Original Research Article

Harvesting and Potable Use of Rooftop Water to Tackle Imminent Drinking Water Crisis

---

.

ABSTRACT

Rooftop water harvesting is an ideal technique to collect and store rainwater for drinking purposes. However, with time, in spite of all precautions, there is a possibility of development of microbes in stored water, making it unsafe for drinking. An attempt was made at Navsari Agricultural University, Gujarat to design the rooftop water harvesting system in such a way that stored water meets the annual water demand maintaining the quality of water at minimum cost. The water harvesting system was constructed at six locations and water quality in the storage tanks was monitored at regular intervals. Physical, chemical and bacterial quality of harvested rainwater was evaluated in laboratory and the water was found to be of excellent quality. However, microbial growth was found to be present at few places over the time. Laboratory study was undertaken to find economical solution to remove microbes from the stored water before consumption using copper vessel, silver strip of 30 cm × 10 cm × 0.03 cm size, commercially available cloth filter, earthen pot, and control (without any treatment). The results revealed that copper vessel showed maximum inhibitory effect on coliform as well as total bacterial count when water was stored for 12 h and 24 h. Though, there was a slight increase in copper residue, but it remained within the permissible limits. Therefore, vessel made up of copper could safely be used for antimicrobial treatment to purify the drinking water. The methodology could be useful to meet the precariously deteriorating potable water situation in rural areas especially for the poor people of developing economies.

Keywords: Harvested rooftop water, water purification, copper vessel, drinking water

1. INTRODUCTION

Water shortages start occurring with slightly deficit rainfall as well as in high rainfall areas due to climate change, population pressure, removal of trees and seawater ingress. These shortages are experienced more by the poor rather than the rich, who may afford to purchase and maintain costly modern technologies for their survival. People need economic and comprehensive techniques of water harvesting and safe storage for round the year consumption. Roof water harvesting and its consumption is an age old practice followed in arid and semi-arid regions. In tropical rural areas, roof water harvesting offers the only means of improving their household's water supply (1). Approaches adopted to harvest roof water for domestic consumption in Bangalore were by discussed (2). The roof water harvesting systems offers tremendous potential for independent bungalows having large roof area (3). The potential for rainwater harvesting in Abeokuta, Nigeria was assessed and it was found that harvested rainwater could satisfy household monthly water demand for flushing and laundry (4). In urban Zambia, (5) the water quality was assessed and the roof water harvesting system was designed on the basis of mass curve analysis for storage and rational formula for the gutters, but maximum storage of 10 m^3 was chosen due to budgetary limitation. The water balance approach for rainwater harvesting while using remote sensing and geographic information system (GIS) was used by (6), in Jammu. A relationship between rooftop area and cost of domestic rooftop water harvesting was developed by (7). An action plan to cope with the water scarcity problem, in Sankalchand Patel Sahakar Vidhyadham Campus, Visnagar, Gujarat was prepared (8) for rainwater harvesting and subsequent use for domestic purpose (9). The cost of installation of rainwater harvesting system for an average area of 300 to 400 m^2 was reported to be around Rs. 30,000 to 35,000 at SSJ College of Engineering and Technology, Asangaon, Mumbai University, Maharashtra (9). The combination of satellite image analysis and water evaluation and planning (WEAP) system or demand model, as a tool for development of urban rainwater harvesting policy was demonstrated in Kenya (10). In Lebanon (11) proposed collection and storage of water in existing roof water tanks instead of underground or over ground tanks and also reported saving of 7% electric energy required in pumping groundwater. It was found that rainwater collected from ground catchment systems was generally subjected to high levels of microbial contamination and had to be treated before being consumed (12). The samples of harvested rainwater from residential roofs were evaluated (13), which indicated that the measured inorganic compounds generally matched standards for drinking water prescribed by the world health organization (WHO) whereas, fecal coliform, exceeded the limits for drinking water. It was reported that before potable use, a copper device kills enteric bacteria in drinking water (14). An overview of available water treatment technologies for potable water use was presented (15, 16). Therefore, in the present study, an attempt has been made to harvest and conserve rainwater in such a way that it meets the standard permissible limits (17) of potable water quality.

