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Sewage land disposal and unpaved drains: threat to groundwater quality

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ABSTRACT

Lack of proper wastewater management infrastructure is an alarming threat to the ground water quality, especially in developing countries. The objective of this study was to investigate the transport of coliform bacteria and other pollutants through soil to ground water in Taxila (Pakistan), near the unpaved sewage drain. An experimental setup was installed with five circular columns of variable depths of 0.3, 0.3, 0.9, 1.2, and 1.8 m clayey soil, taken near from drain, filled and compacted thoroughly in the columns. The sewage was poured into experimental setup from top and treated effluent was collected from the bottom. Sewerage before and after treatment were examined regularly. The Biological oxygen demand $(BOD)_5$, Chemical oxygen demand (COD), Total suspended solids (TSS) and Total dissolved Solids (TDS), and coliform bacteria were monitored in the influent and effluent. Samples from the bores near the drain were also taken and analyzed. Coliform bacteria removal efficiency was 98.25%, in 1.8 m depth column, after 15th day of start. Similarly, BOD_5, COD, and TSS maximum removal efficiencies achieved at 1.8 m depth were 90, 80, and 100%, respectively. Coliform bacteria were detected from the ground water near the sewage drain. A significant concentration of coliform bacteria was detected, even at the depth of 45 m, from the bores.

Keywords: Sewage; Unpaved drains; Land disposal; Pollutants infiltration; Deep groundwater contamination

1. Introduction

Developing countries' sewage drainage infrastructure is usually very poor. Usually, sewerage is disposed of on land. Approximately, 64% of total sewage of Pakistan is disposed of either into a river or into the Arabian Sea. Similarly, 400,000 m^3/d is discharged into canals [1].

In Pakistan, untreated sewage is directly used for irrigating agriculture land (32,500 hectares) [2]. Due to this activity, groundwater is at great risk of contamination. Recently, it is examined that the quantity of nitrates, microorganisms, organic pollutants, and other pollutants have increased, and this is attracting public concerns about groundwater quality. The old traditional method of collecting and discharging wastewater using septic tanks also some time leads to wastewater leakages, which tempers with soil and groundwater quality as well [3].

It has been reported that the leachate from sewage dump sites constitute both soil and water pollution in the environment [4]. Improper sewage management

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methods could leads to the contamination of ground water [5,6]. Most of the contaminants contained in the municipal wastewater are being washed away by run-off into streams and rivers, some fraction infiltrate the soil and contaminate the groundwater aquifers [7,8].

Municipal wastewater can transfer various organic and inorganic constitutes with pathogenic microorganisms in groundwater [9,10]. As the sewage move through different soil layers, a number of processes come in operation, (e.g. filtration, dilution, oxidation, and biological decay), that can lessen the eventual impact of the substances once it finally reaches the groundwater [11]. The impact on groundwater quality of sewage and wastewater is well documented and a major concern globally [12,13]. Studies have also revealed that waste dumpsites can transfer significant amounts of toxic and persistent metals into the soil environment [14].

Previous researches showed that contaminants concentration in sewage varies as it passes through different soil types. The consensus of most researchers is that the groundwater pollution depends upon the discharging period of wastewater and soil permeability [15]. Lance (1980) conducted soil column tests to compare the water quality improvement and infiltration rate obtained, when primary and secondary wastewater is applied to the loamy sand soil. They observed that the infiltration rates for primary wastewater were slightly less than those of secondary wastewater. Furthermore, the study concluded that the removal of PO_4^{2-}, organic carbon, Fecal Coliforms and viruses were similar in both types of wastewater [16]. Das (2003) studied the impact of septic tank effluent on groundwater quality and observed from his survey that the discharge of wastewater onto the land effectively reduces the BOD_5 and microbes concentration due to adsorption/chemical reaction in the soil media [17,18]. Cha (2004) studied the evaluation of wastewater treatment in Sandy Soil. BOD_5 fractions and residual dissolved organic carbon concentrations for the effluents ranged from 19.3 to 59.9% and from 1.0 to 7.5 mg/L, respectively, depending on the reaction time [19]. Effects of different soil types and infiltration rates on the removal of organics during soil aquifer treatment were investigated by Quanrud (1996). The study revealed that organic removal for columns containing sandy loam (56%), sand (48%), and silty sand (44%) did not correlate well with the infiltration rate [20].

