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An Investigate The Removal Efficiency Of Waste Water Through Laboratory Scale Soil Aquifer Treatment For Sustainable Reuse

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Abstract: *Soil Aquifer Treatment (SAT) has emerged as a significant method for the reuse of treated wastewater, leveraging natural filtration and biochemical processes during the percolation of effluent through unsaturated and saturated zones of the soil. This study aimed to investigate the effectiveness of SAT in removing various pollutants from primary and secondary treated sewage using a laboratory-scale soil column setup. The research focused on understanding the treatment performance, contaminant removal efficiency, and implications for full-scale SAT pond simulation. To achieve this, two identical soil columns were constructed, each with a length of 1000 mm and an internal diameter of 450 mm. The effective soil depth available for treatment was 700 mm. The experimental setup included a feeding tank, feeder assembly, distributor lines, and a pump to ensure a constant hydraulic loading rate (HLR) throughout the study. Two different types of sewage—primary treated and secondary treated—were fed separately into the two soil columns over a period of 90 days, simulating continuous SAT operations under controlled conditions. Throughout the experimental duration, samples were collected at regular intervals and analyzed for key water quality parameters. These included Suspended Solids (SS), Total Phosphorus (TP), Specific Conductance (SC), Nitrate-Nitrogen (NO_3-N), Chemical Oxygen Demand (COD), and Total Hardness (TH). The study revealed substantial pollutant removal across both soil columns. The soil matrix demonstrated significant efficacy in filtering and biologically transforming contaminants, especially under saturated and unsaturated flow conditions that mimic natural aquifer recharge processes. Notably, the results showed high removal efficiencies for Total Phosphorus and Total Suspended Solids, with removal rates reaching approximately 83% and 65%, respectively. These findings underscore the potential of SAT systems to effectively polish treated effluents, thereby reducing nutrient loads and suspended particulates before aquifer recharge or reuse applications. Additionally, considerable reductions in COD, nitrate nitrogen, and total hardness were observed, indicating the broader applicability of SAT in improving the physicochemical quality of reclaimed water.*

Overall, the study provides critical insights into the removal mechanisms of pollutants within the soil matrix and establishes the feasibility of using soil column experiments as predictive tools for the performance of full-scale SAT systems. The comparative evaluation of primary and secondary treated sewage further emphasizes the advantages of using higher quality effluents for maximizing treatment efficiency and ensuring environmental safety. These findings can inform future design and optimization strategies for SAT-based wastewater reuse systems in arid and semi-arid regions.

Keywords: *Removal Efficiency, Soil Aquifer Treatment, Sewage, Waste Water, Water Reuse.*

1. INTRODUCTION

1.1 Background

The purpose of this research is to evaluate and the study of effects of applying different management practices in order to improve the soil surface infiltration, lowering the amount of pollutants transfer of treated municipal wastewater, such as TSS, COD, BOD_5, nitrate, and phosphate into shallow aquifers through time. In general, soil Aquifer treatment (SAT) refers to artificial recharge or infiltration of effluent through the vadose (unsaturated) zone to recharge the underlying aquifers. It is a managed Aquifer recharge (MAR) and treatment technology for multiple Contaminant removal that, together with different out their water and effluent treatment technologies, will produce effluent of acceptable quality for non-potable or indirect potable reuse (Idelovitch, 1978; Kanarek and Michail, 1996; Fox et al., 2001a, 2001 b; US EPA, 2012; Angelakis, and Gikas, 2014). As a result of poor wastewater quality due to inadequate treatment in vast majority of developing countries, application of primary effluent (PE) in SAT systems in these countries has the potential to augment existing water resources to meet the growing water demand and enhance water availability for different uses (Sharma et al., 2011). SAT is an environment-friendly and robust multi-contaminant removal system which is effective in removing pathogens, nitrogen, bulk organic matter and the majority of organic micro pollutants.(Saroj K. Sharma,2016)Municipal waste water infiltrate through soil from the bed of the pools and by passing through the unsaturated and saturated zones, physiochemical and biological reactions occur which can result in decreasing the amount of organic and inorganic matters, such as nitrogen, phosphate, TDS, and heavy metals. (P. Fox et.al,2006, M.B. Pescod, et.al,1992, A.N. Bdour, et. al, 2009). (R.C. Rice et.al,1984) conducted a study on using soil columns for pollutant removal in primary and secondary treated wastewater and came to a conclusion that removal efficiency of nitrogen, phosphate, bacteria, and virus for columns with primary treated effluent was considerably higher than other columns.

