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Performance Evaluations of Groundwater Recharge Rectangular Filtration System for Sand-Mixed Storm-Runoff

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Abstract: Need of artificial recharging of groundwater is gaining importance due to sharp decline of groundwater table at many places. For artificial recharging it is desirable that the injected water to the groundwater system is devoid of the sediments and other foreign materials which may hamper the quality of groundwater. This necessitates the storm water runoff to pass through the filtration system before injection. However, there is often problem of clogging of filter, which requires frequent maintenance. Thus, there is a need of proper understanding of working of the filtration system. The present study focuses on performance evaluations of the various filtration systems of varying influent sediment concentrations of the storm runoff in the laboratory.

The experiments were conducted in a rectangular filtration chamber having length, width and depth as 200mm×160mm×1200 mm. The filter media consisted of three layers viz. top layer of coarse sand (CS), the second layer of gravel (G) and bottom layer of boulders/pebbles (P). Observations of the recharge rate, filtration efficiency and clogging time of coarse sand (CS) were taken for three different sediment sizes, viz. 0.300-0.425 mm, 0.425-0.600 mm and 0.600-1.18 mm by changing their thicknesses to 150 mm, 200 mm and 250 mm under seven influent sediment concentrations ranging 250–3,000 mg/l of the storm runoff. It is observed that recharge rate, filtration efficiency and clogging time of coarse sand (CS) are changing with time and change in runoff sediment concentration. Various relationships have been derived between recharge rates, inflow sediment load, size of CS and thickness of CS. R2 obtained for these relationships are ranging from 0.906 to 0.982.The results obtained from the experiment shall be useful to field engineers in improving the performance of the recharging systems.

Keywords: Groundwater, coarse sand, storm water, filter, sediment load.

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1. Introduction

Ground water is used in meeting about 60% of irrigation demand and 80% of drinking water requirements in India. Due to excessive use groundwater table is declining at an alarming rate in about 15% of India's geographical area. Water tables in fresh groundwater regions of the north western states of India, particularly in Haryana and Punjab, have fallen 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(Taneja and Khepar, 1996). 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. Artificial groundwater recharge is a process by which the groundwater reservoir is augmented at a rate higher than the rate of natural recharge. Problems and questions arising from the field operation indicates there is need for thorough investigation of the use of filtering media to achieve high infiltration rates in recharging wells.The filtration unit must perform effectively to get potential benefits from the installed recharge structures. 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.

In addition, there are no well-defined criteria for designing the thickness of different layers of filter material. Coarse sand (CS) or medium sand (MS) 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 or MS, therefore, plays an important role, but it is not standardized. This leads to uncertainty in achieving adequate recharge rates and causing frequent clogging of the filter. The present studyis 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.

2. Experimental Setup

The Narwana As it is difficult to study 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, therefore laboratory study is conducted under uniform flow conditions.

The laboratory study is conducted in a rectangular column of (B×W×H) 200mm ×160mm ×1200 mm and having provision of regulated water inflow and free outflow. Inlet is provided in the upper portion of the column to maintain a constant hydraulic head manually during the test run. Sampling ports, consisting of PVC pipes of 12.5 mm size and perforated in the upper half portion are fitted horizontally at different depths in the column to collect samples of flow-through water and spatial movement of sediments in the filtering medium . Outlet is provided at the bottom of column to drain out filtrate water. Measuring bucket is provided at the bottom of the column to measure filtrate water from the outlet. One concentric gallon is provided at the bottom of the column in such a way that only the flow-through water is collected in the gallon. The filtrate collected in the gallon is utilized for further analysis. In total nine sampling ports are installed: the first three being 5 cm apart and the remaining six at 10 cm distance from each other. These sampling pipes are not perforated up to 5 cm on both sides near to the column walls to ensure that the water moving along the side 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 flowthrough water was collected in the inner collector and the water flowing along the sides of the column was collected in the outer collector.

Gravel (size8-20 mm and 220 mm thickness) and boulders (size20-40mm and 200 mm thickness) are used as supportive layers below CS. Experiments are conducted with varied concentration of sediment load in the recharging water to simulate field condition of runoff. Gravelsand boulders' sizes as well as thicknessesare kept constant for all treatment combinations. wA cloth net is used at the top of the coarse sand to dissipate the impact of inflow sand mixed runoff water to minimize the displacement of CS particles. Clean tap water is passed through filtering medium for 10 minutes before each experiment run to drain any soluble materials. Experiment runs are performed with sediment load of 250, 500, 1,000, 1,500, 2,000, 2,500 and 3,000 mg/l and replicated three times. Scheme of experimentation is summarized in Table 1.

