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Ammonia Behaviour in Wastewater Reclamation by Soil Aquifer Treatment

Selvakumar Thiagarajan[1*] and Madhavi Ganesan[2]

[1]Civil, KCG College of Technology, Chennai - 97, Tamil Nadu, India; selva301164@gmail.com
[2]Centre for Water Resources, Anna University, Chennai - 600025, Tamil Nadu, India; madhaviganesan@yahoo.com

Abstract

Groundwater use is increasing all over India and Chennai is not an exception. A good possibility exists to recharge artificially the excess treated wastewater through Soil Aquifer Treatment (SAT) and use the recharged water for purposes other than drinking. Soil column experiments were performed, in order to study the ammonia, nitrite and nitrate reduction from Real Secondary Treated Wastewater (RWW). SAT was simulated in four 15 cm long soil columns packed with soils of Sandy Clay Loam (SCL) texture collected from Anna University Sewage Treatment Plant (STP), Chennai, India. Soil Columns were ponded with wastewater to a depth of 2.5 cm above the soil surface and operated for a period of Ten cycles under 4 different alternating wet and dry cycles, 0.25 day wet/1.75 days dry (R1), 0.25 day wet/2.75 days dry (R2), 0.25 day wet/3.75 days dry (R3) and 0.25 day wet/7.75 days dry (R4). The effect of wetting and drying periods on SAT ammonia removal performance was assessed comparing ammonia, nitrite, nitrate nitrogen and TDS rates. The removal of ammonia was through nitrification process which is found to be a dominant removal mechanism of nitrogen. Nitrification differed according to the different drying cycle's time with fixed flooding period. When the reduction performance achieved with different drying cycles were compared, it could be seen that longer drying periods with R3 column yielded with the least nitrate value of 0.58 mg/l. From this study, it was found that with the fixed wetting period, maximum drying period is required for nitrate reduction and minimum drying period is required for TDS reduction.

Keywords: Ammonia Transformation, Nitrate Removal, Nitrite, Real Secondary Treated Wastewater, Soil Aquifer Treatment

1. Introduction

Chennai formerly known as Madras, is the capital of the state of Tamilnadu and India's fourth largest Metropolitan City. Over burden by means of population pressure, unplanned urbanisation, unrestricted exploration policies and dumping of the polluted water at inappropriate place enhance the infiltration of harmful compounds to the groundwater. The hydrogeochemical conditions are also responsible for causing significant variations in groundwater quality[1]. Creative water management will become essential in future. There are 39 temple tanks in the city of Chennai, most of which have been dry for the past one decade due to rapid urbanisation and continuous withdrawal of groundwater. The temple tanks of Chennai act as water conservation structures, apart from serving their traditional function. They can be filled to their capacity by having storm drains from the surrounding urban area directed to the tanks. A full tank has an aesthetic value, and the quality of water is also good for a limited exposure use category[2].

Dumping of solid waste in unscientific manner and discharge of sewage effluents are the main reasons for contamination of groundwater. The electrical resistivity technique is particularly suited for the detection of ionic impurities in groundwater owing to the resistivity contrast between the polluted zone and the hard rock. It is faster and more economical than going through the

**Author for correspondence*

process of drilling to the target formation. Geophysics provides spatially integrated information, which may be superior for some purposes to the point data provided by drilling. Near Perungudi dumping yard area along the Pallikaranai marsh land in Chennai, the groundwater in contaminated upto approximately 1.5 to 1.75 km from the dumping yard spatially and for a 100 m depth[3,4].