2. METHODOLOGY

2.1 Study Area Description

The study was conducted in the campus of Navsari Agricultural University (NAU), Navsari, Gujarat that lies between 210 N latitude, 720 E longitude, 10 m above mean sea level and is around 13 km from the seacoast. As per the agro-climatic bifurcation, the region comes in South Gujarat Heavy Rainfall Zone. Due to nearness to sea and over exploitation of groundwater resources, the area suffers from seawater ingress resulting in scarcity of quality potable water. To tackle the shortage of potable water, rooftop water harvesting system was adopted. The water harvesting system was constructed at six locations, viz. Forestry College (T1), Farmers Hostel (T2), Krishi Vigyan Kendra (KVK) (T3), Administrative Block of University (T4), Vice Chancellor Residence (T5), Residential House (T6), whereas, control consisted of groundwater of Borewell (T7), in the area.

2.2 Designing Rooftop Water Harvesting System

The success of roof water harvesting system mainly depends on its cost, demand and supply of potable water, groundwater quality, and available area of rooftop for harvesting rainwater. The capacity of the water storage tank was decided as per the water demand of the building. The water demand of a building is calculated by collecting the information about number of guests, and visitors coming to the building during the year, number of employees and servants serving the building and approximate duration of their stay in the building, then total drinking water demand of the buildings was calculated considering per person drinking water demand of 4 L / head / day. The availability of rainwater from the rooftop was calculated by considering the total rooftop area and average rainfall during monsoon season. The rooftop areas of the selected buildings, where the system was installed, were Forestry College (T1) – 775 m^2, Farmers Hostel (T2) – 940 m^2, Krishi Vigyan Kendra, KVK (T3) – 600 m^2, Administrative Block of University (T4) – 400 m^2, Vice Chancellor Residence (T5) – 280 m^2 and Residential House (T6)- 90 m^2. The rainfall data weres collected for the last 100 years (1911 to 2011) from Meteorological Station of NAU, Navsari, and 1500 mm is the average annual rainfall for this Agro-climatic zone. The runoff coefficient of roof having RCC slab was considered to be 0.75 (18). The other requirements were space availability for construction of storage tank, fund availability and social acceptance of technique. Since there were sufficient rains during monsoon as compared to drinking water demands of buildings, so the optimum size and shape considered was based on budget available to construct the tank that meets the demand and the free space available for construction. The other components are conveyance pipes, filter, diversion valves and ladder provision to enter into the groundwater tank for cleaning purposes and outlet for excess flow which was diverted to a percolation pit.

Initial rainwater was allowed to flush through the gutter or collection pipes which may have atmospheric pollutants and algae growth. Air-borne pollutants settle on rooftop and get mixed, while collecting rainwater for potable use. Effective monsoon period to harvest rainwater was considered from July 15 to September 15 = 30 × 2 = 60 days. Also, by this time there complete onset of monsoon takes place, more number of rainy days without long breaks between rainfall events. Rainfall from mid June till July was considered to have atmospheric pollutants, and dust on rooftop completely gets washed away by July 15. Thus, non-monsoon dry season is (360 – 60) = 300 days. Initial investment made for installing rooftop water harvesting system for potable use was approximately 5 Rs/L at the base price of 2012 and with negligible annual recurring cost of cleaning and white washing of tank. Maintenance included checking cleanliness of roofs and conveyance pipes for vegetation and debris before monsoon, cleaning screens around the tank, draining and cleaning the tank of algae, mud or silt inside and white washing walls of tank with lime solution as it acted as a disinfectant. A major share of the contamination comes from the material on the rooftop / terrace, e.g. dust, parts of weeds, bird/rat droppings etc. The filtering mechanism used was a three-layer filter consisting of sand, followed by gravels and boulders. Slow sand-filters reduced organic content in the water and usually also disinfect water. Further, lime or calcium carbonate powder was kept in an earthen pot of 7 L capacity which was sufficient to disinfect water storage of 5000 L capacity, the pot was tied with muslin cloth on the neck and submerged into the storage, which acted as a disinfectant (19) Calcium carbonate precipitates providing the opportunity for adsorption and coagulation of microorganisms and causes increased removal of bacteria over that obtained from pH effect alone (20).

