JOURNAL OF
ENVIRONMENTAL HYDROLOGY

The Electronic Journal of the International Association for Environmental Hydrology
On the World Wide Web at http://www.hydroweb.com

VOLUME 20 2012

WATER QUALITY PERFORMANCE OF SOIL AQUIFER TREATMENT (SAT) USING MUNICIPAL TREATED WASTEWATER OF CHENNAI CITY, INDIA

K. Deepa
M. Krishnaveni

Center for Water Resources
Anna University, Chennai, India

Treated municipal wastewater is used as an input water source for recharge of groundwater using the Soil Aquifer Treatment (SAT) method. The aim of this study is to assess the treated waste water quality performance before and after SAT by using short term soil column development for aquifer recharge applications. The water quality parameters considered during, before, and after SAT are Biological Oxygen Demand, pH, Total Suspended Solids (TSS), Nitrite and Nitrate. The quality of effluents is improved after passage through the soil layers in the soil columns. The final effluent quality from the soil columns of the different sites show different performance percentages. The infiltration rate varied in all soil columns due to development of clogging layer at the top of the soils.

INTRODUCTION

Fresh water shortage is becoming an increasingly acute problem facing many nations in the world (Bielorai et al. 1984). The quality of the water of a recharged aquifer is a function of the quality of the recharge water, the recharge method used, the physical characteristics of the vadose zone and the aquifer layers, the water residence time, the amount of blending with other sources. Where soil and groundwater conditions are favourable, a high degree of upgrading can be achieved by allowing sewage effluent to infiltrate into the soil and move down to the groundwater. The unsaturated zone then acts as a natural filter and can remove essentially all suspended solids, biodegradable materials, bacteria, viruses and other microorganisms. Significant reductions in nitrogen, phosphorus, and heavy metals concentrations can also be achieved. This gives an advantage to artificial recharge with wastewater over the direct application method. This process is known as soil-aquifer treatment (Fadlelmawla, 2008*)*. In other words Soil Aquifer Treatment (SAT) is defined as a treatment and storage system that allows for augmentation of potable water supplies with recycled water (indirect potable reuse). It includes three components; 1) infiltration through a biologically active interface less than three feet in depth, 2) percolation through a vadose zone, 10 to 100 feet deep and 3) storage and/or transport in an underlying aquifer (0.5 to 10 years duration), prior to withdrawal via wells (Allen, 2007). Recharged water through mechanisms of geopurification, providing additional storage for future reuse and protection against salt water intrusion in aquifers (Asano and Cotruvo, 2004). Soil systems play a key role in terrestrial ecosystem processes. Understanding flow and transport through the soil is a key in understanding the functioning of soil systems. It is also at the basis of environmental engineering and management, including water management, agriculture management and waste management, aiming to sustain life and to alleviate soil controlled pressures exerted on terrestrial ecosystems (Vanclooster et al., 2007). When water is being used as drinking source, the main aspect to consider in aquifer recharge with recycled water is public health. During soil aquifer treatment most of the purification takes place at the uppermost layer of the soil. Also, several studies have suggested that most faecal bacteria die off at the top of the soil, and most viruses are adsorbed in the top 5 cm (Bouwer et al., 1990). The section discuss the removal performance of physical and chemical parameters after soil aquifer treatment.

The study area lies between 80 º 90' E to 80 º 15' E longitudes and 12º 51’ N to 12 º 57’ N latitudes of Survey of India Toposheet No. 66C and 66D, and covers an area of 118 sq. km. of Sholinganallur Administrative boundary of South Chennai City (Figure 1). The study area consists of 19 town panchayat and 4 village panchayat. The population density of south Chennai is 13451, the number has witnessed a tremendous growth in its manufacturing, retail, health care and IT sector in the last 10 years. South Chennai has become an important destination for trade and tourism in recent years. It has evolved as a city with tremendous potential for industrial growth because of its economic viability and available infrastructure. Major types of soils exist in the study area are the beach sands, clay & alluvial, and soils. Major water bearing formations are sand, sandstone, weathered and fractured granites, gneisses and Charnockite. The study area receives the Average Annual Rainfall of 1200 mm. The temperature is usually in the range of 13.9° to 45° C.

