.88″E longitude. The land area of the upazila is about 308.09 km^2, total population is about 271,014 and literacy rate is 52% (BBS, 2007). It has 174 villages and about 58,391 households. This upazila is far away from the capital city (350 km). Average economic condition of the people of the study area is relatively poor. Culture of the people is mostly village oriented and professions of people are mostly agriculture. Households are mostly collective and community-oriented. Acceptance of any new technology or idea is less difficult; i.e. people are more open-minded.

Jhikargachha upazila was selected as study area because the biggest local NGO Bangladesh Rural Advancement Committee (BRAC) has been working in this area for a couple of years to mitigate the As problem and has already completed the testing of tube wells and the awareness level of the people. BRAC distributed different safe water options among the community as free demonstration units. These free options were located and distributed among people selected by the community itself. A limited number of options were distributed in each village, the intention being to motivate and raise the awareness of the villagers about the provided options. A small questionnaire survey was conducted to get the users perception about different options. Since the number of provided options in any one village was very low, perceptions of villagers about these options were collected from different parts of the study area.

Rainfall analysis

Bangladesh is a tropical country and it experiences heavy rainfall during the monsoon. Monsoon usually lasts from May to October and there is occasional rainfall also in November. Thus, during this period it gets ample rainwater, which could reduce the dependency on As-contaminated groundwater if it is harvested and stored properly. The rainfall in monsoon generally varies from 150 cm to 350 cm annually. Rainfall data collected from Jessore rainfall station from the year 1996 to 2005 (10 years) were analyzed and simulated for the study. Among these years, around 115 cm was found to be the lowest rainfall in year 2003 and used for the determination of the optimum tank size. This year's data was also congruent with the average annual change ± 5% of the trend in annual precipitation from 1901 to 2005 which was determined by Working Group 1 of Intergovernmental Panel on Climate Change (IPCC AR4, 2007). IPCC determined average annual rainfall of 149 cm which is nearly equivalent to the study area's minimum annual rainfall of that period. Thus, the annual rainfall used in the simulation to optimize the tank capacities for the study, was reasonable.

Demand analysis

The total per capita water demand for a family was very high. If rainwater harvesting system is considered to satisfy the total demand, then the storage capacity would be huge. The rainfall only lasts about five months in Bangladesh and for the rest dry period, the required storage volume would be very big and cost would be very high which would not be feasible for the rural poor people. On the other hand, it was found that As-toxicity mostly occurs through drinking water and contaminated food [11]. Considering these situations, only drinking, cooking food and dishwashing purposes were considered as demand for the study. The study area has different sizes of family members varying from three to seven or even more. But the survey study found that the majority of the families having five family members. This study has simulated considering different sizes family members like: three, four, five, six and seven. An average water requirement of 2 L/day/person for drinking purposes [12] was considered for the study area. According to the survey findings, the water demands for cooking and dishwashing purposes of the families having family members of 3,4,5,6 and 7 were assumed to be 16, 18, 20, 22 and 24 L/day/family respectively for the study. These volumes seem to be very small compared to the standard water use rate, but these volumes were exclusively assumed for hardcore safe drinking water shortage area. The safe drinking water will be used only to clean the rice and vegetables and final washing the cooking pots. The meaning of dishwashing was to wash/clean the pots, plates and wash the hands before having foods.

Initial flushing device

Rainwater collects impurities and contaminants during flowing

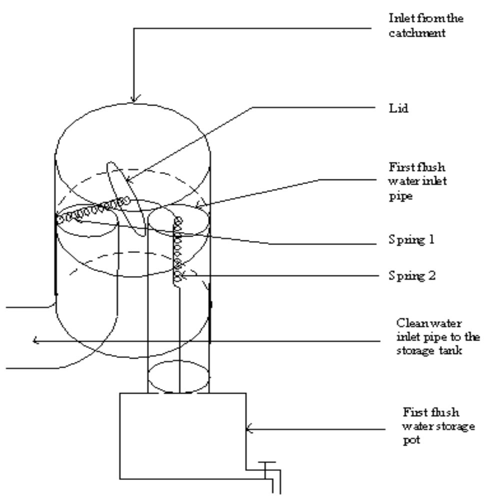

Figure 1: An initial flushing device.

