AQUIFER RECHARGE WITH RECLAIMED WATER THROUGH SOIL AQUIFER TREATMENT

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PROBLEM INVENTORY

With ever growing population and rise in living standards, urbanization and industrialization, the demand of water has increased rapidly. Chennai city is developing exponentially which has four reservoirs to support drinking water needs. In addition to this, demand is managed with the help of well fields, existing at north and south Chennai. More than 1000 MLD of wastewater is generated in Chennai city alone, out of which 486 MLD is treated secondarily. The capacity of the treatment plants is to be expanded to 590 MLD, the remaining sewage is let as raw waste water into the nearby drainages, like Adyar, Cooum, Otteri nullah and Buckingham canal. Only 36 MLD of secondary treated sewage water is being supplied to the industries in North Chennai. One way these secondary treated waste water has been wasted by discharging into streams which are already polluted by raw sewage and other pollutants. At the same time, Groundwater has also been over exploited, and its level is declining down that causes other consequences such as seawater intrusion. To overcome this situation there should be a balance between discharge and recharge of groundwater. Either storm water or wastewater may be the source for aquifer recharge. Storm water is available during monsoon period alone, but wastewater is generated throughout the year which can be properly pretreated and used for recharge.

TERTIARY TREATMENT METHODS

Many tertiary treatment technologies are now available. Some processes used in tertiary treatment include filtration, carbon adsorption, phosphorous removal and nitrogen removal. Removal of inorganic constituents is accomplished by chemical processes on membrane filtration.

The principal unit operations and processes are chemical precipitation, ion exchange, ultra-filtration, reverse osmosis, electro-dialysis and distillation. Membrane treatment like reverse osmosis (RO) is also used for bringing secondary treated effluent to drinking water standards. Other tertiary treatment methods include land application on grass plots, constructed wet lands (Reed bed systems) and lagoons. The selecting method should be environmentally suitable, economically viable, socially acceptable and technically feasible. Soil Aquifer Treatment (SAT) technique is one such system. If it is properly implemented and operated it will satisfy the water demand of Chennai city. Hence this paper aims to evaluate the efficiency of Soil Aquifer Treatment technique to Chennai city.

SOIL AQUIFER TREATMENT (SAT)

Soil Aquifer Treatment can be defined as a three component treatment process consisting of the infiltration zone, vadose zone and aquifer storage. The concept can be expanded to a SAT system that adds the additional components of effluent pretreatment, SAT site operation and the recovery of groundwater after infiltration and aquifer storage for water reuse. Soil Aquifer Treatment is envisioned as a treatment system consisting of three components.

1. Infiltration through a biologically active infiltration interface (<1m in depth) at the soil/water boundary of the infiltration basin;
2. Percolation through the vadose zone, may be 3-30m in depth.and
3. Storage and transport in the underlying aquifer pending withdrawal at production wells.

Soil Aquifer Treatment (SAT) systems are usually designed and operated in such a way that all the infiltrated water is recovered via wells, drains or seepage into surface. SAT systems with infiltration basins require unconfined aquifers, vadose zones free from restricting layers, and soils that are coarse enough to allow high infiltration rates, but fine enough to provide adequate filtration. Sandy loams and loamy or fine sands are the preferred surface soils in SAT systems.

EXPERIMENTAL COLUMN STUDY

To understand the process of SAT, a pilot experimental column study was carried out in the Centre for Water Resources, Anna University, Chennai. The Soil column set up with one metre height and 6 cm dia of acrylic material was fabricated along with ports at different depth to take effluent sample for analysis in order to check which depth is suitable for effective removal. The lower part of the column was filled with pebbles, above which the soil for 50 cm was placed. The columns were provided with outlets at the bottom to collect the effluent. The columns were equipped with sampling ports to obtain liquid and soil samples at various depths. The column setup is shown in figures 1 and 2.

The column study was conducted with different types of soil, different depths of soil, different hydraulic loading rate, different wetting and drying cycles, UV light to the influent, aerating the influent to the column and mixing hydrogen peroixde in the influent. Experiments were tried to reduce pH, Total Dissolved Solids (TDS), Chemical Oxygen Demand (COD), Bio Chemical Oxygen demand (BOD), Turbidity, Nitrate, Nitrite, Total Coliforms (TC) and Faecal Coliforms (FC). The parameters responsible for removal efficiency of the above descriptions and the feasibility of using SAT treated waste water for groundwater recharge were evolved.

