Reclaimed water recharge: A review of water quality improvement during column studies of soil aquifer treatment (SAT)

T. Selvakumar[1 *], Madhavi Ganesan[2]
[1]*Research Scholar, Centre for Water Resources, Anna University, Chennai, India.*
[2]*Associate Professor, Centre for Water Resources, Anna University, Chennai, India.*
[1*]selva301164@gmail.com; [2]madhaviganesan@yahoo.com

Abstract

Water recycling and reuse is a major component of contemporary water management strategies as the world faces increasing fresh water demand and problems associated with disposal of wastewater. The use of soil aquifer treatment (SAT) is the most common method for Artificial recharge as it does not require high technology levels. It is simple and cost effective to operate and is capable of achieving extremely good quality treatment of the recharged water. However, the success of this method can be limited by clogging issues affecting the overall performance of these systems. This paper deals with the literature review of SAT Technology with soil columns study using primary as well as secondary effluents with related removal efficiency of different pollutants. The use of soil columns test for the study of SAT is a way to better understand removal mechanisms in soil, hence helping to understand SAT full scale performance and eventual risks. The main conclusion of the review is that the soil columns can be effective on removal of the major contaminants from wastewater. The use of 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.

Keywords: Soil columns, wastewater, infiltration rate, clogging layer, review.

1. Introduction

The rapid population growth and urbanization, the phenomenon which is putting tremendous stress on the world's water resources, especially in the drier climates, requires much more reuse and recycling of water to meet increasing water demand. Creative water management will become essential in many countries in the world in future. Groundwater not only is a major water resource in general, it will also be at risk because rising water demands can lead to over-pumping. This depletes aquifers, increases pumping costs and may cause land subsidence and water quality problems such as sea water intrusion in coastal areas. [1]

Water reclamation and reuse provides a unique and viable opportunity to augment traditional water supplies. As a multi-disciplined and important element of water resources development and management, water reuse can help to close the loop between water supply and wastewater disposal. [2]

The alternatives for water augmentation are the reuse of municipal wastewater to address the ever increasing water demand. Nevertheless, the amount of wastewater, that can be reclaimed for this purpose is affected by many factors, ranging from technical possibility to socio – economic and institutional aspects.

1.1 Groundwater recharge

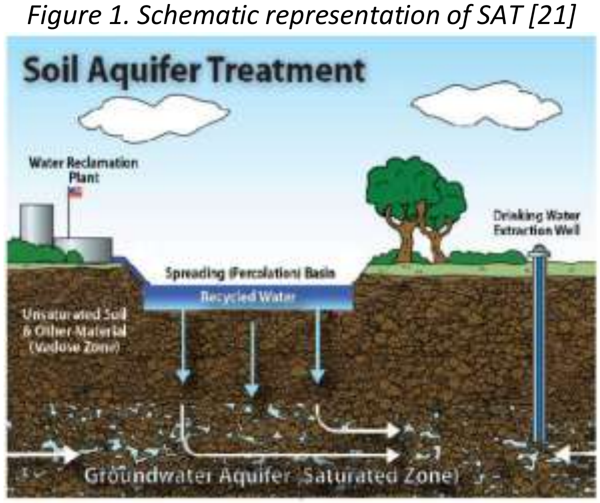
Groundwater recharge is reinforced by different techniques and for different purposes but it is classified into two main categories.[3] Surface infiltration and direct well recharge. The well recharge requires water of much higher quality. While it is not necessary for the surface infiltration since the desired role of the unsaturated soil zone in the recharge system is to remove or reduce the chemical and biological constituents in the applied water. Storing water in aquifers presents many advantages over surface water as a potable water source as it provides more economically, environmentally and socially acceptable option than surface storage.

1.2 Soil aquifer treatment system (SAT)

Land treatment of wastewater has emerged as a promising alternative to the conventional wastewater treatment technologies. In land treatment, appropriately, pretreated wastewater is allowed to infiltrate through the aerated unsaturated soil zone where it undergoes purification through unit operations and processes *viz* filtration, adsorption, chemical processes and biodegradation. After reaching the water table, the soil treated wastewater further moves laterally for some distance through the underlying saturated zone (aquifer) where it receives additional purification by dispersion and dilution. Since, both soil and aquifer participate in the renovation process, such a land treatment system is also called Soil-Aquifer Treatment (SAT) system. Fig.1 shows the schematic representation of SAT.

