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Assessment of Low-Cost Filter Material for Rooftop Rainwater Harvesting Structure

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***Abstract*:** RRWH is the technique through which rainwater is captured from the roof catchments and directed to groundwater. The present study focused on to design low-cost filter material for rooftop rainwater harvesting structure (RRWH) for groundwater recharge. Three technology options (TO) with different filter viz. TO-I (2 meter boulder + 0.5 meter stone + 0.5 meter sand), TO-II (1 meter boulder + 1 meter stone + 0.50 meter sand fill with bottle + 0.5 meter sand), and TO-III (1.5 meter boulder + 1 meter stone + 0.5 meter charcoal + 0.5 meter sand) were evaluated at six locations for comparative performance of these filters during the pre and post monsoon of year 2019 and 2020. Pooled analysis of both the year shows that about 83-97% of roof water passes through the filter which designates a very good and satisfactory performance. Post monsoon study after the installation of RRWH structure revealed that during the year 2019 the water table uplifted from 5.9 to 3.76 meters while during the year 2020, the water table raised from 5.41 to 2.89 meters. Among all the technology options used the filter of TO-II was found to be best in respect of infiltration rate, cost and overall performance. Therefore, the adoption of this technique at mass level with community participation could help in getting the significant results to mitigate the water requirement.

Keywords: Filter, Groundwater recharge, Infiltration rate, Roof Top Rainwater Harvesting, Water table

Conservation and management of water, is essential for sustainable development of any region (Santhoshi and Kumar 2021). The proper augmentation and management are needed through proper planning in groundwater resource development and management (Ayyandurai and Venkateswaran 2021). Groundwater and surface water may be unavailable for drinking water in numerous cases. The groundwater level may be too deep, contaminated with minerals and chemicals such as arsenic or salt as well as surface water may also be contaminated with faces or chemicals. In these cases, rainwater harvesting can be an effective and low-cost solution to resolve the above problems (Li et al 2000, Jothiprakash and Mandar 2009). Singh et al (2021) suggested that the use of fertilizer and crop manure in the fields should be reduced to sustain the water quality parameters. The good thing about rainwater is that it falls on your own roof, and is almost always of excellent quality. Several studies have shown that water from well-maintained and covered rooftop tanks generally meets drinking water quality standards. Roof rain water harvesting systems can be implemented to any type of roof constructed materials, but some material has high efficiency on collecting rain water from the roof, with less retention and evaporation at the roof (Hofman and Paalman 2014). It can be applied as a successful urban storm water management or flood mitigation method. This method also reduces surface runoffs in to the urban sewage system, control peak load and overload of the system, and therefore minimizes water borne diseases (Ranasinghe and Dissanayake 2019). This method is less expensive and very effective if implemented properly for augmenting the groundwater level of the area.

Rooftop rain water harvesting can be established at any building, it can be large or small, where each of the parts contributes to RWH structure. The RWH system mainly consists of catchment area, transportation, flushing and filter media like sand gravel filter, charcoal filter etc. Rooftop Rain Water Harvesting is the technique through which rain water is captured from the roof catchments and recharge to groundwater (Kumar et al 2011, Awuah et al 2014, Krishnaveni and Vighnesh 2016). RRWH is made of roof catchment, down pipe, first flushing pipe and filter unit. The dipping groundwater levels and deterioration in its quality in some districts of Bihar over the past two years have become a cause of worry for the state authorities. Previous year, most of the place in the state recorded low rainfall during monsoon season. Out of 534 blocks of Bihar, 280 blocks have been declared as agricultural drought prone area as per weather parameter in the state. In the Muzaffarpur district, many villages and panchayat faced water crisis problems due to decrease of groundwater level. Pre experimental survey revealed that in last few years water level has depleted by 10-12 feet in most part of the study area. The best method of recharge through rainwater is to keep earth clean and to prevent entry of garbage into the capacity tank which can be achieved by using quality filter materials (Pandey et al 2003). Bihar is agriculture dominant state and most of farmers having marginal and small land holdings henceforth, establishment of low-cost filter for rooftop rainwater harvesting structure would be economically feasible for groundwater development. In view of above facts, the present study has been carried out to prepare low-cost filter for rain water harvesting structure and assess the comparative performance of filter unit.