The main objectives of our study were as follows (1) to evaluate the treatability of sewage infiltrating through clayey soil, (2) to evaluate the coliform removal at different depths of columns, and (3) to evaluate microbial concentration in groundwater at selected locations near unpaved sewage drain in Taxila, Pakistan.

2. Materials and method

2.1. Experimental setup

Five columns of 0.250 m diameter were used (Fig. 1). The effective depths of uPVC columns; C1, C2, C3, C4, and C5 were 0.3, 0.6, 0.9, 1.2, and 1.8 m, respectively. Samples were collected at the bottom of each column. An aggregate layer of 0.1 m thickness was added from the bottom of the column on which clayey soil was placed. Soil in each column was thoroughly trampled to ensure the field conditions. Soil samples were collected from columns for the investigation of different soil properties (Table 1). Constant head of sewage was maintained to saturate the columns at all times to ensure the field conditions in the unpaved sewage drain.

2.2. Operational plan and sampling

The flow in each column was maintained 3.5 L/d on 24 h basis. Influent BOD_5 varied between 200 and 250 mg/L. The organic loading was kept 0.0244 kg $BOD_5/m^2/d$ [21]. Grab samples of effluent were collected four times a day. A composite sample was prepared by mixing collected sample with equal proportion of time-based collected grab samples.

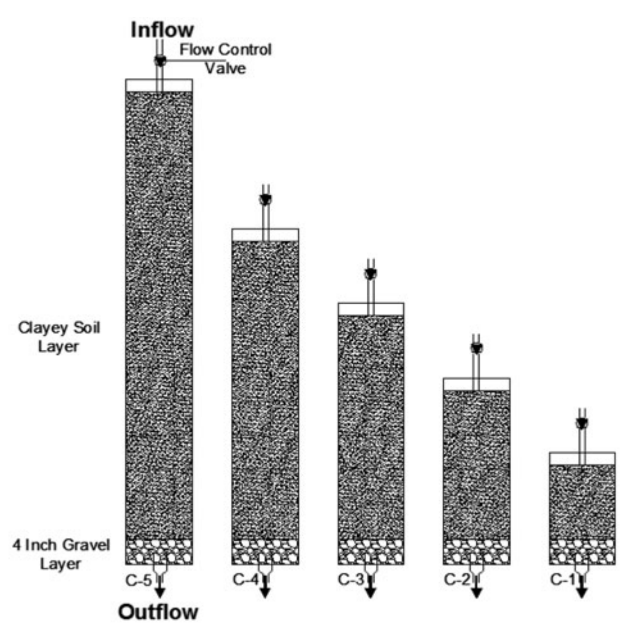

Fig. 1. Experimental setup.

Table 1
Selected properties of soil

S. no.	Parameters	Value
1	Bulk density	2.67 g/cm^3
2	Specific gravity	2.67
3	Porosity	46%
4	Clay and silt fraction	89.49%
5	Sand fraction	11.51%

All the analytical tests, to evaluate effluent quality, were performed on composite samples.

2.3. Experimental monitoring and analysis

Influent and effluent samples were analyzed for BOD_5, COD, TSS, TDS, and coliform bacteria. All tests on the influent and effluent samples were performed according to the procedures laid down in "Standard Methods (2012)" (Table 2).

2.4. Sample collection from field

Furthermore, samples were also collected from the drinking water bore wells near the unpaved sewage drain (3–20 m). The depths of bore wells were from 30 to 45 m. The samples collected from the bore wells were only tested for coliform bacteria. Number of samples collected from each bore well were 10.

3. Results and discussions

The results showed constant decrease in concentrations of BOD_5, COD, and TSS. However, there was no significant removal of TDS.