Overland treatment of sewage effluent with incidental groundwater recharge has been practiced near many cities in the United States and other developed countries around the globe. Since the 1960s, high-rate land treatment of sewage effluent for the specific purpose of recharge has been practiced in a number of research and pilot projects, of which Flushing Meadows in Phoenix, Arizona, is perhaps the best known. This project, which was conducted in 1967, was well documented by Bouwer and Chaney. It was concluded that most of the fecal bacteria die or are immobilized at the top of the soil. Virus removal is primarily due to adsorption by silt and clay particles; most viruses are adsorbed in the top 5 cm of the soil.

Figure 1. Schematic representation of SAT [21]



Bouwer et al. indicated that human bacterial and viral pathogens are largely removed as sewage effluent percolates through the soil. After eight years of continuous operation of the Flushing Meadows Project in Arizona, virus, enteric bacterial pathogens and pollution indicator organisms in the renovated sewage effluent were either not detectable or greatly decreased after wastewater was filtered through soil recharge basins.[4]

2. Process description

SAT is the most widely used method for groundwater recharge due to its economical advantages and the low maintenance required to its operation. [5]

These systems use the vadose zone (zone situated between the surface and the water table) as a filter. Wastewater is then purified by passing through this zone. [6]

SAT systems require suitable hydrological conditions and appropriate particle size distribution of soils (fine sands, loamy sands, sandy loams or even some clay soils) to allow high infiltrations rate [7,8,9] provide adequate filtration and ensure quality improvements. The quality of the effluent injected including suspended solids contents as well as the climate under which recharge is achieved also influence infiltration and hydraulic loading rates in SAT systems.

Whenever using SAT systems, the use of reclaimed wastewater recharge is always associated with its constituents such as residual organic material, nitrogen and phosphorus and pathogenic organisms, which are removed or transformed when effluent percolates through the aquifer [10]. Various studies demonstrated that water Quality can be improved using SAT systems by removing suspended solids, organic compounds, nitrogen, phosphorus, BOD and trace metals very efficiently [5,11,12].

To illustrate, Table 1 briefly describe quality results observed in the Dan Region Project, Israel, where a SAT system is operated since the 70's with secondary treated effluent.

The recharged water used for unrestricted irrigation with 90% of BOD, TSS, NH_4-N and phosphorus removal after SAT.[13] This project, by producing accidental drinking water quality, from the recharge of secondary treated effluent, has proved that SAT systems could be used for many purposes such as unrestricted agricultural uses, industrial uses and also non-potable municipal uses.

SAT systems improve water quality of the recharged water through a range of chemical, physical and biological mechanisms occurring in soil such as filtration in the upper soil layers, biological degradation as nitrification and denitrification, physical adsorption, ion exchange and chemical precipitation In the past 20 years, SAT systems have not shown any direct alteration of groundwater quality and no human health problems were recorded. As a result they are often presented as the best option for aquifer recharge. [5]

Municipal wastewater usually requires high degree of pretreatment prior to recharge, however when using SAT systems pretreatment requirements can be reduced due to the capacity of such systems to improve water quality.[7] For instance,[9] Bouwer shown that phosphate, nitrogen and some trace metals concentrations are considerably reduced as water infiltrates through these systems.

