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Water Quality Improvements in Soil Aquifer Treatment (SAT) Simulated Soil Columns

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Abstract

Artificial recharge of Aquifers with treated wastewater is one of the most promising techniques for its reuse. Usually laboratory and pilot scale field studies are conducted for investigating the feasibility of wastewater recharge for any aquifer. The addition of sand to the local soil can improve the performance of the Soil Aquifer Treatment (SAT) process. Thus, a laboratory study was conducted to investigate the effect of sand amendment with local Sandy Clay Loam (SCL) texture soil collected from Anna University Sewage Treatment Plant (STP), Chennai, India. Four 35 cm long PVC soil columns were fabricated and were filled with 5 % (R5), 10 % (R10), 15 % (R15) and 20 % (R20) sand amended soil. The experiments were run simultaneously for a period of ten cycles with 3 days wet/4 days dry cycles. Water samples were collected at the outlet of the columns and analysed for TDS, ammonia, nitrite and nitrates. The removal of ammonia was through nitrification process which was found to be a dominant removal mechanism of nitrogen. When reduction performance achieved with different sand amendment columns were compared, it could be seen that R10 column yielded with least nitrate value of 0.69 and 1.57 mg/l after 1st and 3rd wetting day.

Keywords: Artificial Recharge, Nitrate Reduction, Sand Amendment, Soil Aquifer Treatment, Wastewater Reuse

1. Introduction

Soil Aquifer Treatment (SAT) are artificial recharge of groundwater through infiltration basins, a high degree of upgrading can be achieved by allowing partially-treated sewage effluent to infiltrate into the soil and move down to the groundwater. The unsaturated or vadose zone then acts as a natural filter and can remove essentially all suspended solids, biodegradable materials, bacteria, viruses and other micro organisms. Significant reductions in nitrogen, phosphorus and heavy metals, concentrations can also be achieved. After the sewage, treated in passage through the vadose zone, the groundwater is allowed to flow some distance through the aquifer before collected. This additional movement through the aquifer can produce further purification[1,2].

Ammonia removal is a significant problem in a range of SAT. The municipal wastewater generates large volumes of ammonia contaminated water after primary and secondary treatment. There is no proper understanding of the behaviour of ammonia through the aquifer recharge with treated wastewater and factors affecting it.

There are no tools available for the estimation of the removal of ammonia and nitrate with different process conditions during SAT with respect to time and adsorption without conducting pilot studies or extensive field investigation. Therefore, it is important to understand the behaviour of ammonia compounds during SAT which will help to make preliminary estimation or prediction of final water quality that could be obtained from SAT system. Furthermore, will be very useful in decision making for the acceptability of technology understanding the nature of the influencing factor effect on nitrification process and will result in correcting the behaviour of ammonia compounds in the integrated management of waste water usage.

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During SAT, cyclic flooding/drying operations is necessary. The primary purpose of wet/dry cycle operation is to control the development of clogging layers and maintain high infiltration rates. As a clogging layer develops during a wetting cycle, infiltration rates can decrease to unacceptable rates. The drying cycle allows for the desiccation of the clogging layer and the recovery of infiltration rates during the next wetting cycle.

The primary objective of this laboratory scale study is to evaluate the performance of sand amended soil for recharge of groundwater by SAT with secondary treated wastewater. The specific objectives of this study are 1) to construct the sand amended soil columns to study the recharge phenomena with respect to ammonia, nitrite and nitrate reduction; 2) to determine the best combination of sand percentage of amended soil that will produce maximum reduction of ammonia, nitrite and nitrates.

2. Materials and Methods

2.1 Design and Operation of Soil Columns

A multi column SAT system was constructed in laboratory conditions. The experimental setup consisted of four identical PVC soil columns of 35 cm length and 6 cm inner diameter, one feeding tank for Real Secondary Treated Wastewater (RWW); feeder assembly and distributor lines. The experimental setup with columns and feeding tank are shown in Figure 1. The columns were operated under 3 days wetting/4 days drying period. RWW was applied for a period of 6 hrs (from 9 am to 3 pm) daily. The samples taken from column were collected at the end of the first and third wetting day, for all 4 combinations.