Water samples from the water surface were collected periodically from the storage tanks of all six locations, for determining the chemical water quality parameters. The pH and EC of water were determined by potentiometric (pH meter) and conductometric (EC meter), respectively as suggested by (21). Dissolved Na and K were determined by using flame photometer while, standard titration methods of Versenate (EDTA) for Ca+Mg, Acid-base (H_2SO_4) for CO_3-- and HCO_3- and precipitation ($AgNO_3$) for Cl were followed.

2.3 Evaluation of Different Methods to Remove Bacteria

After first year of using stored rainwater, it was observed that E. coli remained present, despite observing all cleanliness measures and cutting off light and air from the storage tank, which prompted to treat the stored rainwater before using it for potable purposes. Therefore, a separate laboratory study was conducted at Food Quality Testing Laboratory of NAU, Navsari by giving different treatments to water and analyzing the improvement in water quality. In the study, water from the storage tank was pumped out and kept in 5 L vessels/pots and given different treatments, i.e., M1 - water stored in copper vessel, M2 - silver treatment (Silver strip of 30 cm × 10 cm × 0.03 cm size immersed in container), M3 - water passed through commercially available cloth filter, M4 - water stored in an earthen pot and M5 - control (without any treatment or direct water from storage tank). All vessels were filled with 5 L of water and incubated at room temperature (20-25˚C) up to 24 h. Water samples were collected after 0, 6, 12 and 24 h in sterilized glass bottle and analyzed immediately or at times stored in refrigerator to avoid multiplication of bacteria during holding time.

The whole experiment was replicated four times. Samples were analyzed for total bacterial count (CFU/ml) and total coliform (MPN/100ml). Total bacterial counts were determined by plating on Nutrient agar (Standard Plate Count) and incubated at 37˚C for 24 h while multiple tube technique was used for the enumeration of Most Probable Number (MPN of total coliform bacteria by using standard method, i.e., presumptive coliform test, confirmatory test and complete confirmation test (22) Nutrient agar (NA) as a basal medium and MacConkey agar as a differential medium were used to determine enteric bacteria. Eosin Methylene Blue (EMB) plates were inoculated from positive tubes of water sample and incubated at 35˚C for 24 h to isolate fecal coliforms. Statistical analysis was done using Randomized Block Design (RBD) design and Arcsine (ARC) ARC transformation for MPN and CFU (colony forming units) for water stored in vessels for different time periods.

Water of low pH or acidic rainwater when collected in copper vessel for domestic consumption can cause poisoning in humans. The U.S. Environmental Protection Agency's Maximum Contaminant Level (MCL) for copper in drinking water is 1.3 mg/L. To study the water storage period in a copper vessel, another laboratory study was conducted to find the minimum storage period required to kill bacteria and the maximum storage period after which the copper residue in water will exceed permissible limits for human consumption. The water stored in copper vessel was checked for toxicity effect till 5 days of storage period.

3. RESULTS AND DISCUSSION

The estimation of water demand and availability, and the schematic plan of water harvesting system for farmers hostel of NAU, Gujarat is given in Table 1 and Fig. 1, respectively. The estimate showed that the potable water demand (480,000 l) was much less than the available water during monsoon (1,410000 l) , but the financial constraint could be the deciding factor for finalizing the storage capacity.