Managed artificial water recharge is wont to augment the formation with surface streams or with effluents. once effluents area unit recharged, it's then customary to decision the method Saturday since throughout effluent infiltration to the groundwater, the effluents area unit polished by processes like filtration, biological degradation, surface assimilation of serious metals and pollutants, natural action, and medical care, that occur within the unsaturated zone and to some extent conjointly within the formation. (Elkayam,2015) SAT is relatively inexpensive, except in areas of high land costs. The biggest cost is pumping or otherwise collecting water from aquifers. SAT systems are also robust and do not require highly skilled technical personnel for operation (Bouwer 1992).

Water recycling is becoming a necessity in the integrated water management system in order to solve these issues. The need for new water supplies is being driven by the extensive use of home effluents as drinkable water, an important reuse practise, improved water use efficiency, and increased water management. This formation recharging technique does not seem to be unusual in areas that experience water scarcity and/or drought. However, in cultures with a lack of governmental backing, a major water shortage, and public knowledge of and research on waste water reclamation. This may be influenced by the widespread perception that India is a water-rich nation with few water problems among its citizens. The reality is that water resources are under increasing pressure due to the abruptly increasing needs of growing business and population around the world, and changes in global weather patterns are projected to amplify these stressors. Investigating the viability of there foreil formation treatment for waste water reclamation in India is, thus, the right step towards resource management and creating resilience to global warming.

Although there are many SAT systems, the majority use the vadose zone and treated effluents with organic content. Only a small amount of research has been done so far to show how effectively and practically applying SAT may remediate primary treated waste water. Monitoring the removals of DOC, Total Phosphorus, Total suspended Solids, and COD in SAT helps this study answer these unresolved issues. These research showed that the SAT's working parameters affected the removal of a particular pollutant, however the study's target substances were few in number.

2. MATERIAL AND METHOD

2.1 Design and Operation of Soil Columns

Three experimental physical setups run for simulating artificial recharge ponds for study and determine the amount of contaminants which are maximum removal from the soil column study. Columns were made up of PVC Material and in cylindrical shape. The experimental setup consisted of Two Identical Experimental setup of 1000 mm length and 450 mm inner diameter, a feeding tank, a feeder assembly, distributor lines, and a pump. Experimental studies, effective soil depth was 700 mm. Flanges were fitted to the top and bottom of the column for attachment of the top and bottom end caps. The soil column was fed from top to bottom throughout the experiments to maintain fully saturated conditions. A variable speed peristaltic pump was used to deliver wastewater to the column through soft tygon tubing and a flow meter, which was fully opened and used for monitoring of flow to the column. The columns were packed with the soil sample, the bottom of each column was filled with a Coarse sand layer of 250 mm thickness in order to prevent clogging of the column outlet. And another 450 mm for fine sand layer provided above coarse sand layer as per Figure. The columns were operated downward conditions with 300 mm ponding depth in each setup. A pump was used to supply wastewater to the top feeder assembly, from which distributor lines served to column. The pump was connected to a storage tank of 100 L capacity. Preceding to the measurement, the system was adapting for one month in order to stabilize the rate of infiltration and have homogeneous conditions within soil columns. Performance of SAT was evaluated in terms of individual parameter. The overall performance of SAT under each treatment of layered soil was evaluated by combining all parameters.