Soil columns were operated inside centre for water resources building, without any additional climatic temperature control inside the building during the study period. The lower part of the columns (approximately 5 cm) were filled with pebbles. The columns were provided with outlets for sample collection at bottom. All the columns were filled with 22.5 cm of soil. The soil selected was Anna University STP mixed with different proportions of Sand (5%, 10%, 15% and 20% given Table 1). Soils were poured into the columns and no compaction of soils inside the columns was carried out.

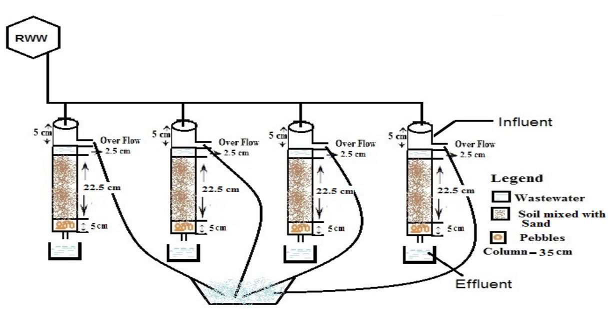


Figure 1. Schematic illustration of the soil columns setup.

2.2 Soil Samples and Properties - Anna University STP Soil

Soil samples from Anna University STP were collected from depth ranging between 0 and 0.75 m (referred to as top soil). The selection of the depth range was based on the fact that previous studies indicated that most of the purification takes place at the upper most layer of the soil[3]. It is the natural soil that has been collected from the STP without any treatment. In order to eliminate the interference with the secondary treated wastewater, it was washed several times with distilled water and left to dry. The bulk soil were homogenized, sieved and the gravel fraction > 1.7 mm excluded. The addition of sand to the local soil can improve the performance of the Soil Aquifer Treatment (SAT) process. Hence river sand was mixed with the local sandy clay loam (SCL) texture with 5 % (R5), 10 % (R10), 15 % (R15) and 20 % (R20). Soil columns were left submerged in distilled water for 48 hrs to remove trapped air from the bottom and to remove soluble irons. This was made to minimize the interference of the soil on the behaviour of ammonia. The soil textural classification, physical and chemical characteristics of the soil are given Table 2 and Table 3 using methods of Analysis of Soils as per HLS Tandon[4].

2.3 Real Wastewater (RWW)

Secondary treated wastewater from Anna University STP, where wastewater is treated by an activated sludge process was used in this study as a feed solution for SAT simulated soil columns. The wastewater characteristics collected from Anna University STP is given in Table 4.

Table 1. Operation schedule for this column study

S.No	Column Id	Wetting Period (days)	Drying Period (days)	Sand Mixed in %	No of Cycles
1	R5	3	4	5	10
2	R10	3	4	10	10
3	R15	3	4	15	10
4	R20	3	4	20	10

Table 2. STP soil textural classification

S.No	Name of the STP	% Sand	% Silt	% Clay	Textural class of soil as per USDA* Texture
1	Anna University	67	4	29	Sandy Clay Loam

* United States Department of Agriculture

Table 3. Physical and chemical characteristics of the study area soil

S.No	Parameter	Unit	Anna University STP
1	pH	-	7.25
2	Electrical Conductivity	µS/cm	198
3	Organic matter	%	0.32
4	Nitrate Nitrogen	ppm	7.0
5	Available Phosphorus	ppm	8.90
6	Potassium Exchangeable K	ppm	48
7	Calcium Exchangeable Ca	ppm	1550
8	Magnesium Exchangeable Mg	ppm	426
9	Sulfur Available S as So_4^{2-}	ppm	49.1
10	Sodium Exchangeable Na	ppm	161
11	Zinc Available Zn	ppm	0.32
12	Manganese Available Mn	ppm	16.45
13	Iron available Fe	ppm	13.80
14	Copper Available Cu	ppm	1.48
15	Cation Exchange capacity	Meq/100g	19.23