3.1. BOD_5 and COD removal efficiencies trends

Biodegradation and adsorption are two major processes responsible for organic removal. BOD_5 and COD concentrations varied between 200–250 mg/L and 400–425 mg/L, respectively. In the effluent, BOD_5 and COD concentrations decreased gradually with time. Minimum BOD_5 and COD concentrations, which were observed, varies 120 and 150 mg/L in C1 and 30 and 95 mg/L in C5, respectively, at 15th day. Ripening period of soil columns was 15 d. With increase in depth of columns, BOD_5 and COD concentrations also decreased as more detention time was available for the biological degradation of pollutants. A greenish biological layer witnessed at 10th day of experimentation, provided enhanced BOD_5 and COD removal. Maximum BOD_5 removal efficiencies achieved in C1, C2, C3, C4, and C5 were 60, 70, 76, 84, and 90%, respectively. Maximum COD removal efficiencies achieved in C1, C2, C3, C4, and C5 were 56, 63, 73, 76, and 80%, respectively. BOD_5 and COD removal efficiencies trends for different depths columns are also shown in Figs. 2 and 3.

Table 2
Tests performed

S. no.	Test	Standard test procedure
1	TSS	2,540 D
2	BOD_5	5,210 B
3	COD	5,220 D
4	Coliform	9,222

3.2. TSS removal

Removal efficiencies of TSS were remarkable even at first day. The soil acts as a filter media for the suspended solids. Fig. 4 presents TSS removal efficiency as a function of time and depth. With passage of time, removal efficiency increases and TSS concentrations became undetected for C4 and C5 at 9th day. Maximum TSS removal efficiencies achieved in C1, C2, and C3 were approximately; 72, 86, and 96%, respectively. C4 and C5 removal efficiencies reached up to 100% even at 9th and 7th day of startup, respectively. TSS removal efficiencies trends for different depths columns are given in Fig. 4.

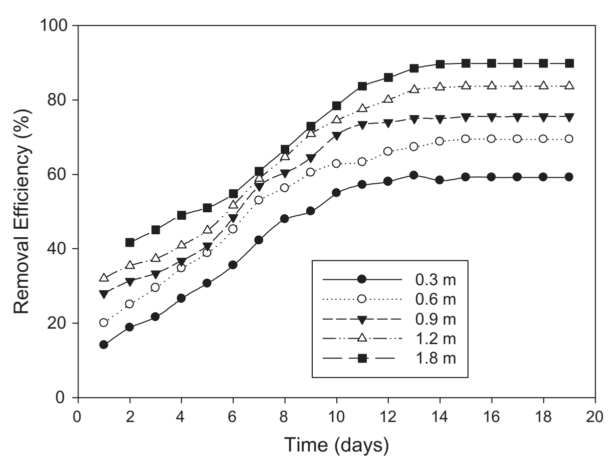

Fig. 2. The BOD_5 removal efficiencies at different depths.

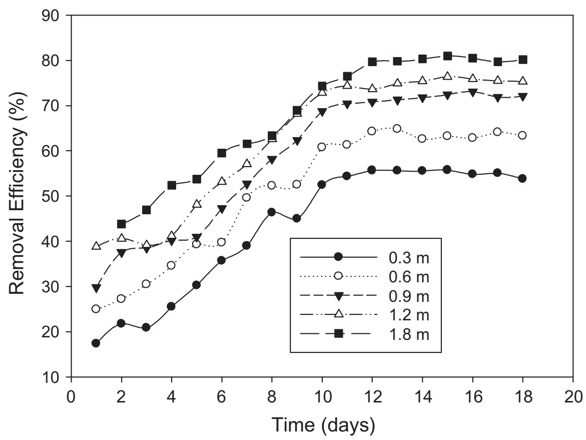

Fig. 3. The COD removal efficiencies at different depths.