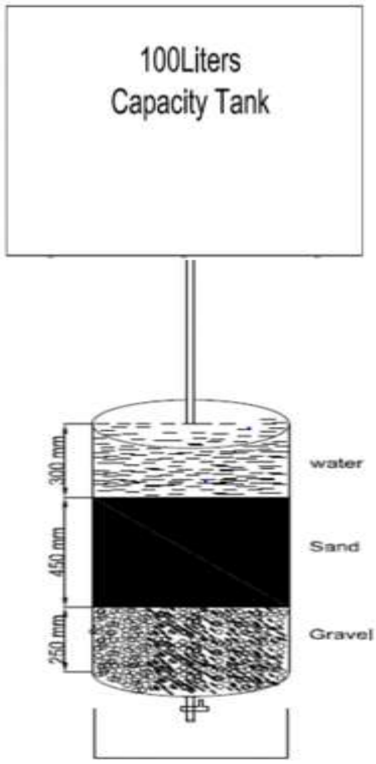

Figure No. 1 Experimental set up for soil column study

During operation of the columns, samples were collected from sampling ports and stored in plastic bottles that were sealed to prevent air entry. Both the columns were operated for 90 days. A variable speed peristaltic pump was used to deliver wastewater to the column through soft tygon tubing and a flow meter, which was fully opened and used for monitoring of flow to the column Each of the Experimental studies were started with new soil samples. An injection port consisting of a T-shaped glass tube with a septum stopper was provided in the influent line at the column entry for injection of a tracer during residence time studies. The SAT system was operated under gravity flow conditions with a constant head, which was maintained by the use of a top feeding tank in which provide a peristaltic pump and flexible PVC tubing with overflow weir. The column study operated at hydraulic retention times (HRT) 7 days under wetting and saturated conditions.

2.2 Soil Samples and Properties

Soil samples for column preparation were collected from a field near Tapi river. Some physical and chemical properties of the soil are measured. The soil samples were air-dried, crushed, and sieved using 2 mm and 1.18 mesh before packing the columns. The soil textural classification, physical and chemical characteristics of the soil are given Table 1.

Table: 1 Soil Sample characteristic

Sr. No	Test Name	Test Results	Test Method
1.	Fineness Module	4.03	IS:2386-1-1963, RA 2016
2.	Water Absorption	7.21	IS:2386-3-1963, RA 2016
3.	Specific Gravity	2.25	
4.	Density Kg/m^3	1470.0	
5.	Porosity, %	35.97	

2.2 Feed water

The Primary Treated sewage samples and secondary treated sewage were collected from the Sewage treatment plant, Surat. Sewage sample from an actual Sewage Treatment plant followed primary and secondary treatment, in Surat was used as the feed water for the experiments. The use of PE in SAT also provides an economic benefit since wastewater treatment to PE level does not require sizable investment compared to secondary effluent and tertiary levels and SAT does not require extensive use of energy and chemicals. However, PE is characterized with high ammonium, high sediment load, low nitrate and relatively high phosphorus concentrations (Abel et a., 2012; Ho et al., 1992). Water quality of feed water is shown in Table 1.

Table: 2 Water quality of feed water

Sr. No	Parameter	Unit	Result(Inlet) (primary treated sewage)	Result(Inlet) (Secondary treated sewage)
1.	PH	-	7.10	6.8
2.	BOD5	mg/l	ND	15
3.	Total Suspended solids	mg/l	30	22
4.	Chlorides	mg/l	650	620
5.	Total hardness	mg/l	753	731
6.	Nitrate nitrogen	mg/l	43.67	42.96
7.	Ammonical Nitrogen	mg/l	1.68	1.12
8.	Specific conductance	µmohs/cm	0811	0692
9.	Total Phosphorus	mg/l	0.40	0.40
10.	DOC	mg/l	3.7	2.6
11.	COD	mg/l	ND	48

Table 3: Water quality of treated water

Sr. No	Parameter	Unit	Result of primary treated Sewage(mg/l)	Result of Secondary treated Sewage(mg/l)
1.	PH	-	7.10	7.40
2.	BOD5	mg/l	ND	ND
3.	Total Suspended solids	mg/l	5	10
4.	Chlorides	mg/l	455	600
5.	Total hardness	mg/l	670	615
6.	Nitrate nitrogen	mg/l	24.49	23.08
7.	Ammonical Nitrogen	mg/l	0.84	0.56
8.	Specific conductance	µmohs/cm	2106	1753
9.	Total Phosphorus	mg/l	0.17	0.14
10.	DOC	mg/l	2.1	1.8
11.	COD	mg/l	ND	08

2.3 Wastewater analysis

The influent and Treated water of the various Sewage treatment were monitored over 3 months. All samples were analysed for total suspended solids (TSS) measured according to Standard Methods of (IS: 3025 (Part 17)-1984 Reaffirmed 2012). Conductivity and pH were measured using a PH Meter. conductivity meter and turbidity (NTU) were measured using a turbidity meter. Nitrate Nitrogen were analysed by APHA 23rd .4500 NO_3 B (4-127), 2017,

Total hardness were analysed by IS: 3025(Part 21)-2009 For each train, influent and effluent chemical oxygen demand (COD) measured with IS:3025(Part 58)-1984 Reaffirmed 2012. Total Phosphorus were analysed by APHA 23rd Ed. 4500 PC (4-161),2017 and DOC were analysed by IS: 3025 methods. Specific conductance were analysed by IS: 3025(Part 14)-2013 Reaffirmed 2017. Chlorides were analysed by IS: 3025(Part 32)-1988 Reaffirmed 2003.