The electrical resistivity technique is particularly suitable for identifying the subsurface formations - the aquifer zone as well as the formations saturated with saline/brackish water. The electrical resistivity method provides a veritable tool for mapping the degree and the immediate subsurface vicinity. It is a fast, economic and non-invasive method of studying groundwater contamination as well as other environmental issues and it has proved to be promising and useful as predicted. The method is not used to directly detect the contaminants; rather it is used in the investigation of the geological environment through which the contaminants move, and in the determination of the distribution of pollutant in space and time through monitoring. An integration of geophysical methods with data interpretation largely resolves the uncertainty. The chemical analysis of groundwater samples is helpful in studying the hydrogeological conditions and saline contamination of aquifer zones. This also discriminates between the lithology and water quality effects when the two cannot be differentiated by a resistivity survey alone[5]. The electrical resistivity technique involves the measurement of the apparent resistivity of soils and rock as a function of depth or position. The most common electrical technique needed in hydrologic and environmental investigations is vertical electrical sounding (resistivity sounding)[6]. When trying to perform an integrated management of water resources, groundwater volumes can be increased by reusing reclaimed water for recharge. The geoelectrical resistivity survey of the Chennai sewage treatment plants revealed that vertical electrical sounding measurements are effective to study the suitability of reclaimed water recharge and to understand the present groundwater conditions; Anna University and Koyambedu sewage treatment plant sites are suitable for reclaimed water recharge[7].

Reclaimed water is an ever more valued non-conventional water resource. Where hydrogeological conditions are favourable, wastewater reclamation can be implemented in a simple way by the Soil Aquifer Treatment (SAT) process. SAT is a cost effective natural wastewater treatment and reuse technology. It is an environmentally friendly technology that does not require chemical usage and is applicable to both developing and developed countries. Reuse of treated wastewater through infiltration basin serves as a medium for transport of ammonia and nitrate to groundwater through SAT[8–12]. A great amount of ammonia is transformed to nitrate in the vadose zone, resulting in the high nitrate concentrations within groundwater aquifers. The release of excess nitrogen-containing compounds into groundwater is a major concern in aquifer recharge by SAT. SAT technology makes use of Soil to treat the reclaimed wastewater, the treatment process occurs through infiltration, Soil Percolation and transport through the groundwater aquifer[13–15]. During the groundwater recharge through the Vadose zone and transport through the groundwater aquifer, water quality improvements occur that are collectively described as Soil Aquifer Treatment[16]. Filtration, Sorption and biodegradation processes in the soil are mechanisms that can reduce or remove microbial and other contaminants in wastewater[17]. SAT is a process of geo-purification designed and operated to improve the quality of the infiltrating water.

Understanding removal mechanisms achieved by aquifer recharge is complex at full site and therefore, soil column experiments are performed in order to test how the quality of the wastewater effluents can be improved as well as to investigate how different types of soils can influence the removal of specific contaminants[18–20]. However no trend exists regarding the configuration of the columns used. Soil columns can vary in size from 5 cm[21] upto 2.4 m[22]. During SAT, Cyclic flooding/drying operations is necessary. The primary purpose of wet/dry cycle operation is to control the development of clogging layers and maintain high infiltration rates. As a clogging layer develops during a wetting cycle, infiltration rates can decrease to un-acceptable rates. The drying cycle allows for the desiccation of the clogging layer and the recovery of infiltration rates during the next wetting cycle.

The main objective of this study is to investigate the ammonia behaviour of the Real Secondary Treated Wastewater (RWW) during groundwater recharge by SAT under Anna University STP conditions using soil columns. Centred on this objective, this study intends to investigate ammonia transformation and removal under nitrification condition and to measure the significance of the adsorption process on fate of ammonia.

2. Materials and Methods

2.1 Design and Operation of Soil Columns

A multi column SAT system was constructed in laboratory conditions. The experimental setup consisted of four identical PVC soil columns of 15 cm length and 6 cm inner diameter, one feeding tank for RWW; feeder assembly and distributor lines. The experimental setup with columns and feeding tank are shown in Figure 1. The columns were operated under 4 different alternating wet and dry cycles, 0.25 day wet/1.75 days dry, 0.25 day wet/2.75 days dry, 0.25 day wet/3.75 days dry and 0.25 day wet/7.75 days dry. RWW was applied for a period of 6 hrs (from 9 am to 3 pm). The samples taken from column were collected at the end of the first wetting day, for all 4 cycle combinations.