over the catchment, thus, it was necessary to have a first flush removal mechanism included in the system. During the dry period, dirt and bird droppings may seriously concession the quality of the collected rainwater. An automatic initial flushing device is shown in Figure 1 was designed and fabricated for the study to flush the roof or catchment. This device was developed to prevent the first rain from contaminating stored water with bird's dropping, sediment and debris from the roof. To fabricate an automatic initial flushing device, a plastic pot (first flush water storage pot) having capacity of approximately 10 L (because it was determined that 6 to 10 L of water can clean the catchment), two PVC pipes (one is to collect first flush water and the other is to collect the clean water) of 30 cm length each, one lid which would close and open two inlets with the help of springs, two springs etc. were used. The device would work automatically. There were two inlets at the top of the device of which one carried first flush water and the other carried the clean water to the storage tank. The inlets would be closed and opened by one common lid on it with the help of two springs. Spring 1 would help to close the clean water inlet using the lid and it has less tension than spring 2. The first flush water collection inlet would be closed with the help of spring 2. If the lid opens the first flush water collection inlet, the clean water inlet would be closed by the lid simultaneously. Initially the clean water inlet would be closed and the first flush inlet would be opened. As the rain starts, the first flush water will store into the first flush water storage pot. When the water holding capacity will exceed the tension on spring 2, then it would pull the lid and would close inlet of the first flush inlet. On the other hand, the clean water inlet would open and store the clean water to the storage tank. When the rain would be stopped then the first flush water holding pot would be emptied manually by opening the stop cork. If the water from the first flush water storage pot is emptied, spring 1 will pull the lid and the clean water inlet would be closed automatically. The stop cork of the first flush water holding pot would be closed again to use it before starts the next rain.

Hydrological simulation

A lot of methods are available for determining the size of the rainwater storage capacity which could satisfy a given demand. The methods could be categorized as: graphical, mass curve, statistical, and simulation methods. Graphical and mass curve methods that could be used for rapid assessment are designated as preliminary design techniques. The choice of the analysis method is determined by the level of accuracy required and the type of storage being assessed: within-year storages that go through the full–empty–refill–spill cycle several times a year, and over-year (carry-over) storages that go through this cycle over a much longer time period, often in the order of years. Many researchers have used simulation to investigate the performance of rainwater systems [13,14]. For most rainwater harvesting systems, the volume of rainwater supplied depends on the quantity of rainfall, the area of the catchment, and the calculated yield.

Two water release rules are considered, namely: YAS (Yield After Spillage) and YBS (Yield Before Spillage). The YAS rule could be understood by considering that the demand is withdrawn after the rainfall has been added to the storage facility and spillage has been determined. The YBS rule assumes that the demand is withdrawn before spillage is determined. Liaw and Tsi [15] invented that for a small size storage tank, the YBS model is more effective. Mitchell [16] has provided the detailed explanation of the YBS model. YBS model (developed using spreadsheet) was developed for this study considering some required design parameters like: rainfall data, demand, catchment area and volume of the storage tank to optimize the required capacities of the tanks which could satisfy the demand having different family members for a whole year. The operation principles of YBS can be illustrated mathematically as,

$$Y_t - Min\begin{cases} D_t \\ S_{t-1} + Q_t \end{cases} \tag{1}$$

$$S_t = Min\begin{cases} S_{t-1} + Q_t - Y_t \\ C_a \end{cases} \tag{2}$$

where, D_t is water demand at time t; S_{t-1} is storage at the beginning of the $t\text{-}1^{th}$ time period; S_t is storage at the beginning of the t^{th} time period; Q_t is inflow during the t^{th} time period; Y_t is release during the t^{th} time period; and C_a is storage capacity.

For the simulation, the catchment area of 20 m^2 (rural households' average roof area), different everyday demands (varies with different family members), the runoff coefficient of 0.85 and initial losses of 0.002 m^3 were used. The rainfall data of the year 2003 (May 2003 to 2004 because rainfall starts from May) were used in the simulation because the rainfall of this year was the minimum rainfall of the study area with in the study period. A lot of simulations were performed using different sizes of tanks and finally revealed the sizes which could provide rainwater throughout a year (365 days) to a family having different family members.

Results

Considering five different groups of family members (3 to 7) and their respective demands, the model was simulated to get the suitable tank sizes. The simulated results are shown in Figures 2 - 6. Each of the figures has three parts. The upper part of the figures shows the effective rain volume (m^3) which could be stored in the tank. The middle part of the figures shows the overflow situations. The tank can store the rainwater up to the maximum capacity of it and the excess rainwater will be overflowed. The lower part of the figures shows the water storage and release situations.