Table1: Scheme of experimentation

Treatment	Size of CS Treatment size (mm)	Mean size (mm)	Thickness of bed (cm)	Sediment concentration (mg/l)	Replications
T1	0.300-0.425	0.357	60	250, 500, 1000, 1500, 2000, 2500, 3000	3
T2	0.425-0.600	0.505	65	500, 1000, 1500, 2000, 2500, 3000	3
T3	0.600-1.18	0.890	70	500, 1000, 1500, 2000, 2500, 3000	3

3. Analysis

Experiments are conducted to determine the recharge rate, clogging time, suspended material and particulate matter removed from recharge water by CS filter layers. The experiments studies show that the recharge rate by CS filter media is dependent on the suspended solids from influent recharge water. The percent removal of solids increased as the recharge rate decreased.

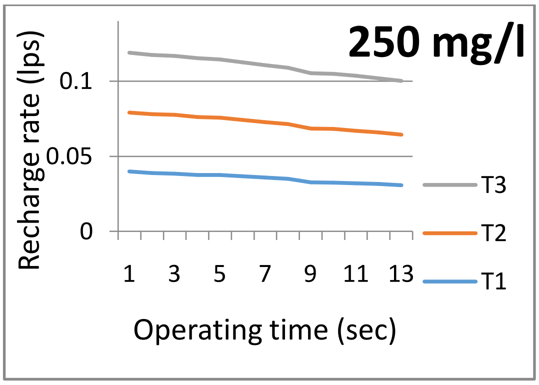


Fig. 1

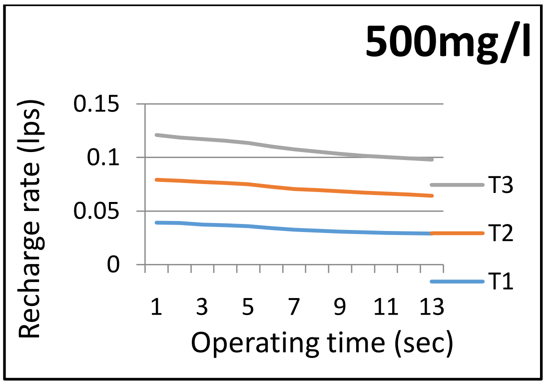


Fig.2

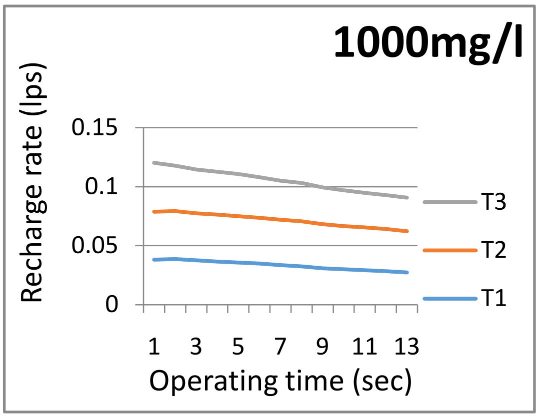
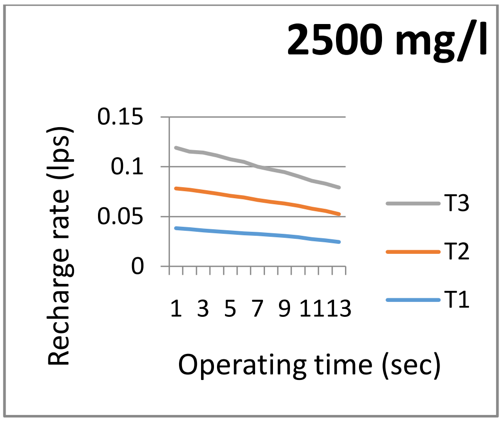


Fig.3



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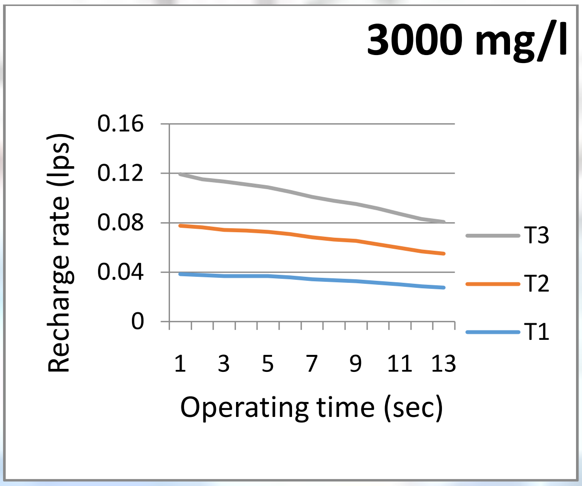


