Evaluation of sand-based stormwater filtration system for groundwater recharge wells

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Groundwater recharge wells have proven effective in augmenting and improving the quality of groundwater, but clogging remains a serious constraint in the absence of properly designed recharge filters. A laboratory study was undertaken in a PVC column of 22.5 cm diameter and 120 cm length to evaluate the efficiency of coarse sand (CS) of three particle sizes ranging between 0.35 and 1.0 mm as the top layer of a recharge filter for seven influent sediment concentrations of 250–3,000 mg/l. The performance was evaluated in terms of spatial movement of sediments, removal efficiency, recharge rates and clogging time. The results indicated that more than 60% suspended solids were entrapped in the upper 10 cm layer of CS, the removal efficiency improved with increasing thickness of the CS layer and the recharge rates declined sharply for influent concentrations of more than 1,000 mg/l. The study suggests use of larger particle size CS and reducing sediment load of inflow water. Field adaptation of these findings involves use of CS beds of 0.7–1.0 mm particle size and minimum 75 cm thickness as the top layer in recharge filters and providing a sediment tank or biological filters near the recharge structures to reduce sediment load of run-off water before entering the filter bed.

Keywords: Groundwater recharge, sand-based filter, storm-water filtration, wells.

GROUNDWATER is the basic resource that fulfils about 60% irrigation and 80% drinking water requirements of India[1]. Though groundwater has played a vital role in stabilizing Indian agriculture, indiscriminate use has resulted in fast depletion and degradation of this key natural resource. Water table is declining at an alarming rate in about 15% of India's geographical area[2]. Water tables in fresh groundwater regions of the northwestern states of India, particularly in Haryana and Punjab, are falling at an annual rate of 25–70 cm over the past 2–3 decades and threatening the sustainability of agriculture due to escalation in pumping costs, deterioration in groundwater quality and associated socio-economic and environmental factors. The rate of groundwater decline can be slowed down to some extent by enhancing groundwater recharge (GR) using rainwater, which may also lead to improvement in groundwater quality. Groundwater recharging may be natural or artificial. Artificial groundwater recharge is a process by which the groundwater reservoir is augmented at a rate higher than the rate of natural recharge. It involves regulated movement of excess surface water through a constructed recharge structure into an aquifer. The choice of the recharge structure is governed by the hydro-geological conditions, water availability and composition of recharging water. Injection well-type recharge structures like vertical and horizontal recharge shaft, recharge cavity and recharge wells have proven effective in falling water table areas, though clogging of the system by sediments present in recharging water remains a constraint[3,4]. In order to improve efficiency, the recharge structures must be combined with an efficient filtering unit to prevent entry of physical impurities of the run-off water into the recharge system.

The filtration unit must perform effectively to get potential benefits from the installed recharge structures. The two primary measures for any filter are its hydraulic efficiency, which indicates the fraction of the incoming stream that penetrates the filter and the filtration effectiveness that represents the fraction of incoming particulates that are removed by the filter[5]. As these two indices are inversely proportional to each other, the optimum design should be evolved considering other factors such as amount and type of inflow water, soil and climate characteristics and location and end-use of the filtered water. The most critical issue with regard to the efficiency of the filtering unit is clogging, i.e. decrease in permeability of filtering medium as a result of governing physical processes. Laboratory and field tests have shown that a filter medium consisting of concrete sand provided a good balance between the flow-through rates and filtering efficiency[6,7]. Initially the flow-through rates were high, but as the filtrate of fine sediments accumulated on its surface, the flow-through rates diminished. Stormwater filters which utilize coarser filter medium such as gravel are susceptible to clogging[8]. It occurs due to the migration of fine sediments through the medium and formation of a layer of low permeability at the bottom of the filter reducing the hydraulic efficiency of the filter. Its cleaning will require removal and replacement of the whole filter medium, which can be cumbersome. Finer medium system such as coarse sand (CS) also gets

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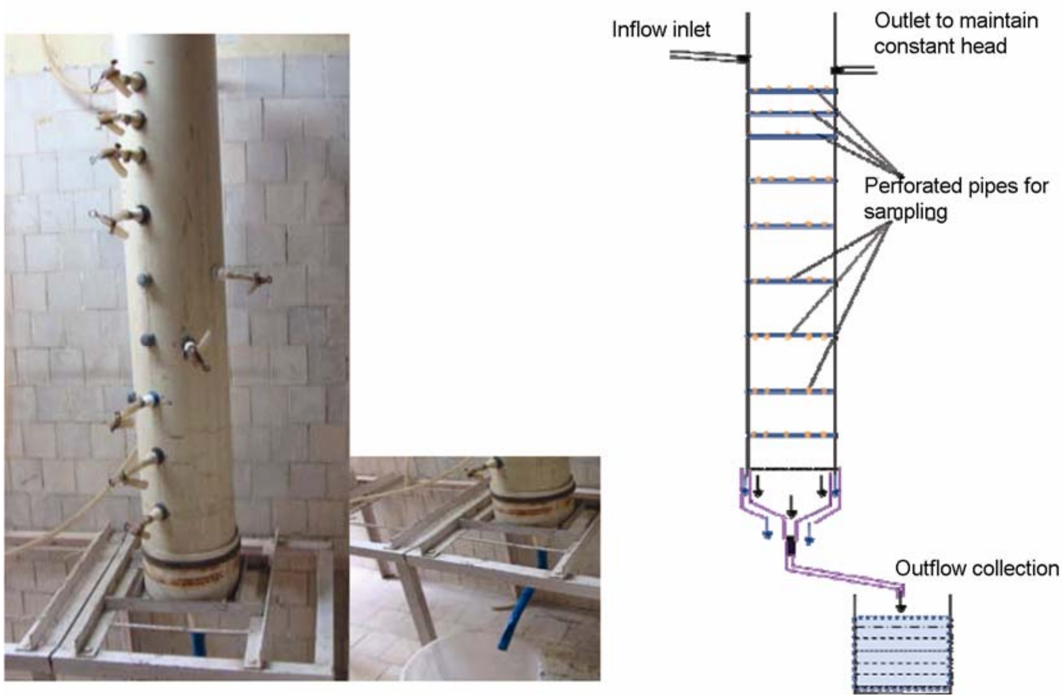