Soil columns were operated inside centre for water resources building, without any additional climatic temperature control inside the building during the study period. The lower part of the columns (approximately 5cm) was filled with pebbles. The columns were provided with outlets for sample collection at bottom. All the columns were filled with 5 cm of soil. Soils were poured into the columns and no compaction of soils inside the columns was carried out.

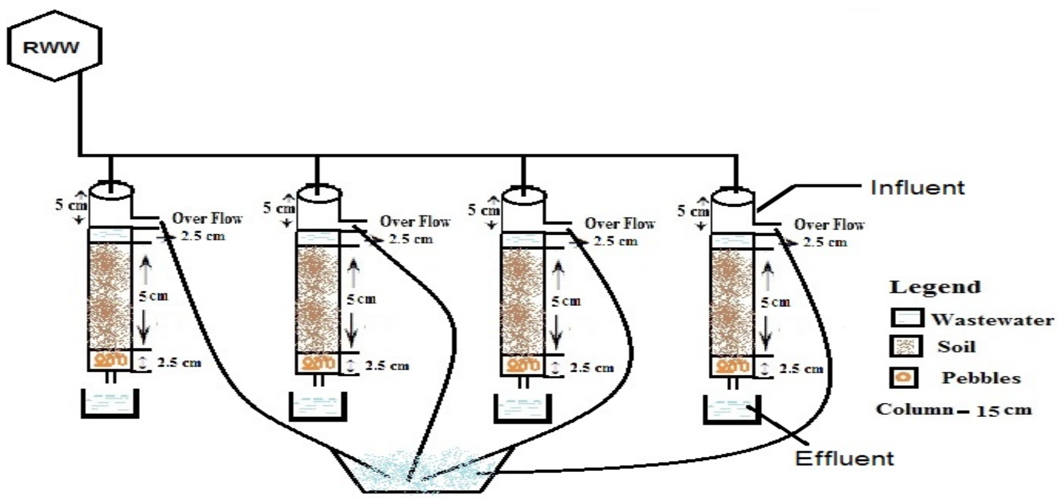


Figure 1. Schematic illustration of the Soil Columns setup.

Table 1. Typical wet/dry ratios for SAT systems[23]

Location	Pre Application Treatment	Application Period, Days	Drying Period, Days	Wet/Dry Ratio
Barnstable, MA	Primary	1	7	0.14
Boulder, CO	Secondary	0.1	3	0.03
Calumet, MI	Untreated	2	14	0.14
Ft.Devens, MA	Primary	2	14	0.14
Hollister, CA	Primary	1	14	0.07
Lake George, NY	Secondary	0.4	5	0.08
Phoenix, AZ	Secondary	9	12	0.75
Vineland, NJ	Primary	2	10	0.20

Table 2. Wet/Dry ratios for this short column study

Sl. No.	Column Id	Wetting Period (Days)	Drying Period (Days)	Wet/Dry Ratio
1.	R1	0.25	1.75	0.14
2.	R2	0.25	2.75	0.09
3.	R3	0.25	3.75	0.06
4.	R4	0.25	7.75	0.03

The ratio of wetting to drying in successful SAT system varies, but is always less than 1[23]. For secondary effluent the ratio varies with the treatment objective, from 0.1 or less where nitrification or maximum hydraulic loading is the objective, to 0.5 – 1.0 where nitrogen removal is the treatment objective. The selection of wet/dry ratio for this study ranges from 0.03 to 0.14 and is also in accordance with the EPA process design manual[24]. Typical wet/dry ratios for some SAT system in USA and wet/dry ratios for this short column study are given in Table 1 and Table 2.