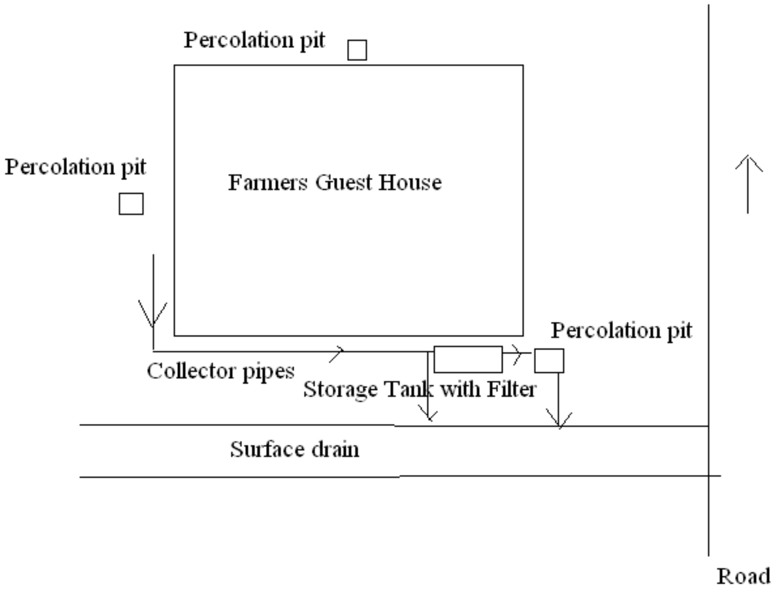

Fig. 1: schematic diagram of rooftop water harvesting system

Table 1. Estimation of water demand and availability for Farmers Hostel, NAU, Navsari

Water Demand	**Number**	**Total Requirement**
Average number of daily guests (considering 3 L drinking requirement)	20	60 L
Staff (considering 4 L drinking requirement)	5	20 L
Total daily drinking water requirement		80 L
Storage required for, days (other than monsoon period)	300	
Total drinking water demand (L/yr)		480,000
Not feasible, will be too expensive		
Therefore, in the first phase, constructing the tank to meet the demand (L/yr)		30,000
Calculation of availability of rainwater		

Roof area (m^2)		940
Annual average rainfall (m)		1.5
Volume available (m^3)		1,410
Runoff coefficient for rooftop consisting of RCC slab	0.75	
Total storage (m^3)		1,057.5

Water demands for all the other buildings, i.e., T1, T3, T4, T5 and T6 were calculated based on similar lines. The demand and supply of each building depend upon number of persons using the building and rooftop area of the respective buildings. However, the residential buildings have less number of people using the building, so the storage tank of 10,000 l each in T5 and T6, whereas, of 300,000 l capacity of T3 was constructed at a time. Whereas, storage tank in buildings T1, T2, T4 of 30,000 l capacity was constructed in phase i, due to budgetary constraints and also the storage capacity could be increased as per its 100% demand in phase ii, provided the system is maintained properly and water is used for its intended use, after construction.

3.1 Physical quality of harvested water

Since water is collected from rooftop and rainwater of first storm was flushed out, and since the water was collected during mid-monsoon, the stored water didn't have any impurities. Despite this, during the first year of study, collected water in the tank was found to be black in colour with a peculiar smell (cabbage like odor). Further, on investigating the rooftop, black colored soot particles were found near the outlet of collection pipes. These black colored particles may have been the ‘carbon’ particles that come down from the atmosphere during rainfall. The carbon particles may have been there in the atmosphere in mid monsoon as industries release gases during late nights or in early mornings, and high humidity prevent gases from rising up and diffusing quickly in the atmosphere. The rains during this period bring these particles down to building rooftop. Also, gaps between two monsoon events cause some pollutants to settle on the rooftop, which may get mixed and collected in tanks, in subsequent rain storms. However, during four years of study, only once such incidence took place in Navsari.

3.2 Chemical quality of harvested water

Well water quality of the area showed highest TDS, which needs to be treated for removing salts for making it potable. In the second year also similar results were observed, as construction work of the top floor continued at Forestry College and Administrative Block of the University, mixing of overflow from overhead took place, resulting in rise of TDS levels. Administrative block recorded high TDS for the third year in succession, whereas the groundwater quality deteriorated to 1440 TDS. In rest of the locations, groundwater quality was found to be good.