Table 4. Secondary Treated Wastewater characteristics from Anna University STP (Test methods as per HLS Tandon[4]

S.No	Parameter	Unit	Values
1	pH	-	7.00
2	Electrical Conductivity	µS/cm	1121
3	TDS	mg/l	717.44
4	Total Alkalinity as Calcium Carbonate	mg/l	120
5	Sulphate	mg/l	23.3
6	Chloride	mg/l	184.6
7	Nitrate	mg/l	4.9
8	Iron	mg/l	0.11

(*Continued*)

Table 4. Continued

S.No	Parameter	Unit	Values
9	Pottassium	mg/l	37
10	Calcium	mg/l	71
11	Magnesium	mg/l	24
12	Sodium	mg/l	250
13	Manganese	mg/l	0.04
14	Zinc	mg/l	Below Detection Level
15	Copper	mg/l	0.01
16	Aerobic Microbial Count @ 30° C	cfu/ml	176
17	E Coli	cfu/ml	Nil
18	Total Coliform (MPN method)	cfu/ml	7
19	Fecal Coliform	MPN/100 ml	1,76,366
20	TSS	mg/l	41
21	COD	mg/l	117
22	BOD	mg/l	26
23	Oil & Grease		4

2.4 Experimental Procedure and Analytical Methods

During the studies, EC, TDS, ammonia (NH_3), nitrite (NO_2) and nitrate (NO_3) were measured in Centre for Water Resources, Anna University wet chemistry lab. These measurements were made in samples collected from the outlet of each column as well as the stock solution during all studies. After the RWW stock samples were taken from the STP for RWW studies, the samples were immediately transferred to the laboratory where it was stored in the refrigerator at 4°C.

Samples taken from column were collected at the end of first wetting day for all 4 cycle combinations. When the samples were taken into plastic bottles of 500 ml. their caps were right away closed to prevent air entry.

EC and TDS measurements were made by using EQ8361 EQUINOX Pen type EC/TDS meter. Wastewater was stored in plastic bottles and kept at 4°C in order to reduce the effects of biochemical reactions. No additives or preservatives were used to preserve wastewater quality. Wastewater was warm to the room temperature before application on soil columns. Samples were collected from the bottom of each column. The samples were filtered with 0.45µm filters and stored at 4°C, NH_3, NO_2 and NO_3 were detected in each sample.

Ammonia was measured using Phenate method. Ammonia (NH_3) was determined using the standard curve after measuring the absorbance at 640 nm of standards and samples using Visiscan systronics spectrophotometer. The calibration curve (NH_3) vs. absorbance was prepared using the standard stock solution of NH_4Cl.

Nitrite was analysed with Visiscan systronic spectrophotometer. The method is based on the reaction of nitrite ions with sulfanylamide in acidic medium and the diazo compound obtained further reacts with diamine yielding in an azo color. The nitrite ion concentrations determined by measuring the absorbance of the azo colour at 543 nm.

Nitrate was analysed using cadmium reduction method. The analysis was conducted according to the American Public Health Association (APHA) standard methods for the examination of water and wastewater[5].

3. Results and Discussion

The influent (i.e the secondary treated wastewater) is having fluctuating inputs of NH_3, NO_2 and NO_3 daily. Due to non uniform NH_3, NO_2 and NO_3 in the daily influent of RWW, Effluent NO_3 behaviour have to take care of all the 3 mentioned with the mechanisms of adsorption of soil with high CEC (19.23 meq/100g) & nitrification. Since influent NH_3 and NO_2 is transformed to NO_3, only the effluent NO_3 behaviour are explained in this study.

As per Figures 2 c and f, among the four combinations of R5, R10, R15 and R20, it was found that R10 column after the end of 10^{th} cycle have the least concentration of nitrate with 0.69 mg/l at 1^{st} wetting day sampling and 1.57 mg/l at 3^{rd} wetting day sampling.