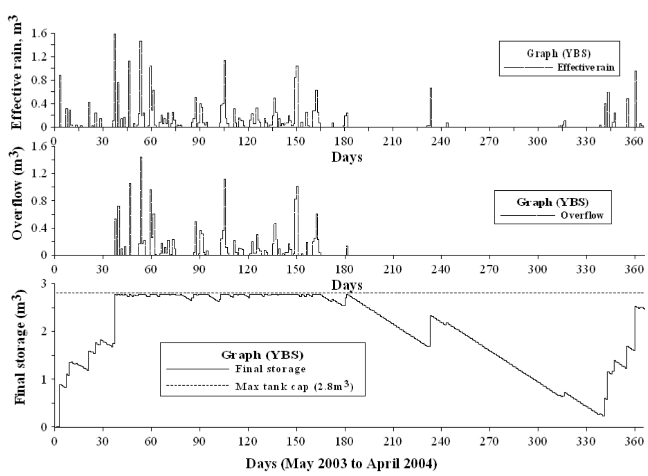

Figure 2: Water release and storage conditions for a family having 3 members using Yield before Spillage (YBS) model.

The simulated results for a family having 3 members could not find any water shortage during the whole year (Figure 2). A huge volume of water left unused at the end of the year which could be used for a few months at the next year if there is no any rainfall. But at the beginning of the year there was no any rainfall for first two days. This kind of shortage situation could be satisfied when the simulation will be considered continuously for a couple of years using the end of year storage. The simulation provided that the optimum capacity of the tank would be 2.8 m^3 which can support the required water demand. However, there was a huge volume of water overflowed from the tank.

The results of the simulation for a family consisting 4 members are shown in Figure 3. The figure shows that the optimum size of the tank would be 3.5 m^3 and this tank will not create any shortage during the year. Even though the tank overflowed a huge volume of water, at the end of the year it stored a huge volume of water as carry over storage which can continuously supply water for the family for long time without further any rainfall.

The simulated results of a family having 5 members which was the highest number of a family in the study area are illustrated in Figure 4. The optimum size of the tank was found to be 4.1 m^3 which

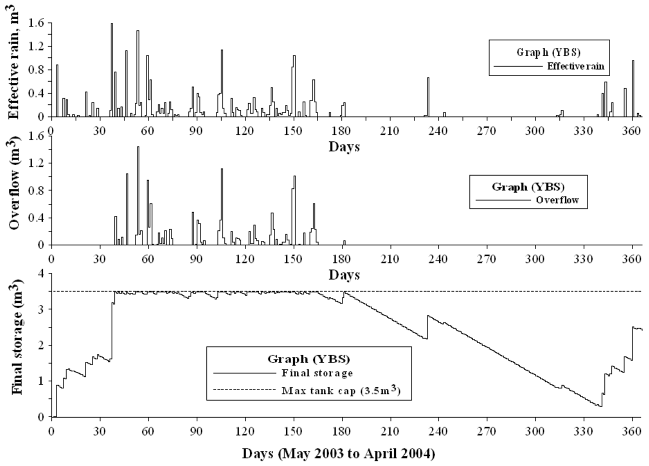

Figure 3: Water release and storage conditions for a family having 4 members using Yield before Spillage (YBS) model.

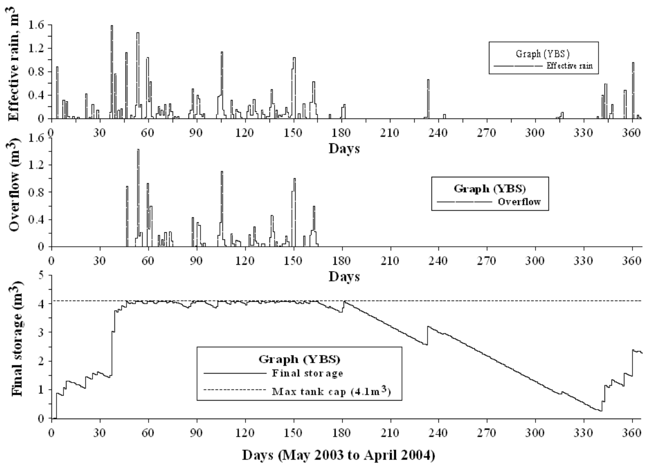

Figure 4: Water release and storage conditions for a family having 5 members using Yield before Spillage (YBS) model.