Statistical analysis of chemical water quality, using simple RBD design for the water samples collected from different locations and at different points of time during three years shows that water quality was found significantly better in treatments T1, T2 and T5 in all the parameters (Table 2). Whereas, most of the parameters in treatment T3 were significantly better than that in T4 except for Ca+Mg and Cl contents. All the rainwater harvesting locations (T1 To T6) had superior water quality as compared to well water (Fig. 2). High CV values could be attributed to variations caused due to mixing of well water with rainwater and poor quality groundwater of borewell, which starts deteriorating after withdrawal of monsoon, till the onset of next year’s monsoon and also because groundwater quality varies spatially as well.

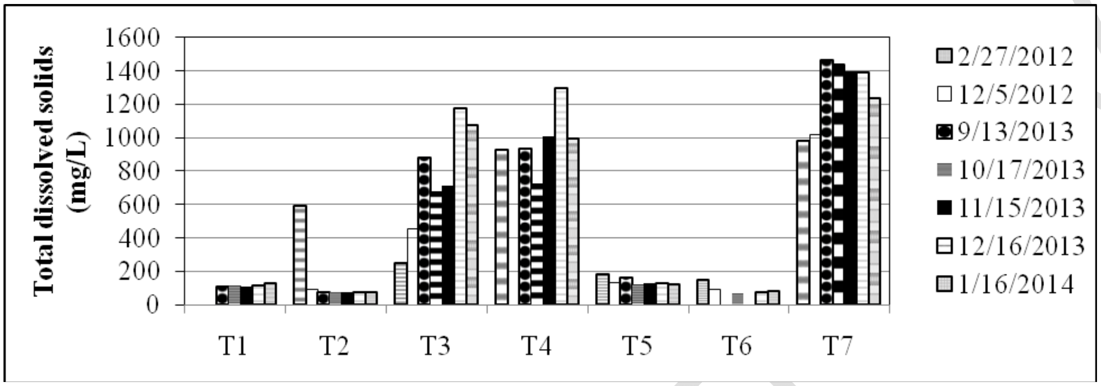

Fig. 2: total dissolved solids in roof harvested water v/s borewell water

Table 2. ANOVA table of chemical water quality of harvested water

Treatment	**pH** (-)	**EC** (dS/m)	**Ca + Mg** (me/L)	**CO_3^-** (me/L)	**HCO_3^-** (me/L)	**Cl^-** (me/L)	**Na^+** (me/L)	**K^+** (me/L)	**TDS** (mg/L)
T1	8.47	0.18	1.07	0.20	1.18	0.49	0.96	0.056	115.2
T2	8.45	0.12	0.92	0.12	0.78	0.72	0.55	0.026	76.8
T3	8.42	1.41	6.78	1.16	3.28	7.08	6.40	0.076	904.9
T4	8.34	1.55	4.89	2.12	6.12	5.39	9.73	0.048	993.2
T5	8.25	0.20	1.38	0.24	1.12	0.53	0.89	0.034	131.8
T7	7.78	2.16	10.66	1.56	5.48	11.06	9.34	0.078	1384.9
SEM	0.07	0.08	0.58	0.18	0.41	0.47	0.49	0.004	54.7
CD	0.22	0.25	1.73	0.54	1.22	1.39	1.45	1.06	161.3
CV%	2.04	20.34	30.65	46.21	31.07	25.05	23.75	15.17	20.3

Later, the changes in water quality of two years old stored water were studied, as shown in Table 3, which shows that all applied treatments did not have much effect on TDS. Moreover, all of them were found to be much superior to control, i.e., well water. On testing the chemical water quality of stored water, no changes could be found due to the treatments given to harvested rainwater stored in a tank (Table 4).