Figure 1. Photograph and diagram of experimental column used in the laboratory study.

clogged at the top of filter, but it can be conveniently scrapped-off and managed[9]. In India, a filtering unit comprising CS, gravel and boulders has been used for recharge structures at a number of locations. Filtration unit comprising 0.75 m of CS at the top followed by 1.25 m of gravel in the middle and 2.0 m of pebbles was used for a recharge well installed in the bed of old Sirsa canal, which flows on a seasonal basis[10]. The average recharge rate was observed to be 11.5 and 10.5 l/s during the first and second year of the experiment. The effectiveness of vertical filtering unit, consisting of 0.5 m thick layers each of CS on the top followed by gravel (G) and boulders/pebbles (P) at the bottom, was also studied for tube well-type recharge structure at Bindrala in the Assandh block, Haryana and at 32 locations in Haryana and Punjab[11]. In a column study of 60 cm length and 31 cm diameter, provision of CS, G and P in the ratio 1.5 : 1 : 3, i.e. 15 : 10 : 30 cm was found to be most efficient in filtration unit for a recharge shaft[12]. However, there are no well-defined criteria for designing the thickness of different layers of filter material. CS is the finest among all the filter materials and is exposed first to runoff water for retaining particulates suspended in it. The particle size of CS, therefore, plays an important role, but it is not standardized. This leads to uncertainty in achieving adequate recharge rates and avoiding frequent clogging of the filter. The present laboratory experiment was undertaken with the specific aim to evaluate the filtration efficiency of CS as the top layer of the filter medium in groundwater recharge wells, and its effect on the quantity and quality of recharged water. Though the flow of stormwater in the field is non-uniform and unsteady, the laboratory study was conducted under uniform flow condition because it was difficult to analyse the impact of a large number of treatments involving different media size and sediment load of influent water on clogging, removal efficiency, recharge rate and sediment penetration under actual field conditions.

Materials and methods

The laboratory study was conducted in a PVC circular column of 22.5 cm diameter, 120 cm length and having provision of regulated water inflow and free outflow. Inlet and outlet were provided in the upper portion of the column to maintain a constant hydraulic head during the test runs. Sampling ports, consisting of PVC pipe of 1.25 cm diameter and perforated in the upper half portion, were fitted horizontally at different depths in the column to collect samples of flow-through water and spatial movement of sediments in the filtering medium (Figure 1). A total of nine sampling ports were installed; the first three being 5 cm apart and the remaining six at 10 cm distance from each other. These sampling pipes were not perforated in the 5 cm portion from both sides of the column to ensure that the water moving along the sides of the column is not mixed with the flow-through water. Two concentric collectors were provided at the bottom of the column in such a way that only the flow-through water was collected in the inner collector and the water flowing along the sides of the column was collected in the outer collector.

Table 1. Filtering material size to support coarse sand bed for column study

Coarse sand (CS)		Gravel (G)		Boulders/pebbles (P)		
Diameter (mm)	Thickness of bed (cm)	Diameter (cm)	Thickness of bed (cm)	Diameter (cm)	Thickness of bed (cm)	Results
0.3–0.5	40	1.1–2.0	15	5–8	20	Sand and few gravel passed through boulders
0.3–0.5	40	1.1–2.0	20	2–4	20	Sand passed
0.3–0.5	40	1.1–2.0	25	2–4	20	Few sand particle passed
0.3–0.5	40	0.8. 2.0	25	2–4	20	Successful to support CS bed

Table 2. Experimental design and sediment concentration level

Treatment	Particle size diameter (mm)**	Thickness of coarse sand bed		Sediment concentration (mg/l)	Replications
		A*	B*		
T1	0.3–0.5	55	55	250, 500, 1000, 1500, 2000, 2500, 3000	3
T2	0.5–0.7	55	70	250, 500, 1000, 1500, 2000, 2500, 3000	3
T3	0.7–1.0	55	75	250, 500, 1000, 1500, 2000, 2500, 3000	3

A* Set 1 : Spatial distribution of sediments and removal efficiency studies. B* Set 2: Recharge rate and clogging time studies.
**Gravel size (8–20 mm diameter) and thickness (25 cm), and boulders size (20–40 mm diameter) and thickness (20 cm) were constant for all treatment combinations.