MATERIALS AND METHODS

Soil Sample Collection and Testing

Fifteen soil profiles were collected from different sites of the study area based on geology, hydrogeology and environment such as temperature, precipitation and health safety considerations.

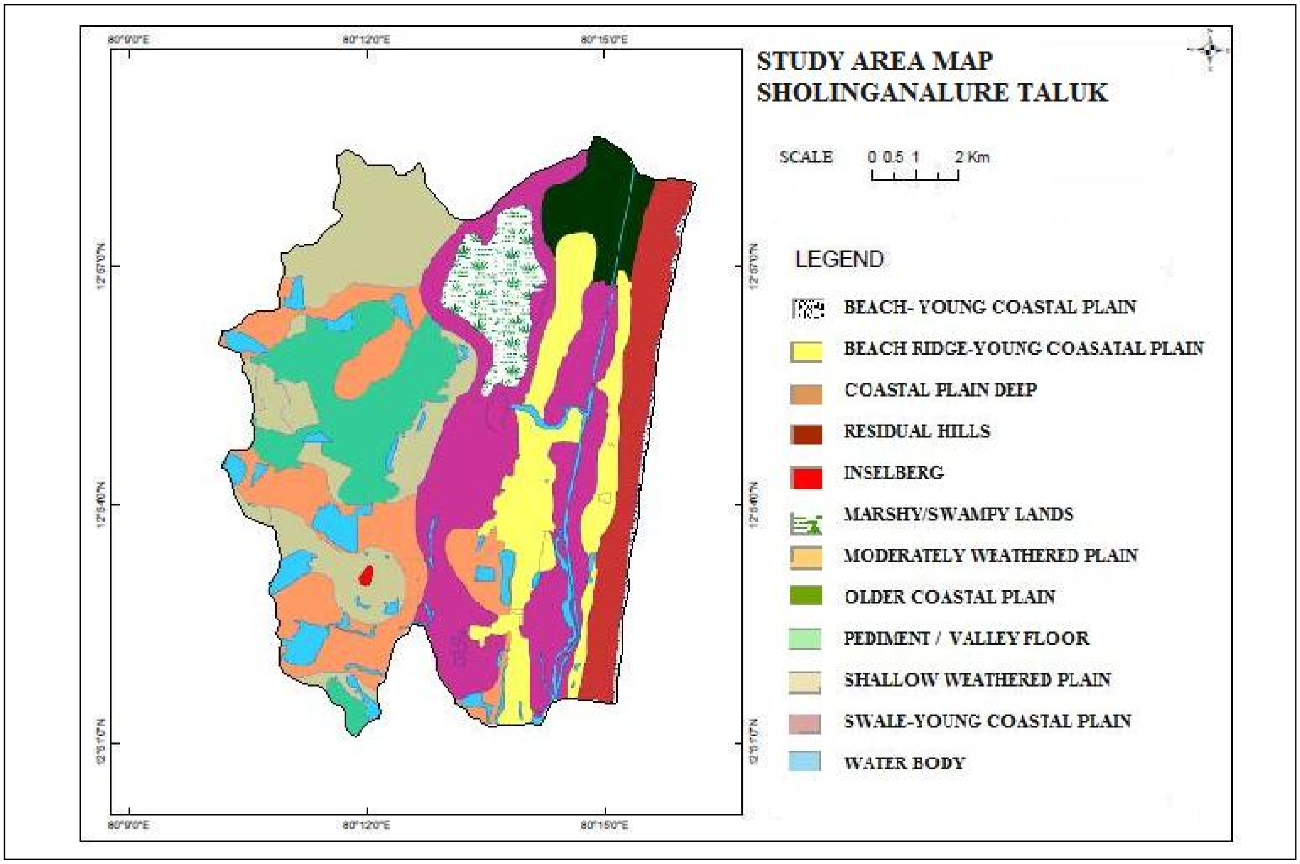

Figure 1. Study Area Map of Sholinganalure Taluk.