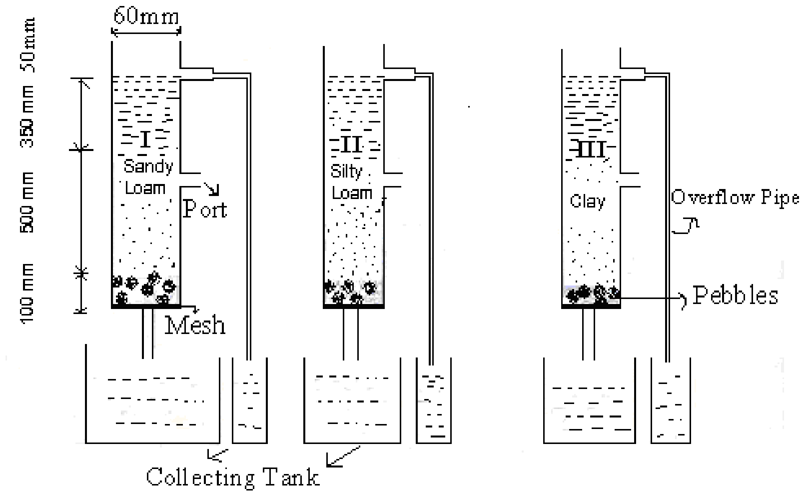

Figure 1 Soil Column Design

Figure 2Fabricated Soil Columns

Preliminary Studies

Three columns were filled with sandy loam, silty loam and clay soils. The soil in the columns were not compacted. The experiments were carried out with one day wetting and one day drying cycle, two days wetting and two days drying and three days wetting and three days drying to evolve which cycle and soil removes maximum constituents. Secondary treated waste water was collected from Nesapakkam Sewage Treatment Plant and analyzed for its quality. The experiment was carried out for three months and the effluent was collected at the outlet of the column. During drying cycle the soil from the columns were taken out and spread on the ground surface in such a way that the soil gets enriched with oxygen and micro organisms from the atmosphere. Table 1 shows the maximum parameter efficiency attained at which type of soil under which wetting and drying cycle.

Table 1: Maximum reduction of Parameters after SAT under Different Cycles

Parameters	**Before SAT**	**Type of Soil**	**Wetting and Drying cycle (W/D)**		
			1 W/1D	**2W/2D**	**3W/3D**
pH	7.77	Silty loam	8.2	7.6	7.1
Turbidity (NTU)	6.64	Sandy loam	2.51	2.4	2.0
TDS (mg/l)	1470	Silty loam	1010	810	960
Nitrate (mg/l)	0.168	Clay	0.27	0.006	0.051
Nitrite (mg/l)	0.497	Clay	0.485	0.483	0.484
BOD (mg/l)	28	Clay	7	9	13
COD (mg/l)	53.5	Clay	45.09	45.10	45.12

- Limited change in pH, Turbidity and TDS;
- Out of three soil used, clay soil was found to be suitable to reduce organic compounds BOD and COD;
- Removal of Nitrate and Nitrite was very less;

Remaining experiments were carried out with clay soil under different wetting and drying cycles. Table 2 shows the removal efficiency of various parameters.

Table 2: Comparative study of wastewater Quality after SAT with Clay Soil

Before SAT							
Date	**pH = 7.62**	**TDS = 967 (mg/l)**	**NO_3^- = 0.273 (mg/l)**	**NO_2^- =0.4864 (mg/l)**	**NH_3-N = 5.6 (mg/l)**	**BOD_5 = 29 (mg/l)**	**COD = 64 (mg/l)**
One day wetting/ one day drying							
8/06/2010	7.9	885	3.846	0.5216	5.6	9	54.7
10/06/2010	-	-	-	-	-	-	-
12/06/2010	8.3	871	3.319	0.4911	2.24	11	45.8
14/06/2010	8.5	866	2.552	0.4907	1.12	10	45.7
16/06/2010	7.5	855	2.295	0.4903	1.12		45.3
Two days wetting / two days drying							
9/06/2010	7.9	993	1.250	0.4816	2.24	15	48.2
13/06/2010	7.8	823	1.238	0.4842	2.24	19	44.0
17/06/2010	7.8	830	1.195	0.4840	1.12	16	44.0
Three days wetting / three days drying							
10/06/2010	8.2	817	1.904	0.4849	2.24	19	45.6
16/06/2010	7.8	806	1.647	0.4875	1.12	15	44.3