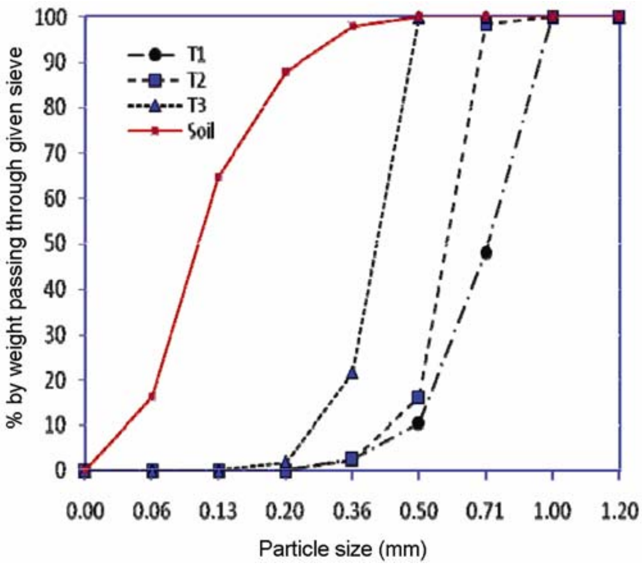

Figure 2. Gradation curve for the materials used in the laboratory study.

The filtrate collected in the inner collector only was utilized for further analysis. A series of initial tests, using tap water and gravel and boulders of different sizes and thickness as supportive layers for CS at the top (Table 1), were conducted to finalize these parameters for further studies. Gravel (8–20 mm diameter, 250 cm thickness) and boulders (20–40 mm diameter and 20 cm thickness) were used as supportive layers below CS in subsequent studies involving treatments of CS and sediment load of inflow water (Table 2). It is seen from Table 2 that two sets of studies were conducted using CS of three sizes and involving: (i) spatial distribution of sediments and removal efficiency and (ii) estimating recharge rates and clogging time. In the first set, the thickness of CS was kept constant as 55 cm. In the second set of studies aimed to evaluate recharge and clogging time, the thickness of CS was kept equal to the thickness estimated by empirical models developed in this study corresponding to the highest sediment load encountered in real field conditions.

The gradation curves of CS used in the laboratory study and the base soil (used for preparation of water of different sediment loads) are presented in Figure 2. It is seen that almost all particles of the finer CS (T1) were less than 0.5 mm diameter, whereas more than 80% of the particles of CS bed T2 were within 0.5–0.7 mm range. In T3 CS bed, about 50% particles were more than 0.7 mm size and 90% more than 0.5 mm size. Majority (65%) of the particles of the base soil were smaller than 0.13 mm diameter.

The synthetic water of different sediment loads was prepared using the surface soil brought from the field adjacent to 32 recharge structures installed by the Central Soil Salinity Research Institute (CSSRI), Karnal in Haryana and Punjab under Farmers' Participatory Action Research Project. This was done to ensure that the physical and chemical characteristics were truly representative of the run-off water passing through the 418 mg/l to 2,240 mg/l depending of land cover and soil tillage conditions (Figure 3). It was observed that the first storm generated more sediment in run-off water than the succeeding ones. Sediment load up to 2,560 mg/l in run-off water was also reported in Punjab soils[13]. Considering the above, synthetic water for the laboratory tests was prepared with sediment load of 250–3,000 mg/l using dried soil sieved through 0.2 mm sieve. Test runs were performed with sediment load of 250, 500, 1,000, 1,500, 2,000, 2,500 and 3,000 mg/l and replicated three times. The synthetic water of different sediment loads was introduced in the column through a perforated pipe covered with plastic net to dissipate the impact of inflow water and to minimize the displacement of CS particles. Plain tap water was passed through filtering medium for 10 min before each test run using water-specific sediment load to drain any soluble materials.

Sediment load in the water samples collected from sampling ports and at the bottom outlet was estimated by filtering its known volume and drying and weighing the residue left on filter paper. The difference in weight of filter paper before the test and after oven drying along with residue after filtration provided an estimate of the sediment load expressed as mg/l (ppm). Removal efficiency was estimated as a percentage of sediment load of inflow water retained by the particular medium or layer.

$$\text{Removal efficiency (\%)} = \left[1 - \frac{\begin{pmatrix}\text{Sediment load in water}\\ \text{sample collected from the outlets}\end{pmatrix}}{\begin{matrix}\text{Sediment load}\\ \text{of inflow}\end{matrix}}\right] \times 100.$$

For estimation of deposited sediment load on the top of the sand column, the top 10 cm of filter material along with deposited sediments was carefully removed after each test run. The material was dried and weighed. It was then washed to remove the adhering sand particles, and dried and weighted again. The difference in weight of the medium before and after washing was considered as the amount of the deposited material during the test run as desired.

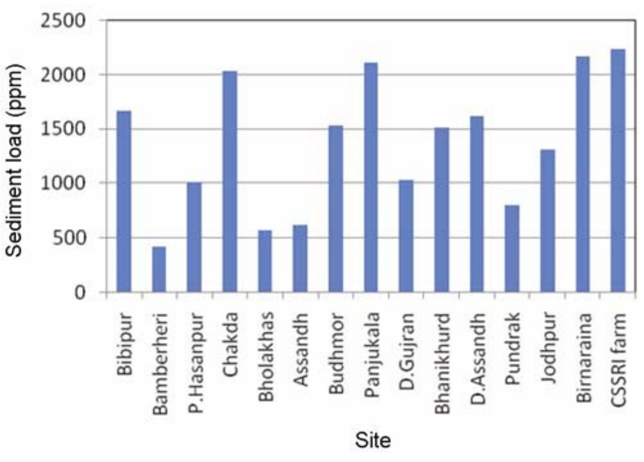

Figure 3. Sediment load of run-off water collected from different sites.