The soil samples were collected to a depth of about 1 m to 10 m below the ground surface using manual augur and rotary drilling methods respectively. Out of fifteen soil samples four soil samples from four sites were considered for soil aquifer treatment system based on the physical and chemical laboratory testing. Table 1 describes the soil depth profile from each soil sample site. Physical properties of the four soil samples are listed in Table 2.

Table 1. Soil depth profile from soil sample sites.

Name of the Soil sample site	Description	Depth (cm)	Sample	Remarks
Karappakam (Augur Method)	Yellowish fine Sand	0.0 to 300	DS	Water table was encountered at 2.5m
	Greyish yellow clayey fine Sand	300 to 600	SPT	
Mambakkam (Rotary Drilling Method)	Brownish medium Sand	0.0 to 300	DS	Ground Water table was encountered at 2.0m
	Brownish very fine sand	300 to 450	SPT	
Kovilambakkam (Rotary Drilling Method)	Greyish medium to fine sandy Clay	5. to 450	SPT	Water table was encountered at 2.5m
	Greyish clayey fine Sand	450 to 600	DS	
Chitlapakkam (Augur Method)	Reddish medium to fine sandy Clay	0 to 600	DS	Water table was encountered at 2.0m

Table 2. Physical properties of soils from the study area sites.

Soil Type	particle size and distribution	Density Mg/m^3	Specific gravity	water content(%)
fine Sand	0.25mm	2.11	2.07	26.6
clayey fine Sand	0.150mm	1.90	2.21	21.21
medium Sand	0.56mm	1.85	2.4	25.12
fine sandy Clay	0.09mm	2.25	2.28	24.11

The laboratory set up of four soil columns consisted of 1-m long, 12 cm internal diameter tubes. The soil columns used are transparent and clear acrylic columns. Initially constant head tests were applied with fresh water, infiltration rate test were observed and degree of saturation profiles were determined. Secondary treated wastewater samples collected from Perungudi Sewage treatment plants stored in plastic containers were kept in a refrigerator at around 4° C in order to minimize the effects of chemical and/or biochemical reactions in wastewater. Peristaltic pumps and spygon tubing were used to transfer wastewater to each column. Soils were packed in the soil columns by layer (Table 1). The soil columns were named as C1 (Karapakkam) consisting of a 30 cm thick fine sand at the top layer with a 30 cm thick of clayey fine sand, C2 (Mambakkam) consisting of a 30 cm thick medium sand at the top layer with a 150 cm thick of fine sand, C3 (Kovilambakkam) with top layer fine sandy clay of 45 cm thick followed by 15 cm clayey fine sand and C4 (Chitlapakkam) with single soil layer of 60 cm thick fine sandy clay respectively. All four soil columns were packed with two layered soils as exist in the original ground with a ratio of 1:10 (Figures 2 and 3).

Soil Column operation

The Soil columns were operated to study the infiltration rate using secondary treated wastewater from the Perungudi Sewage treatment plants, South Chennai. Primary objective of operating the Soil Aquifer Treatment systems with wet and dry cycles is to control the clogging layers and

Figure 2. Soil packing in the columns.