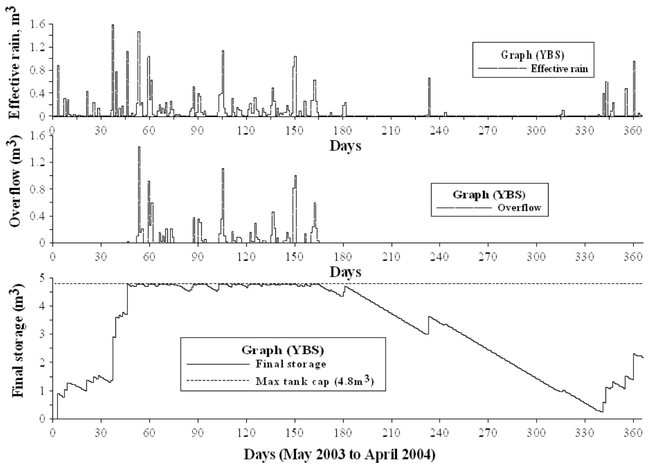

Figure 5: Water release and storage conditions for a family having 6 members using Yield before Spillage (YBS) model.

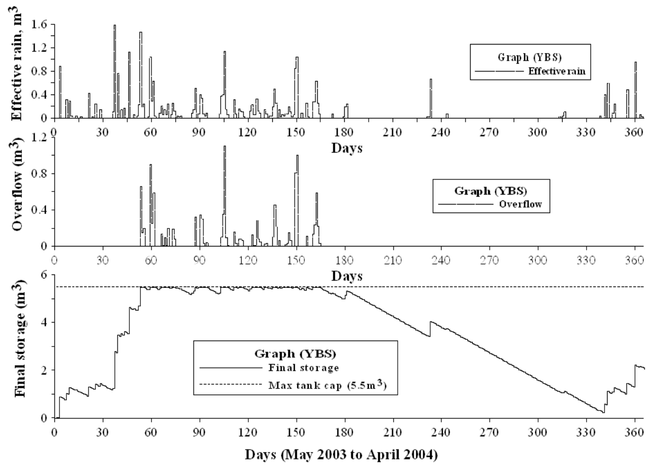

Figure 6: Water release and storage conditions for a family having 7 members using Yield before Spillage (YBS) model.

could provide water throughout the year without any shortage. Even though there was a huge spillage from the tank, at the end of the year it was found that there was a carry over storage which could support a long time without any rainfall.

The optimum size of the tank was found to be 4.8 m^3 of a family having 6 members. The water storage and release situations of the tank are shown in Figure 5. The figure shows that the tank would be good enough to support to the six members family for drinking, cooking and dishwashing purposes water up to a one year without any shortage. A carry over storage volume was found at the end of the year though there would be a huge spillage from the tank.

The tank size having volume of 5.5 m^3 can support to a family of 7 members for a whole year. The water storage and release situations of the tank are shown in Figure 6. The water release situation reveals that the tank could overflow a huge volume of water and it would not create any shortage during the whole year. On the other hand, it could produce a huge volume of carry over storage at the end of the year which could support the demand for a long time without any rainfall.

The demands, the rainwater availability, effective rainfall volume,

Table 1: Demand, rainwater availability, water storage and overflow situations.

No of Users	Demand/ Day (m³)	Demand/ Year (m³)	Rainwater/ Year (m³)	Effective Rainfall (m³)	Overflow (m³)	Final storage (m³)	Minimum storage (m³)	Minimum storage day	Capacity (m³)
3	0.022	8.03	10.45	27.28	16.81	2.48	0.23	340	2.80
4	0.026	9.49	11.85	27.28	15.40	2.44	0.29	340	3.50
5	0.030	10.95	13.16	27.28	14.10	2.30	0.25	340	4.10
6	0.034	12.41	14.50	27.28	12.76	2.19	0.24	340	4.80
7	0.038	13.87	15.84	27.28	11.42	2.04	0.23	340	5.50

overflow volume, carry over storage etc. conditions are shown in Table 1. From the table, it is apparent that there is a linear relation between the number of users and the corresponding demands. The second row of the table illustrates that for a family having 3 users, the yearly water demand is 8.03 m^3. The tank having optimum capacity of 2.8 m^3 could satisfy the demand but it can use 10.45 m^3 rainwater for the year which is more than that of the yearly demand. The second row also depicts that the tank can overflow a volume of 16.81 m^3 water, even the final storage or end of year storage of the tank is 2.48 m^3. From this situation, it is apparent that even the final storage is large, it could not make any significant contribution during a one year period, and it could be regarded as wastage like overflow. It could be illustrated also that this end of year storage could support demand for the next year for more than 3 months without any rainfall. But the row shows a minimum storage of 0.23 m^3 occurred at 340th day in that year. The minimum storage is a kind of safety factor for the simulation. It means if there is no any further rainfall, this minimum storage can support for the 3 members family up to 10 more days. It means if there is no any rainfall within this 10 days, the tank will not support demand any more.