The second set of tests was aimed at estimating the recharging rate through different CS beds; the tests were conducted for a fixed time duration of 30 min. Temporal changes in recharge rates were also studied to estimate the clogging period. The time required to reach constant recharge rate was considered as the clogging time. In order to determine recharge rate for different CS beds, the thickness of gravel and boulders was fixed as 25 and 20 cm respectively, whereas the thickness of different CS media (Table 2) was kept equal to the minimum thickness required to bring down sediment concentration from 3,000 to 50 ppm in the outflow water. The required minimum thickness of CS beds was estimated using the developed empirical models discussed later. EC, pH and residual sodium carbonate (RSC) of inflow and outflow water were determined as water quality parameters to analyse the impact of the filter bed.

Results and discussion

Laboratory tests were performed to evaluate the relationship among recharge rate, particle size of the medium, sediment load of inflow water and efficiency of sand-based filtering unit. Results of the study are discussed below.

Spatial distribution of sediments

Retention of particulates contained in the inflow water at different depths in filtering medium is presented in Figure 4. It is seen that the spatial movement of the suspended particulates varies with the size of CS and the sediment load of inflow water. Sediments contained in the inflow water were entrapped at different depths of the CS bed; maximum in the top few centimetres and reducing at lower depths. In all the CS beds, more than 60% of the suspended solids were entrapped within the top 10 cm. The extent of accumulation of sediments within the top layer increased with increase in turbidity of influent water as also reflected by steep slope of higher sediment concentration curves in Figure 4*a*. Further, the sediment movement of inflow water having 3,000 ppm concentration occurred to a greater depth compared to water having 250 ppm concentration.

Comparative performance of CS beds of different particle sizes for three sediment concentrations (250, 1,500, 3,000 ppm) is presented in Figure 4*b*. It is seen that regardless of the influent sediment load, sediments penetrated to deeper layers in bigger particle CS beds (T3) compared to T1 and T2, suggesting the need for greater thickness of CS beds to reduce sediment concentration in influent water to the desired level (Figure 4*b*).

Empirical relationships were developed between the sediment load and the distance travelled in the CS medium corresponding to different sediment concentrations of the inflow water. The relationships were