2.1 Conditions of Applications

Both primary and secondary effluents can be used for recharge through SAT, depending on the specific characteristics of the site.[8] Although the higher levels of organic carbon and the available nitrogen for denitrification of the primary effluent may be an advantage [8,11] these types of effluent favour clogging due to their higher content in suspended solids.[7] Consequently the use of secondary treated effluent presenting lower organic matter contents and low

Table 1. Water Quality improvement in the Dan region SAT site (Israel) [13]

Water parameters	Secondary effluent (mg/L) before SAT	Recovery samples after SAT system (mg/L)
Suspended Solids (ss)	40	0
Total N	22.8	<2.1
Ammonium as nitrogen (NH_4^+-N)	15	<0.10
Phosphorus (Po_4^3)	6.0	0.02
BOD	27	<0.5
TOC	25	3.9

concentration in BOD has been preferred in a majority of the wastewater reclamation projects.[2] For SAT, denitrified effluents rather, than conventional biological treated effluents is the option to be chosen. [5]

Although SAT systems are simple to operate and offer removal advantages for groundwater recharge, their long term performance and maintenance is dependent on how often they are flooded. A cycle of flooding/drying of the basins is typically necessary to increase infiltration rates to limit surface clogging phenomena and to control aerobic/anoxic conditions of the soil in the vadose zone. [5]

2.2 Clogging issues

One of the main limitations of using SAT systems is their clogging propensity while effluent percolates through the soil.[14] There are three possible types of clogging resulting from the injection of reclaimed wastewater: chemical, biological and physical clogging. [15]

Chemical clogging occurs when wastewater containing dissolved salts, such as sodium, interacts with the soil blocking the pores and therefore decreasing the permeability. During chemical clogging, the pH can raise upto 9 or 10 which can cause further precipitation of calcium carbonate. [5,16]

Physical clogging happens when suspended solids clog the soil pores. Solids smaller than the average pore size can also lead to clogging at great depths.[17]

Biological clogging is caused by the growth of micro organisms (Fungi, anerobic bacteria, etc.,) in reclaimed wastewater, [10,18] which can lead to formation of a clogging layer either on the soil surface or in soils by decreasing the quality of the recharge water.[19]

Reclaimed water used for recharge, even if pre-treated, always contain micro organisms such as algae, which under specific conditions like high temperatures (direct light) or longest retention time of the water above soil surface can lead to their regrowth in soil causing severely biological clogging of the infiltration basins.[5] As a result, infiltration rates of the recharged water decrease.[7] Clogging potential can also increase when varying the hydraulic loading rate, especially with high concentrated organic waters. For instance, when coarse soils like sand are used, faster infiltration rates are observed during SAT hence affecting organics removal efficiencies due to lower retention times during percolation.[10]

For SAT clogging problems occur more frequently at the soil surface where a compact and less permeable layer is formed as water passes through the soil and suspended solids are retained.[15] To manage part of this problem, flooding and drying cycles of the basins are required to increase infiltration rates. For example, whenever using secondary treated effluent with a concentration of suspended solids below 20 mg/L, a specific flooding drying period of 2 weeks each should be applied to minimize blockage of the system.

3. Understanding SAT systems using soil columns

Understanding removal mechanisms achieved by aquifer recharge is complex at full site and therefore, soil columns experiments are performed in order to test how the quality of the wastewater effluents can be improved as well as to investigate how different type of soils can influence the removal of specific contaminants.[3,10]

Several studies have been performed regarding soil columns; however no trend exists regarding the configuration of the columns used. Wastewater effluents are usually applied to the top of the soil columns at a specific constant rate. Soil columns are usually packed with soil material from either a specific location where SAT is planned, or a material of similar characteristics. They can either be used to test the performance of soils in removing specific contaminants or to assess their clogging capacity. The sources typically investigated are secondary treated effluent. Soil Columns can vary in size from 5 cm [20] upto 2.4 m. [21,22]

Generally, soil columns are saturated with the effluent under specific periods of time, depending on the purpose of the study, (removal of contaminants, clogging mechanisms, permeability of soils).[23]

The temperature of the columns is usually maintained constant with values ranging from 10 upto 45^{o}C depending on the climate conditions under which aquifer recharge is meant to take place. However, the average temperatures used are typically around 25^{o}C in order to limit variations of the initial characteristics of the effluent as well as to minimize regrowth of bacteria.