- There is no much change in pH and TDS;
- Very limited reduction in NO_2^-
- NO_3^- increased initially and reduced later during one day wetting and drying cycle;
- BOD_5 reduced from 29 mg/l to 9 mg/l in one day wetting and one day drying cycle compare to other two cycles;
- COD was reduced from 64 mg/l to 45 mg/l maximum of 20 percent in all the three cycles;
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COD Removal

In the earlier experiments only 20 percent of COD (ie. 64 to 44 mg/l) was removed whose permissible limit for groundwater recharge is less than 10 mg/l . Hence in the following column experiments removal efficiency of COD and coliforms were carried out with sandy loam of 0.001 to 0.6 mm that was experimented with various hydraulic loading rates(HLR), different head of water, and wetting and drying cycle, aerated the effluent, application of UV light, mixing of hydrogen peroxide in the influent wastewater. Seven experiments with various combinations were carried out. First four experiments removed very low COD. But the experiments 5, 6 and 7 were able to remove better COD which are discussed here.

Table 3: Comparison of COD Removal in the Experiments 1,2, 3 and 4

Sl. No.	Experiment	Soil Type	Depth of Soil (cm)	Hydraulic Loading Rate	Wetting and Drying Cycle	UV light /Aeration	COD Removal (%)	Remarks Maximum COD removal attained at
1.	Different HLR	Sand <0.6 mm	98	0.1 to 0.6 m/day	4 W/4D	-	0.2	Medium loading rate 0.25 to 0.4 m/d
2.	Different Head of Water	Sandy Silty Loam	50	5 cm to 20 cm head of water	4 W/4D	-	0.9	5 cm head of water above the soil
3.	Different wetting and drying cycle	Sandy Silty Loam	50	5 cm head of water	4W/4D to 7 W/7D	-	0.7	5days wetting/5 days drying cycle
4.	UV light and Aeration	Sandy Silty Loam	50	5 cm head of water	5W/5D	UV light/ Aeration	6.5	Aerated the influent

- **Limited COD was removed in the above four experiments**

From the table 3, it is clear that sandy loam with other parameter combinations it was able to remove COD to a maximumof 6.5 percent ie. 42 mg/l to 38 mg/l only. In order to reduce the COD, extensive literatures were reviewed.

M.Asano et al. (2008) expressed that it is very hard to reduce non degradable COD from the wastewater due to presence of toxic substances such as humic acid which are resistant to microbial degradation. They used ozone oxidation and UV irradiation to remove the non biodegradable substances. Humic acid was decomposed into lower molecules, in turn COD wad reduced under Ozone/UV treatment. **A.Ried et al.** (2006) installed an ozone/H_2O_2 treatment step to degrade COD. Ozonation of effluents is an efficient way to reduce the COD by oxidation of the organic molecules. The oxidation properties were improved by combining ozone with Hydrogen Peroxide (H_2O_2) which generated additional hydroxyl radicals that react very fast with organic molecules.

Based on the above works Hydrogen Peroxide was added with secondary treated wastewater at different concentrations in such a way that the pH should be between 7 to 8. Experiments were conducted at four days wetting and 4 days drying cycles at 5 cm constant head of wastewater with 50 cm soil column depth. Dissolved Oxygen in the applied water was between 2 and 4 mg/l. Aeration was supplied at the rate of 1.5 l/min. DO in the effluent collected from the bottom of the column was 9 to 10 mg/l. Philips UV 6W bulb of 16 mm dia with 161 mm length under 254nm wavelength was used. The results are shown in Table 4, 5 and 6.

Experiment 5: Hydrogen Peroxide 50 ppm

Table 4: pH, TDS, COD and the Removal efficiency of COD in Experiment 5

pH Range before SAT 7.5 to 8.6 TDS Range before SAT 500 to 790 mg/l COD Range before SAT 40 to 45 mg/l				
Column 1 – UV light + Aeration + 50 ppm concentration of Hydrogen Peroxide				
Date (Mar)	pH	TDS mg/l	COD mg/l	Removal Efficiency (%)
COD				
15	7.72	670	32	25.58
16	7.73	680	31	27.82
18	7.51	509	**29**	**30.95**
19	7.83	490	32	25.58
Column 2 - UV light + 50 ppm concentration of Hydrogen Peroxide				
15	7.75	650	33	23.25
16	7.80	649	31	27.82
18	7.54	503	30	28.57
19	7.88	475	33	23.25