3. RESULTS AND DISCUSSION

Effect of pre-treatment options on the columns' performances is mentioned below. A higher removal of about and 100%,83% and 65% for BOD, Total phosphorus and Total suspended solids were observed in all three columns. Comparisons of percentage removal through treatment is mentioned in Figure 2.

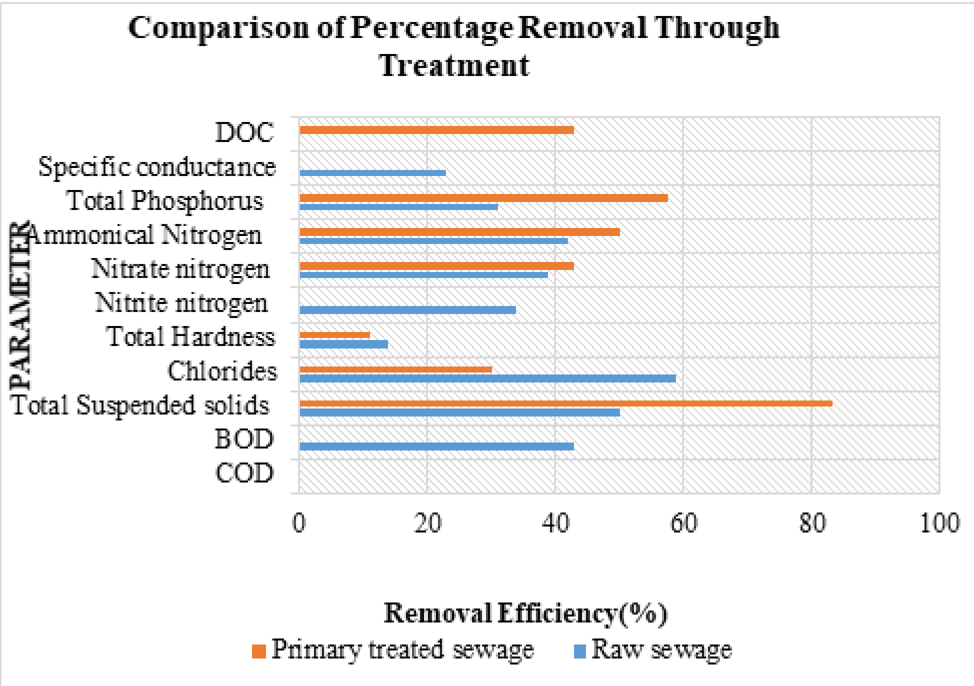

Figure 2. Comparisons of percentage removal through various Treatment

3.1 Effect of Different Parameter on Removal Efficiency

Electric conductivity and pH: pH and EC were measured as additional information for a better understanding of the bulk organic matter and organic micro pollutants removal.

Phosphate: phosphate removal in this study indicates that phosphate removal is more dependent upon the characteristics of the soil column than on the depth of unsaturated zone and that the composition of the column soil used in this study is not conducive to its removal. Therefore, differences in phosphorus removal efficiency is likely attributed to differences soil type and travel distance.

NH4-N removal: NH4-N removal, and that adsorbed ammonia breakthrough is not expected. Also assuming that under normal operating conditions ammonia removal during SAT increases with travel distance and residence/travel time.

Effluent organic matter (EfOM) It consisting of natural organic matter (NOM) derived from the drinking water source(s) and dominated by humic substances, plus soluble microbial products (SMPs) derived from biological (secondary) wastewater treatment reflecting a microbial.

4. CONCLUSION

Phosphate removal during this study indicates that phosphate removal is dependent upon the characteristics of the soil column than on the depth of unsaturated zone which the composition of the column and soil utilized. Therefore, variations in phosphorus removal potency are probably going attributed to variations soil condition and travel distance. Removal of Nitrate Nitrogen which absorbable ammonia break through is not expected. Additionally, presumption that below traditional operative conditions ammonia removal throughout weekday will increase with travel distance and residence/travel time. No significant difference in removal efficiency of ammonical nitrogen could be observed with columns SAT systems could be integrated with other water and wastewater management systems to provide effective treatment. When adequate depth (travel time) and appropriate process conditions (Head space) are provided, SAT is equally effective in treatment After Primary Treated sewage and Secondary Treated Sewage. The pre-treatment and post treatment are required to full fill wastewater effluent quality and reuse regulations.

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