As the water percolates through the soil, degradation of the wastewater may occur but problems such as clogging at the soil surface can decrease the infiltration of water and therefore the effective removal of contaminants. A layer of biomass slows down infiltration (increases local water retention time) and therefore the purification process due to suspended solids accumulation or bacterial growth, which is dependent on the effluent characteristics and hydraulic loading rate. [10]

Columns used for clogging tests require an overflow weir near the inlet to allow a constant head and minimize any return flow and problems such as particles accumulation or long retention times of the water near the inlet. [3,10]

Soil column tests have demonstrated that the performances of SAT systems are widely affected by

1) The degree of the wastewater pre-treatment prior to recharge
2) The physical characteristics of the soil used in these systems such as groundwater depth and distance to recovery wells
3) The operational procedure of infiltration basins (meaning flooding and drying period) as defined by the NCSWS (2001) as well as
4) Loading rate and temperature. [5,10]

Dissolved organic matter can be removed from the wastewater from a combination of chemical, physical and biological processes.[10] Significant reductions can be achieved whilst effluent passes through the soil columns. For instance, Fox [21] achieved 80% DOC removal for chlorinated secondary effluent in 2.4 m length column fed over 475 days under various wetting and drying period. Such removals are mainly achieved during the early stages of soil column tests due to biological degradation. Soils with high fraction in organic carbon generally achieve better removal for DOC.[24]

Bacteria and viruses can also be removed as water percolates by interactions with anaerobic bacteria within the soil. In their study on the removal of viruses (HCPA) entero viruses and coliphage in miniature soil columns filled with sand.

Sobsey M.D et.al [25], demonstrated that virus reduction can be extensively achieved in soil columns (upto 5.1 log_{10} virus reduction), although depending on virus type, soil type and water quality.

Fine textured soils are more efficient to retain viruses and bacteria.[10,25] The effluent pre-treatment also influence the removal of viruses and pathogens. For instance, a high DOC concentration at columns inlet interferes negatively with the adsorption of viruses due to retention of soils. Temperature can also have an important role as higher reductions can be achieved with increasing temperatures (ie 25^{o}C and above) however, some viruses tend to be more resistant at such temperatures.

If it is already known that the use of treated wastewater, independently of the reuse purposes, always involves risks associated with residual pollutants such as bacteria and pathogens. The ability to control these micro organisms is critical in order to protect public health and acceptance. Cordy [26] shown that, some pathogens can persist in the treated wastewater recovered from soil column which suggests that they could reach groundwater levels at full scale. However a significant reduction of the pathogens compounds can be obtained with 70% decrease achieved. Soil column studies have shown that long infiltration cycles (upto 2 months) can create specific conditions for the microbial communities to develop and therefore, minimize the possibility of having persistent pathogens in the effluent.[10] However, reducing levels of pathogenic organisms before infiltration is advised in order to avoid risk of break through into the soil and to reduce risks of health problems.

Nitrogen levels in the recharged wastewater are mostly measured as ammonium (NH_4^+, nitrate (NO_3^-) and nitrite (NO_2^-). The presence of nitrogen in SAT is a concern when its initial concentration in the wastewater effluent is greater than 10 mg/L. Soil column tests proved that nitrogen levels tend to be highly reduced during SAT as aerobic conditions develop to support nitrification by conversion of NH_4^+ to NO_3^- within autotrophic bacteria. It is also important to notice that long periods of infiltration affect the denitrification by enhancing ammonium break through and therefore nitrate [6] removals as demonstrated by Gungor and Unlu on their study of nitrite and nitrate removal efficiencies of Soil Aquifer Treatment Columns [3,27] in Table 2, it was demonstrated that nitrogen removals are dependent on the depth of the vadose zone with better removals as soil depth increases.[10] For nitrite however, these removals are not associated with the change in depth of soil although overall removal of 90 % can be achieved.[6]

Significant reductions in ammonium also take place within the columns as water infiltrates. NH_4^+ is adsorbed by the soil, within the top few meters of sediment, where the amount of DO available and pH levels control that process. [6,27] This means that ammonium requires high concentrations of oxygen in the soil to be treated which is also important for the total amount of nitrogen to be removed.[9]

Phosphate concentration can be removed from the wastewater either by adsorption or through precipitation with ions (Al or Fe) presented in the soil.[6,27] This means that ammonium requires high concentrations of oxygen in the soil to be treated which is also important for the total amount of nitrogen to be removed.[9]

Phosphate concentration can be removed from the wastewater either by adsorption or through precipitation with ions (Al or Fe) presented in the soil, Cha [27] showed that phosphate removal is more dependent on the soil characteristics and effluent quality rather than on the depth of the soil column.