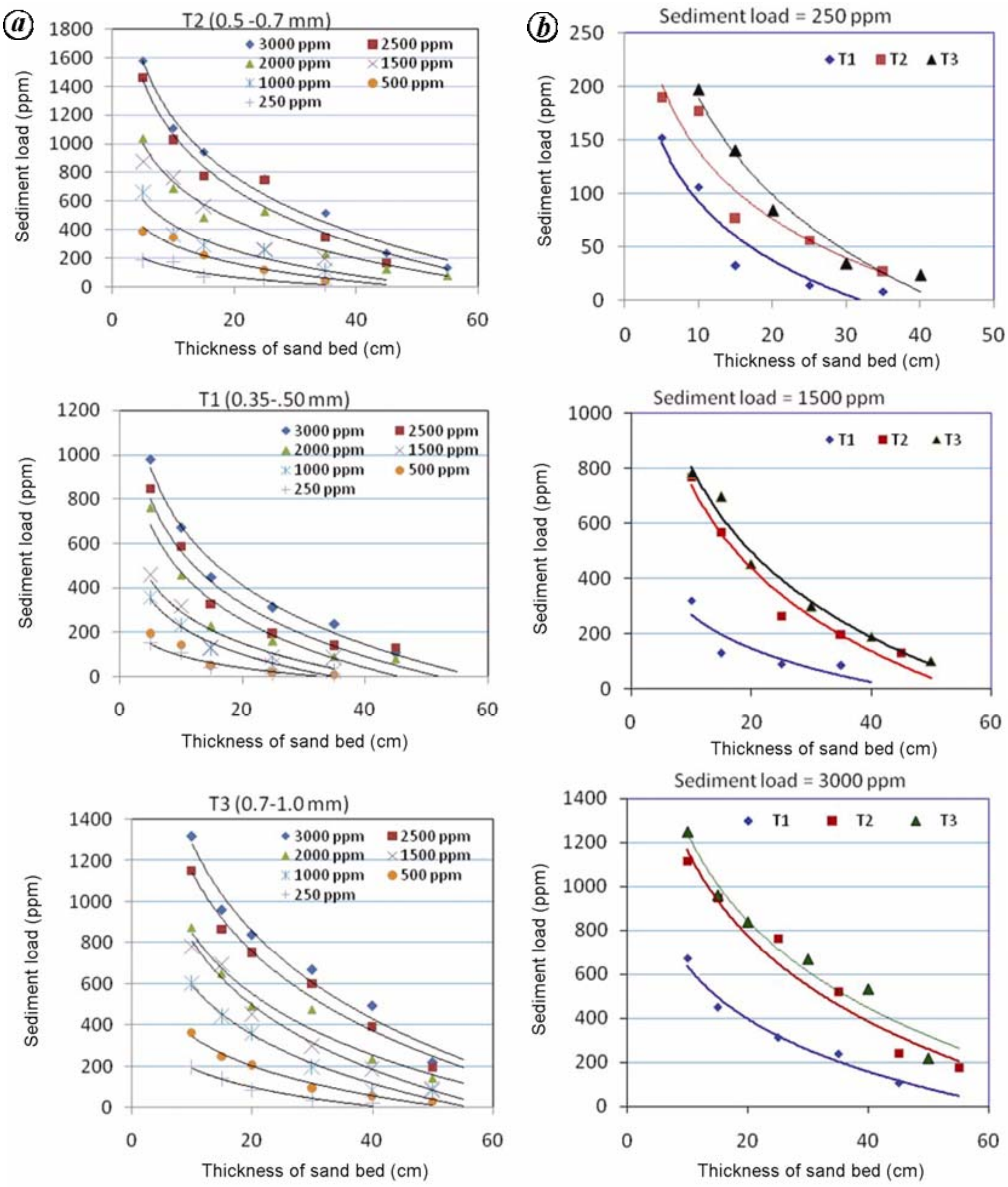

Figure 4. ***a***, Effect of thickness of filtering medium and sediment concentration of influent water on sediment load of filtered water under different coarse sand beds. ***b***, Effect of thickness of filtering medium and CS beds on sediment load of filtered water under varying inflow water sediment loads.

Table 3. Values of estimates *a* and *b* obtained for different CS beds and inflow water concentration

Inflow water sediment concentration (ppm)	Particle size of CS medium					
	T1 (0.3–0.5 mm)		T2 (0.5–0.7 mm)		T3 (0.7–1.0 mm)	
	a	*b*	*a*	*b*	*a*	*b*
250	78.8	275.9	85.6	336.1	131	491.4
500	101	355.6	186	727.9	207	824.3
1,000	179	638.6	255	1023	340	1373
1,500	205	766.6	382	1560	449	1843
2,000	309	1183	384	1620	428	1835
2,500	341	1350	532	2291	554	2417
3,000	384	1561	579	2511	616	2702

nonlinear because sediment entrapment was maximum in the top layers of the CS beds and decreased drastically as influent water moved to lower layers. The general form of these relationships is as follows

$$Y = -a \ln(x) + b,$$

where Y is the sediment load in ppm, x the depth of observation in the sand bed (cm) and a and b are two fitting constants. a represents the rate of change of sediment movement with depth, a negative value indicating a decrease with increase in thickness of the CS bed. The derived values of a and b for different influent water concentrations and media sizes are presented in Table 3. Using these relationships, the minimum thickness of CS beds required to reduce sediment load from 250 to 50 ppm and from 3,000 to 50 ppm was estimated as 17 and 51 cm for T1, 25 and 70 cm for T2, and 29 and 75 cm for T3 size CS. Based on these results it can be stated that the expected inflow sediment load, outflow turbidity and size of CS should be taken into consideration while designing the filter bed; thick CS beds will be always helpful in handling higher turbidity inflow water.

The results on suspended solids retained within 10 cm of filter material, including those retained on top of the filter bed for inflow water of different sediment concentrations are presented in Figure 5. The sediment load retained within the top 10 cm layer was determined after the recharge rate became nearly constant. It is seen that minimum retention of suspended solids in the top 10 cm filtering medium was in the CS bed T1, whereas CS bed T3 recorded the maximum retention. This occurred because recharge rate attained a constant value later in T3 due to the passing of a larger volume of water than in T1 and T2 regardless of sediment concentration of inflow water. The results reveal that CS medium (T3) due to the presence of larger intrinsic pores, can work for a longer time and yield higher volume of recharge water.

Removal efficiency

Removal efficiency (RE) represents the percentage of suspended material in the inflow water retained at the top and in different zones of the filter media, i.e. CS in this study. For different depth layers, RE represents the cumulative retention of sediments in a particular layer or those above it. In this context, different depth ranges can be treated as thickness of the filtering medium. Table 4 presents RE for CS of different particle sizes (T1, T2, T3) and thicknesses corresponding to varying sediment loads of inflow water. It is seen that irrespective of the sediment load of the inflow water and sizes of CS, RE increases with increasing thickness of the CS bed. The top 10 cm of the filter bed retained the bulk of the particulate matter and the removal fraction reduced with each increment of depth, though the extent of removal varied with the medium size. CS bed T1 recorded more than 75% and 85% RE in the top 10 cm and in surface 25 cm of the medium, respectively, for inflow sediment concentration of 500 ppm or more. Regardless of sediment concentration, T1 with small particle size recorded maximum RE compared to larger-sized T2 and T3. CS bed T3 recorded the lowest RE (Table 4) probably because the bigger size filter had larger intrinsic pores which allowed more sediment to pass through and hence required more

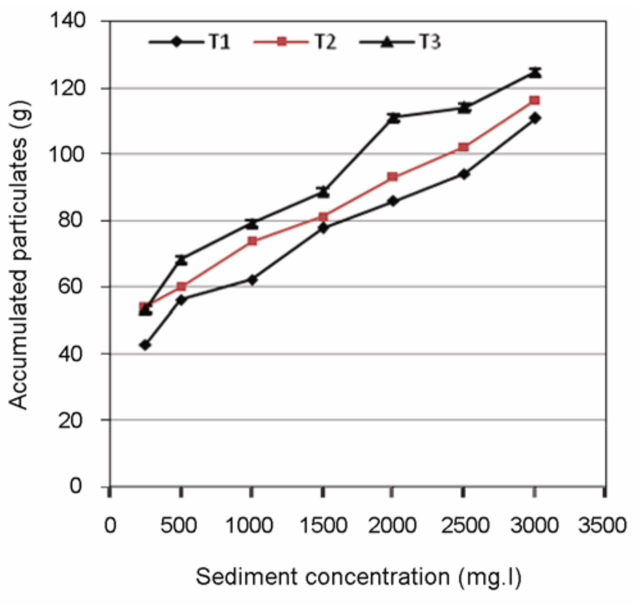

Figure 5. Suspended particulates retained by top layer (10 cm) of different CS beds.