Figure 3. Soil column setup.

thereby increase the infiltration rates. On the other side the development of insects breeding such as mosquitos. The number of wetting days depends on the wastewater clogging capacity and the soil porosity and hence its permeability. The soil columns were first tested with fresh water with constant head conditions during the infiltration tests for period of about 2 months. By continuous ponding of freshwater the maximum wetting day that each soil column can able to absorb the water is observed. Based on the fresh water ponding depth test, the days of wetting / drying cycle were considered for wastewater application for the soil columns. A constant ponding depth of 25 cm was maintained using an overflow weir during wetting cycle. Normal room temperature (20 ºC) is maintained during the laboratory test (Figure 3). The water quality changes along the length of the soil columns were studied for a period of about 10 months using secondary treated wastewater. The 7 days of wetting and 7 days of drying cycle of wastewater into the soil columns were operated. The water quality removal performance of Soil Aquifer Treatment study from the soil columns were analysed for each wetting cycle. The daily release of waste water of Chennai city (North and South zone) is 427 Million Liters per day (Mld) . This quantity of wastewater received by the Chennai Sewage Waste Water Treatment Plants (at Nessapakkam, Kodungaiyur, Koyambedu, Perungudi) is getting treated by primary and secondary treatment and bringing the level of treated waste water to quality standard of 20 mg/l of BOD and 30 mg/l of suspended solids. This quality standard of wastewater from Perungudi Sewage Treatment Plants of South Chennai city was taken as an influent to the soil columns and measured the level of removal efficiency of BOD, COD, pH, TSS, nitrate and nitrite respectively.

RESULTS AND DISCUSSION

Hydraulic characteristics of columns

The soil columns were examined daily in the laboratory. Water Samples were collected every two days from the columns. The readings were measured for volume of discharge, pressure and hydraulic conductivity in order to study the performance of water quality after SAT. The daily analysis of water quality after SAT helps to assess the clogging behaviour in each column. The constant head is maintained so that the column is saturated with the effluent all the time during wetting cycles and the flow rate should be slow to allow more time for treatment to take place. During the drying cycles wastewater application ceased, allowing time for re-establishing hydraulic permeabilities and for allowing oxygen diffusion into the subsurface (Westerhoff and Pinney, 2000). Initially the infiltration rate was good in all the four soil columns due to absence of clogging effect and increased soil suction. On the fourth cycle of wetting period the infiltration rate decreased to 5% to 10% in soil Columns C1 and C2 and C3. The infiltrate rate decreased to a higher rate of 60% in soil column C2 due to higher moisture content of the soil layer developed a higher thickness of clogging layers at the top of the soil water interface surface. When the thickness of the clogging layer is small, relative to water depth, and the conductivity and thickness of the saturated clogging layer remain constant, the infiltration rate theoretically is directly proportional to the water depth. On this basis it is possible to compare the measured rate of infiltration, at the deeper water depth, to a prediction made by multiplying the rate of infiltration observed at the lower water depth by the ratio of the deeper and shallower depths (Houston et al., 1999). The average infiltration rate for Wet/Dry cycle applications to the four soil columns were shown in Figure 4. The measured values of infiltration rate resulted a relative decrease in infiltration rate in all the four soil columns.