The presence of heavy metals in wastewater constitutes a threat whenever planning reuse, especially for groundwater applications. In that sense, studies evaluated the metals removals such as Cu, Zn, Pb, Cd and Cr under specific conditions. For instance, [28] it was shown that metals can be effectively removed from wastewater by soil adsorption.

3.1 Pre-Treatment of Effluents used for Recharge

Whenever using treated wastewater, the quality of the water prior to SAT can influence removal efficiencies of the major contaminants and the overall treatment performance of the process. [10]

In the same way, the degree of treatment of the reclaimed water can depend on the specific reuse applications as well as the regulations established for each specific site. The Dan Region Project in Israel, one of the most important full scale SAT in the World, use effluent issued from an activated sludge plant with nitrification – denitrification.

The effluent passage in soil improves its quality significantly so it can be reused directly for irrigation although the quality of the effluent produced after SAT is comparable to drinking water quality standards. [13,29]

The use of secondary effluent is however often associated with the possibility of soil clogging due to the suspended solids content generally leading to surface clogging. This phenomenon can be

Table 2. Concentration of nitrogen in SAT Soil Columns at different depth of soil [27]

Parameters	Effluent to SAT (mg/l)	Column at 0 m (mg/l)	Column at 0.5 m (mg/l)	Column at 1 m (mg/l)
NH_4-N	10.0	5.0	4.0	3.2
NO_3-N	1.5	0.8	0.2	0.5
NO_2-N	6.4	4.3	5.8	7.8
TN	18.0	10.0	10.0	11.5

minimized with tertiary treatment as significant reductions in solid contents are achieved.[30]

In Europe (mainly in France and Spain) wetlands are often used as a polishing step prior reuse.[29] Some indirect potable reuse projects can be found in the United State where tertiary filtration (UF/RO) is used prior to SAT [31] to reduce levels of pathogen and viruses, which can be very effective by removing these components to levels near zero. [22, 26]

The costs of treatment involved in tertiary treatment such as additional filtration or extended cementation as disinfection are high while soil column tests have proved that treatment comparable or even better than conventional tertiary treatment can be achieved through percolation of effluent within the soil. [32]

As Quanrud et al [10] shown in their study on the rate of organics during column studies of SAT, chlorinated secondary effluent better remove DOC (54%) compared to tertiary treated effluent (30%) due to higher biological activity.

Some studies even suggest that column fed with primary effluent, due to their additional carbon source, seem to get final quality waters of levels similar to those obtain when using secondary treated effluent [33].

The increasing water demand encourages the growing trend for membrane technologies such as microfiltration (MF), ultra filtration (UF) or reverse osmosis (RO) in water reuse projects [29] MF pre-treatment followed by NF or RO has been used in the United States to achieve high quality water for aquifer injection.[31]

When dealing with clogging during groundwater recharge, particularly when using secondary effluent, an extensive membrane process may be required to minimize clogging as well as eliminating the clogging parameters. Membrane filtration works as a pre treatment to remove organic carbon, one of the parameters responsible for clogging in SAT systems.[7] Although this technique is very efficient, final TOC concentrations are not as different as shown with 0.3 mg/l for membrane technology and 1.0 mg/l for soil columns. [31]

Although membrane technologies are increasing their potential on behalf of producing high quality water [34] it still continues to be very expensive to apply for reuse schemes and some facilities prefer to adopt disinfection with chlorine prior to recharge.[7,35]

4. Conclusions

The use of municipal wastewater effluent as a source for aquifer recharge is shown to be a good way of storing water for future reuse and then to help balancing water supply and demand. However the application of reclaimed municipal water to soil has to be well controlled to avoid potential contamination of groundwater causing health risks linked to its reuse. The use of soil columns 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 showed 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.

