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Save water and safe water: Evaluation of design and storage period on water quality of rainwater harvesting system

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Abstract
The present research has been aimed to assess the appropriateness of different aspects of rooftop rainwater harvesting system as an alternative of ground water installed at Chitra Topi. 25 households were purposively selected for the collection of relevant data with the help of interview schedules, focus group discussions, and water sampling. Average rooftop area of surveyed households was 100 m^2. Ideal storage system and proper management of surplus during peak seasons can ensure water availability throughout the year. From quality perspective, there are few issues in the physical, chemical and microbiological parameters. But by the introduction of simple components there problems can be rectified to a large extent. Based on results, it is concluded that rain water harvesting systems were shown to be a relatively low cost option for improving a households' geographical and temporal access to a water source, increasing convenience and decreasing collection times.

Keywords: Rainwater, Harvesting, Design, Water quality

1. Introduction

The quantity and quality of water in many low-income countries is grim and is getting worse (Rahman *et al*., 2003). During the twentieth century the use of rainwater harvesting techniques declined around the world, partly due to the provision of large, centralized water supply schemes such as dam building projects, groundwater development and piped distribution systems (Devi *et al*, 2005). Rainwater harvesting (RWH) primarily consists of the collection, storage and subsequent use of captured rainwater as either the principal or as a supplementary source of water (Fewkes, 2006). Examples exist of systems that provide water for domestic, commercial, institutional and industrial purposes as well as agriculture, livestock, groundwater recharge, flood control, process water and as an emergency supply for firefighting (Gould and Nissen-Peterson, 1999; Konig, 2001; Datar, 2006). The provision of safe drinking water supply during the dry season makes women's daily lives much easier. The cisterns liberate women from the chore of fetching water daily (Hatibu *et al.*, 1999). However, in the last few decades there has been an increasing interest in the use of harvested water with an estimated 100,000,000 people worldwide currently utilizing a rainwater system of some description (Heggen, 2000). Rainwater is not a reliable water source in times of dry period or prolonged drought (Tallon *et al*., 2005). Research has shown that the initial "first flush" of runoff is more polluted than subsequent flows and that the concentration of contaminants associated with a given rainfall event tend to reduce exponentially with time. Although rooftop runoff was found to have higher chemical pollutant levels than that of the rainwater alone (Melidis et al., 2007). Therefore, diverting the initial portion of runoff generated by a storm away from the storage device will mean that the quality of water entering storage is improved and the need for subsequent treatment reduced or even eliminated altogether (Wu *et al*, 2003; Martinson and Thomas, 2005). Knowing that constituents have the possibility of being present in the collected rainwater leads to the task of addressing the concern. (Kim *et al*., 2005). The initial periods of runoff from rainwater catchments contain the highest levels of contamination due to constituents being washed off of the roof surfaces. Due to the fact that the initial periods contain the highest levels of contamination, diverting this water can reduce the concentration of contaminants in the storage component of rainwater harvesting systems (Coombes *et al*., 2000). These contaminants are most likely transferred to the catchment surface as a result of contact with animals such as birds, rodents, and insects. Typical, healthy adults tend to tolerate the low levels of bacteria that are present in properly maintained rainwater harvesting systems although the effect of these contaminants, just like others, are amplified in the very young, elderly, and those with weakened immune systems (Lye, 1996). Understanding the quality of runoff from rooftop surfaces and their potential for public health concerns reinforces the need for use of a first flush diverter as an additional level of protection (Evans *et al*., 2006). Water supply through pipe is a conventional wisdom for supplying water (Abbott *et al*., 2006). The purpose of this study is to assess a sustainability of rainwater harvesting system installed at Chirta Topi in District Bagh, Azad Jammu and Kashmir. The importance of rain water for drinking purpose is often ignored; in fact the harvested rainwater has enough potential to fulfill all the basic water requirements of the people of AJK and Pakistan if managed. Objectives of present research are to study the potential and design of rainwater harvesting systems installed in Chitra Topi, AJK and to assess the water quality of the harvested rainwater.