The third row of the table provides the yearly water demand is 9.49 m^3 for a family having 4 users. The optimum tank capacity of 3.5 m^3 could satisfy the demand effectively without any shortage. The tank can use 11.85 m^3 of rainwater for the year which is more than that of the yearly demand. It overflows a volume of 16.81 m^3 water and could produce end of year storage of 2.44 m^3. This end of year storage could support demand for the next year for more than 3 months without any rainfall. It also shows a minimum storage of 0.29 m^3 occurred at 340th day in that year. The minimum storage can support for the family up to 11 more days without any rainfall.

The fourth row of the table reveals the yearly water demand is 10.95 m^3 for a family having 5 users. The optimum tank capacity is found to be 4.1 m^3 which could satisfy the whole year's demand effectively without any shortage. The tank can use 13.16 m^3 of rainwater for the year which is more than that of the yearly demand. The spillage volume was 14.10 m^3 and the tank was able to produce carry over storage of 2.30 m^3. This carry over storage could support demand for more than two and a half months without any rainfall. It also shows a minimum storage of 0.25 m^3 occurred at 340th day which can support for the family up to 8 more days without any rainfall.

The fifth and sixth rows represent 6 and 7 number of family members respectively. From these rows it was found that 4.8 m^3 and 5.5 m^3 tanks can satisfy 6 and 7 number of family members water demand for a whole year. These two tanks also could produce huge volume of overflow and end of year storage as well. The minimum storages of these tanks were also significant as safety factor.

The relationship between the number of users' vs storage tank volume which was found from the simulation is shown in Figure 7. The figure illustrates a linear relationship between the number of users and the storage tank volumes. The relation could be expressed mathematically as:

$$S=0.67\,N+0.79 \qquad (3)$$

where, S denotes the volume of the tank in m^3 and the N denotes number of users.

This equation could be used to determine the required storage volume of a family having different sizes of the family members. The R^2 value of the trend line is 0.9993 which indicates that the regression line fitted very well.

Discussion

A huge number of people affected with arsenic related diseases, ranging from melanosis to skin cancer and gangrene (Figure 8), have been identified in Bangladesh. According to WHO (2001), As-contamination will cause 200,000 to 270,000 deaths from cancer in Bangladesh alone. Rural people are more affected than urban people and As-contamination is not contagious or transferable [17].

The As-contamination in Bangladesh is a severe health problem. There are a lot of methods are available in Bangladesh to reduce or to remove As from the drinking water. A remarkable technological development in As removal from rural water supply based on conventional As removal processes has been taken place during the last couple of years. Brief comparisons of the methods could be shown in the Table 2. From the table, it is apparent that the technologies could be suitable to reduce or in some cases to remove As-contamination from drinking water but most of the technologies are not suitable for the rural poor people of Bangladesh. Some of the technologies are technologically not suitable to use by rural uneducated people and

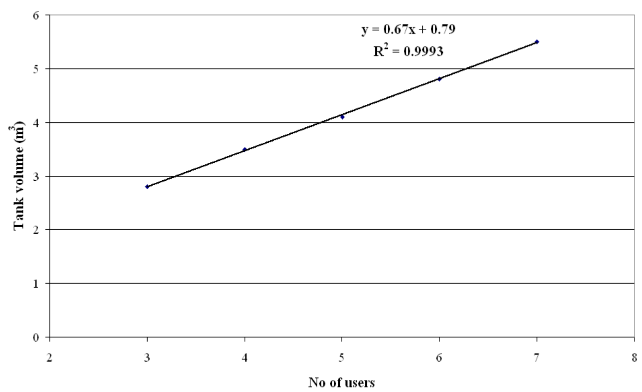

Figure 7: The relationship between the number of users and the tank volume.