2.2 Soil Samples and Properties - Anna University STP Soil

Soil samples from Anna University STP were collected from depth ranging between 0 and 0.75 m (referred to as top soil). The selection of the depth range was based on the fact that previous studies indicated that most of the purification takes place at the upper most layer of the soil[25]. It is the natural soil that has been collected from the STP without any treatment. In order to eliminate the interference with the secondary treated wastewater, it was washed several times with distilled water and left to dry. The bulk soil was homogenized, sieved and the gravel fraction >1.7 mm excluded. Soil columns were left submerged in distilled water for 48 hrs to remove trapped air from the bottom and to remove soluble irons. This was made to minimize the interference of the soil on the behaviour of ammonia. The Soil textural classification, physical and chemical characteristics of the soil are given Table 3 and Table 4 using methods of Analysis of Soils as per HLS Tandon[26].

2.3 Real Wastewater (RWW)

Secondary treated wastewater from Anna University STP, where wastewater is treated by an activated sludge process was used in this study as a feed solution for SAT simulated soil columns. The wastewater characteristics collected from Anna University STP is given in Table 5.

2.4 Experimental Procedure and Analytical Methods

During the studies, EC, TDS, ammonia (NH_3), nitrite (NO_2) and nitrate (NO_3) were measured in Centre for Water Resources, Anna University wet chemistry lab. These measurements were made in samples collected from the outlet of each column as well as the stock solution during all studies. After the RWW stock samples were taken from the STP for RWW studies, the samples were immediately transferred to the laboratory where it was stored in the refrigerator at 4°C. Samples taken from column were collected at the end of first wetting day for all 4 cycle combinations. When the samples were taken into plastic bottles of 500 ml. their caps were right away closed to prevent air entry.

EC and TDS measurements were made by using EQ8361 EQUINOX Pen type EC/TDS meter. Wastewater was stored in plastic bottles and kept at 4°C in order to reduce the effects of biochemical reactions. No additives or preservatives were used to preserve wastewater quality. Wastewater was warm to the room temperature before application on soil columns. Samples were collected from the bottom of each column. The samples were filtered with 0.45μm filters and stored at 4°C, NH_3, NO_2 and NO_3 were detected in each sample.

Ammonia was measured using Phenate method. Ammonia (NH_3) was determined using the standard curve after measuring the absorbance at 640 nm of standards and samples using Visiscan systronics spectrophotometer. The calibration curve (NH_3) vs. absorbance was prepared using the standard stock solution of NH_4Cl.

Nitrite was analysed with Visiscan systronic spectrophotometer. The method is based on the reaction of

Table 3. STP Soil Textural classification

Sl. No.	Name of the STP	% Sand	% Silt	% Clay	Textural class of soil as per USDA* Texture
1.	Anna University	67	4	29	Sandy Clay Loam

* United States Department of Agriculture

Table 4. Physical and Chemical characteristics of the study area soil

Sl. No.	Parameter	Unit	Anna University STP
1.	pH	-	7.25
2.	Electrical Conductivity	µS/cm	198
3.	Organic matter	%	0.32
4.	Nitrate Nitrogen	ppm	7.0
5.	Available Phosphorus	ppm	8.90
6.	Potassium Exchangeable K	ppm	48
7.	Calcium Exchangeable Ca	ppm	1550
8.	Magnesium Exchangeable Mg	ppm	426
9.	Sulfur Available S as So_4^{2-}	ppm	49.1
10.	Sodium Exchangeable Na	ppm	161
11.	Zinc Available Zn	ppm	0.32
12.	Manganese Available Mn	ppm	16.45
13.	Iron available Fe	ppm	13.80
14.	Copper Available Cu	ppm	1.48
15.	Cation Exchange capacity	Meq/100g	19.23

Table 5. Secondary Treated Wastewater characteristics from Anna University STP (Test methods as per HLS Tandon)[26]

