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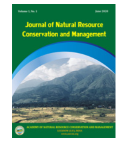

Design and evaluation of structure for roof top harvested rainwater for fluoride affected area of Unnao

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ABSTRACT

Fluoride decontamination is an expensive process. Use of roof top harvested rainwater for meeting domestic needs in fluoride affected regions seems to be a practical option. For an average size family of five members a storage volume of 3.6 m^3 is sufficient to meet the eight month water needs of the family. One side lined brick storage structure of size 2 m x 1.5 m x 1.5 m would take care of water losses during storage period and cater the needs of the family. Cost of construction of one such structure comes out to be Rs. 13000.00. Seepage loss from the inside lined brick storage structure was zero and evaporation losses under cover was 20.2 mm and without cover 74.0 mm. The EC and pH of rain water were measured during the month of July as 0.0644 dS/m and 5.62 and storage water at the end of October as 0.933 dS/m and pH was 8.04. The water was transparent in the tank with very good appearance with visible bottom. Standard water disinfection is recommendation before use of stored water. Roof top harvested rainwater if stored properly in underground or overhead storage tank, it could solve the problems of domestic drinking water demand safely in flouride affected area of the country.

Keywords: Fluoride, rainwater, losses, harvesting, storage, roof top

INTRODUCTION

Fluoride (F) is quite beneficial for bone and dental health if its concentration in drinking water ranges 0.5-1.0 mg l^{-1} (WHO, 1994). Excess fluoride presence in drinking water (>1.5 mg L^{-1} as per WHO and 1.0 mg L^{-1} as per BIS) may cause 'fluorosis' initially dental and skeletal after excessive and long term exposure (WHO, 2011). Poor intake of vitamin C, micronutrients, and calcium result in greater risks of fluorosis (Reddy and Srikantha, 1971). India maintains the permissible fluoride limit as 1.5 mg L^{-1}, but target concentration is only 1.0 mg L^{-1} after accounting the large quantities of water consumption due to hot weather conditions over a large part of the country (Shah & Bandekar, 1998). Maximum permissible limit of F in drinking water is prescribed by WHO (2006) and United States Environmental Protection Agency (2001) as 1.5 mg L^1. Bureau of Indian Standard (2009) had set the F limit as 1.0 mg L^{-1} keeping the high temperature regime of country in mind. Nearly 20 states in India are facing endemic to fluorosis by the ingestion of F up to 38.5 mg L^{-1} (UNICEF 1999; Meenakshi *et al.*, 2004; Singh 2007; Barghouthi and Amereih 2017). Pathogenicity of F is not well understood (Krishnamachari 1986; Pawar *et al.*, 2014). Kidney, liver and brain ailment are non-skeletal manifestation of F toxicity due to chronic exposure (Pawar *et al.*, 2014; Shamsollahi *et al.*, 2015). Muscle fibre degeneration, low haemoglobin level, excessive thirst, headache, skin rashes, nervousness and depression are also reported to be associated with high intake of F (Meenakshi 2006; Sharma *et al.*, 2012). Cardiovascular system is also reported to be adversely affected (Scarpa *et al.*, 1993; Xu and Xu 1997; Aghaei *et al.*, 2015).