2. Material and Methods

2.1 Epistemological approach

A descriptive research systematically describes a situation, problem, services provided to people, preferences of people, living conditions of a community and attitude of a community towards an issue (Kumar 2008: 10). Descriptive studies answer questions like ‘what’, ‘where’, ‘when’ and ‘how’.

2.2 Quantitative and Qualitative research

Quantitative research is generally associated with the positivist/post-positivist paradigm. A correlational research is focused to find a relationship among various aspects of a situation (Kumar 2008). The objectives to be achieved for this research work demanded both qualitative and quantitative data collection with dominating contribution of the quantitative research approach while in qualitative research, the collected data are more in a verbal and pictorial form than in a numerical one. There is also a tendency to incorporate an integral and in-depth comprehension of phenomena in as natural a setting as possible, as well as in the context of concrete circumstances (Mesec, 1998). It is a general belief that the concept of reliability and validity are coined for the quantitative research approaches but the idea is now equally applied to the qualitative research also.

2.3 Universe of study

The study area for this research is Chitra Topi, a village in district Bagh, Azad Jammu and Kashmir. The reason for the selection of Chitra Topi was that a pilot project of rainwater harvesting system was launched by ERRA Pakistan with the financial support of OXFAM Pakistan and Implemented by Maqsood Welfare Foundation (AJK) in 2008. It was the first ever initiative on RWHS by Government of Pakistan. 50 households were selected after a need based survey; also two high schools and one mosque were benefited by it. This initiative helped almost 50 households consisting on almost 310 individuals, particularly women who are mainly responsible for fetching water for their family’s use. At Rural Health Centre (RHC), not only the residential staff benefited by this project but at OPD where daily almost 90 to 100 patients come to get the treatment. In the schools 470 boys, 346 girls and 37 staff members are getting benefit by this project, whereas at mosque indirectly all the village community are benefited by this facility.

2.4 ample unit

Households (HH) of the village were selected as unit of analysis and household heads (HHH) as the majority of respondents. Household heads have important role in decision making towards adoption or rejection of certain interventions at household level and as a result their usage. All the house hold decisions are, to a large extent acceptable to all HH members in the rural areas of the developing countries.

2.5 Sampling technique and sampling size

The total population of the Chitra Topi village is two thousand four hundred and eight (2408). The total numbers of household in the village are four hundred and nineteen (419). The total numbers of household with rooftop RWHS were fifty (50). Only four (4) households had a painted GI (Galvanized Iron) Sheets rooftop. Remaining forty six (46) households had unpainted simple GI sheets. The sampling technique used in this research is the *Purposive Systematic Sampling*. Two sampling techniques were simultaneously incorporated in the research, purposive and systematic. The reason for selecting these two sampling technique was that the purpose was to select a household with RWHS and to get a feedback from the households having rooftop RWHS. Table 1 shows the sample size for water quality analysis of the harvested rainwater.

Table 1 Sample size for water quality analysis of the harvested rainwater

Area/Place	**No. of samples**
Households with painted GI Roof Sheets	04
Households without painted GI Roof Sheets	21
From Masjid (Mosque)	01
From Primary School	01
From Rural Health Centre	01
Total	28

2.6 Research design

A cross-sectional study design was applied to collect the data from the field. This design is best suited to ascertain any problem, an ongoing process, situation, problems, attitude or issue, by taking a cross section of the population. These studies are useful in representing an overall picture of the situation prevailing at that nick of time at which contact is being made with the study community (Babbie 1989). These studies are economical to conduct as only one contact is usually made with the study population and analysis is also easy (Kumar 2008).

2.7 Interview schedule

Questions were asked in national language Urdu. No difficulty was faced during the interview schedule in interacting with the respondents and to minutely observe the behavior and actions of the respondents shown in terms of the gestures. Interview schedule was conducted both with males and females of the village. The interview schedule comprised of both open ended and closed ended questions, and the interview conduction was an interactive and continuous process as questions were continuously redesigned throughout the research work so as to incorporate the deficiencies.