Sl. No.	Parameter	Unit	Values
1.	pH	-	7.00
2.	Electrical Conductivity	µS/cm	1121
3.	TDS	mg/l	717.44
4.	Total Alkalinity as Calcium Carbonate	mg/l	120
5.	Sulphate	mg/l	23.3
6.	Chloride	mg/l	184.6
7.	Nitrate	mg/l	4.9

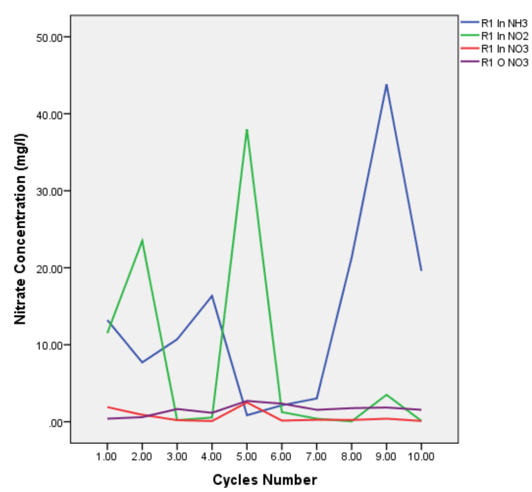
8.	Iron	mg/l	0.11
9.	Pottassium	mg/l	37
10.	Calcium	mg/l	71
11.	Magnesium	mg/l	24
12.	Sodium	mg/l	250
13.	Manganese	mg/l	0.04
14.	Zinc	mg/l	Below Detection Level
15.	Copper	mg/l	0.01
16.	Aerobic Microbial Count @ 30° C	cfu/ml	176
17.	E. Coli	cfu/ml	Nil
18.	Total Coliform (MPN method)	cfu/ml	7
19.	Fecal Coliform	MPN/100 ml	1,76,366
20.	TSS	mg/l	41
21.	COD	mg/l	117
22.	BOD	mg/l	26
23.	Oil and Grease		4

nitrite ions with sulfanylamide in acidic medium and the diazo compound obtained further reacts with diamine yielding in an azo colour. The nitrite ion concentrations determined by measuring the absorbance of the azo colour at 543 nm.

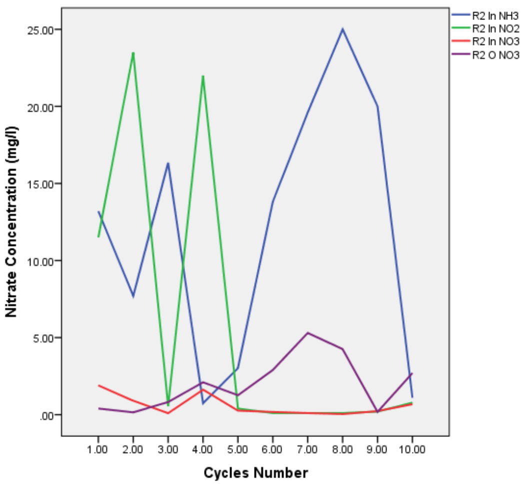
Nitrate was analysed using cadmium reduction method. The analysis was conducted according to the American Public Health Association (APHA) standard methods for the examination of water and wastewater[27].

3. Results and Discussion

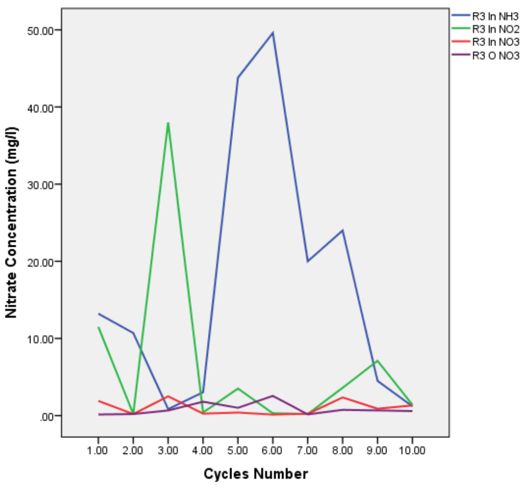
The influent (i.e. the secondary treated wastewater) is having fluctuating inputs of NH_3, NO_2 and NO_3 daily. Due to non uniform NH_3, NO_2 and NO_3 in the daily influent of RWW, Effluent NO_3 behaviour have to take care of all the 3 mentioned with the mechanisms of adsorption of soil with high CEC (19.23 meq/100g) and nitrification as shown in Figure 2(a), 2(b), 2(c) and 2(d).