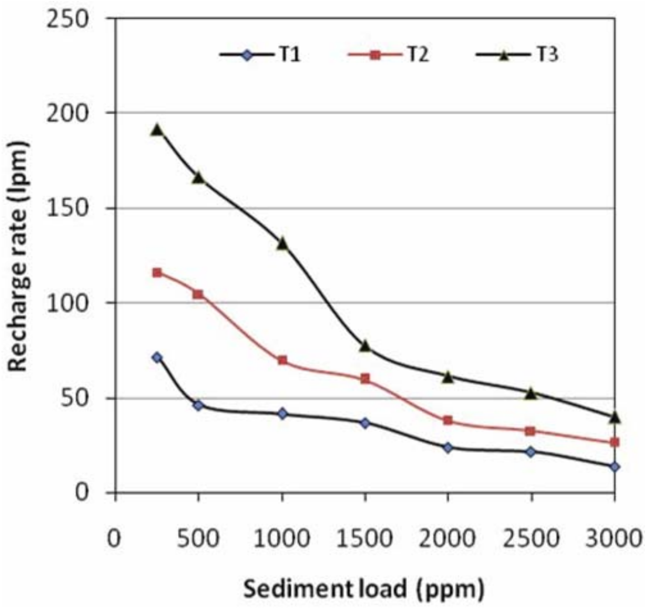

Figure 6. Effect of inflow water sediment load on average recharge rate of different coarse media.

Table 4. Removal efficiency (%) of different CS media and thicknesses under various sediment concentrations

	Sediment load in inflow water (mg/l)														
	CS bed T1 (0.3–0.5 mm)					CS bed T2 (0.5–0.7 mm)					CS bed T3 (0.7–1.0 mm)				
Depth (cm)	250	500	1000	2000	3000	250	500	1000	2000	3000	250	500	1000	2000	3000
10	66.4	75.7	77.1	76.4	77.4	44.4	42.2	56.4	63.2	60.7	34.2	36.5	41.0	57.5	58.6
25	92.47	89.7	88.2	87.1	86.3	68.1	69.3	74.1	76.5	73.9	59.1	59.2	64.6	72.4	72.1
35	99.53	97.9	96.8	93.4	89.5	82.0	85.1	84.4	84.3	81.6	79.5	82.2	78.3	83.0	79.9
45	100.0	99.6	99.4	97.8	93.2	98.9	98.4	94.8	89.8	87.1	94.8	89.9	88.5	87.2	85.5
55	100.0	100.0	99.7	98.0	97.4	99.5	99.2	97.5	94.1	91.3	98.4	97.1	95.7	91.9	89.9

depth of CS than T1 and T2 to achieve the desired turbidity level in the outflow. In other words, the thickness of the CS bed would be different for different media sizes to achieve similar removal efficiency. It confirms that entrapping of turbidity particles from the inflow water depends upon the size of the intrinsic pores of the medium. Further, the sediment concentration of recharged water also influenced removal efficiency of CS beds (Table 4). Removal efficiency of the top 25 cm was 84–90%, 68–77% and 59–72% in CS bed T1, T2 and T3 respectively, for different sediment loads. The increase in removal efficiency was marginal after 25 cm thickness of sand bed. It can be concluded from these results that the minimum thickness requirement for the sand bed to achieve a desired removal efficiency level, would be different for different sediment concentrations of the influent water.

Recharge rate

Variation in average recharge rate of different CS beds corresponding to varying sediment loads of inflow water during test run of 30 min is presented in Figure 6. The following empirical relationships were derived between recharge rates (q) and inflow sediment concentration (C) for T1, T2 and T3.

$$q = 0.00002C^2 - 0.119C + 221, \quad R^2 = 0.98 \text{ for } T1, \quad (1)$$

$$q = 0.00001C^2 - 0.069C + 133.2, \quad R^2 = 0.99 \text{ for } T2, \quad (2)$$

$$q = 0.000005C^2 - 0.333C + 71.52, \quad R^2 = 0.91 \text{ for } T3. \quad (3)$$

Recharge rate in the initial stages in CS bed $T3$ was substantially higher (almost 1.5 and 3.5 times) than the rate in T2 and T1 respectively. However, the difference in recharge rates of T1, T2 and T3 gradually decreased with increase in sediment concentration of the inflow water. Higher sediment concentration (1,500 ppm or more) reduced recharge rate drastically in CS bed T3, probably due to a rapid blocking of intrinsic pores with higher concentration of suspended particulates. The higher recharge rate in T3 through larger intrinsic pore size resulted in higher permeability of the medium as well as to lower removal efficiency and consequently less clogging of the top layers.