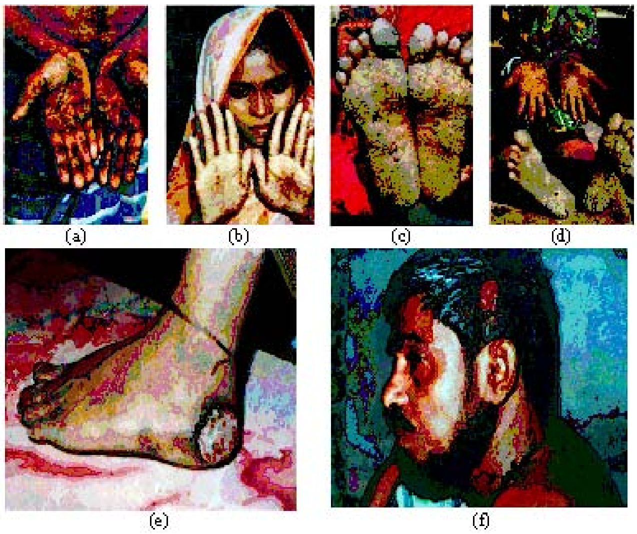

Figure 8: Arsenic-affected diseases in human body: (a) Melanosis-palm (b) Melanosis-hand (c) Keratosis-sole (d) Keratosis-palm (e) Gangrene-foot-toe and (f) Gangrene-head [27].

some of the technologies are economically not suitable for the users of Bangladesh. Comparing rainwater harvesting with these technologies, rainwater was found to be the best option to provide As-free water to the rural people of Bangladesh even though the rainwater harvesting has some contamination risks.

A study conducted by the Development Technology Unit of the University of Warwick [18] suggested that for each mm of first flush the contaminate load will halve. The use of inlet filters provides another way to separate dirt from good rainwater. In order not to waste precious rainwater, inlet filters should have capacity to handle larger volumes of water and should therefore preferably by self cleaning. Clever inlet filters are nowadays commercially available in industrialized countries that are promoting rainwater harvesting. During storage, and depending on the time after the last rainfall, bacterial die-off can be substantial, with a log-reduction achieved in one or two weeks. Bio-films developing at the tank-water interface were also considered to have a positive effect on the water quality [19]. The volume of first flush water that needs to be removed before water is safe to drink has been found to vary between different studies. Yaziz et al. [20] found that 0.5 mm of rain was sufficient to reduce the faecal coliforms count to zero on two roofs in a Malaysian campus. Coombes et al. [21] have found that even after 2 mm was flushed, there were still significant faecal coliforms in the runoff from a building located close to a bus depot in Australia. Field studies in Uganda have shown unacceptable turbidity after 2 mm have removed although faecal coliform counts were in the WHO "low risk" category. Despite this uncertainty, first flush systems are considered a very good method of improving the quality of roof runoff prior to storage [22]. The first flush which was designed for the study could reduce the risk of contamination.

Some studies reported that there are some possibilities of total coliform contamination of stored rainwater. Islam [10] has proved that locally made sand filters having different depths like 30 cm, 45 cm and 60 cm could reduce about 30%, 40% and 60% of total coliform respectively. From literature, it is known that a sand filter having 1 m of sand layer may remove from 95% to 98% of the total coliform. It is desirable that coliform bacteria would be totally absent from drinking water; this is not always economically or technically feasible in developing countries. In such cases, a TC bacteria guideline of 10 or 20/100 mL may be more appropriate [23].

Jakariya et al. [24] assessed the available options on several criteria such as: initial and running costs, ease of implementation, operation and maintenance, continuity and flow of supply, arsenic removal capacity, and sustainability of preventing bacteriological contamination and acceptability to the community. The grades were lower due to continuity and flow of supply and acceptability criteria. But another study observed that people were happy with the quality of rainwater. The study also revealed that one rainwater harvester was used by more than one family, so, the stored rainwater only lasted for a limited period (maximum one month), not long enough to cover the full dry period [25]. Study made it clear that even with the problem of managing the utilization of rainwater effectively; people of those areas accepted the system which reflected the social feasibility of the system. The required tank capacities which have designed by this study could provide the continuity and flow of supply throughout a whole year.

The initial consideration of the feasibility of rainwater harvesting system concerned water availability as compared to its use or demand. The supply of the system depends on how much rainfall occurs during the year and the variability of rainfall. The demand imposed on the system depends on water use. If the supply exceeds the demand, then the rainwater harvesting system would be feasible from a technical point of view (UNDP – World Bank, 1990). From the Figures 2-6, it is clear that on an average supply exceeded the demand for a family having all available family numbers. Besides, a large volume of water overflowed from the system, a small part of it could be used by taking special measure if needed. Hence, the rainwater harvesting system was found technically feasible.