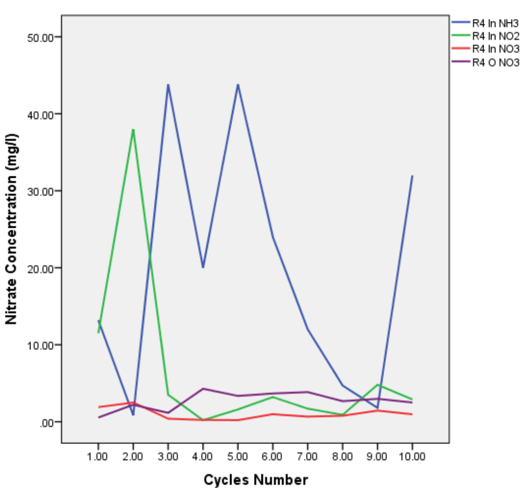
(a)


R2 In NH3
R2 In NO2
R2 In NO3
R2 O NO3
Nitrate Concentration (mg/l)
Cycles Number

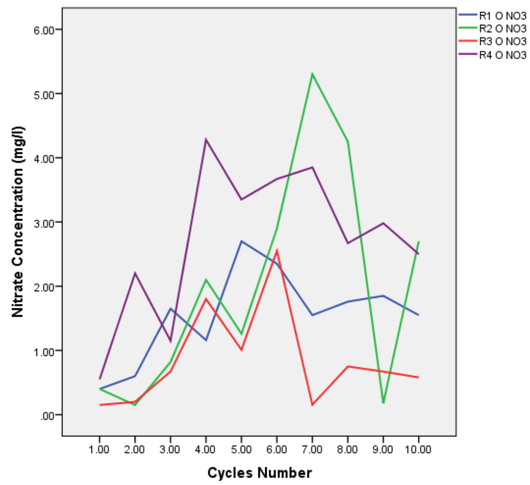
(b)


R3 In NH3
R3 In NO2
R3 In NO3
R3 O NO3
Nitrate Concentration (mg/l)
Cycles Number

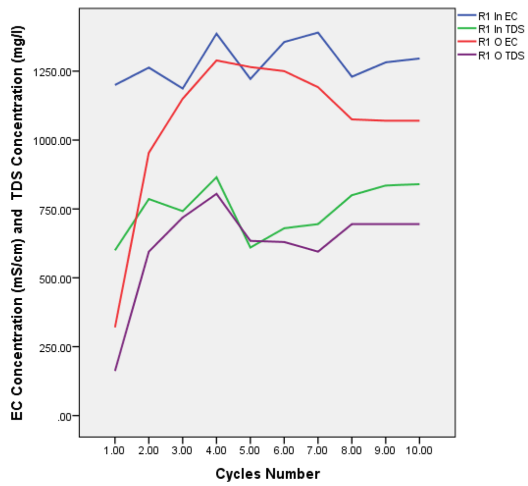
(c)


R4 In NH3
R4 In NO2
R4 In NO3
R4 O NO3
Nitrate Concentration (mg/l)
Cycles Number