5. Reference

1. H. Bouwer [1994] Groundwater and artificial recharge in future water resources management, Future groundwater resources at risk. In: Proceedings of the Helsinki conference, Tune. *The International Association of Hydrological Sciences (IAHS)*, No. 222.
2. T. Asano [2002] Water from (waste) water-The dependable water resource. *Water Science and Technology*, 45(8) pp.24-33.
3. W Cha, H Choi, J Kim and I.S Kim [2004] Evaluation of wastewater effluents for SAT in South Korea *water science and technology,* Vol. 2, pp 315-322.
4. H. Bouwer , R. C. Rice, J. C. Lance and R. G. Gilbert [1980] Rapid-Infiltration Research at Flushing Meadows Project, Arizona. *Journal of Water Pollution Control Federation*, 52(10), pp. 2457–2470.
5. T. Kopchynski, P. Fox, B. Alsmadi and M. Berner [1996] The effects of soil type and effluent pre-treatment on soil aquifer treatment. *Water Science and Technology,* Vol 34, (11), pp. 235-242.
6. K.Gungor and K Unlu [2005] Nitrite and nitrate removal efficiencies of soil aquifer treatment columns. *Turkish Journal of Engineering & Environmental Sciences*, Vol. 29, pp.159-170.
7. H.Bouwer [1996] Issues in artificial recharge, *water science and technology,* Vol. 33, 10-11, pp 381-390.
8. H.Bouwer [1993] From sewage farm to zero discharge, *European water pollution control,* vol.3,(1), 9-16.
9. H. Bouwer [1991] Groundwater recharge with sewage effluent, *water science and technology,* Vol. 23, pp. 1099-2108.
10. D.M. Quanrud, R.G. Arnold, L.G Wilson and M.H. Conklin [1996] Effect of soil type on water quality improvement during SAT. *Water Science and Technology,* Vol. 33, (10-11), pp. 419-431.