Ellis and Garelick [26] plotted a graph for percentage As removal Vs utility score considering all of the available As mitigation technologies and options. From the plot, it was revealed that rainwater harvesting was one of the best ranking options. They investigated the operation and maintenance cost for all of the potential treatment options such as: coagulation-precipitation, adsorption media, bioremediation, membrane technology, solar distillation, rainwater harvesting, slow sand filter, deep tube well, filtration, hybrid technology, ion exchange and dug well. The rainwater harvesting achieved a very good grade value among the other options. They have made a few more studies such as: Community acceptance of various technology treatment options, local expertise and competency ratings for implementation and management of As-mitigation technologies. Both of the cases, rainwater harvesting had achieved very good grades. The Influence of rural community location and setting on sustainability of As-mitigation technologies assessed by Ellis and Garelick [26] and the rainwater harvesting achieved the best utility score and highest grade. The above illustration could clearly demonstrate that rainwater is the best solution for the rural poor people to mitigate the As related health hazards.

Conclusions

A model was developed to design the optimum tank capacities to satisfy drinking, cooking and dishwashing purposes water demands.

Table 2: A comparison of the available arsenic removal technologies in Bangladesh.

Technologies	Merits	Demerits
Air oxidation	Relatively simple and low cost	The processes remove only a part of arsenic but slow process
Chemical oxidation	Relatively simple and rapid process, oxidizes other impurities and kills microbes	Highly technical and not easy to use by rural people
Solar oxidation	Easy to use	Initial cost involvement is high
Bucket Treatment Unit (BTU)	Easy to construct	Mixing chemicals in right proportion is difficult for rural people, a bit slower process
Stevens Institute Technology	Faster than BTU	It requires washing at least twice a week
Ferruginous Manganese Ore	Low cost	In case of higher pH, it may not suitable
Household co-precipitation and filtration system	Simple and affordable process	Slower process
Fill and Draw Units	Suitable for community	Demonstration type
Chemical packages	Easy to apply	Quality assurance and dosage control is difficult, the residuals of added chemicals in water after treatment also harmful.
Alam coagulation, Iron coagulation	Relatively low capital cost, relatively simple operation, common chemicals available	Produces toxic sludges, low removal of As(III), pre-oxidation may be required
Activated Alumina	Relatively well known and commercially available	Produces toxic solid waste, replacement/ regeneration required
Iron coated sand	Well defined technique	High tech operation and Maintenance required
Iron exchange resin	Plenty possibilities and scope of development	Relatively high cost required
Nanofiltration	Well defined and high removal efficiency	Very high capital and running cost
Reverse osmosis	No toxic solid wastes produced	High tech operation and Maintenance required
Electrodialysis	Capable of removal of other contaminants	Toxic wastewater produced

The tank capacities were different on the basis of the family members ranging from three to seven. The study found that the capacities would be 2.8 m^3, 3.5 m^3, 4.1 m^3, 4.8 m^3 and 5.5 m^3 for the families having family members of 3,4,5,6 and 7 respectively. The study also revealed that there was a liner relation between the number of family members and the tank capacities. The relation could be used to determine the tank capacities for the number of family members which were not considered in this simulation. Some NGOs' were providing micro credit support to install the storage tank having capacity between 2.0~3.0 m^3 without considering the family members or actual demand and without considering the actual hydrological behavior. But those capacities were unable to satisfy their required demand and it was a negative impact to implement the system to the users. The optimum tank capacities revealed from the study could satisfy the whole year water demand of a family of different members for drinking, cooking and dishwashing purposes.

The rainwater harvesting option is found to be very effective and completely safe from As-contamination but needs awareness from Government by mass media. Many NGOs' are working to implement the system with micro credit system. But to eliminate such a severe problem, Government's intervention is a must with some incentives. More research is necessary to reduce the cost to construct the storage tank.