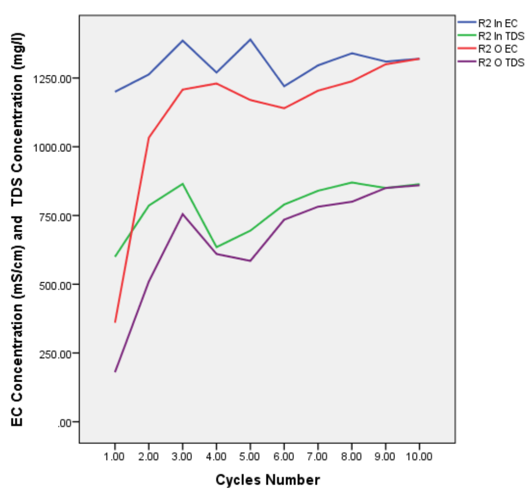
(d)


R1 O NO3
R2 O NO3
R3 O NO3
R4 O NO3
Nitrate Concentration (mg/l)
Cycles Number

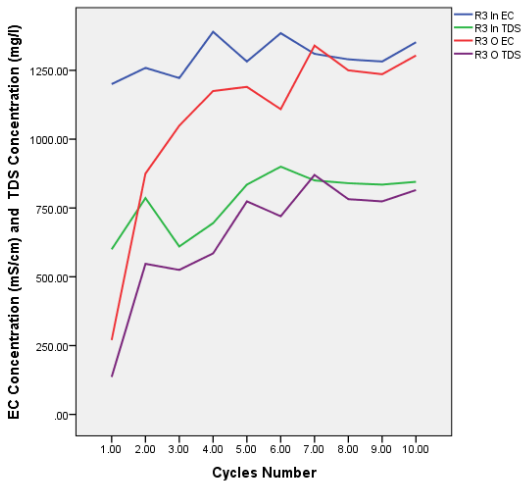
(e)


R1 In EC
R1 In TDS
R1 O EC
R1 O TDS
EC Concentration (mS/cm) and TDS Concentration (mg/l)
Cycles Number

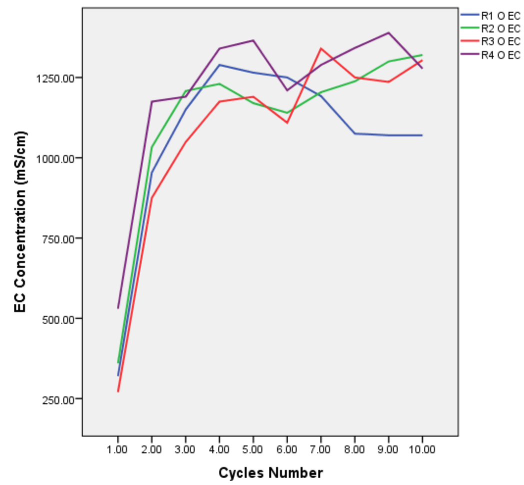
(f)


R2 In EC
R2 In TDS
R2 O EC
R2 O TDS
EC Concentration (mS/cm) and TDS Concentration (mg/l)
Cycles Number

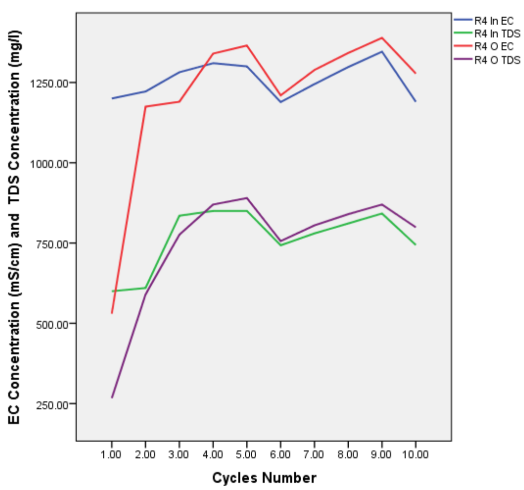
(g)