The results pertaining to temporal changes in recharge rate at different influent water sediment concentrations during the test duration are presented in Figure 7. The recharge rates through all three CS beds were substantially higher at lower inflow sediment concentrations of up to 1,000 ppm in comparison to rates at 1,500 ppm and above. A sharp decline in recharge rate at higher sediment concentrations was observed in all three CS beds due to immediate blocking of flow pathways of the recharging water. The recharge rate at 250 ppm turbidity level was almost constant throughout the test duration. At 500 ppm level, the recharge rate was constant initially for some time after which it decreased rapidly to reach the minimum level within a few minutes. This occurred due to entrapment of initially suspended particles in the pores followed by accumulation of the suspended particles on the top of the bed in the form of a clogging layer, which drastically reduces the recharge rate. These results suggest that the performance of CS beds in the field can be improved by making some provision to reduce higher sediment load of inflow water to a lower level before it approaches the filter bed.

It is also observed in Figure 7 that the medium size also influences the recharge rate. Medium with coarser particles (T3) recorded the highest recharge rate among all three beds during initial stages before reaching a minimum level. There is no major difference in the recharge rate of different CS beds after a constant rate is reached due to the formation of a layer of particulates retained on the top. It also highlights the significance of the removal of deposits from the top and from the upper layers to restore the filtration efficiency of the system. Figure 7 also depicts that regardless of sediment concentration inflow water, recharge rate reached a constant level in CS bed T3 later than T2 and T1. These results suggest that the performance of CS filtering medium can be improved using higher proportion of CS particles in the filtering unit.

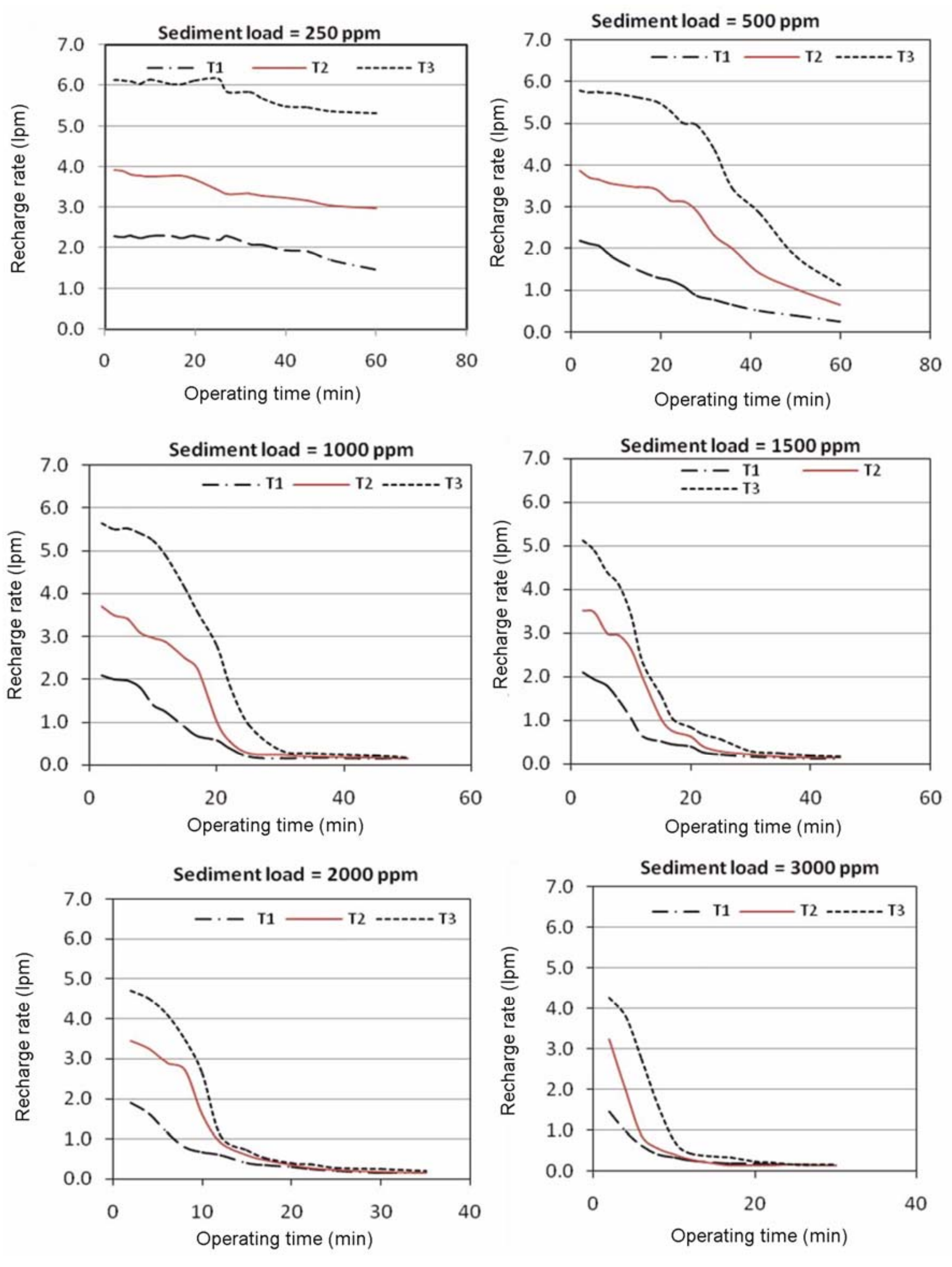

Figure 7. Effect of operating time on performance of different CS beds.

