Assessing the Wastewater Pollutants Retaining for a Soil Aquifer Treatment using Batch Column Experiments

V. R. Raji [1*], S. Packialakshmi [1]

[1] Department of Civil Engineering, School of Building and Environment, Sathyabama Institute of Science and Technology, Chennai, India.

Abstract

In this study, the Secondary Treated Waste-Water (STWW) to infiltrate through the soil matrix, hence eliminating the contaminants in the effluent. For this study, three types of soil, such as loamy sand, fine sand, and clayey soil, were subjected to two cycles of wetting and drying to assess the type of soil that removes the maximum contaminants under which cycle. At diverse locations, soil samples were collected and examined to determine the soil types. Likewise, STWW was collected from Chennai Metropolitan Water Supply and Sewerage Board (CMWSSB) and Perungudi Sewage Treatment Plant (PSTP) to illustrate the quality of water before Soil Aquifer Treatment (SAT). About 1.5 m in height and 8 mm in diameter of fabricated acrylic material columns are used for the soil aquifer treatment efficiency studies. Water quality parameters, namely pH, TDS, and turbidity, were monitored throughout the study. All the organic compounds present in water were reduced to a higher level only in the fine sand in the one-day wetting/drying cycle. pH was reduced from 8.55 to 7.5, TDS was reduced from 1580 mg/l to 850 mg/l, and Turbidity was reduced from 7.24 to 4.04 NTU. This proposed method is to minimize the amount of water pollution from the environment. It is an effective way to manage aquifer recharge (MAR). SAT is the easiest method, aquifer and/or soil-based treatment systems improve the effluent quality of wastewater by removing the trace elements in the aquifer during the recharge of groundwater. It is likewise attractive for technologically advanced as well as emerging countries, and it is supple enough to allow adaptation to home-grown requirements by uniting it with predictable natural or bringing about water and technologies of wastewater treatment.

Keywords: Secondary Treated Water; Sewage Water; Water Quality; Treatment; Soil Aquifer.

1. Introduction

Groundwater is the main source of water supply in both the regions, namely arid and semi-arid [1]. Various countries are suffering from the water scarcity problem due to the extreme groundwater withdrawal due to human activities. Recently, the water tables in some of the foremost grain manufacturing areas in the universe have hastily become exhausted, which not only sources a risk of geological calamities, but it also leads to variation in the progress of different regions [2]. Hence, the wastewater treatment progressions have made for the improvisation and the pollutants' degradation by cost-effective resources dangerous to certifying safe wastewater release and its reuse [3, 4].

The SAT method may help to overcome the scarcity problem of water in many countries, and it is also used to remove all the major and micro-pollutants in water. It is an effective to manage aquifer recharge [5, 6]. Normally, SAT refers to an artificial recharge of water or infiltration of the effluent of wastewater through the unsaturated zone (Vadose) to revitalize the aquifers. This is an attractive technique and removes multiple contaminants at the same time [7, 8]. Soil Aquifer treatment technique can be useful to supplement water supply in both regions (arid and semi-arid) of the ecosphere where the resources of groundwater have over exploited. It is very attractive for developing countries and

also developed countries in the world as it is healthy, removes numerous contaminants, eco-friendly, and uses of chemicals are minimized [9]. Moreover, this method provides an innovative conducts to help with wastewater reclamation in a safe way. Subsequent to predictable treatment for reuse of waste water, this method (SAT) is an eco-friendly based solution for the retrieval of secondary treated wastewater or tertiary treated wastewater [10–12]. SAT shows that effluent organic matter is changed to closely look like background natural organic matter, and some studies have shown that the removal of several chemicals which are intractable to SAT, although quickening the rate and, possibly, the overall amount of total organic carbon elimination in this procedure itself [13–15].

Numerous studies examined the efficiency removal of organic matter in water and CECs (chemicals of emerging concern) during SAT (list those studies as Table for concise presentation with parameters considered and the efficiency). Still, existing knowledge is inadequate to appropriately reveal the conversion dynamics of chemical emerging conversion conditions during the initial phase of infiltration [16, 17]. In order to reduce the contamination, field scale method experiments have been carried out, but this method is costly and essential to resist environmental factors. Hence, column studies were conducted because of this easiness and cost effective, has been carried out in a choice of settings, with a fixed temperature [18-20]. Mostly, column studies were conducted and compared with different selections of sites and operational factors separately, namely soil type or depth of ponding, but little work has been achieved to scientifically test a choice of factors on congestion of porous media [21, 22]. This method is quite useful for water management systems, mainly in semi-arid regions. This is a very simple method, low cost, and reduces environmental problems [23–25].

In this paper, a detailed laboratory column experiment that examines clogging and permeation rates as exaggerated by dissimilar soil types, pre-treatment levels, and depths is presented. The main objective is to investigate the vadose zone capability in transforming the secondary treated wastewater and to analyze the soil aquifer treatment parameters that are responsible for reducing the constituents of the wastewater.