11. S. Kaur and S. Mandeep [2002] SAT system: A case study. *Indian Journal of Environmental Health*, Vol. 44, (3) pp. 244-246.
12. T. Selvakumar and Madhavi Ganesan [2013] Artificial groundwater recharge with reclaimed water: An overview of soil aquifer treatment technology and management practice. In: Proceedings National Groundwater Conference (NGWC -2013) on problems, Challenges and Management of Groundwater in Agriculture 9-11 December 2013, Water technology Centre, Tamilnadu Agricultural University, Coimbatore, India.
13. A. Kanarek and M. Michail [1996] Groundwater Recharge with Municipal effluent: Dan region reclamation project, Israel. *Water Science and Technology*, Vol. 34, (11), pp. 227-233.
14. T. Kawanishi, H. Kawashima, K. Chihara and M. Suzuki [1990] Effect of biological clogging on infiltration rate in soil treatment systems. *Water Science and Technology,* Vol. 22, (3-4) pp. 101-108.
15. R.C Rice [1974] Soil Clogging during infiltration of secondary effluent*. Journal of Water Pollution Control Federation*, Vol. 46, (4), pp. 708-716.
16. EPA Guidelines (September 2004) Guidelines for water reuse. *U.S Environmental Protection Agency*, Vol. EPA/ 625/R-04/108.
17. N.R Siriwardene, A Deletic and T.D Fletcher [2007] Clogging of Storm water gravel infiltration systems and filters: insights from a laboratory study. *Water Research,* Vol. 41, pp. 1433-1440.
18. Rinck-P S. Feiffer, S. Ragusa, P Sztainbok and T.Vandevelde [2000] Inter relationships between biological, chemical and physical processes as on analog to clogging in aquifer storage and recovery (ASR) wells. *Water Research*, Vol. 34. (7), pp. 2110-2118.
19. T. Okubo and J. Matsumoto, [1983] Biological clogging of sand and changes of organic constituents during artificial recharge. *Water Research,* Vol. 17 (7) pp. 813-821.
20. E Smith and S. Hegazy [2006] *E.coli* transport in soil columns: implications for reuse of treated wastewater in irrigation. *Water Science and Technology*, Vol. 54, (11-12), pp. 175-182.
21. P. Fox and W. Aboshanp and B. Alsamadi [2005] Analysis of soils to demonstrate sustained organic carbon removal during soil aquifer treatment. *Journal of Environmental Quality*, Vol. 34, pp. 156-163.
22. G.E. Cordy, N.L. Duran, H. Bouwer, R.C. Rice, E.T. Furlong, S.D. Zangg, M.T. Meyer, L.B. Barber and D.W. Kolpin [2004] Do pharmaceuticals, pathogens and other organic wastewater compounds persist when wastewater is used for recharge? *Groundwater Monitoring & Remediation*, Vol. 24, (2) pp. 58-69.
23. I. Alimi-Ichola and L. Gaidi [2006] Influence of the saturated zone of soil layer on the solute migration. *Engineering Geology*, Vol. 85, pp. 2-8.
24. P. Westerhoff and M. Pinney [2000] Dissolved organic carbon transformation during laboratory-scale groundwater recharge using lagoon treated wastewater. *Waste Management*, Vol. 20, p 75-83.
25. M.D Sobsey, R.M .Hall and R. Hazard [1995] Comparative reductions of hepatitis A virus, enteroviruses and coli phage MS 2 in miniature Soil Columns. *Water Science and Technology,* Vol. 31, (5-6) pp. 203-209.
26. Cordy, L.G. Wilson, G.L Amy, C.P. Gerba, H Gordon, B.Johnson and J Miller 1995 [2004] water quality changes during SAT of tertiary effluent. *Water Environment Research*, Vol. 67, (3) pp. 371-376.
27. W. Cha, H. Choi, J. Kim and J. Cho [2005] Water quality dependence on the depth of the vadose zone in SAT- Simulated Soil Columns. *Water Science and Technology: Water Supply*, Vol. 5, (1), pp. 17-24.
28. S.Y. Lee, J.U Lee, H. Choi, and K.W. Kim [2004] Sorption behaviors of heavy metals in SAT (Soil Aquifer Treatment) System. *Water Science and Technology*, Vol. 50, (2), pp. 263-268.
29. D. Bixio, B. De heyder, H. Cikurel, M. Muston, V. Miska, D. Joksimovic, A.I. Schafer, A. Ravazzini, A. Aharoni, D. Saric and C. Thoeye [2005] Municipal wastewater reclamation: where do use stand? An overview of treatment technology and management practice. *Water Science and Technology:Water Supply,* Vol. 5, No 1 p 77-85.
30. T.G. Bule [2006] Long term Performance of a Constructed wetland for landfill leachate treatment, *Ecological Engineering*, Vol. 26, pp. 365-374.
31. J.E Drewes, M. Reinhad and P. Fox [2003] comparing microfiltration – reverse osmosis and Soil Aquifer Treatment for indirect potable reuse of water. *Water Research*, Vol. 37, pp. 3612-3621.

32. G. Amy, L.G.Wilson, A.Conroy, J. Chahbandour, W. Zhai and M. Siddiqui [1993] Fate of Chlorination byproducts and nitrogen species during effluent recharge and Soil Aquifer Treatment (SAT). *Water Environment Research,* Vol. 65, (6), pp. 726-734.
33. Sofia Figeiredo [2007] Development of a short term soil column test for aquifer recharge. M.Sc. Thesis, Cranfield University.
34. A Ravazzini, A.F. Van Nieuwenhvijzen and J.H.M. J Van der Graaf [2005] Direct ultra filtration of municipal wastewater, comparison between filtration of raw sewage and primary clarifier effluent. *Desalination*, Vol. 178, pp. 51-62.
35. T. Selvakumar and Madhavi Ganesan [2014] An overview of understanding Soil Aquifer Treatment (SAT) systems using soil columns study. In: Proceedings of the International Conference on Advances in Civil Engineering and Chemistry of Innovative materials (ACECIM'14) March 13th & 14th 2014, SRM University, Chennai, India.

The Publication fee is defrayed by Indian Society for Education and Environment (iSee). www.iseeadyar.org

Citation:

T. Selvakumar, Madhavi Ganesan [2014] Reclaimed water recharge: A review of water quality improvement during column studies of soil aquifer treatment (SAT). *Indian Journal of Innovations and Developments,* Vol 3 (2), pp. 35-44.