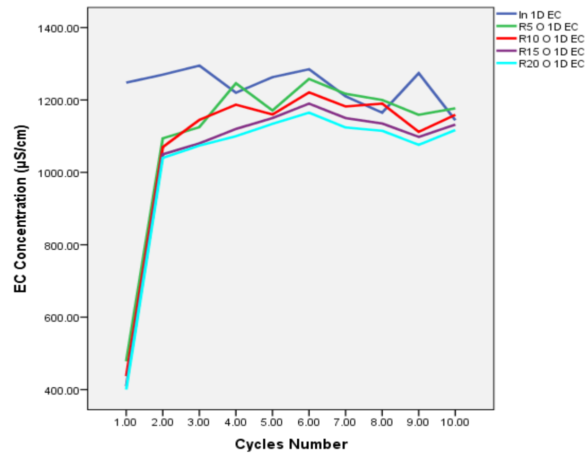
The influent (i.e the secondary treated wastewater) is having fluctuating inputs of EC and TDS. Due to non uniform EC and TDS in the daily influent of RWW, the output of EC and TDS also differs as per Figures 2a ,2b, 2d and 2e.

The removal of ammonia was thro nitrification process which is considered to be a dominant removal mechanism of nitrogen. The transport of ammonia depends upon the availability of oxygen, nitrifier bacteria and inorganic carbon source.

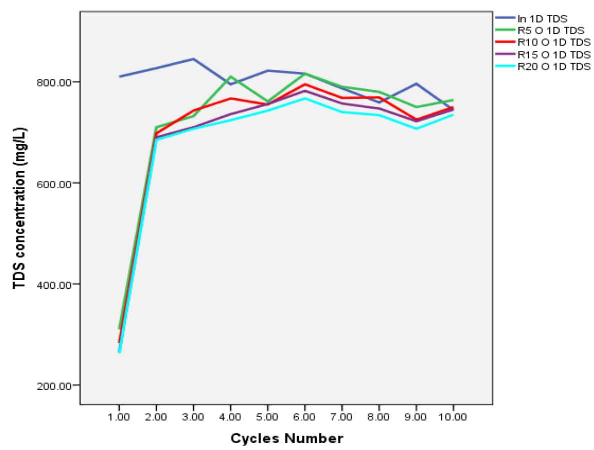
This is consistent with previous findings demonstrate that biodegradation is the dominating mechanism for the removal of ammonia[6–9].

Nitrite (NO_2^-) develops as an intermediate product of NH_3 and NO_3. Nitrite concentration in the experiment was rapidly oxidised to nitrate.

The bio reaction is generally coupled and proceeds rapidly to nitrate form. Therefore, nitrite levels at any given time are usually low. Increased concentration are usually an indication of a disturbance of microbiological



(a)



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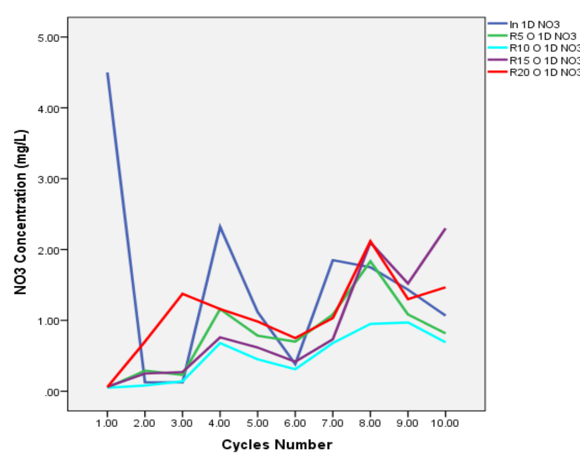
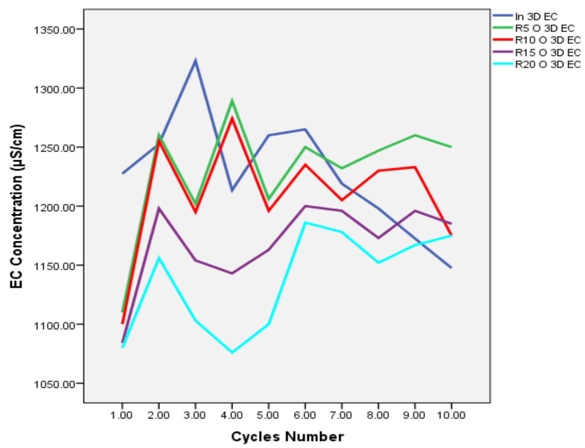