2. Study area and Methodology

2.1. Details of Study Area

The experimental set up was carried out in Civil Engineering Department, Sathyabama Institute of science and technology, Chennai during Feb-March 2020. The geographic location of the study area is 12° 52′ 23″ N, 80° 13′ 19″ E. The study area was shown in Figure 1.
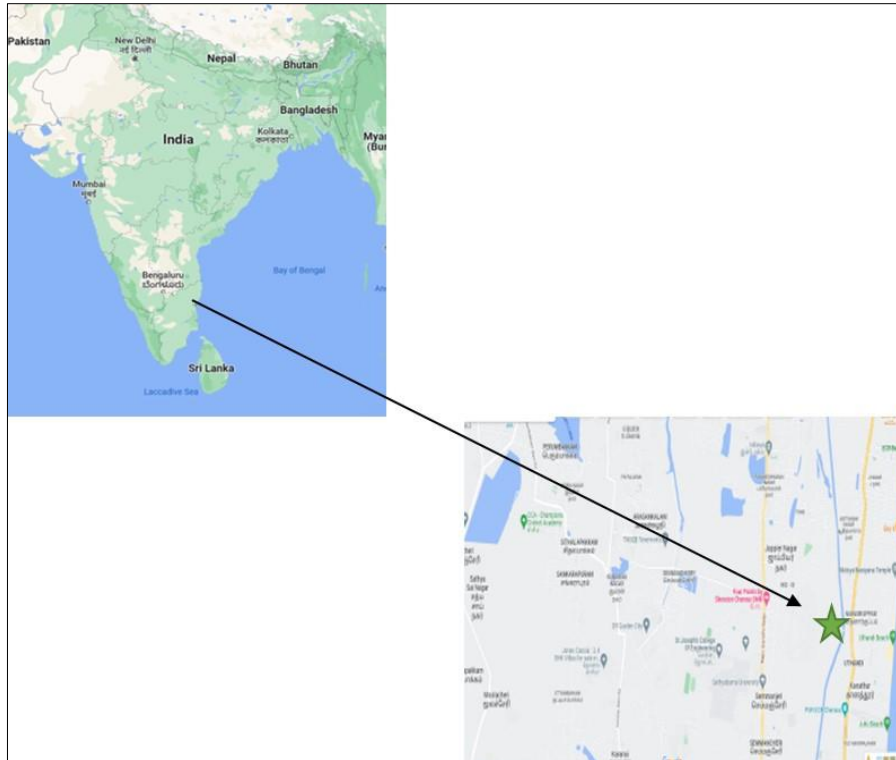

Figure 1. Study area map

2.2. Study Area Map

Secondary treated wastewater (STWW) was collected from Chennai Metropolitan Water Supply and Sewerage Board (CMWSSB) and Perungudi Sewage Treatment Plant (PSTP). Wastewater quality parameters namely pH, Turbidity, TDS, Nitrate, Nitrite, BOD5 and COD was tested. Soil samples were collected nearby area of CMWSSB and

PSTP. Then the soil characteristics were identified by physical analysis (International Pipette Method) method. Soil chemical properties such as pH, Salinity (EC), Cation Exchange Capacity (CEC), Organic matter were identified by testing. Column set up for soil aquifer treatment was designed and fabricated. Testing the effluents (liquid samples) from the outlet of the column for the parameters such as pH, Turbidity, TDS, Nitrate, Nitrite, NH3-N, BOD5 and COD. Analytical measurements were carried out is to investigate the vadose zone capability in transforming the STWW and to analyse the soil aquifer treatment parameters that are responsible to reduce the constituents of the wastewater. The detailed methodology was shown in Figure 2.
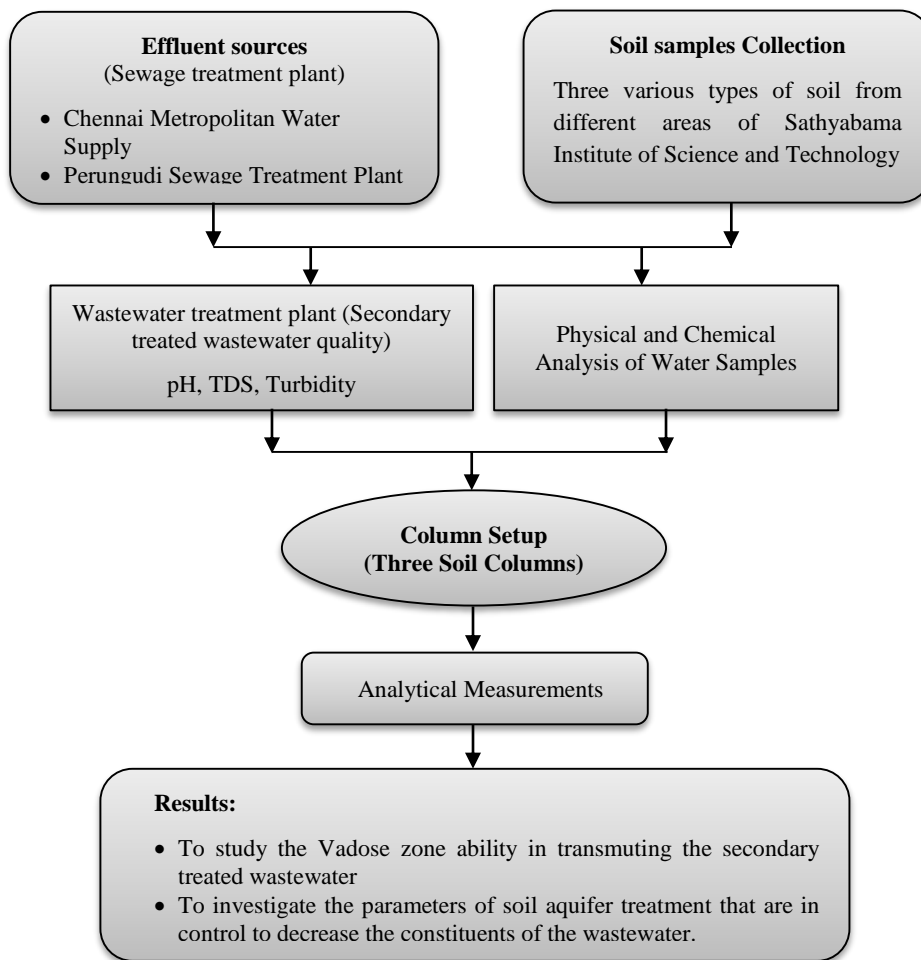