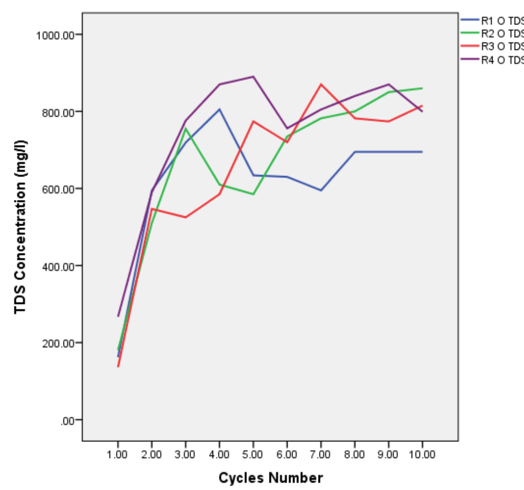
(h)



(j)



(i)



(k)

Figure 2. Real Wastewater (RWW). (a)-(d) Influent NH_3, NO_2, NO_3 with Effluent NO_3 for R1, R2, R3 and R4; (e) NO_3 Distribution; (f)-(i) Influent and Effluent EC and TDS; (j)-(k) Effluent EC and TDS Concentration.

At the end of 10th cycle it was found that R3 column was most efficient with least nitrate content of 0.58 mg/l followed by R1, R4 and R2 columns of the corresponding nitrate values with 1.55. 2.50 and 2.70 mg/l respectively as per Figure 2(e).

The influent (i.e. the secondary treated wastewater) is having fluctuating inputs of EC and TDS. Due to non uniform EC and TDS in the daily influent of RWW, the output of EC and TDS differs as per Figure 2(f), 2(g), 2(h), 2(i). The effluent EC and TDS values are shown in Figure 2 j and 2 k.

The removal of ammonia was thro nitrification process which is considered to be a dominant removal mechanism of nitrogen. The transport of ammonia depends upon the availability of oxygen, nitrifier bacteria and inorganic carbon source.

This is consistent with previous findings which demonstrate that biodegradation is the dominating mechanism for the removal of ammonia[28–31].

Nitrite (NO_2^-) develops as an intermediate product of NH_3 and NO_3. Nitrite concentration in the experiment was rapidly oxidised to nitrate.

The bio reaction is generally coupled and proceeds rapidly to nitrate form. Therefore, nitrite levels at any given time are usually low. Increased concentration is usually an indication of a disturbance of microbiological processes, of an overloaded in the system or insufficient aeration capacity[32]. A common hypothesis for ammonia removal is the two-step process of autotropic nitrification and adsorption of ammonia to the clay particle and organic fraction in the soil. The amount of adsorbance depends on the cation exchange capacity of the soil[33].

CEC is reported as a soil's ability to hold cations. It is an estimated value based on extracted cations from the soil analysis (Calcium Ca^{++}, Magnesiam Mg^{++}, Potassium K^{+}, Sodium Na^{+} and Hydrogen H^{+}). Since the clay and organic sites in the soil have a negative charge, the positively charged cations bond with these sites[34]. Therefore, CEC is closely related to soil texture. In Anna University soil from Table 4, the values of Ca, Mg, K, Na are 1550, 426, 48 and 161 mg/l respectively. Hence good adsorption of ammonia was present.

CEC is considered as an important factor in process of adsorption of ammonia which sticks to soil particle. In addition, the COD value of 117 mg/l found in the secondary effluent (Table 5.) which is the most critical parameter of the nitrification process because it directly influences the growth competition between microorganism populations.

4. Conclusion

The concentration of ammonia decreases with time and completely oxidised to nitrate at the end of the each cycles. The removal of ammonia was through nitrification process which is found to be a dominant removal mechanism of nitrogen.

Nitrogen was not removed from real secondary treated wastewater. From this study, it was found that with the fixed wetting period, maximum drying period is required for nitrate reduction and minimum drying period is required for TDS reduction. When soil columns were flooded on short, frequent flooding cycles, almost all of the ammonium nitrogen was transformed to the nitrate form. This type of management system could be used to retain the nitrogen in the reclaimed water intended for agricultural use.

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