Table 3. Effect of treatments on 2 year old harvested water (Sample date: 03.08.2012)

Location	**pH**	**EC (dS/m)**	**TDS (mg/L)**
Home without filter	6.67	0.28	179
Home + Silver treated	7.72	0.29	186
Home + Silver treated	7.42	0.33	211
Home + Boiled	9.71	0.22	141
Well water (Control)	8.70	1.68	1075

Table 4. Effect of different treatments on water quality (Sample date: 05.12.2012)

	pH	**EC (dS/m)**	**Ca+Mg (me/L)**	**CO_3^- (me/L)**	**HCO_3^- (me/L)**	**Cl^- (me/L)**	**Na^+ (me/L)**	**K^+ (me/L)**	**TDS (mg/L)**
Silver treated	8.00	0.14	2.04	0.80	0.40	1.14	0.40	0.21	90
Copper treated	7.98	0.14	1.02	0.80	0.80	0.76	0.41	0.16	90
Residential House	8.21	0.15	1.02	0.80	0.40	1.14	0.43	0.17	96
Well Water	7.89	1.59	6.12	2.40	6.80	5.70	9.72	0.20	1018

3.3 Bacterial / microbiological quality of harvested water

In the first year of feeler trial, MPN of fecal Coliform / 100 ml were observed (4) in harvested rainwater, although much less as compared to city municipal water supply (220). The second-year water samples' results (Table 5) show that rooftop water was free from presence of Coliform bacteria whereas, borewell water sample showed presence of Enterobacter spp. The results of microbial analysis of stored water, without prior filtration, showed the presence of 65,000, 25,000 and 3,000 cfu/ml after one year, one and half year and two years of storage, respectively. There was a decline in Coliform bacteria measured in CFU/ml because the water was stored in a tank without allowing light and air to pass inside the tank. Though, the study was not repeated due to short-time involved and also because there was no point in designing a tank for two-year storage capacity when sufficient rainfall occurs annually. Also because, over-design could have merely increased the construction cost. Microbial analysis of the rainwater collected in monsoon of 2013 showed measurable amount of Coliform bacteria at most of the locations. The results of MPN test and those performed on emb plates, showed colony having greenish metallic shine. From the results, it could be interpreted that the samples T1, T5 and T7 (borewell water) are free from e. Coli but samples T2, T3, T4 and T6 showed presence of e. Coli (Table 6). According to the bacteriological standards, samples T1 and T5 are of excellent and drinkable quality, samples T3 and T6 are satisfactory and drinkable while samples T2 and T4 are suspicious as well as non-potable without disinfection.

Table 5. Water analysis report

Methods adopted for identification of Coliform	**Borewell water**	**Rooftop water**

MPN (Most probable number of Coliform)	24	<1.8
SPC (Standard Plate Count / Total Viable Count)	4.6 × 10^6	Nil
Biochemical Test	Colonies Observed	Nil
Gram Staining Test	Colonies Observed	Nil

Table 6. Results of Coliform Test

Water sample	**Coliform Test**			**Completed test**		
	(2X) ***E. coli*** **+ ve plates**	**(X)** ***E. coli*** **+ ve plates**	**(X)** ***E. coli*** **+ ve plates**	**(2X) Lactose Broth**	**(X) Lactose Broth**	**(X) Lactose Broth**
T1= Forestry College	0	0	0	-	-	-
T2= Farmer’s Hostel	1	1	0	⊕	⊕	-
T3= KVK	1	0	0	⊕	-	-
T4= Administrative Block	2	1	0	⊕ ⊕	⊕	-
T5= Vice Chancellor Residence	0	0	0	-	-	-
T6= Residential House	1	0	0	⊕	-	-

3.4 Efficacy of different methods in removing bacteria

There was significant reduction in MPN in all treatments as compared to control. Copper treatment gave significantly high reduction followed by silver when water was stored for 6 h period. There was a non-significant difference between copper and silver treatments when water was stored for 12 h and 24 h. Water storage in earthen pot for 24 h also showed reduction in MPN. Similarly, total count or CFU were significantly reduced in all treatments, but when the water was stored for 24 h in copper or silver pots, total CFU was markedly reduced. Both the copper and silver treatments had non-significant difference and were significantly superior to rest of the treatments. However, E. Coli were not observed during laboratory analysis in any water samples collected from various locations during the year. Table 7 show that both MPN and total count show significant reduction in bacteria with time, i.e., 6 to 24 h, when water was kept in a pot. Moreover, E. Coli bacteria was not found in any treatment.