Fig.5

Figs. 1 to 5: Variation of Recharge Rate with Time for Different Concentrations of Recharging Water having Thickness of CS = 60 cm & three sizes

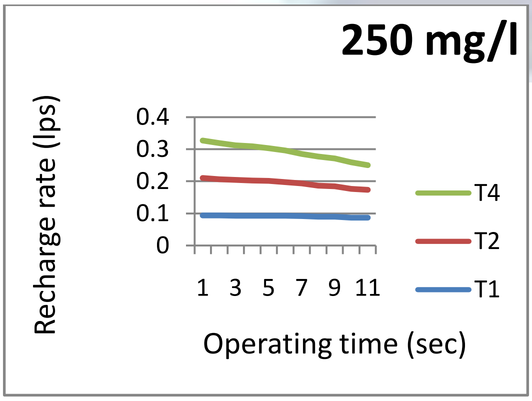
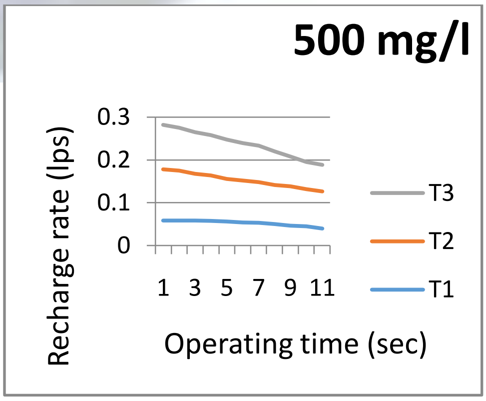


Fig.6



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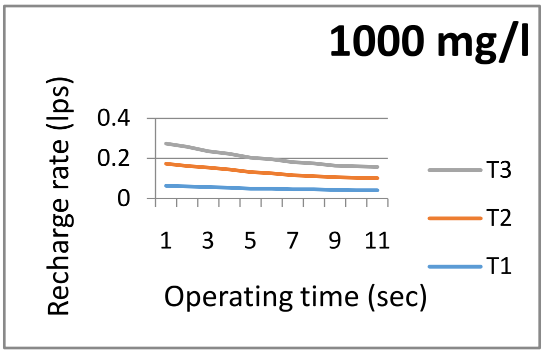

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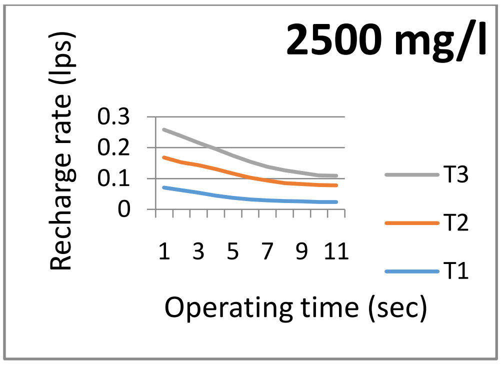


Fig. 9

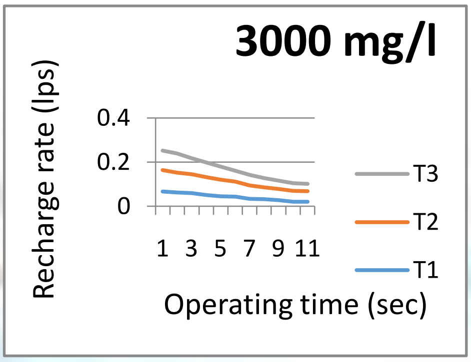
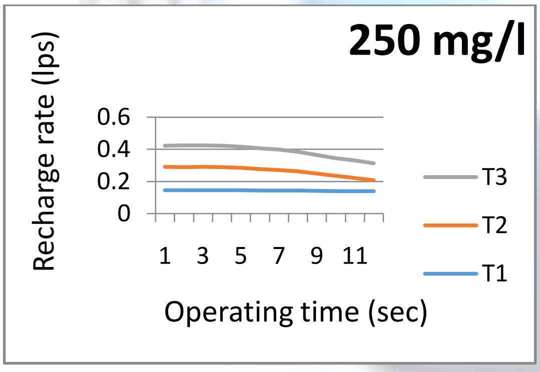


Fig. 10

Figs. 6 to 10: Variation of Recharge Rate with Time for Different Concentrations of Recharging Water having Thickness of CS = 65 cm & three sizes