Outflow water quality

Electrical conductivity (EC), pH, residual sodium carbonate (RSC) and nitrate of outflow water were determined using different tests. The results showed virtually no effect of different CS media on these quality parameters in the outflow water (Figure 8), or at different depths of the medium (not shown here). The practical implication of these observations is that in areas where soluble chemicals (e.g. nutrients like nitrate) are the critical pollutants, the CS bed filtering system may not be effective to prevent movement of these chemicals to underground layers and groundwater. Similar results for nutrients have been also reported for gravel-based filtering media, although relevant modifications to promote biochemical processes may result in improvement of nutrient removal[14].

Summary and conclusions

Sand-based filters, consisting of vertical layers of CS (at the top), gravel and boulders/pebbles in a brick-masonry chamber, are used as a mandatory component of injection well-type groundwater recharge structures. However, there are no well-defined design criteria for the thickness and size of different filter materials. A laboratory study was undertaken in a PVC column of 22.5 cm diameter and 120 cm length to evaluate the efficiency of CS of three particle sizes, viz. 0.35–0.5 mm (T1), 0.5–0.7 mm (T2) and 0.7–1.0 mm (T3) as the top layer of a recharge filter bed for seven influent sediment concentrations of 250–3,000 mg/l. The performance was evaluated in terms of spatial movement of sediments, removal efficiency, recharge rates and clogging time. The salient results and conclusions are summarized below.

1. More than 60% of the suspended solids were entrapped in the top 10 cm layer of CS, the level of accumulation in the upper layer increased with increasing turbidity of influent water.

2. Using empirical relationships developed in the study, the minimum thickness of CS beds required to reduce sediment load from 250 to 50 ppm and from 3,000 to 50 ppm was estimated as 17 and 51 cm for T1, 25 and 70 cm for T2 and 29 and 75 cm for T3.

3. Maximum retention of sediments in the top 10 cm layer was observed in T3 having larger intrinsic pores and its recharge rate also reached a constant level later than in T1 and T2, regardless of influent sediment concentration. These results suggest that the performance of CS media can be improved by using higher proportion of CS particles in the filtering unit.

4. RE increased with the increasing thickness of the CS bed and ranged from 84% to 90%, 68% to 77% and 59% to 72% in the top 25 cm of T1, T2 and T3 respectively, depending upon the influent sediment load. The sediments could pass through the larger intrinsic pores of T3 and required more depth of CS than T1 and T2 to achieve the desired level of RE. This means that minimum thickness of CS bed would be different for different media sizes to achieve similar RE.

5. The recharge rates through all CS beds were substantially high at inflow concentrations of 1,000 ppm or less. A sharp decline in recharge rate was observed at higher sediment concentrations in all sizes due to quick blocking of flow pathways of recharging water. These results suggest that the performance of CS beds in the field can be improved by making some provision to reduce higher sediment load of inflow water to a lower level before it approaches the filter bed.

6. The surface area of the filter in the field is governed by the catchment area contributing to run-off and the permissible ponding time depending upon the submergence tolerance of the crops etc. Despite difference in cross-sectional area of the filtering unit in the laboratory and in the field, the thickness of the filtering media was comparable (both being about 1.2 m thick). Consequently, results of the laboratory studies are also valid in the field in terms of particle size of 0.7–1.0 mm and minimum 75 cm thickness of the sand layer. The design of the filtration system has been modified by increasing the particle size of the CS layer from 0.5–1.0 mm to 0.7–1.0 mm and thickness from 50 to 75 cm in new recharge structures installed by CSSRI in the farmers' fields.

7. The other recommendation for reducing the sediment load of the run-off water before entry in the filter bed is also being evaluated in the field trails by providing a sedimentation tank adjoining a recharge filter or installing radial/biological (grass) filters around the recharge structure.

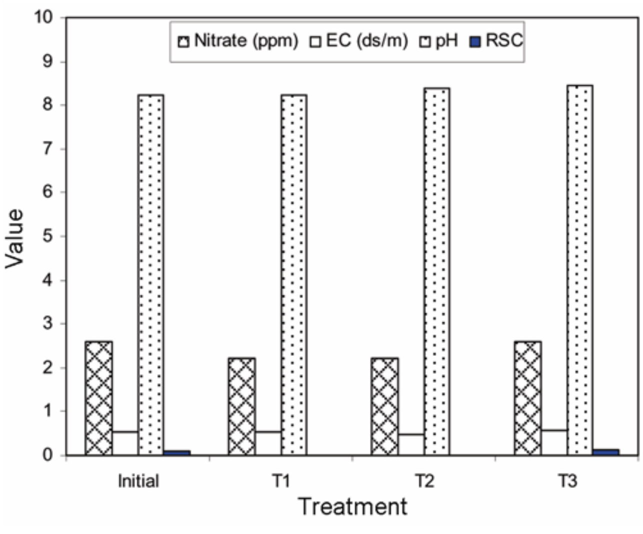

Figure 8. Quality attributes of filtered water under different CS beds.

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Received 14 December 2011; revised accepted 26 June 2012