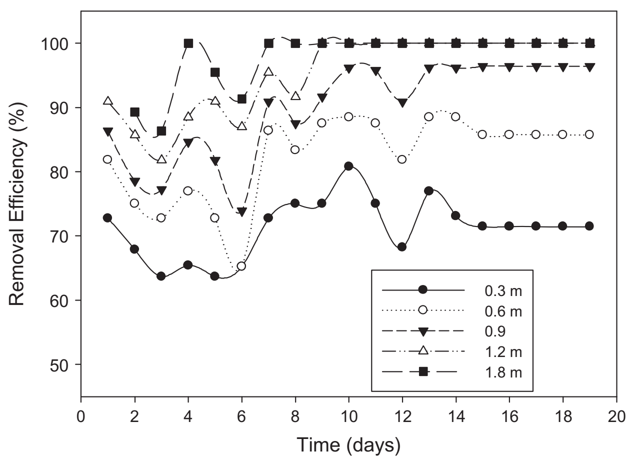

Fig. 4. The TSS removal efficiencies at different depths.

3.3. TDS removal

No significant change in the TDS concentrations was observed in outflow. Although, at the initial stage, the soil particles may significantly capture the dissolved solids, continuous build-up of leached chemicals in soil materials may eventually cause a significant drop in the adsorption capabilities of the soil, and hence, no further improvement in terms of TDS was observed. This is reflected in almost all of the tested soil columns where an initial drop of TDS values is followed by a steady and continuous increase of TDS values, which may be attributed to the dissolution of some of the minerals like gypsum, anhydrite and chloride, especially in case of C5 which showed sudden increase in TDS in start. After that it was reduced. As the depth increased, the concentration of TDS increased. It was due to the degradation of soluble and suspended impurities as well as due to

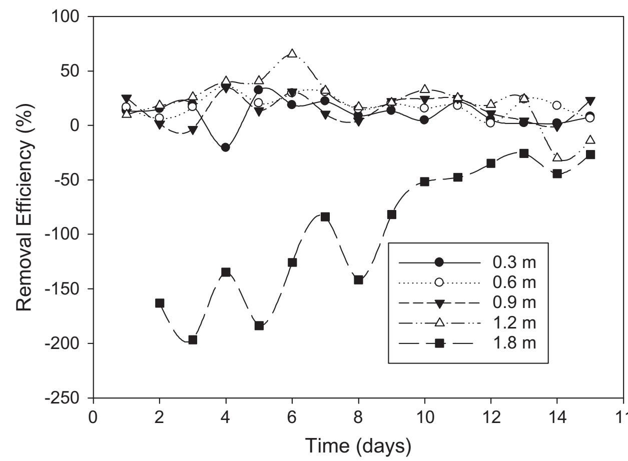

Fig. 5. The TDS removal efficiencies at different depths.

dissolution. Results of TDS removal efficiency in each column as a function of time is given in Fig. 5.

3.4. Coliform bacteria

Bacteria were removed effectively as sewage percolated through the soil. Sorption at soil surface and at intergrain contacts coupled with sedimentation was the major removal mechanism [21]. Soil columns showed a maximum coliform removal of 98% in C5 and minimum removal of 41% in C1. Generally, coliform levels showed a steady decrease with depth. Fig. 6 presents removal efficiencies of coliform bacteria in columns as a function of time and depth. There was no significant reduction in coliform concentration

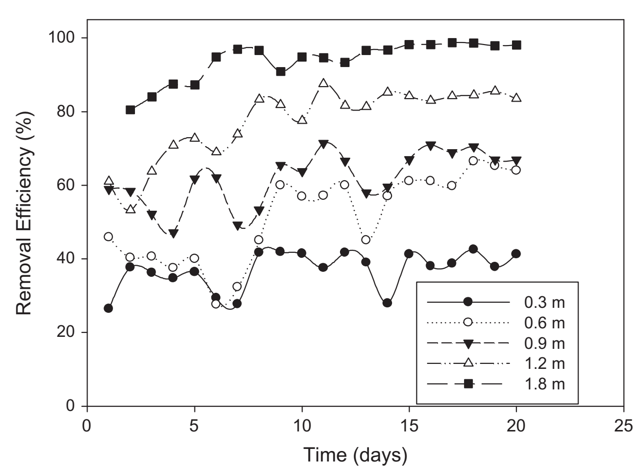

Fig. 6. The Coliform bacteria removal efficiencies at different depths.