References

1. Nordstrom DK. Public health. Worldwide occurrences of arsenic in ground water. Science. 2002; 296: 2143-2145.
2. Iqbal S. Rural drinking water supply and sanitation in Bangladesh: A case study of Satkhira, South-Western district (Khulna Division), AIT Thesis no.EV-04-27. 2004.
3. Chowdhury UK, Biswas BK, Chowdhury TR, Samanta G, Mandal BK, Basu GC, Chanda CR . Groundwater arsenic contamination in Bangladesh and West Bengal, India. Environ Health Perspect. 2000; 108: 393-397.
4. Nickson R, McArthur J, Burgess W, Ahmed KM, Ravenscroft P, Rahman M. Arsenic poisoning of Bangladesh groundwater. Nature. 1998; 395: 338.
5. Chen Y, Ahsan H. Cancer burden from arsenic in drinking water in Bangladesh. Am J Public Health. 2004; 94: 741-744.
6. Gomes UAF, Heller L, Pena JL. A National Program for Large Scale Rainwater Harvesting: An Individual or Public Responsibility?, Water Resources Management. 2012; 26: 2703-2714.
7. Wang CH, Blackmore JM. Supply–Demand Risk and Resilience Assessment for Household Rainwater Harvesting in Melbourne, Australia, Water Resources Management. 2012; 26: 4381-4396.
8. Ghisi E, Schondermark PN. Investment Feasibility Analysis of Rainwater Use in Residences, Water Resources Management. 2013; 27: 2555-2576.
9. Parra MVV, Rovira MR, Gabarrell X, Villalba G. Cost-effective rainwater harvesting system in the Metropolitan Area of Barcelona, Journal of Water Supply: Research and Technology. 2014; 586-595.
10. Islam MM. Study on Rainwater Harvesting Techniques. M.Sc. Engineering thesis, Department of Water Resources Engineering, Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh. 2001.
11. FAO. Arsenic contamination of irrigation water, soil and crops in Bangladesh: Risk implications for sustainable agriculture and food safety in Asia. 2006.
12. Kahn HD, Stralka K. Estimated daily average per capita water ingestion by child and adult age categories based on USDA's 1994–1996 and 1998 continuing survey of food intakes by individuals. Journal of Exposure Science and Environmental Epidemiology. 2008; 19: 396-404.
13. Liaw CH, Chu SH, Tsai YL, Chen WY. Development of Urban Rainwater Cistern Systems Technology. Engineering Science & Technology Bulletin NSC. 1997; 26: 75-78.
14. Fewkes A. Modeling the Performance of Rainwater Collection Systems: Towards a Generalized Approach. Urban Water. 1999; 1: 323-333.

15. Liaw CH. Tsai Y. Optimum storage volume of rooftop rain water harvesting systems for domestic use. Journal of the American Water Resources Association. 2004; 40: 901-912.

16. Mitchell VG. How important is the selection of computational analysis method to the accuracy of rainwater tank behaviour modelling? Hydrological Processes. 2007; 21: 2850–2861.

17. Hossain MF. Arsenic contamination in Bangladesh-an overview. Agriculture, Ecosystems & Environment. 2006; 113: 1-16.

18. Martinson DB, Thomas TH. Quantifying the first flush phenomenon. Proceedings of 12th International Conference on Rain Water Catchment Systems, New Delhi, India. 2005.

19. Coombes P, Kuczera G, Kalma J, Dustan HR. Rainwater Quality from Roofs Tanks and Hot Water Systems at Fig Tree Place. Proceedings of the 3rd International Hydrology and Water Resources Symposium, Perth. 2000.

20. Yaziz MI, Gunting N, Sapari N, Ghazali A. Variations in rainwater quality from roof catchments. Water Research. 1989; 23: 761-765.

21. Coombes PJ, Dunstan RH, Spinks A, Evan C.A, Harrison T. An overview of a decade of research into the quality of rainwater supplies collected from roofs. Proceedings of 12th International Conference on Rain Water Catchment Systems, New Delhi, India. 2005.

22. Faisst EW, Fujioka RS. Assessment of four rainwater catchment designs on cistern water quality. Proceedings of the 6th international conference on rainwater catchment systems, Nairobi, Kenya. 1994.

23. Amin MT, Han M. Catchment effects on rainwater quality and Microbial quality enhancement by storage. 2nd International RWHM Workshop, 11 Septmeber, 2006, Beijing, China.

24. Jakariya M, Chowdhury AMR, Hossain Z, Rahman M, Sarker Q, Khan RI, et al. Sustainable community-based safe water options to mitigate the Bangladesh arsenic catastrophe: an experience from two upazilas. Current Science 2003; 85: 141–146.

25. BRAC (2000) Early experiences with a community based Arsenic mitigation project in Bangladesh, BRAC Research and Evaluation Division, Bangladesh.

26. Ellis B, Garelick H. A multi-criteria approach for assessing options to remediate arsenic in drinking water. Rev Environ Contam Toxicol. 2008; 197: 129-161.

27. Haque AM, Thwe HM, Jayasuriya HPW, Hossian MZ, Rahman M, Harun-ur-Rashid M, et al. Groundwater Arsenic Contamination: Food Safety and Human Health Hazards in Bangladesh. CMU J Nat Sci. 2007; 6: 321-339.

Austin J Hydrol - Volume 1 Issue 2 - 2014
ISSN : 2380-0763 | www.austinpublishinggroup.com

Citation: Md. Manzurul Islam, Chou FNF, Maity JP and Kabir MR. Rainwater Harvesting: An Alternative Source of Safe Drinking Water in Bangladesh. Austin J Hydrol. 2014;1(2): 8.