Figure 2. Methodology for Soil Column study

2.3. Soil Collection and Analysis

The soil samples were collected from Sathyabama campus, Chennai, at 10 locations. Its depth ranged between 0.0 and 1 m (referred to as top soil). These places are Block 12, Field lab, Near Central Library, Bio Department, Research Centre, Front Side, Back Side of Architectural Department, Admin Block, Back Side, Near Ladies' Hostel, Boys' Hostel, and near Jeppiar sewage treatment plant (JSTP). Then the soil was classified based on the percentage of loamy sand, fine sand, and clayey sand. Soil classification based on the method of the Indian Standard System of Soil classification. The percentage of soil analysis is shown in Table 1. The soil, which was classified as loamy sand, fine sand, and clayey soil, was taken for the experiment.

Table 1. Soil sampling locations

Location	Loamy Sand	Fine sand	Clayey sand
Block 12	38.50	52.60	10.75
Field lab	41.10	44.08	25.15
Near Central library	43. 67	45.95	31.00
Bio department	45.66	47.50	16.78
Research Centre front side	50.90	48.52	35.55
Back side of architectural department	40.11	39.20	26.01
Admin block back side	45.14	52.54	27.63
Near Ladies hostel	25.40	32.24	46.32
Boys hostel	52.07	50.05	48.36
JSTP	36.05	44.56	50.66

2.4. Collection and Analysis of STWW

The STWW was collected from Sathyabama Institute of science and technology and Perungudi sewage treatment plant (PSTP). The secondary treated wastewater was analysed to find its characteristics. It was taken as an influent for the soil column experiment. The characteristics were shown in Table 2.

Table 2. Characteristics of Influent before SAT

Parameters	Sathyabama (STP)	Perungudi (STP)
pH	9.510	8.580
Turbidity	5.18 NTU	4.05NTU
TDS	731 mg/l	1250 mg/l
Nitrate	3.034 mg/l	1.568 mg/l
Nitrite	1.859 mg/l	0.998 mg/l

2.5. Batch Study

The batch studies were needed before doing the column study, which was to investigate the capability of the vadose zone to transform the STWW and to examine the SAT parameters that are responsible for reducing the elements of the wastewater. The batch study consists of two methods, namely before and after soil filling up. Before the soil filled up, the bucket height taken was 20 cm. A number of holes were made at the bottom of the bucket. Then, by using the fine mesh, all the holes were covered. The main use of mesh was to collect water without any soil particles. By using gravel and pebbles, the mesh was filled on the top up to 2.5 cm. After the soil had filled up, the soil was sieved properly through a 2 mm sieve before placing the pebbles and gravel. Then, over the gravel and pebbles, the soil, which has been properly sieved, was placed up to a depth of 12 cm. The last step of the batch study is that after pouring the water, the depth of ponding was kept at a depth of 5 cm, and as free board, 2 cm was provided. The STWW collected from Sathyabama Jeppiar STP was poured to a 5 cm depth for batch study. While doing the experiment, keep the soil column fully saturated. After the wastewater was pouring over the soil in the column, the water penetrated the soil, and the water was collected at the bucket bottom, which is called effluent. There were no soil particles found in the sample and its characteristics were analysed for the influent characteristic comparison. Initially, in column operations, a one-day wetting followed by a one-day drying process was started. Soil was taken out of the column during drying and it was spread on the earth which is exposed to the air. Thus, the soil gets enhanced with O2 and micro-organisms from the wildlife. The exposed soil was kept in the column during drying and then allowed them to STWW. The batch setup is shown in Figure 3.

**Figure 3. Fabricated Soil Columns**

3. Results and Discussion

3.1. Physical and Chemical Parameters

The study was concerned with monitoring the effect of SAT on eliminating physical, chemical parameter pollutants from the wastewater. It was decided that at the beginning, most parameters that characterize wastewater quality was monitored and then the most significant parameters in assessing the degree of quality improvement were selected for monitoring throughout the study. To verify the reliability of the results obtained, samples from the outflow were analysed