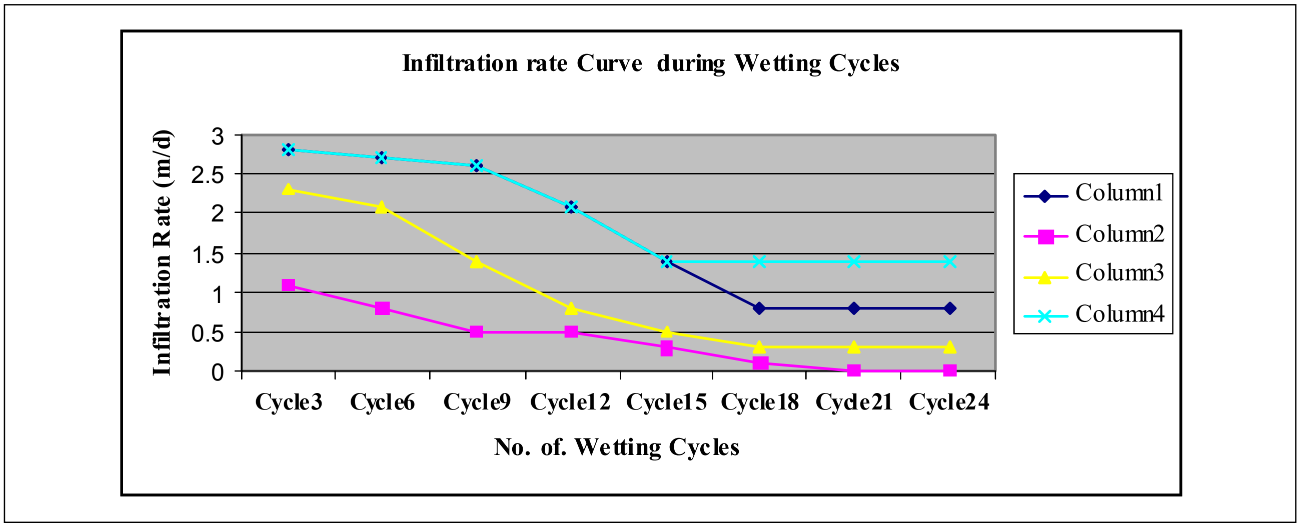

Figure 4. Infiltration rate decline curve for wetting cycles.

Water Quality Performance after Soil Aquifer Treatment

The standards of secondary treated wastewater quality maintained as influent before SAT to the soil columns and the testing procedure for the effluents after SAT are listed below in Tables 3 and 4. Initially the soil columns were treated with fresh water for a period of two months to remove all the impurities present the soils.

Biochemical Oxygen Demand (BOD_5)

Soil columns showed a maximum BOD_5 value of 8 mg/1 and a minimum value of 0.5 mg/l. The BOD_5 level showed a steady decrease with time (Figure 5). All the values were below the inlet value. The high values obtained during the initial period of the experiment may be influenced by the time needed for the microbial population to adapt to the organic compounds in the effluent.

Hydrogen Ion Concentration (pH)

The removal performance of pH in all the four soil columns shows a slight increase in pH value ranges between 7.4 to 8.01 when compared with the influent pH value of 6.8.

Table 3. Wastewater quality from Perungudi treatment plants (Source: CMWSSB 2008).

S.N	Parameter	Mean±SD
1	Biological oxygen Demand for 5 days @20º C(mg/l)	20
2	Total Suspended Solids (TSS) (mg/l)	30
3	pH (mg/l)	6.8
4	Nitrite(mg/l)	14.2
5	Nitrate (mg/l)	15.3

Table 4. Testing methods of the water quality parameters.

S.N	Parameter	Units	Method of Testing
1	Biological oxygen Demand for 5 days @20º C	mg/l	5210 B, APHA 21^{ST} Edition 2005
2	Total Suspended Solids	mg/l	Conductivity Meter
3	pH	-	pH metry
4	Nitrite	mg/l	4500-NO_2B, , APHA 21^{ST} Edition 2005
5	Nitrate	mg/l	4500-NO_3B, , APHA 21^{ST} Edition 2005