Groundwater is the safe and major source of domestic water supplies at most places over the globe. In India as well as other parts of the world people are using groundwater for drinking and domestic needs without additional physical or chemical treatments which may lead to number of health related issues. More than 260 million people consume water with F concentration above 1.0 mg l^{-1} (WHO, 1984). About 28 tropical countries with 200 million people are facing fluoride associated problems in drinking water (Yang *et al.*, 2003; Chakrabarti *et al.*, 2012; Singh *et al.*, 2013; Singh and Verma 2013; Verma *et al.*, 2018). Researchers are reporting F in groundwater from time to time in India, China, Japan, Sri Lanka, Iran, Pakistan, Turkey, Southern Algeria, Mexico, Korea, Italy, Brazil, Malawi, North Jordan, Ethiopia, Canada, Norway, Ghana, Kenya, South Carolina, Wisconsin and Ohio (Jha *et al.*, 2010; Dissanayake, 1991; Gaciri and Davies, 1993; Srinivasa Rao, 1997; Banks *et al.*, 1998; Oruc, 2003; Rukah and Alsokhny, 2004; Kim and Jeong, 2005; Tekle-Haimanot *et al.*, 2006; Valenzuela-Va ìsquez *et al.*, 2006; Zheng *et al.*, 2006; Chae *et al.*, 2007; Farooqi *et al.*, 2007; Mirlean and Roisenberg, 2007; Msonda *et al.*, 2007; Vivona *et al.*, 2007; Davraz *et al.*, 2008; Messaïtfa, 2008; Moghaddam and Fijani, 2008; Oruc, 2008; Suthar *et al.*, 2008; Desbarats, 2009; Li *et al.*, 2009; Karthikeyan *et al.*, 2010; Keshavarzi *et al.*, 2010; Kim *et al.*, 2010; Looie and Moore, 2010; Naseem *et al.*, 2010; Reddy *et al.*, 2010a; Yidana *et al.*, 2010; Young *et al.*, 2010; Brindha *et al.*, 2011). The fluoride problem is more severe in tropical and subtropical countries due high per capita water intake. The problem of fluorosis is serious in heavily populated countries like India and China (Ayoob and Gupta, 2006). Over exploitation and groundwater mining is resulting to steep decline in groundwater level is the main reason for increasing in F concentration in groundwater (Hudak and Sanmanee, 2003; Edmunds and Smedley, 2005; Kim and Joeng, 2005; Valenzuela-Va ìsquez *et al.*, 2006). High F concentration in groundwater is generally associated with neutral to alkaline pH, low Ca concentration and high Na and HCO_3 concentrations (Jha *et al.*, 2010; Brindha and Elango; 2011; Handa, 1975; Ramamohana Rao *et al.*, 1993; Kundu *et al.*, 2001; Smedley *et al.*, 2002; Edmunds and Smedley, 2005; Chae *et al.*, 2007). The natural concentration of F in groundwater depends on the geological, chemical and physical characteristics of the aquifer, properties of the soil and rocks and weathering rate (Feenstra *et al.*, 2007). Water table depth, fluctuation rate, rainfall of the area and recharge pattern also affects the F concentration in groundwater significantly. Groundwater mining may result steep decline of groundwater table forcing people to use marginal quality water in agriculture and domestic sectors (Hassanein *et al.*, 2013).

Fluoride treatment is the best way of handling the fluoride associated crises in drinking water. The most common methods for removal of F from contaminated water are use of alum and lime, bone char, ion-exchange resin, reverse osmosis and activated alumina. The sludge disposal remains an associated problem while using alum and lime for removing F from F contaminated water. Replenishment of resin at frequent intervals remains a serious problem while using ion-exchange resin for removing F ions under acidic medium (pH range of 2.8 to 4.2). The reverse osmosis wastes plentiful water and requires electricity for operation. It also removes beneficial salts from water. Use of activated alumina is limited to alkaline water only. Mixing of good quality water with F contaminated water can dilute it by reducing the F concentration within the permissible limit and could be treated as a solution for the management of the F contaminated groundwater. Storage of good quality water and mixing with F contaminated water has limited applications. Groundwater recharge using surface runoff or roof top harvested rainwater has a great potential to dilute fluoride concentration in groundwater. Groundwater recharge through individual farmers may not be very effective. Storage and use of roof top harvested rainwater for domestic needs in fluoride affected area has a great potential and need to be tried individually, community basis with or without government support. Design, storage and quality of roof top harvested rainwater with time has given a clue to combat fluoride menace in country like India where plenty of rainfall is received annually.

MATERIALS AND METHOD

Variation of Fluoride Concentration

The range of fluoride concentration in sampled water from hand pumps at Maheshkheda village ranged 0.67 to 10.20 mg/L with an average value of 4.42 mg/L after the end or rainy season in September 2020. The range of fluoride concentration in open wells ranged 5.17 to 9.96 mg/L with an average of 7.68 mg/L. Similarly TDS ranged from 356.90 to 2879.0 mg/L with an average of 1237.8 mg/L for hand pumps and 313.9 to 4054.0 mg/L with an average of 2169.97 mg/L for open wells (Table 1).