for all parameters [19, 22]. For Hydrogen Ion Concentration (pH), the column processes were started with one day wetting process trailed by one day drying process. Initially pH of STWW (influent) was 8.55. pH values for all the three different soil types after the SAT was shown in Table 3. pH average (influent) was fewer than the water outflow. This value shows an overall rise in the pH values when comparing with the influent. This may be accredited to manufacture of CO_2 in organics biodegradation. pH variations in soil columns after transient the STWW for various cycles [23] were shown in Figure 4. This indicates that the pH value was reduced in fine sand under two days wetting and two days drying cycle which was clearly detected in the Figure 5. In this study, turbidity was presence due to the suspended solids. At first STWW turbidity level (before SAT) was 7.24 NTU. The values of turbidity for three types of soil sample after Soil Aquifer Treatment were shown in Table 4. From the table the loamy sand soil has exposed better removal efficiency of turbidity under cycle 1 were shown in Figures 6 and 7. At first TDS [24, 25] level in STWW (before SAT) was 1580 mg/l. At the primary stage, the particles presence in the soil may pointedly capture the TDS of the effluent [18, 23]. The values and efficiency removal of TDS for three types of soil taken after SAT were shown in Table 5. From the Table, the fine sand has revealed healthier TDS removal efficiency in two days wetting/drying cycle and the variation of TDS in soil columns later transient the STWW were shown in Figures 8 and 9. Based on these results, this method has proven to be an efficient accepted barrier in take away contaminants and refining the water quality more for renewing ground water recharge and waste water reuse purposes.

Table 3. Hydrogen Ion concentration (pH) Values after SAT

pH (before SAT) = 8.55			
Date	**Loamy Sand**	**Fine sand**	**Clayey sand**
One day wetting / one day drying			
1/02/2020	8.5	7.7	8.4
3/02/2020	8.4	7.8	8.3
5/02/2020	8.4	8.4	8.2
07/02/2020	8.2	8.0	8.1
09/02/2020	8.3	8.3	8.2
11/02/2020	8.4	8.0	8.4
13/02/2020	8.5	7.4	8.3
15/02/2020	8.6	7.9	8.4
Two days wetting / two days drying			
19/02/2010	8.5	7.7	8.3
20/02/2010	8.4	7.5	8.3
23/02/2010	8.4	7.5	8.3
24/02/2010	8.3	7.6	8.4
27/02/2010	8.3	7.5	8.2
28/02/2010	8.3	7.5	8.0
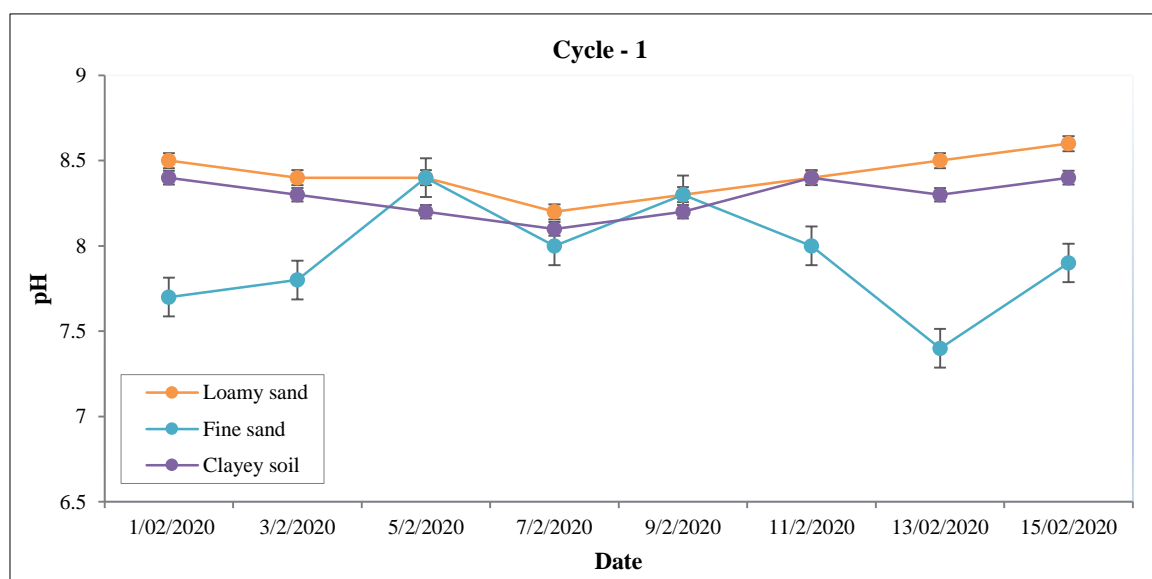
Figure 4. pH variations in soil columns in one day wetting /drying cycle
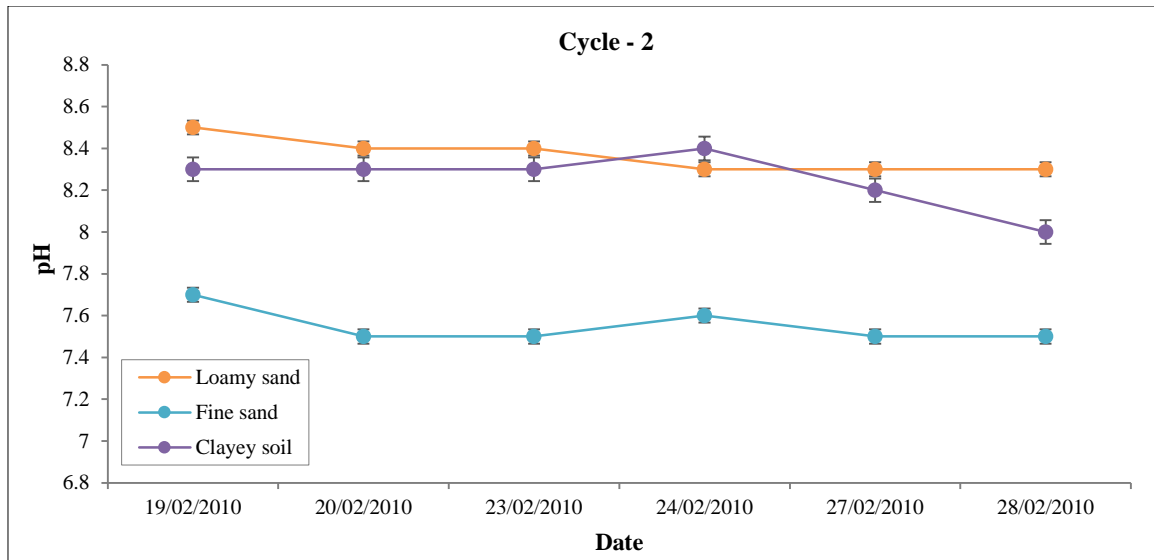
Figure 5. pH variations in soil columns in two-day wetting/drying cycle