2.8 Transect walk and personal observation

This information resulted to understand the water scarcity problem and helped in the design and implementation process of Rooftop rain water harvesting structures. Daily activities of the study population and timing of different activities were also keenly observed so as to know the time at which respondents can be approached for data collection with minimum possibility of disturbing their routine activities. A systemic walk with the local of the area observed, asked, listened and discussed the resources is very helpful in seeking the problems faced by the people, solutions sought for them, and opportunities available (Chambers, 1997).

2.9 Water sampling & data analysis

For the purpose to collect water samples, 28 of the samples were collected from household rainwater tank (Tap water). Samples were collected, leaving a ½ inch or cm space at the top of the bottle or filled the sterilized bottle up to 75% of the volume. Then caped the bottle and proceed to the laboratory for the experiments. To analyze the physiochemical parameters for drinking water quality, the data should compare with the World Health Organization (WHO) limit for the drinking water quality.

3. Results and Discussion

3.1 Design along with components of RRWHS (rooftop rainwater harvesting system) in Chitra Topi

Rainwater collection systems are commonly believed to provide safe drinking water without treatment because the collection surfaces (roofs) are isolated from many of the usual sources of contamination (e.g. sanitation systems). The purpose of this research is to outline best-practice and sustainable techniques for rainwater collection systems in order to produce good water quality. This design was chosen by OXFAM, MWF and ERRA after considering the following factors: Type and size of catchment area, local rainfall data and weather patterns, family size, length of the drought period, alternative water sources, and cost of the rainwater harvesting system. Even though all the mentioned factors were considered before the finalization of the design still there are many drawbacks in the design of the RRWHS.

3.2 Roof material used in Chitra Topi

3.2.1 Non painted galvanized iron (GI) sheets

Out of the fifty households that were provided with RRWHS, forty six were using the non-painted GI sheets. According to established literature mentioned above it is clear that these GI sheets are the best option for RRWHS. Also the water quality analysis from the non-painted GI sheets showed no metal or chemical presence.

3.2.2 Painted galvanized iron sheets

Only four households are using a painted GI sheet for the rooftop rainwater harvesting. These households were not intimidated by designing and the implementing partners that water gets polluted by toxic chemicals and metals during the harvesting. Therefore, the water quality was tested in order to analyze the presence of the heavy metals and chemicals. High concentration of lead presence was detected far more than the permissible limit by W.H.O, as presented and discussed in Graph 1.

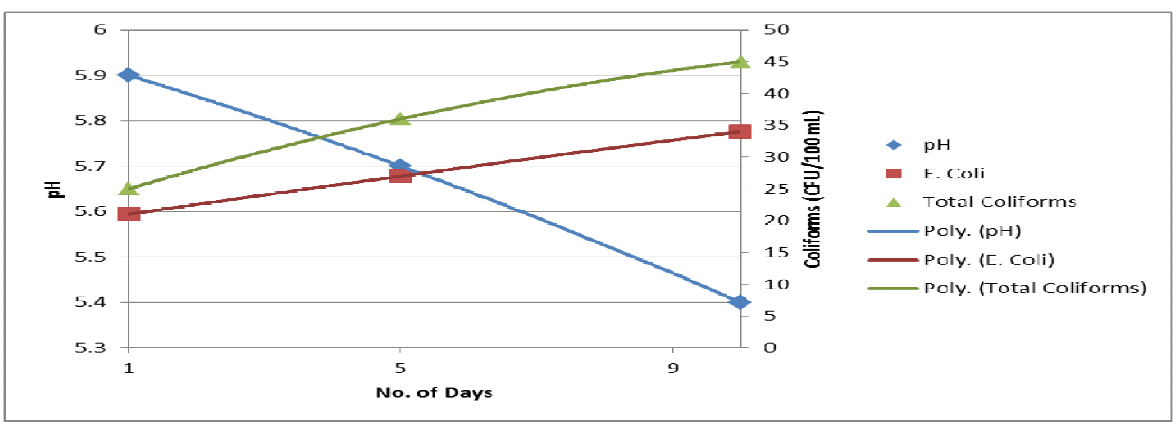
3.2.3 Gutters

The selection of gutter material was according to the standard specifications of the RWHS. The material used in Chitra Topi for guttering was PVC. The guttering material showed no contamination, as the water quality analysis was conducted regularly.