Table 1. Fluoride levels in hand pumps and open wells during September 2020

Name	F, mg/L	TDS, mg/L
Hand Pumps		
Ram Naresh	10.20	1637.0
Suresh	8.96	1439.0
Chandra Pal	0.67	483.0
Sajivan	7.86	2879.0
Shiv Ratan	2.32	356.9
Well-Road	5.94	1305.0
Ballu Yadav	2.98	787.8
Vasdev	0.68	385.4
Putti Gokul	8.95	2240.0
Prem Kumar	1.05	1920.0
Narendra Yadav	2.63	959.9
Putti Lal	0.83	460.8
Average	4.42	1237.8
Wells		
Arun Kumar- Well	9.96	313.9
Main Well	5.17	2142.0
Alok-Well	7.83	4054.0
Average	7.65	2169.97

Annual Water Demand and Size of Storage Structure

If drinking water requirement of a person is 3.0 liter/person/day and family size comprises of five members then daily drinking water requirement of a family is 15 liter/day. Thus the monthly water requirement of the family becomes 450 liter/month and for 8 months excluding rainy season of the year becomes 3600 liter (3.60 m^3). If expected loss of water during 8 month storage period is 10-12% the total storage volume becomes 4000 liter (4.0 m^3).

Construction of Rain Water Storage Structure

A rain water storage structure of size 2.0 m × 1.5 m × 1.5 m was constructed at CSSRI Regional Research Station, Lucknow for the study of storage and other associated losses from the tank. Fig. 1 shows the construction of storage tank. A cover in two splits was also designed to cover the tank to minimise evaporation losses and also to minimise contamination risk of stored water. The side space between brick wall and soil was filled in layers for several days for minimizing the air entrapment and provide strength to the side wall. The expenditure involved in the construction of rain water storage structure is presented in Table 2. The highest expenditure occurred on the procurement of the brick (49.22%).

Linking of Roof top Harvesting System with Storage Tank

Roof top harvesting system was connected with PVC pipe lines through couplers as shown in Fig. 2.

Fig. 1. Construction of brick lined rain water storage structure

Table 2. Expenditure on account of construction of Rain Water Storage

S.N.	Particulars	Quantity	Rate	Total	Percent
1	Bricks	800	Rs. 8.00/brick	6400.00	49.22
2.	Cement Bag	6	Rs. 360.00/bag	2160.00	16.61
3.	Morang/sand, ft^3	16	Rs. 75.00/ft^3	1200.00	9.23
4.	Gravel	4 ft^3	Rs. 60.00/ft^3	240.00	1.85
5.	Reinforcement	80 ft	Rs. 3.80/ft	304.00	2.34
6.	Mason days	2	Rs. 750/mason day	1500.00	11.53
7.	Labour days	4	Rs. 300.00/lab. day	1200.00	9.23
8.	Total	13004.00	100		