Table 4. Values of Turbidity after SAT

| Turbidity (before SAT) = 7.24 NTU			
Date	**Loamy sand (NTU)**	**Fine sand (NTU)**	**Clayey soil (NTU)**
One day wetting/ one day drying			
1/02/2020	3.84	6.32	4.82
3/02/2020	3.78	6.24	4.58
5/02/2020	3.68	6.88	4.56
07/02/2020	3.64	6.21	4.85
09/02/2020	3.50	6.16	4.27
11/02/2020	3.44	6.15	4.68
13/02/2020	3.39	6.12	4.53
15/02/2020	3.26	6.16	4.55
Two days wetting / two days drying			
19/02/2020	2.75	4.55	3.22
20/02/2020	2.78	4.39	3.17
23/02/2020	2.69	4.41	3.16
24/02/2020	2.66	4.30	3.05
27/02/2020	2.58	4.19	3.12
28/02/2020	2.50	4.04	2.99
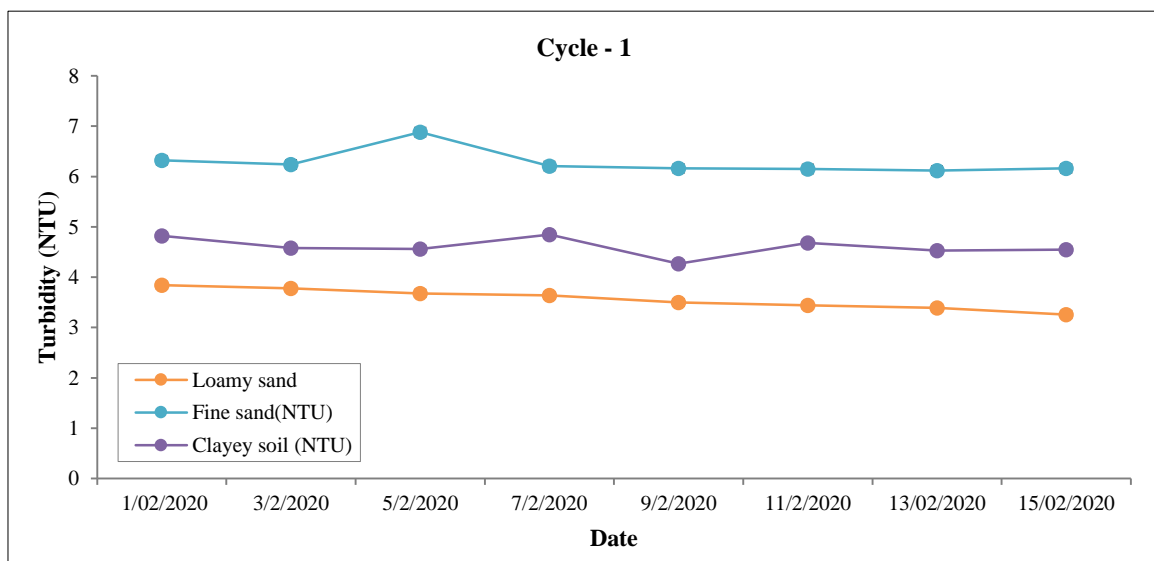
Figure 6. Turbidity variations in soil columns in one day wetting /drying cycle
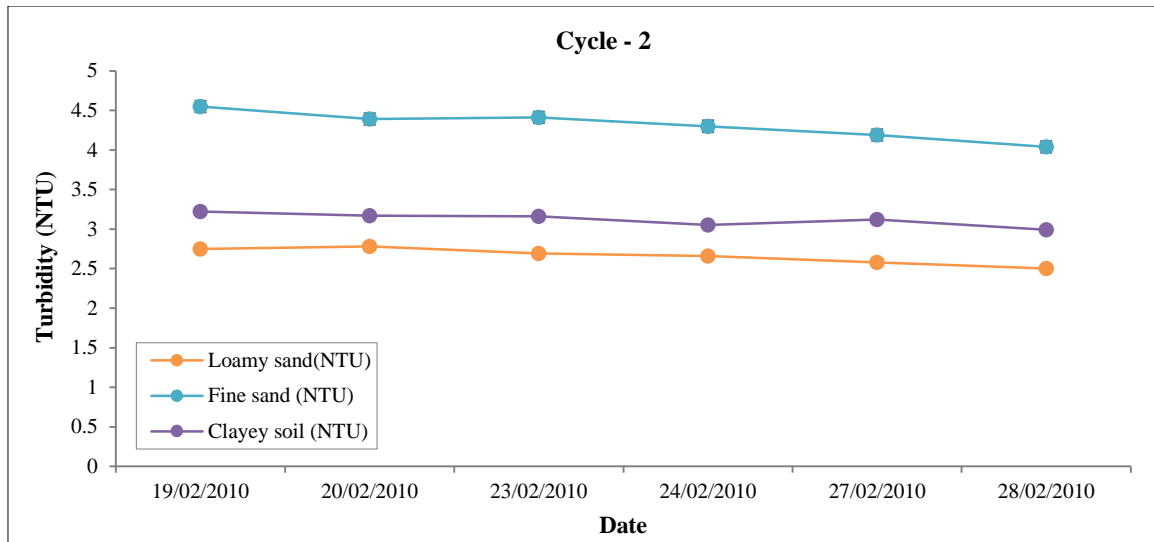
Figure 7. Turbidity variations in soil columns in two days wetting /drying cycle