Table 3
Coliform concentrations in the bores wells near unpaved sewage drain

Bore depth (m)	CFU/100 ml	No. of samples	Standard deviation
33	98	10	±15.23
36	55	10	±8.26
42	35	10	±11.03
45	11	10	±2.99

after 13 d, in all columns, as it reached up to its maximum removal.

Beside the higher removal efficiency the concentration of coliform in the effluent was much higher. It was 215,000, 125,000, 45,600, and 5,000 CFU/100 ml in the C1, C2, C3, C4, and C5 columns, respectively. Concentration of coliform in the bore near the unpaved drain is given below in Table 3. The results show that the sewage can contaminate the ground water, even at the higher depths, if it is not properly managed and disposed.

4. Summary of results

The maximum removal efficiency of BOD_5, COD, TSS, and coliform at different depths of strata is shown in Fig. 7. Removal efficiency of BOD_5, COD, TSS, and coliform was 90, 80, 100, and 98% in C5, respectively. Most of the treatment occurs in upper 1-feet layer of the soil due to the active biological treatment. Coliform contamination was found in the ground water even at the depth of 45 m near the unpaved sewage drain. Table 4 presents the regression test analysis for the removal of pollutant at different depths. The regression analyses for different pollutants were as; coliform ($R^2 = 0.97$, $p = 0.000039$), COD ($R^2 = 0.687$, $p = 0.00037$), BOD ($R^2 = 0.73$, $p = 0.0043$), TSS ($R^2 = 0.8$, $p = 0.0047$), and TDS ($R^2 = 0.65$, $p = 0.00093$). The results showed the linear and proportional relation of depth with removal efficiencies.

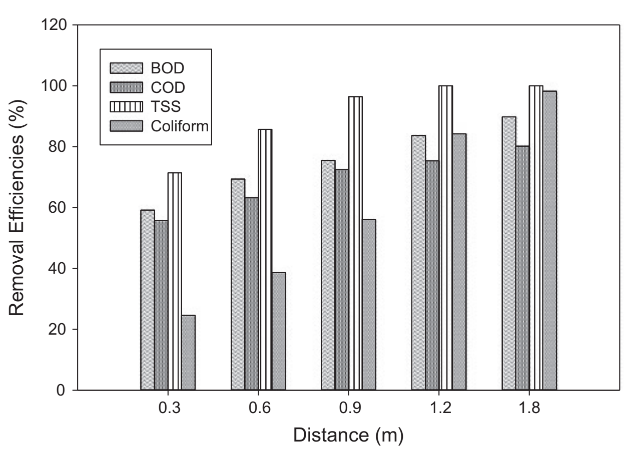

Fig. 7. The maximum removal efficiencies at different depths.

Table 4
Regression test results

S. no.	Parameter	R^2	p-value
1	Coliform	0.97	0.000039
2	COD	0.687	0.0037
3	BOD	0.73	0.0043
4	TSS	0.8	0.0047
5	TDS	0.65	0.00093

5. Conclusion

Ground water is getting contaminated with the disposal of untreated sewage. Therefore, the groundwater recharge with treated wastewater is becoming more valuable with time in developing countries because of the scarcity of water resources. The study underlined the treatment potential of soil using column experiment for the removal of various pollutants of concern from sewage. Results showed that BOD_5, COD, and TSS removal increased with the increase in the depth of columns.

From the results, it was observed that maximum removal of BOD_5, COD, TSS, and coliform was achieved in C5 but still some contaminants may pass through soil and remained untreated. Most of the treatment was observed to be occurred at upper layers of soil. The coliform contamination can happen in the deep ground water sources if the sewage is applied continuously and without appropriate treatment. So before disposing of the sewage:

(1) Sewage drains must be paved.
(2) Wastewater must be given primary treatment.
(3) Wastewater must not be disposed of in areas having shallow groundwater.

(4) Infiltration rate may be maintained in such a way to provide sufficient retention time to wastewater in soil strata for better treatment.
(5) A relaxation time must be provided while land treatment of sewage to avoid the saturation of strata throughout the depth above the water table. The saturation (presence of water) throughout the depth is the cause of bacterial contamination in deep groundwater sources.

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