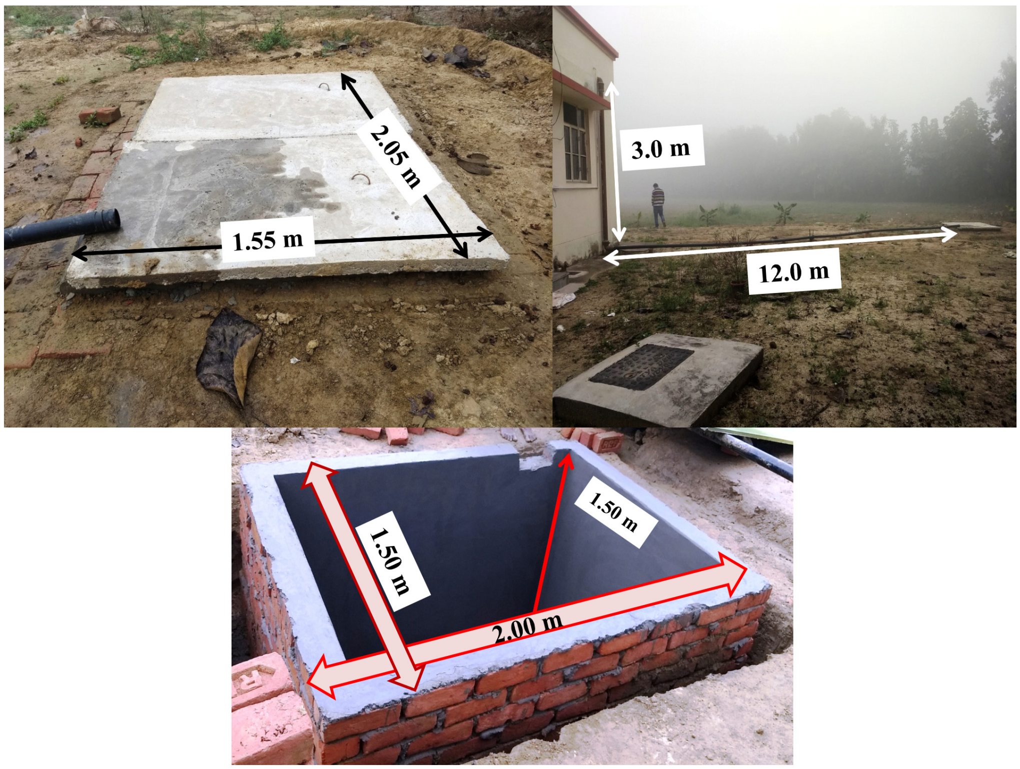

Fig. 2. Interlinking of roof top water harvesting system with rain water storage structure

The exit drain outlet of roof top was connected with 10 cm size PVC pipe of 12 m length. Opposite end of the pipe was connected with water storage tank.

Filling of Rain Water in Storage Tank

Rain water was filled in the storage tank and covered with split design cover. The drops in water levels with and without cover are being recorded continuously. Fig. 3 shows the loss of stored water with and without cover. It may be seen from Fig. 3 that the appreciable amount of water could be saved with the provision of proper cover from the top of the tank besides maintaining good quality of stored water. Monthly water losses are presented in Table 3 and Fig. 4. The maximum water loss was observed during the month of September. As temperature dipped evaporation losses also reduced accordingly under open and cover conditions. The minimum water loss was observed to be 20.2 mm during the month of December 2020 when covered on the top. The monthly water loss under covered conditions were observed to be 143.75, 89.25, 43.4 and 20.2 mm and under open conditions 334.95, 235.5, 150.3 and 74.0 mm for the months of September, October, November and December 2020, respectively.