Table 7. ANOVA RBD, % reduction in MPN and Total count with time

Treatment	**Reduction (%) in MPN with time**				**Reduction (%) in total count**			
	6 h	**12 h**	**24 h**	**Pooled**	**6 h**	**12 h**	**24 h**	**Pooled**
M1	66.86	85.18	89.57	80.54	48.64	66.94	80.74	65.44

M2	56.44	81.54	87.64	75.21	40.51	60.05	75.69	58.75
M3	47.18	63.36	65.64	58.73	36.08	47.5	60.65	48.08
M4	52.35	64.94	72.94	63.41	39.28	53.25	63.16	51.90
M5	41.23	58.36	55.84	51.81	13.49	34.09	44.8	30.79
SEM	2.12	2.7	1.76	2.04	3.12	1.63	1.95	1.39
CD	6.53	8.32	5.44	6.68	9.61	5.03	6.03	3.96
Time (h)								
h1 (6 h)				52.81				35.6
h2 (12 h)				70.68				52.37
h3 (24 h)				74.33				65.01
SEM				6.24				6.24
CD				17.64				17.64
Interaction (T×H)								
SEM				2.22				2.32
CD				6.39				NS
CV (%)	8.04	7.64	4.75	6.76	17.54	6.24	6.02	9.13

3.5 Investigation of copper residue

The results of copper residue in water at different storage periods are shown in Fig. 3. Bacterial contamination was removed within 12 h of storage, so amount of stored water should be enough to cater the demands of a day. Copper residue observed in the drinking water was found to be within acceptable range, even when water is stored for 4 to 5 days.

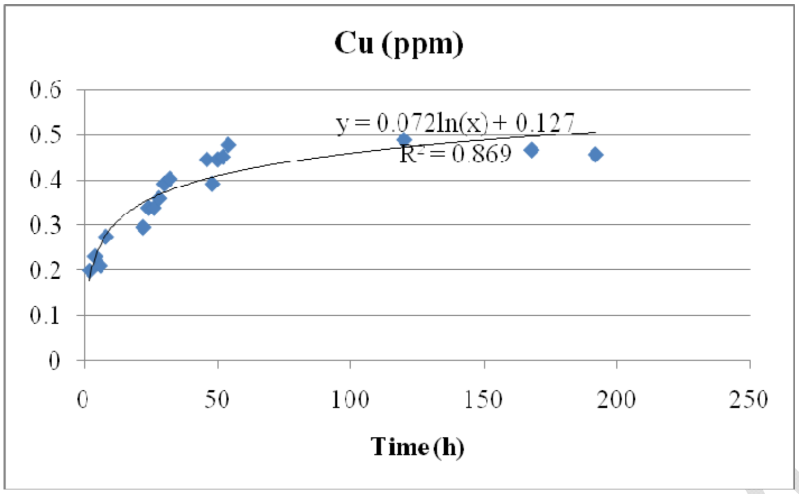

Fig. 3: Copper residue in water stored in copper pot for eight days

4. CONCLUSION

This study concluded that roof water harvesting should be recommended for potable water requirements in areas suffering from acute water scarcity after monsoon. The storage tank should be of 1000 l/ person/year capacity, constructed in such a way that no light or air enters inside the tank to prevent bacterial growth, and the tank should be at least 0.5 m above ground level to stop direct entry of runoff water. First flush of rainwater should be allowed to bypass the storage tank, as well as rainwater should be flushed through the system after long gaps between two rainy events. Calcium carbonate powder kept in earthen pots (7 l capacity / 5000 l), tied with muslin cloth on the mouth may be submerged into the storage tank to keep the water disinfected. The study shows that despite all precautions, with the passage of time, anaerobic bacteria (E. Coli) develops in the stored water which could be removed by pumping the water out of storage tank and keeping the same in a copper vessel of 5 to 10 l, capacity for 8-10 h, to fully disinfect rainwater and make it potable.