(c)



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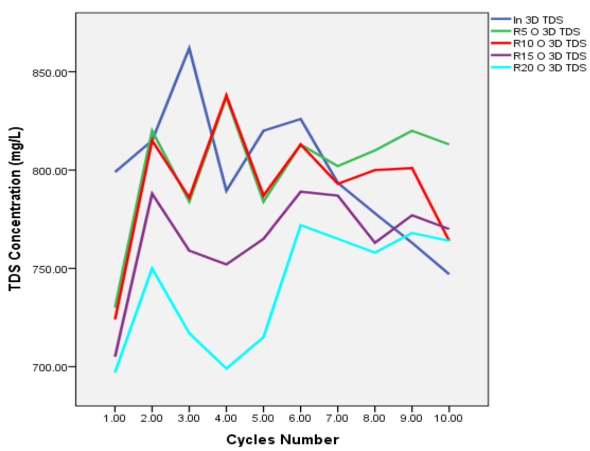

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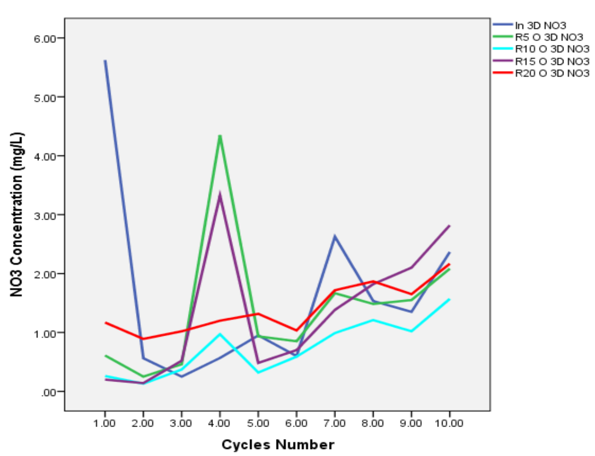

(f)

Figure 2. Real Wastewater (RWW) influent and effluent first wetting day samples **(a)** EC values, **(b)** TDS values, **(c)** NO_3 values; influent and effluent third wetting day samples **(d)** EC values **(e)** TDS values and **(f)** NO_3 concentration.

processes, of an overloaded in the system or insufficient aeration capacity[10]. A common hypothesis for ammonia removal is the two-step process of autotropic nitrification and adsorption of ammonia to the clay particle and organic fraction in the soil. The amount of adsorbance depends on the cation exchange capacity of the soil[11].

CEC is reported as a soil's ability to hold cations. It is an estimated value based on extracted cations from the soil analysis (Calcium Ca^{++}, Magnesiam Mg^{++}, Potassium K^{+}, Sodium Na^{+} and Hydrogen H^{+}). Since the clay and organic sites in the soil have a negative charge, the positively charged cations bond with these sites[12]. Therefore, CEC is closely related to soil texture. In Anna University soil from Table 4, the values of Ca, Mg, K, Na are 1550, 426, 48 and 161 mg/l respectively. Hence good adsorption of ammonia was present.

CEC is considered as an important factor in process of adsorption of ammonia which sticks to soil particle. In addition, the COD value of 117 mg/l found in the secondary effluent (from Table 4) which is the most critical parameter of the nitrification process because it directly influences the growth competition between microorganism population.

4. Conclusion

The results of this laboratory column study clearly demonstrate the positive effect of sand amendment on the nitrate reduction. Based on the results of this column study 10% sand amendment can be recommended for a pilot scale field study. However, several cycles of recharge should be performed before a field scale project is under taken in order to optimize the cycle duration (i.e flooding and drying periods). Further more, for any specific soil, laboratory studies should be performed for determining the optimum sand percentage for amendment.

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