- **Maximum of 31 percent of COD reduced under UV light, aeration and 50 ppm concentration of H_2O_2 combination**

Experiment 6: Hydrogen Peroxide 40 ppm

Table 5: COD and the Removal Efficiency of COD in Experiment 6

pH Range before SAT 7.5 to 8.6 TDS Range before SAT 500 to 790 mg/l COD Range before SAT 44 to 45 mg/l				
Column 1 – UV light + 40 ppm concentration of Hydrogen Peroxide				
Date	pH	TDS mg/l	COD mg/l	Removal Efficiency (%)
COD				
26-Apr	7.698	670	31	24.39
27-Apr	7.564	630	28	34.81
28-Apr	7.69	495	**21**	**50.00**
29-Apr	7.895	490	25	41.86
Column 2 – 40 ppm concentration of Hydrogen Peroxide				
26-Apr	7.789	650	35	18.60
27-Apr	7.632	620	31	27.82
28-Apr	7.984	503	29	30.95
29-Apr	7.89	498	33	23.26

- **Maximum of 50 percent of COD was removed under UV light, aeration and 40 ppm concentration of H_2O_2 combination;**

Experiment 7: Increased Soil Depth (100 cm)

Table 6: Values of pH, TDS, COD and the Removal Efficiency of COD in Experiment 7

pH Range before SAT 7.5 to 8.6 TDS Range before SAT 500 to 610 mg/l COD Range before SAT 40 to 45 mg/l				
Date (May)	pH	TDS mg/l	COD mg/l	Removal Efficiency (%)
COD				
3	7.80	530	25	37.50
4	7.56	510	19	52.50
5	7.72	480	**16**	**60.00**
6	7.63	490	17	57.50

- **Maximum of 60 percent COD was removed under UV light, aeration and 40 ppm concentration of H_2O_2 and double the depth of soil column(100 cm) w.r.to earlier experiments;**

Hence it was concluded that maximum reduction of COD was observed during third day of wetting cycle. Even after mixing of 40 ppm of hydrogen peroxide it was not able to reduce the COD to 10 mg/l.

Removal of Coliforms

More than 99 percent of total coliforms (TC) and faecal coliforms (FC) were removed in the combination of 2 to 4 mg/l of oxygen and UV light. It is found that UV light was the main parameter to remove the bacteria and viruses. Maximum removal efficiency of TC and FC was after 4 days of wetting. The values and removal efficiency of TC and FC are shown in table 7.

Table 7: Removal Efficiency of Total Coliforms and Faecal Coliforms

Total Coliforms range before SAT 2000 to 20000 MPN/100 ml Faecal Coliforms range before SAT 500 to 7000 MPN/100 ml					
Date (2011)	Total Coliforms (T.C) (MPN/100ml)	Faecal Coliforms (F.C) (MPN/100ml)	Volume of Water collected(lit/d)	Removal Efficiency (%)	
Column 1 - 5 Days Wetting / 4 Days Drying + UV Light + Aeration				T.C	F.C
1-Mar	136.08	1482.34	10.980	28.11	72.80
2-Mar	988.22	1430.91	9.300	54.15	65.94
3-Mar	120.99	1126.44	6.660	92.49	81.11
4-Mar	24.74	206.20	4.200	99.01	**99.65**
5-Mar	37.90	258.90	2.400	96.50	97.46
Column 2 - 5 Days Wetting / 5 Days Drying + UV Light + Aeration					
1-Mar	360.56	1425.52	6.30	30.87	27.93
2-Mar	1040.27	1103.37	6.18	64.64	64.14
3-Mar	37.55	258.56	4.38	98.28	83.99
4-Mar	37.55	150.55	4.26	99.28	**99.46**
5-Mar	66.15	198.45	2.34	97.31	97.44
Column 3 - 5 Days Wetting / 4 Days Drying + UV Light					
1-Mar	321.87	950.35	6.66	53.91	35.66
2-Mar	577.35	950.35	6.36	69.55	80.10
3-Mar	31.02	237.25	4.68	98.42	84.21
4-Mar	12.10	73.39	1.98	99.65	**99.83**
5-Mar	24.74	112.64	0.90	98.48	99.35
Column 4 - 5 Days Wetting / 5 Days Drying + UV Light					
1-Mar	384.90	359.00	6.60	82.59	23.06
2-Mar	136.08	950.35	6.42	69.55	95.31
3-Mar	50.41	148.23	6.00	99.01	83.54
4-Mar	10.26	73.39	5.64	99.65	**99.85**
5-Mar	24.74	112.64	2.58	98.48	99.35