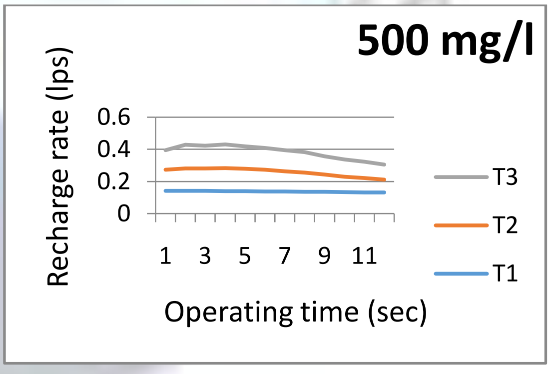


Fig. 11Fig. 12

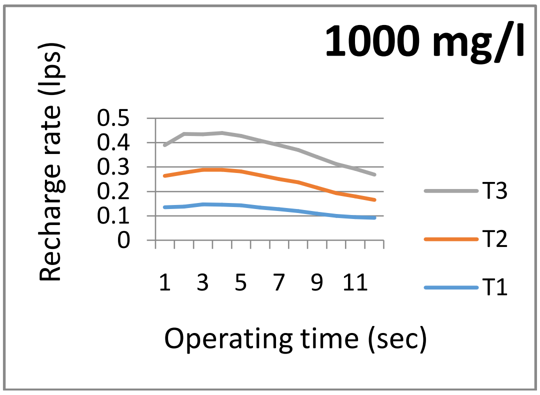


Fig. 13

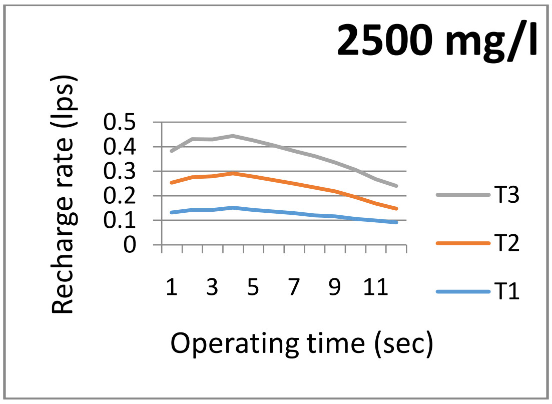


Fig. 14

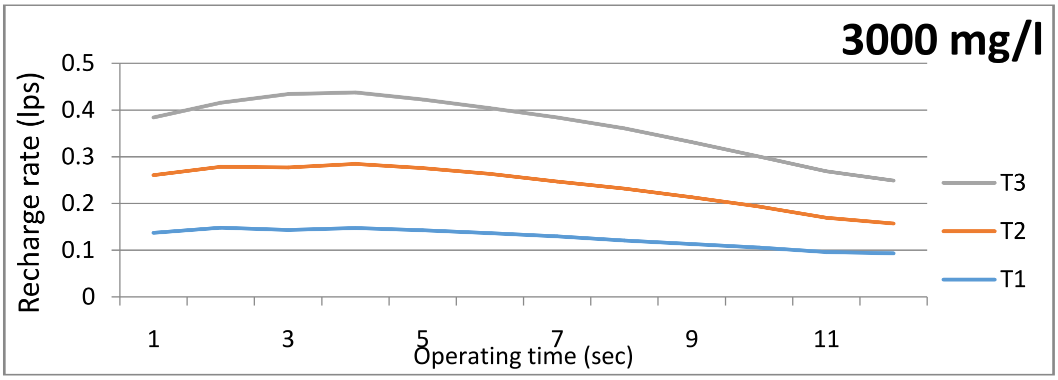


Fig. 15

Figs. 11 to 25: Variation of Recharge Rate with Time for Different Concentrations of Recharging Water having Thickness of CS = 70 cm & three sizes

4. Results and Discussion

For the experiment data, seven varying influent of sediment load (ppm), three varying size of CS and three varying thickness of CS are used to derived the relationship among them. Relationship among recharge rate, particle size of the CS, sediment load of recharging water and efficiency of filtration system are discussed below.

A) Using Multiple Linear Regression analysis (MLR)

The following relationships has been derived between recharge rates (Q in lpm), inflow sediment load (S in ppm), size of coarse sand (D in mm) and thickness of coarse sand (T in cm). The relationship obtained is given below as

Q = - 2.607E – 02 - 5.359E 06×S + 0.1690×D + 6.524E - 04×T

The R^2 for best-fitted curve obtained is 0.912 and Correlation coefficient obtained is 0.916. The observed and predicted recharge rate by MLR is shown in Fig. 16.