REFERENCES

1. Thomas, T., 1998. Domestic water supply using rainwater harvesting. Building res. Inf., 26(2), 94-101.
2. Vishwanath S. 2001. Domestic rainwater harvesting some applications in Bangalore, India, RWH conference, IIT New Delhi. H2. 1- 5.
3. Kumar M D.- 2004. Roof water harvesting for domestic water security: who gains and who loses?. Water int., 29(1), 43-53.
4. Aladenola O O; Adeboye O B. 2010. Assessing the potential for rainwater harvesting. Water Resour. Manag., 24(10), 2129-2137.
5. Handia L; Tembo J M; Mwiindwa, C. 2003. Potential of rainwater harvesting in urban Zambia. Physics and chemistry of the earth, parts a/b/c, 28(20-27). 893-896.
6. Jasrotia A S; Majhi A; and Singh, S. 2009. Water balance approach for rainwater harvesting using remote sensing and gis techniques, Jammu Himalaya, India. Water Resour. Manag., 23(14), 3035-3055.
7. Dwivedi A K; Bhadauria S S. 2009. Domestic rooftop water harvesting – a case study. Aprn journal of engineering and applied sciences (JEAS), 4 (6), 31-38.
8. Patel U R; Patel V A; Balya M I; Rajgor H M. 2014. Rooftop rainwater harvesting (RRWH) at SPSV Campus, Visnagar, Gujarat – a case study. International journal of research in engineering and technology (IJRET), 3 (4), 821-825
9. Dagwal P; Swami M R; Patel Y. 2016. Rooftop rainwater harvesting – a case study. Iosr journal of mechanical and civil engineering (iosr-jmce), 13 (3) ver vii, 73 – 76.

10. Ojwang R O; Dietrich J; Anebagilu P K; Beyer M; Rottensteiner, F. 2017. Rooftop rainwater harvesting for mombasa: scenario development with image classification and water resource simulation. Water, 9, 1 -19.

11. Traboulsi H; Traboulsi M. 2017. Rooftop level rainwater harvesting system, Apl. Water Sci.. 7,769-775.

12. Kahinda J M M; Taigbenu A E ; Boroto J R. 2007. Domestic rainwater harvesting to improve water supply in rural South Africa. Physics and chemistry of the earth, parts a/b/c, 32(15-18), 1050-1057.

13. Abdulla F A; Al-Shareef A W. 2009. Roof rainwater harvesting systems for household water supply in Jordan. Desalination, 243(1-3), 195-207.

14. Preethi S V B; Ojit Singha K; Prasad S R; Venkatasubramaniana P. 2009. Killing of enteric bacteria in drinking water by a copper device for use in the home: laboratory evidence, trans. Royal soc. Trop. Med. Hyg., 103, 819-822.

15. Anonymous 2011. Handbook on drinking water treatment technologies, GOI, CSIR – NEERI, Nagpur. 113 p.

16. Wilks S.A., Michels H. and Keevil C.W. 2005 The survival of Escherichia coli O157 on a range of metal surfaces, International Journal of Food Microbiology 105 : 445-454
17. Kumar M; Puri A. 2012 a review of permissible limits of drinking water. Indian j Occup. Environ. Med.. 16(1). 40–44.

18. Subramanya K. 1994. Value of coefficient. Engineering hydrology. 236

19. Shrivastava, P K. 2014. Rooftop rain water harvesting for potable use. Proceedings of 7th combined joint AGRESCO (Agricultural Research and Advisory Committing) meeting of State Agricultural Universities of Gujarat. 27-28.

20. Anonymous, 2019 The Disinfection of Drinking Water - Drinking Water and Health - NCBI Bookshelf, https://www.ncbi.nlm.nih.gov/books/NBK234590/
21. Jackson M L. 1967. Soil chemical analysis. Prentice hall of india, pvt. Ltd., new delhi. 498p.

22. Anonymous. 2012. Methods for bacteriological examination of drinking water: standard analytical method. Laboratory manual, Bureau of Indian Standards. New Delhi.