MATERIAL AND METHODS

Study area: Muzaffarpur district of Bihar covers an area of 3172 sq. km, between latitudes 25°53'52.475"N to 26°15'33.053"N and longitudes 85°43'15.814"E to 84°52'6.792"E. An average annual rainfall of the study area is 1145 mm. The area receives more than 85% rainfall during monsoon season (July-September). The altitude of the Muzaffarpur district varies from 58 m to 62 m above mean sea level (MSL). Soil texture in the study area is sandy and sandy loam. The average monthly weather data for six consecutive years from 2015 to 2020 have been presented in Table 1.

The experiment was conducted at six different locations namely Bhagwatpur, Dawarikanathpur, Bhatoliya, Gobindpur and KVK Saraiya campus across two block of muzaffarpur district during the year 2019 and 2020. Each technology options viz. TO-I, TO-II and TO-III have been installed at two different sites (Table 2).

Methodology for planning and design: Pre experimental field survey was conducted to gather the key information by interacting with local people and the acquired information has been employed to conduct the experiment. Groundwater information was collected from Central Ground Water Board (CGWB) website. The data were utilized for site selection of

Table 1. Monthly average weather parameter for the year 2015 to 2020

Month	Temperature (°C)		Humidity (%)		W/S (km./hr)	Rainfall (mm)	Evaporation (mm/day)
	Maximum	Minimum	Morning	Evening			
January	22.8	8.1	85	56	2.4	1.2	1.7
February	25	10.7	84	55	5.2	25.4	2.4
March	30.3	13.5	75	44	2.9	4.2	4.4
April	34.7	21.4	76	51	3.8	7.6	6.1
May	39	24.7	77	50	5.6	14.4	6.6
June	37.5	26.5	80	59	6.7	30.4	5.5
July	33.2	26.1	88	73	6.4	354.0	3.7
August	34.3	26.8	89	75	5.1	171.7	5
September	31.4	25.2	91	80	5	403.0	2.7
October	29.3	22.1	92	82	0.5	6.6	2.7
November	28.4	16.6	93	68	0.9	0.0	1.9
December	21	9.7	92	75	0.2	22.0	1.0

Source: RPCAU, PUSA, Samastipur, Bihar

Table 2. Location of rainwater harvesting structure

Village	Technology option	Block	Latitude	Longitude
Bhagwatpur (Site-a)	TO-I	Madwan	26° 5'5.42"N	85°13'18.99"E
Dawarikanathpur-A (Site-b)	TO-III	Madwan	26° 4'29.87"N	85°13'53.64"E
Dawarikanathpur-B (Site-c)	TO-II	Madwan	26° 4'37.17"N	85°14'16.73"E
Bhatoliya (Site-d)	TO-I	Madwan	26° 3'0.19"N	85°12'8.01"E
Gobindpur (Site-e)	TO-II	Saraiya	26° 1'52.95"N	85° 5'1.19"E
KVK Saraiya campus (Site-f)	TO-III	Saraiya	26° 1'53.15"N	85° 8'38.81"E

RRWH structure as per the previous study (Li et al 2000, Krishnaveni and Vighnesh, 2016 and Kumar et al 2011). In the study area annual average rainfall 1145 mm data was collected from Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar. Low cost filter material for RRWH structure design methodology was adopted in the present study (Fig. 1).

The catchment area of each site of the roof was calculated by field visit. The total rainwater collected for rainwater harvesting purpose was estimated using rational formula (Awuah et al 2014, Krishnaveni and Vighnesh 2016).

Q = CIA

Where, Q= Peak surface runoff, m^3/s,

C= A runoff coefficient that is the ratio between the runoff volume from an area and the average rate of rainfall depth over a given duration for that area which can varied from 0.8-0.9 in tiles and 0.7-0.9 in corrugated metal sheet .

I= average intensity of rainfall in inches per hour for a duration equal to the time of concentration, T_c, m/s, A= Area, m^2.

Based on runoff coefficient and rainfall intensity, peak runoff discharge was estimated using above equation and the data was utilized for designing RRWH structure. All calculations related to the performance of rainwater catchment systems involve the use of runoff coefficient to account for losses due to spillage, infiltration, catchment surface wetting and evaporation, which contributes to reduce the amount of runoff.

Filter material: The three different filtration techniques were used to set up unit of groundwater recharge structure (Table 3). Distinguish depth of different layer was maintained through filter material layers of boulder, stone, sand, bottle filled with sand and charcoal (Fig. 3). There are numerous contaminants (leaves, fledgling droppings, dust etc.), which may get mixed up with this unadulterated water on the rooftop was shifted away before the water enters into the groundwater recharge unit.