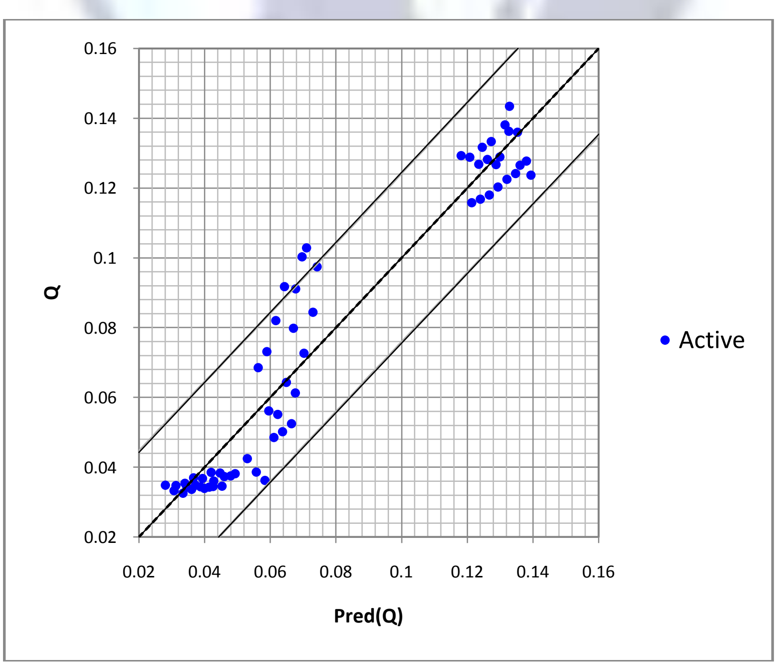


Fig.16: Observed and modelled recharge rate using MLR

B) Using Artificial Neural Network (ANN)

The above relationship between recharge rates (Q in lpm), inflow sediment load (S in ppm), size of coarse sand (D in mm) and thickness of coarse sand (T in cm) has been also tried by using neural network. The neural network analysis has been carried out using 10 fold cross validation. The correlation coefficient obtained is 0.916 and Root mean squared error 0.0074. The observed and modelled recharge rate by ANN is shown in Fig. 17. The R^2 obtained by ANN is 0.965 which is better than as obtained in MLR. The model parameters selected for ANN are hidden layer = 'a' where 'a' = (attribs + classes)/2, learning rate =0.3, momentum = 0.2 & no of seed = 500.

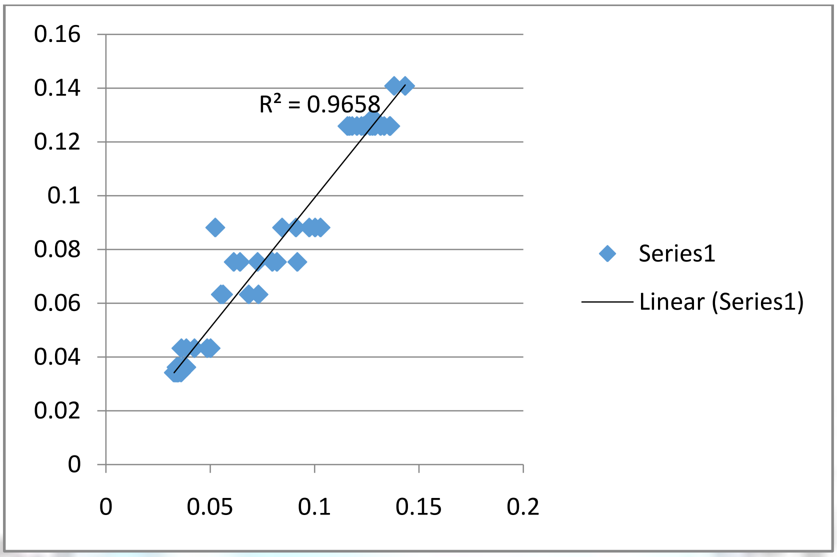


Fig.17: Observed and modelled recharge rate using ANN

5. Conclusions

The performance is evaluated in terms of recharge rate and clogging time. From the experiment carried out the following conclusions are obtained.

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. 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 size of CS particles in the filtering unit.
3. 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 of all sizes due to quick clogging 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.
4. Treatments with higher thickness of CS media indicated that the recharge rate is slightly more than that of treatments with lower thickness of CS media.
5. Relationship is also generated by using multiple linear regressions (MLR). The R^2 obtained is 0.916, Correlation coefficient obtained is 0.912.
6. Artificial neural network (ANN) model performs better than MLR. The value of R^2, Correlation coefficient and root mean squared error are 0.965, 0.972 and 0.007 respectively.

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