Table 5. TDS value after SAT

| TDS (before SAT) = 1580mg/l			
Date	**Loamy Sand (mg/l)**	**Fine sand (mg/l)**	**Clayey soil (mg/l)**
One day wetting/ one day drying			
1/02/2020	1520	1360	1470
3/02/2020	1515	1350	1460
5/02/2020	1510	1240	1460
7/02/2020	1510	1240	1350
9/02/2020	1500	1210	1340
11/02/2020	1480	1200	1350
13/02/2020	1465	1110	1330
15/02/2020	1450	950	1330
Two days wetting / two days drying			
19/02/2020	1450	950	1290
20/02/2020	1380	940	1210
23/02/2020	1360	910	1210
24/02/2020	1310	880	1150
27/02/2020	1290	880	1040
28/02/2020	1280	850	1030
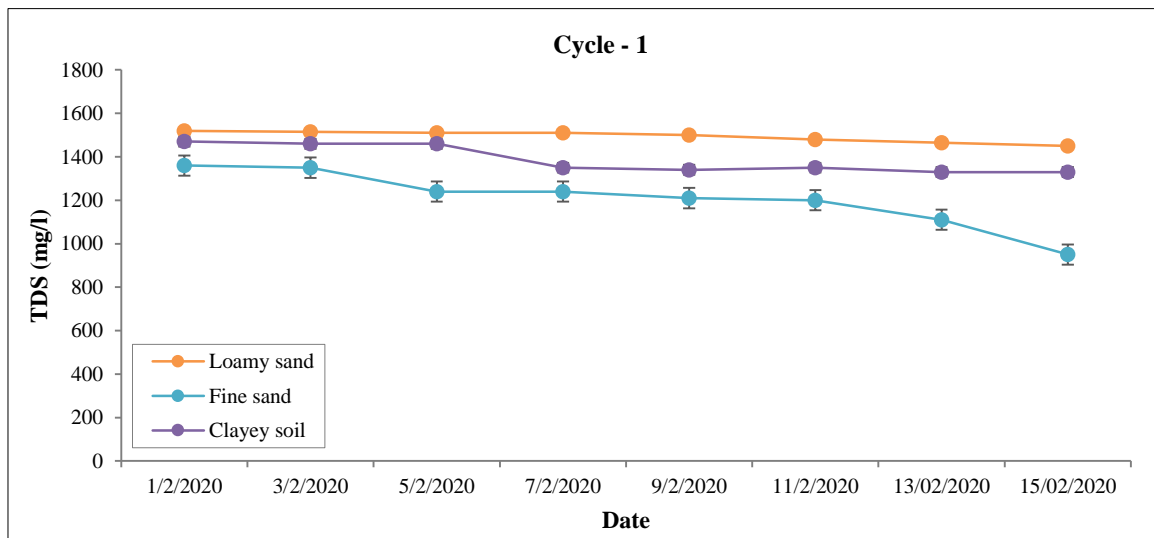
Figure 8. TDS variations in soil columns in one day wetting/drying cycle
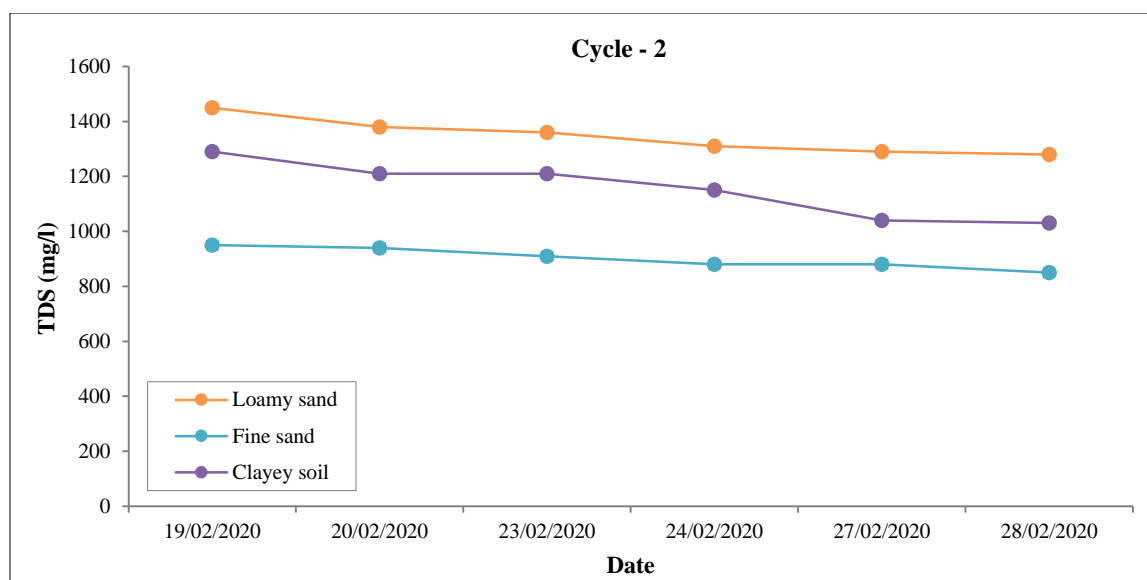
Figure 9. TDS variations in soil columns in two days wetting/drying cycle