3.3 Effect of storage on physiochemical and microbiological parameters of water in summer

The water samples were collected and analyzed for the effect of storage period on the harvested rainwater quality in April. April is a hot month in which temperature remains within the range of 28-25^{o}C. In this month due to high temperature, the microbial activity was observed to be relatively higher than December. The number of E.Coli and total coliforms was relatively higher than in December. Therefore, the pH of the harvested water showed a significant decline. This was due to the increased rate of decomposition of organic material by the microorganism as their number was increasing at a high rate as seen in figure 1.

Figure1: Effect of storage on physical and microbiological parameters of rainwater



3.4 Turbidity variations with seasonal change

According to the W.H.O the permissible limit of the turbidity is 5 NTU. The turbidity of all the 28 samples was analyzed in the months of December, March and April. Accumulatively 84 samples were analyzed thorughout these months. The water samples having tubidity above the permissible milit were 96% and only 4% of the samples were having tubidity within the permissible range. December being a dry month, therefore not even a single sample was found within the permissible range. However, march and april received heavy rainfall but still 96% of the water samples were having high turbidity.

3.5 Total hardness variations with seasonal change

The total hardness of all the water samples was found within the permissible range according to W.H.O standards. The permissible range of the total hardness is 500 mg/l. averagely the total hardness of the water samples lied within the range of 30-40 mg/l. Therefore, the total hardness was found perfect in compliance with the drinkable water standards. The two primary factors affecting toxicity of metals in rain water runoff are pH and hardness, because lower pH or hardness causes an increase in toxicity (Heggen, R.J. 2000). A decrease in pH leads to more metals existing in bioavailable free ionic form. The lower pH will lead to an increase in the dissolved fraction and presumably an increase in the reactivity (toxicity) and mobility of those trace metals. An increase in pH causes formation of insoluble hydroxides and oxides, which are then less bioavailable then the free ions themselves. This trend is especially true for zinc and lead (Dempsey *et al*., 1993).

3.6 Lead Contamination

Only four houses out of fifty households with RRWHS facility were using the painted GI roof sheets. Samples from all the four households were collected in December, March and April respectively. In all the samples lead presence was detected above the permissible limit of W.H.O water quality standards. The permissible limit of lead is 0.01 mg/l. but the lead was found significantly higher than the acceptable levels. All the samples were tested for iron presence but iron was not detected in any of the water sample. Therefore, the water quality analysis suggests that the water should be treated before used for domestic purposes.

3.7 Total coliforms variation with seasonal change

The water samples were tested for total coliforms. 98% of the water samples showed a huge presence of total coliforms. Total coliforms were tested negative for only 2% of the water samples. The trend of the total coliforms showed increase with the progression of months. December showed the lowest cumulative amount of total coliforms as December is relatively cooler than March and April. In April the total coliforms were recorded at a high rate. This shows that the temperature variation from cold to hot increased the number of coliforms in the water.

3.8 Shortcomings of the design

Important components missing in the design of the RRWHS in Chitra Topi were the first flush diverter, filter screen and chlorination for disinfection. These are very crucial to the RWHS, as the water quality is directly affected by them.

4. Conclusions

Domestic rainwater harvesting is relatively simple and readily available technology for water provision. Rooftop rainwater harvesting has a lot of potential to conserve potable water for onsite consumption and reduces dependency of a household on other water resources. Majority of the residents in the study area have access to a source of water that is neither fully fit as per WHO requirements nor adequately meets household water needs. In village Chitra Topi water access point is two kilometer away from a household (on average) which takes a total collection time about two hours. Physical, chemical and micro-biological analysis of rainwater shows that rainwater has the ability to be a perfect alternative of permanent water supply in Chitra Topi. The water quality can be improved by the introduction of screen filter, first flush diverter, chlorination, a slow sand filter, regular cleaning and maintenance of the catchment area before rainfall events. An increased price of potable water would encourage investment in rainwater harvesting systems because they offer a long-term inexpensive supply of water after the initial capital investment. This system should be introduced both at rural and urban areas of Pakistan.

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