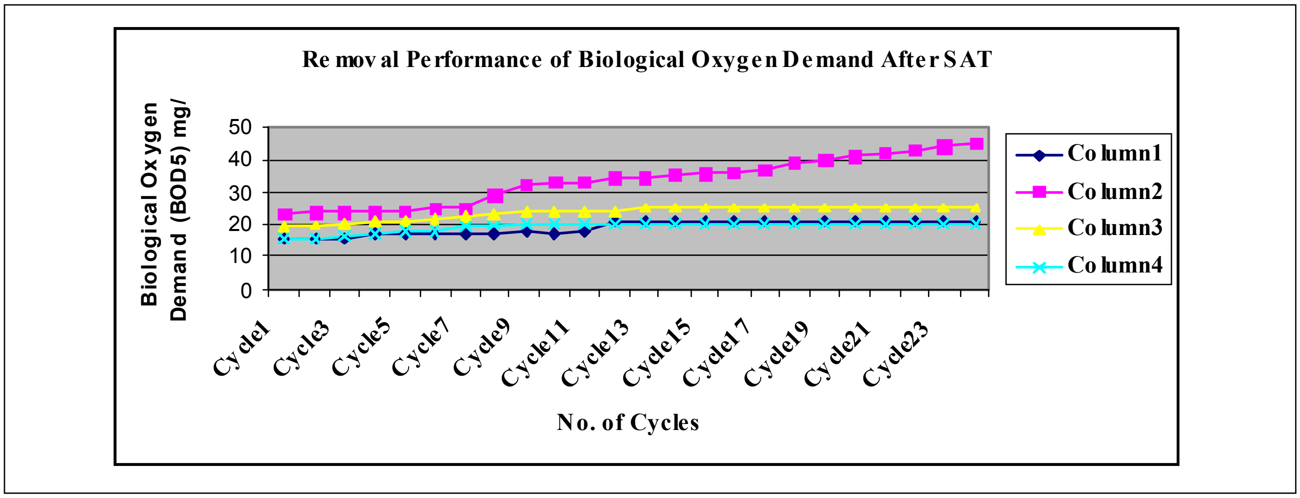

Figure 5. Removal Performance of BOD_5 after SAT.

The decrease in the percentage of pH removal shows development of biodegradation of organics matter in the soil columns. Permissible limit of 7.4 pH value for the soil columns C1, C2, C3 were observed till the 20^{th} wetting cycle. In column C2 the value of pH exceeds the permissible limit of about 8.2 from 6^{th} wetting Cycle. This shows the release of carbon dioxide is higher in soil column C2 during the 6^{th} wetting cycle compared with other three soil columns.

Total Suspended Solids (TSS)

The TSS in wastewater refers to matter suspended and is related to both specific conductance and turbidity. High concentrations of suspended solids can cause many problems for stream health, ground water flow and aquatic life. The measure value of TSS after SAT showed 97% of removal performance in soil columns C1, C3 and C4 respectively. Mean value of 21 mg/l of TSS concentration was measured in column C2. TSS in mg/L can be calculated as:

TSS in mg/L = (dry weight of residue and filter – dry weight of filter)/ ml of sample * 10^6 (1)

Nitrate and Nitrite (NO_3, NO_2)

Nitrogen species present in the recharged wastewater before SAT usually include various forms of inorganic and organic nitrogen. Significant nitrification and simultaneous denitrification can occur during SAT, providing removal of nitrogen from the system (Kanarek et al., 1993). During SAT application for groundwater recharge the important factor to be considered was the nitrate and nitrogen. During wetting cycle of soil columns denitrification process occurs where as during drying period the aerobic condition results in nitrification process. The removal % NO_3 can be calculated as:

Removal % NO_3 = [(Influent Concentration – Effluent Concentration)x100]/

Influent Concentration (2)

Infiltration rate and the length of wetting period were important parameters affecting nitrogen removal efficiency of SAT columns. Soil columns C1, C3, C4 showed the highest (93%) nitrogen removal performance. Soil columns C2 results show only 68% nitrogen removal performance. The nitrate in soil column C4 and C1 significant amount of NO_3 was removed during 4 to 15 cycles. Nitrate removal efficiencies of the soil column C1, C3, C4 during 4 to 15 cycles were 96%, 86% and 98%, respectively. Nitrate removal efficiencies of the soil column C2 is only 57% .