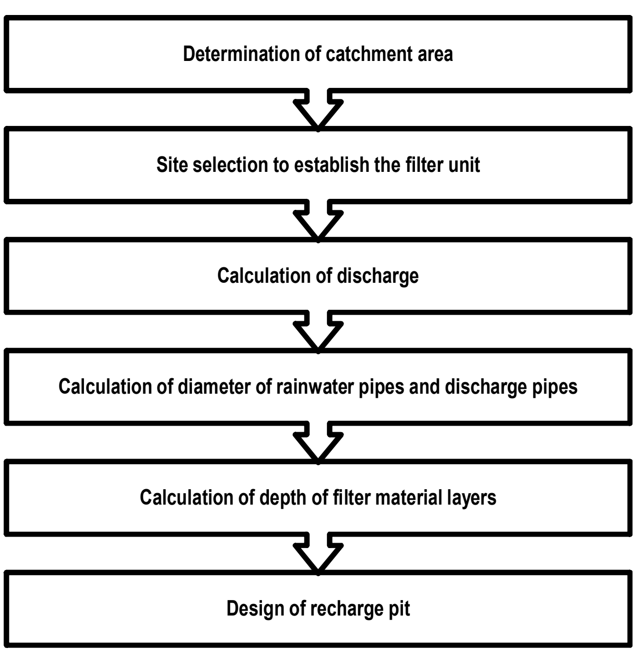

Fig. 1. Fow chart for RRWH structure

RESULTS AND DISCUSSION

The set of parameters were chosen to be the most influential ones to determine the feasibility of RRWH structure (Table 3). Filter unit has been designed by considering the values of parameters viz. roof area, rainfall and filter capacity of water before filtration. The key component of this design is the filter media, where the better result through filter will make the study convenient for groundwater recharge and storage tanks. Since the site is in rural area the natural organic material will be easily available for the purpose of filter unit materials such as boulder, stone, sand fill with bottle, coal, fine sand etc. So, an efficient and economical filter can be designed which is feasible to implement anywhere as filter media, for the construction of RRWH structure. Filter capacity was assessed by peak discharge (m^3/sec) based on rainfall intensity, coefficient of runoff and catchment area of structure. The pooled data of two locations of peak discharge for roof catchments during the year 2019 for TO-I, TO-II and TO-III respectively was calculated as 1 , 0.74 and 1.05 l/s whereas, these for the year 2020 was 1.40 1.03 and 1.45 l/s (Table 4, 5). However, the peak discharge per unit area for all the technology options was statistically at par due to similar rainfall intensity, runoff coefficient for similar roof surfaces received across all the roof catchments. The variation might be due to different roof catchment area taken under the study.

Filter plays a significant role while constructing RRWH system designed for direct use of water, this acts like the heart as in a human body. Once the water enters into this filter, passes through different layers of filter material and recharge to groundwater. About 5-10% of water, depending on the intensity of rainfall, gets rejected by the filter. Pooled analysis of both the year shows that about 83-97% of roof water passes through the filter which designates a very good and satisfactory performance. Maximum filter recharge received through TO-II (95 to 97 %) followed by TO-I (90 to 95 %) and TO-III (83 to 85 %). The highest filter recharge rate during both the year was observed in TO-II (17.12 mm/hr and 19.45 mm/hr) followed by TO-I and TO-III (Table 6). The water reaches the roof to filter tank possesses some finer dust particles, which can be removed by the filter. During first 5-10 minutes of rain, amount of water rejected is more due to high dirt-load in the first-flush water in the downside filter layer was also noticed. However, the new filter is really maintenance-free and there is no need for manual operation to divert the first-flush but such filters require change of upper layer only i.e. sand before rainy season with the help of one mesh. Mostly such systems require a provision for 'First-Rain' to prevent entry in the filter. One control valve is provided in the filter for draining out of first rainfall. Study on assessment of different types of filters for RRWH structure has not been so far done but designing of low cost RRWH structure and its importance has already been discussed earlier by researchers (Pawar et al 2014, Jain et al 2015, Gohel et al 2020, Mishra et al 2020, Himantha et al 2021, Sahu et al 2023).