4. Conclusion

The maximum reduction in organic compounds occurred on one day of wetting followed by a one-day drying cycle. Deposition of organic and inorganic solids at the surface, developing into a clogging mat and leading to outer blockage of soil pores (surface filtration). Deposition at the grain surface in the pores leads to inner blockage of soil pores (volume filtration). The organic compounds were reduced to a maximum level only by the fine sand. Therefore, fine sand was suitable for reducing the organic compounds. More quantities of samples (after SAT) were collected during one day of wetting followed by one day of drying. The quality was also increased after the drying period as the soil got enriched with oxygen and also enriched with microbes. Purification was taking place after the drying period. The parameters were permissible according to Indian standards for recharging groundwater. The quality of the samples (after SAT) was good on one day of wetting and one day of drying. But the work was cumbersome in a one-day wetting and one-day drying cycle when compared to other cycles. In future work Nitrate, Nitrite, BOD5 and COD will be analysed by various cycles, and analytical measurements and comparison of Influent and Effluent parameters will be carried out. Biological contaminants such as coliforms and pathogens should be analysed as they are a major concern whenever using treated wastewater for reuse purposes. The depth of soil profiles can be used to intricate on how the varying operating environments such as discharge or water quality will affect them. In addition, the impact of clogging on contaminant removal may be studied in the future.

5. Declarations

5.1. Author Contributions

Conceptualization, V.R.R. and P.S.; methodology, V.R.R.; writing—original draft preparation, V.R.R.; writing—review and editing, V.R.R.; supervision, P.S. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available in the article.

5.3. Funding

5.4. Acknowledgements

5.5. Conflicts of Interest

The authors declare no conflict of interest.

6. References

[1] Shawaqfah, M., Almomani, F., & Al-Rousan, T. (2021). Potential use of treated wastewater as groundwater recharge using GIS techniques and modeling tools in dhuleil-halabat well-field/jordan. Water (Switzerland), 13(11), 1581. doi:10.3390/w13111581.

[2] Yu, H., Li, J., Liu, J., He, S., Qin, K., Xia, X., Xue, C., Zhao, Q., & Wei, L. (2022). HYDRUS-2D simulations of typical pollutant migration in a soil aquifer system in the Zibo-Weifang funnel area of China. Journal of Cleaner Production, 345,131099. doi:10.1016/j.jclepro.2022.131099.

[3] Jadeja, N. B., Banerji, T., Kapley, A., & Kumar, R. (2022). Water pollution in India – Current scenario. Water Security, 16, 100119. doi:10.1016/j.wasec.2022.100119.

[4] Gharoon, N., & Pagilla, K. R. (2021). Critical review of effluent dissolved organic nitrogen removal by soil/aquifer-based treatment systems. Chemosphere, 269, 129406. doi:10.1016/j.chemosphere.2020.129406.

[5] Sharma, S. K., & Kennedy, M. D. (2017). Soil aquifer treatment for wastewater treatment and reuse. International Biodeterioration and Biodegradation, 119, 671–677. doi:10.1016/j.ibiod.2016.09.013.

[6] Hellauer, K., Uhl, J., Lucio, M., Schmitt-Kopplin, P., Wibberg, D., Hübner, U., & Drewes, J. E. (2018). Microbiome-Triggered Transformations of Trace Organic Chemicals in the Presence of Effluent Organic Matter in Managed Aquifer Recharge (MAR) Systems. Environmental Science and Technology, 52(24), 14342–14351. doi:10.1021/acs.est.8b04559.

[7] Besançon, A., Pidou, M., Jeffrey, P., Jefferson, B., & Le Corre, K. S. (2017). Impact of pre-treatment technologies on soil aquifer treatment. Journal of Water Reuse and Desalination, 7(1), 1–10. doi:10.2166/wrd.2016.163.