CONCLUSIONS

Groundwater recharge with treated wastewater is becoming more valuable with time in developing countries because of the scarcity of water resources. The study presented in this paper underlined the impact of soil type on changes in wastewater quality. The high infiltration rate was observed in soil columns C1 - Karapakkam, C3 – Kovilambakkam, C4 - Chithalapakkam sites with treated wastewater. The results of water quality removal performance of soil aquifer treatment using soil columns with treated municipal wastewater indicated improved water quality. The results of pH after SAT shows increased value compared with the influent pH level. This shows the production of carbon dioxide (CO2) is higher in soil columns. The overall results of TSS, BOD, COD in soil columns showed better removal percentage of 97%, 96% and 96% respectively. 7 days of wetting the soil columns results in nitrification of ammonium under aerobic conditions in the soil columns. The decreased removal of nitrite and nitrate after 15^{th} cycles in soil columns C1, C2 and C3 results denitrification due to anaerobic conditions in the soils. The use of soil column tests for study of SAT is a way to better understand removal mechanisms in soil, hence helping to understand SAT full scale performance and eventual risks. It has been shown that soil columns can be effective on removal of the major contaminants from wastewater, in a way which minimize any public interference. The use of short-term soil columns prove to serve the purpose of removal relates with the configuration of the columns, as well as the soil type affecting infiltration rates and the development of clogging issues.

ACKNOWLEDGMENTS

The authors would like to thank Dr. R. Jayabolu, Former Director of NEERI (CSIR) Taramani, Chennai and Dr. R. Nagendran, Professor, Center for Environmental Studies, Anna University in reviewing this paper and making several suggestions regarding the manuscript.

REFERENCES

Allen, M. 2007. Reuse and Desalination Technologies to Improve the Sustainability of Drinking Water Supplies. Report of AWWA Research Foundation.

Asano, T., and J.A. Cotruvo. 2004. Groundwater recharge with reclaimed municipal wastewater: health and regulatory considerations. Journal of Water Research, Vol.38, pp. 1941-1951.

APHA, 2005. Standard Methods for the Examination of Water and Wastewater, 21st ed., American Public Health Association, Washington, DC.

Bouwer, H., and R.C. Rice. 1989. Effect of water depth in groundwater recharge basins on infiltration. Journal of Irrigation and Drainage. Engineering, ASCE, Vol.115(4), pp.56–567.

Bouwer, H. 1996. New developments in groundwater recharge and soil aquifer treatment of wastewater for reuse. Water Reuse 96, Proceeding AWWA Conference.

Bielorai, H., I. Vaisman, and A. Feigin. 1984. Drip irrigation of cotton with treated municipal effluent and Yield response. Journal of Environmental Quality. Vol.13, pp. 231–238.

Bouwer, H., R.D. Pyne, and J.A. Goodrich. 1990. Recharging groundwater. Journal of Civil Engineering. Vol.60, pp.63-66.

Fadlelmawla, A. 1999. Towards Sustainable Water Policy in Kuwait: Reforms of the Current Practices and the Required Investments, Institutional and Legislative Measures. Journal of Water Resource Management Vol.23, pp.1969–1987.

Houston, S.L., P.D. Duryea, R. Hong. 1999. Infiltration Considerations for Groundwater Recharge With Waste Effluent. Journal of Irrigation and Drainage Engineering, ASCE, Vol.125(5), pp.264-272.

Kanarek, A., A. Aharoni, and M. Michail, 1993. Municipal Wastewater Reuse via Soil Aquifer Treatment for Non-Potable Purposes. Journal of Water Science and Technology, Vol.27, pp.53-57.

Quanrud, D.M., R.G. Arnold, L.G. Wilson, and M.H. Conklin. 1996. Effect of Soil Type on Water Quality Improvement During Soil Aquifer Treatment. Journal of Water Science and Technology, Vol.33, pp. 419-431.

Soil Profile of South Chennai. 2008. Report of Chennai Metropolitan Water Supply and Sewerage Board (CMWSSB).

Vanclooster, M., M. Javaux., and S. Lambot. 2007. Estudios de la Zona No Saturada del Suelo Vol.8, paper 12.

Westerhoff, P., and M. Pinney. 2000. Dissolved organic carbon transformations during lab scale recharge using lagoon-treated wastewater. Journal of Waste Management. Vol.20, pp.75-83.

ADDRESS FOR CORRESPONDENCE
K. Deepa
Research Scholar
Center for Water Resources
Anna University
Chennai 25
India

Email:deepa_deebha@yahoo.co.in