Soil Clogging and Hydraulic Conductivity

Clogging was observed while the wastewater was passing through the soil column. Clogging rate was estimated by measuring the volume of effluent from the outlet of the column after SAT. In order to understand the clogging propensity of soil, ten days continuous wetting of soil was conducted and evaluated as shown in figure 3. Due to continuous wetting, soil pores were blocked hence its saturated hydraulic conductivity was reduced as shown in table 8.

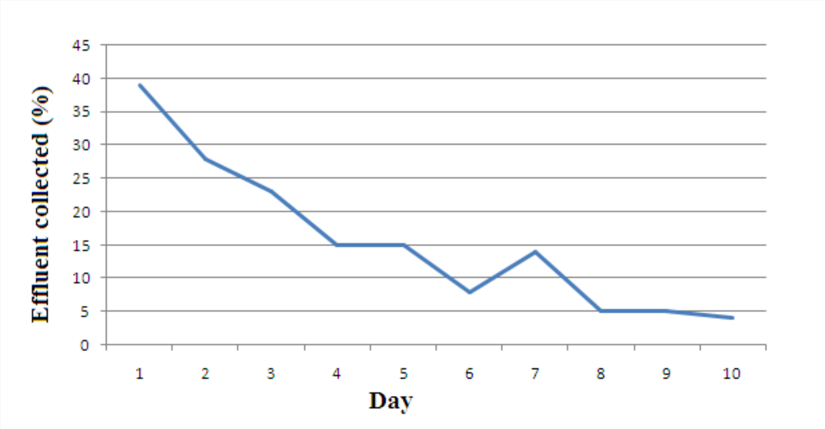

Figure 3 Percent Reduction in the Effluent Quantity after the SAT

Table 8: Reduction in the Saturated Hydraulic Conductivity

Cycle	**Before SAT m/day**	**After SAT m/day**	**Reduction of K %**
4 days wetting and 4 days drying	0.142	0.088	38
5 days wetting and 5 drying	0.195	0.104	47

Algal Growth

Clogging occurred in the top portion and it is dependent on organic mass loading. Algal growth was observed at the top surface of the soil as shown in figure 4. Clogging increased with increase in the wetting period. Effective wetting and drying cycle improves the hydraulic conductivity of the soil.

Figure 4: Suspended Algal Growth

Adsorption of Ions Over Soil

The soil was analysed for the adsorption of the chemical pollutants by the soil after SAT. Soil samples were extracted from the column and analyzed for ion adsorption. Results are shown in table 9, table 10 and table 11.

Table 9: Characteristics of Sandy Loam Soil before and after SAT

Parameters	**Unit**	**Before SAT**	**After SAT**
Nitrate (NO_3)	ppm	6.4	10.0
Phosphorus (P)	ppm	8.3	33.9
Potassium (K)	ppm	9	51
Calcium (Ca)	ppm	186	1453

Magnesium (Mg)	ppm	72	143
Sulphur (SO_4^{2-})	ppm	6.6	13.8
Sodium (Na)	ppm	36	98
Zinc (Zn)	ppm	0.14	3.75
Manganese (Mn)	ppm	1.02	2.13
Iron (Fe)	ppm	9.90	18.85
Copper (Cu)	ppm	0.09	3.21
Boron (Bo)	ppm	0.6	1.1
pH	-	7.51	8.41
Electrical Conductivity	mS/cm	0.018	0.125
Organic matter	%	0.10	0.61
CEC	Meq/100g Soil	1.71	9.01

Table 10: Characteristics of Silty Loam Soil before and after SAT

Parameters	Unit	Before SAT	After SAT
Nitrate (NO_3)	ppm	4.3	6.2
Phosphorus (P)	ppm	40.5	56.4
Potassium (K)	ppm	60	85
Calcium (Ca)	ppm	397	1516
Magnesium Mg)	ppm	78	146
Sulphur (SO_4^{2-})	ppm	5.7	6.9
Sodium (Na)	ppm	75	157
Zinc (Zn)	ppm	0.83	3.47
Manganese (Mn)	ppm	8.69	3.62
Iron (Fe)	ppm	36.74	12.91
Copper (Cu)	ppm	1.42	3.12
Boron (Bo)	ppm	0.5	0.8
pH	-	5.91	8.55
Electrical Conductivity	mS/cm	0.026	0.185
Organic matter	%	0.25	0.35
CEC	Meq/100g Soil	3.11	9.70