The pre survey showed that water table before monsoon during 2019 and 2020 was 5.9 and 5.41meters respectively. Post monsoon study after the installation of RRWH structure revealed that the water table uplifted from 5.9 to 3.76 meters (56.91 %) during 2019 and 5.41 to 2.89 meters (87.19%) during the year 2020. The highest groundwater recharge has been achieved during the year 2020 due to high rainfall intensity as compared to year 2019. The maintenance cost of all filters was almost zero and before onset of monsoon, they only need to change the upper layer of filter that is sand. The filter technique used in TO-II was found to be best among all the technology options under study due to its higher infiltration rate, low cost and overall performance (Table 6). Different approaches have proven the economic viability of

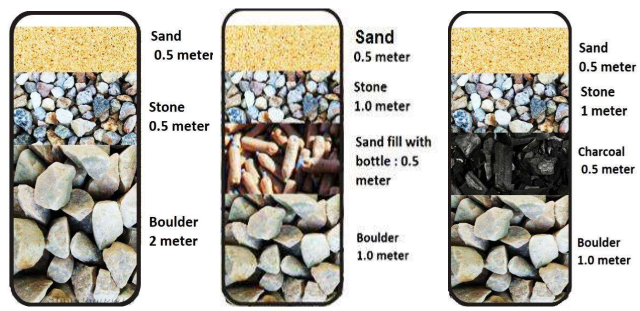

Fig. 2. Construction of different types of filter material used for RRWH

Table 3. Rainwater harvesting filter techniques

Technology option (TO)		Details
TO-I	:	Filter depth: Boulder 2 meter, 0.5 meter stone, Sand 0.5 meter
TO-II	:	Filter depth: Boulder 1.0 meter, stone 1 meter, sand fill with bottle 0.50 meter, Sand 0.5 meter
TO-III	:	Filter depth: Boulder 1.5 meter, stone 1 meter, charcoal 0.5 meter, Sand 0.5 meter

Table 4. Computation of peak discharge (m^3/s) using rational formula for different RRWHS (2019)

Technology option	Coefficient of runoff (C)	Rainfall intensity (mm/hr)	Roof area (m^2)	Peak discharge (m^3/s)	Peak discharge (l/s)
TO-I	0.8	18	313.0	0.001252	1.00
TO-II	0.8	18	232.0	0.000928	0.74
TO-III	0.8	18	327.5	0.001310	1.05

Table 5. Computation of peak discharge (m^3/s) using rational formula for different RRWHS (2020)

Technology option	Coefficient of runoff (C)	Rainfall intensity (mm/hr)	Roof area (m^2)	Peak discharge (m^3/s)	Peak discharge (l/s)
TO-I	0.8	20	313.0	0.0013915	1.40
TO-II	0.8	20	232.0	0.0010310	1.03
TO-III	0.8	20	327.5	0.0014555	1.45

Table 6. Comparison of treatment options for filter performance

Technology options	Maximum rainfall intensity (mm/hr)		Filter recharge rate (mm/hr)		Source of power	Cost	Maintenance	Overall performance
	2019	2020	2019	2020				
TO-I	18	20	16.20	18.45	Gravity	Medium	All filters require change upper layer of filter (sand) before rainy	Good
TO-II	18	20	17.12	19.45	Gravity	Low		Very Good
TO-III	18	20	14.94	17.13	Gravity	High		Good

the RWH through cost-benefits analysis, net present values, and internal rate of return (Hofman and Paalman, 2014).

CONCLUSIONS

Filtration unit is the important component for deciding low-cost filter for rooftop rainwater harvesting structure (RRHS). Filter materials used for filter plays an important role for recharging the structure. All the location selected for the study showed similar rainfall intensity. However, due to change in roof area a variation of peak discharge in the study area was observed. Filter recharge rate was highest in case of TO-II (Filter depth: Boulder 1.0 meter, stone 1 meter, sand fill with bottle 0.50 meter, Sand 0.5 meter) and followed by TO-I (Filter depth: Boulder 2 meter, 0.5 meter stone, Sand 0.5 meter) TO-II filter was best and efficient due to its high recharge rate. Only the upper layer of filter needs maintenance in TO-II which reduces the overall cost and hence found most economical among all filter. All the authors gratefully acknowledge ATMA, Muzaffarpur, of Government of Bihar, for providing financial support, to complete this research.

AUTHORS CONTRIBUTION

Tarun Kumar: Conceptualization, conduct of experiment, data collection , Nidhi Kumari and Prabhat Kumar Singh: Data curation, writing original draft, validation, Anupma Kumari and Jitendra Prasad: review & editing

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