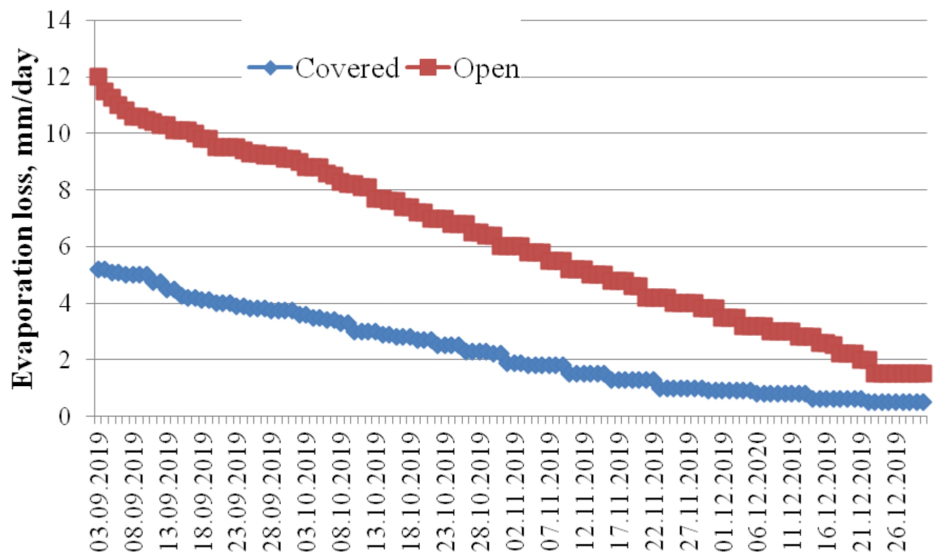

Fig. 3. Evaporation loss from the storage tank

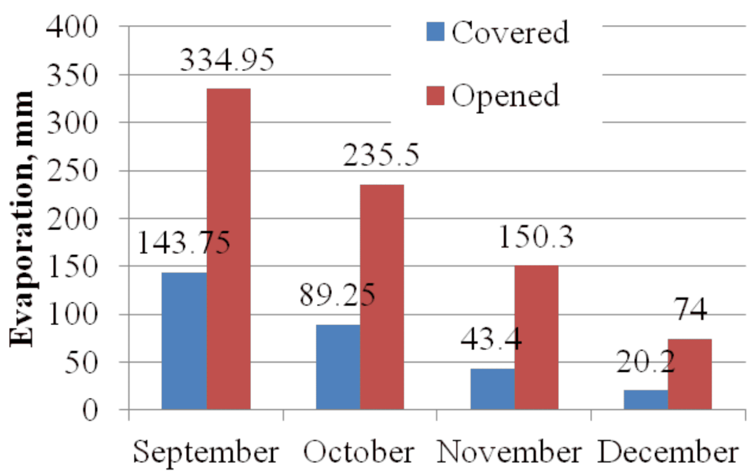

Fig. 4. Monthly waterloss from rain storage structure

Table 3. Monthly water loss (mm) from tank

Month	Covered	Opened
September	143.75	334.95
October	89.25	235.5
November	43.4	150.3
December	20.2	74.0

Seepage loss from the one side lined brick masonry was negligibly small and can be considered for all practical purposes.

Water Quality of Stored Water

For controlled study of water quality the rain water harvested from roof top was conveyed to the storage tank through 100 mm PVC pipe and water filled tank was covered with concrete slab/lid further covered with a thin polythene sheet putting soil all around (Fig. 5). EC of the stored water at the end or October month was observed to be 0.933 dS/m and pH was 8.04. The water was transparent in the tank with very good appearance. The EC and pH of rain water measured during the month of July 2020 were 0.0644 dS/m and 5.62, respectively. The stored water quality in terms of EC and pH satisfactorily well. The stored water need to be filtered before consumption and disinfected using chlorine or iodine tablets. Bleaching powder can be used as cheaper option for cleaning water of whole tank. About 17.5 gm of bleaching powder containing 30% of chlorine would be required.

Water tank covered with plastic sheet during mid July 2020

Water quality towards October 2020 end

Fig. 5. Preserving rain water

CONCLUSION

Groundwater contamination with fluoride due to its geogenic presence is a big problem in rural India. Farmers are not having an access to safe drinking water supply. Excessive ground water pumping for irrigation is the major cause of increased concentration of fluoride in groundwater. Fluoride removal from contaminated water is an expensive preposition and may fail due to one or other reasons in India. Use of roof top harvested rainwater for meeting domestic needs in fluoride affected regions could be a viable practical option. For five member's family, a storage volume of 3.6 m^3 is sufficient to meet the daily drinking water demand for eight months. Water demands during four month rainy season can be directly met out by harvesting and using it in the house. Storage structure of size 2 m x 1.5 m x 1.5 m is sufficient to take care of water demand of a family for whole year. Cost of a rainwater storage structure is about Rs. 13000.00. Evaporation loss was recorded as 20.2 mm only with cover and 74.0 mm without cover over a period of four months. Evaporation loss remains minimum during the winter season due to low temperature. The EC and pH of rain water were 0.0644 dS/m and 5.62 and water after four month storage period as 0.933 dS/m and pH was 8.04. The water quality of stored water was quite good. Disinfection of stored water by appropriate method is recommended. Menace of the F contaminated drinking water could be well addressed by storing roof top rain water in a brick storage tank and making its use.

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