Table 11: Characteristics of Clay Soil before and after SAT

Parameters	Unit	Before SAT	After SAT
Nitrate (NO_3)	ppm	6.5	6.1
Phosphorus (P)	ppm	12.3	9.0
Potassium (K)	ppm	131	219
Calcium (Ca)	ppm	2317	2398
Magnesium (Mg)	ppm	678	620
Sulphur (SO_4^{2-})	ppm	3.0	12
Sodium (Na)	ppm	174	466
Zinc (Zn)	ppm	0.52	3.11
Manganese (Mn)	ppm	14.59	14.08
Iron (Fe)	ppm	4.52	7.38
Copper (Cu)	ppm	2.94	4.99
Boron (Bo)	ppm	0.6	0.9
pH	-	7.06	8.15
Electrical Conductivity	mS/cm	0.121	0.271
Organic matter	%	0.40	0.99
CEC	Meq/100g Soil	18.33	19.74

Through soil analysis before and after SAT following information were derived:

- Sandy loam soil adsorbed more percentage of ions such as P, K, Ca, Ma, Na, Zn, Mn, Fe, Cu because by nature sandy loam soil has less ion content.
- Silty loam soil adsorbed more percentage of Boron compared to other two soild. It also adsorbed good amount of other ions.

- Clay soil adsorbed more percentage of SO_4 and small amount of K, Na, Zn, Fe, Cu and Bo.
- In addition, it is felt that incremental ions over the soil is not only from the wastewater, which is also gathered from the ground surface where the soil is left for drying during drying cycle.

Major findings of the experiments

i. Clay is suitable for removing BOD_5 and COD under frequent wetting and drying cycles;
ii. Soil type and soil depth are important parameters in reducing COD to certain extent;
iii. UV light and Aeration to the influent have little effect on removing COD
iv. COD removal is sensitive with Hydrogen peroxide;
v. Nitrate and Nitrite increased after SAT;
vi. SAT is the excellent technology to remove BOD and coliforms which are removed within 10 to 30 cm of depth of soil from the ground surface;
vii. Wetting and drying cycles are important in improving the hydraulic conductivity of the soil;

CONCLUSION

The objective of this study is to establish the feasibility of the SAT technology in Chennai city sub surface geological formation with secondary treated waste water as an influent. The SAT technology has been investigated with different combinations of wetting and drying cycles, soil types, soil depth, hydraulic loading rate using secondary treated wastewater through experimental column study. Further studies along similar lines over longer periods would add site specific results to the experimental study. This research has to go long way to reduce COD and nitrogen compounds within permissible limit. De-nitrification process is to be activated to reduce nitrate (NO_3^-) during SAT. Extensive research is needed to understand the SAT technology. Based on the further research, SAT technology can be proposed and implemented in the sewage treatment plants of Chennai city by constructing SAT infiltration basins for waste water reuse as a source for aquifer recharge.
" It is sure that Soil Aquifer Treatment technology would provide good quality of water which will definitely be used for aquifer recharge".

BRIEF PROFILE OF THE AUTHORS

Prof. Madhavi Ganesan is basically a Civil Engineer (A.M.I.E.) and did her Post Graduated in M.E. Hydrology and Water Resources Engineering from the Anna University in 1993. She Obtained a Ph.D. in Civil Engineering at the Anna University in the field of Groundwater Management from 1993 - 1998. She worked in the field of rainwater harvesting and recharge, wastewater reuse in the University of Essen, Germany from 1999 to 2001. In 2001 she joined as a Assistant Professor at SRM University and joined in the Anna University during the year 2004 and became a Associate Professor in 2006. Her specialization is Groundwater Prospecting and Modeling, and Aquifer Parameter Estimation through field studies and Numerical Modeling.

Other two authors V.R. Raji and S.Lavanya are PG students of Dr. Madhavi Ganesan who are now working as a Assistant Professor in the private Engineering College affiliated to Anna University.