[8] Sendrós, A., Urruela, A., Himi, M., Alonso, C., Lovera, R., Tapias, J. C., Rivero, L., Garcia-Artigas, R., & Casas, A. (2021). Characterization of a shallow coastal aquifer in the framework of a subsurface storage and soil aquifer treatment project using electrical resistivity tomography (Port de la selva, spain). Applied Sciences (Switzerland), 11(6). doi:10.3390/app11062448.

[9] Brooks, J., Weisbrod, N., & Bar-Zeev, E. (2020). Revisiting soil aquifer treatment: Improving biodegradation and filtration efficiency using a highly porous material. Water (Switzerland), 12(12). doi:10.3390/w12123593.

[10] Morrison, C. M., Betancourt, W. Q., Quintanar, D. R., Lopez, G. U., Pepper, I. L., & Gerba, C. P. (2020). Potential indicators of virus transport and removal during soil aquifer treatment of treated wastewater effluent. Water Research, 177. doi:10.1016/j.watres.2020.115812.

[11] Sallwey, J., Jurado, A., Barquero, F., & Fahl, J. (2020). Enhanced removal of contaminants of emerging concern through hydraulic adjustments in soil aquifer treatment. Water (Switzerland), 12(9). doi:10.3390/w12092627.

[12] Parimalarenganayaki, S. (2021). Managed Aquifer Recharge in the Gulf Countries: A Review and Selection Criteria. Arabian Journal for Science and Engineering, 46(1), 1–15. doi:10.1007/s13369-020-05060-x.

[13] Zucker, I., Mamane, H., Cikurel, H., Jekel, M., Hübner, U., & Avisar, D. (2015). A hybrid process of biofiltration of secondary effluent followed by ozonation and short soil aquifer treatment for water reuse. Water Research, 84, 315–322. doi:10.1016/j.watres.2015.07.034.

[14] Trussell, S., Tiwari, S., Gerringer, F., Trussell, R., Drewes, J., Nellor, M., & Johnson, S. (2015). Enhancing the soil aquifer treatment process for potable reuse. WateReuse Research Foundation. Project, 12-12.

[15] Amin, H. M., Gad, A. A. M., El-Rawy, M., Abdelghany, U. A., & Sadeek, R. A. (2021). Assessment of wastewater contaminant concentration through the vadose zone in a soil aquifer treatment system. Applied Ecology and Environmental Research, 19(3), 2385–2403. doi:10.15666/aeer/1903_23852403.

[16] Regnery, J., Barringer, J., Wing, A. D., Hoppe-Jones, C., Teerlink, J., & Drewes, J. E. (2015). Start-up performance of a full-scale riverbank filtration site regarding removal of DOC, nutrients, and trace organic chemicals. Chemosphere, 127, 136–142. doi:10.1016/j.chemosphere.2014.12.076.

[17] Ajjur, S. B., & Baalousha, H. M. (2021). A review on implementing managed aquifer recharge in the Middle East and North Africa region: methods, progress and challenges. Water International, 46(4), 578–604. doi:10.1080/02508060.2021.1889192.

[18] Alrwashdeh, S. S., Ammari, H., Madanat, M. A., & Al-Falahat, A. A. M. (2022). The effect of heat exchanger design on heat transfer rate and temperature distribution. Emerging Science Journal, 6(1), 128-137. doi:10.28991/esj-2022-06-01-010.

[19] Gharoon, N., & Pagilla, K. R. (2021). Critical review of effluent dissolved organic nitrogen removal by soil/aquifer-based treatment systems. Chemosphere, 269. doi:10.1016/j.chemosphere.2020.129406.

[20] Priyadharshini, B., Nandini, Raji, V. R., & Kavisri, M. (2015). Estimation of aquifer parameter by well dilution technique. International Journal of Applied Engineering Research, 10(5), 11777–11786.

[21] Wei, L., Wang, K., Noguera, D. R., Jiang, J., Oyserman, B., Zhao, N., Zhao, Q., & Cui, F. (2016). Transformation and speciation of typical heavy metals in soil aquifer treatment system during long time recharging with secondary effluent: Depth distribution and combination. Chemosphere, 165, 100–109. doi:10.1016/j.chemosphere.2016.09.027.

[22] Zhang, X., Yang, Y. S., Lu, Y., Wen, Y. J., Li, P. P., & Zhang, G. (2018). Bioaugmented soil aquifer treatment for P-nitrophenol removal in wastewater unique for cold regions. Water research, 144, 616-627. doi:10.1016/j.watres.2018.08.004.

[23] Martins, T., Leitão, T. E., & Carvalho, M. R. (2017). Assessment of Wastewater Contaminants Retention for a Soil-aquifer Treatment System Using Soil-column Experiments. Procedia Earth and Planetary Science, 17, 332–335. doi:10.1016/j.proeps.2016.12.084.

[24] Tsangaratos, P., Kallioras, A., Pizpikis, T., Vasileiou, E., Ilia, I., & Pliakas, F. (2017). Multi-criteria Decision Support System (DSS) for optimal locations of Soil Aquifer Treatment (SAT) facilities. Science of the Total Environment, 603–604, 472–486. doi:10.1016/j.scitotenv.2017.05.238.

[25] Sopilniak, A., Elkayam, R., Rossin, A. V., & Lev, O. (2018). Emerging organic pollutants in the vadose zone of a soil aquifer treatment system: Pore water extraction using positive displacement. Chemosphere, 190, 383–392. doi:10.1016/j.chemosphere.2017.10.010.