



Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng



Treatment of municipal wastewater using laterite-based constructed soil filter

Avinash M. Kadam, Pravin D. Nemade*, G.H. Oza, H.S. Shankar

Department of Chemical Engineering, Indian Institute of Technology, Bombay, Powai, Mumbai 400076, Maharashtra, India

ARTICLE INFO

Article history:

Received 30 September 2008
Received in revised form 12 January 2009
Accepted 23 March 2009
Available online xxx

Keywords:

Constructed soil filter (CSF)
Wastewater
Laterite
Filtration
Oxidation
Pathogen removal

ABSTRACT

The present study reports the performance of municipal wastewater treatment plant located at Mumbai, India using laterite soil-based constructed soil filter (CSF) system monitored over 17 months. The results indicated increase in dissolved oxygen levels and reduction of chemical oxygen demand (COD) from 135.4 ± 79.4 to 28.8 ± 19.5 mg/L with first order rate constant (K_d) of 0.23 h^{-1} . The bio-chemical oxygen demand (BOD) reduced from 92 to less than 10 mg/L with K_d of 0.35 h^{-1} ; suspended solids reduction from mean 188 to 12–18 mg/L and turbidity reduction from mean 140 to 5.0 ± 3.4 NTU. The seasonal data showed 3.2 ± 0.9 , 2.8 ± 0.4 and 2.85 ± 1.0 log order removal for total coliform, fecal coliform and heterotrophic plate count, respectively. The unique features of the system include a single unit, low HRT, high hydraulic loading, no chemicals, pretreatment and mechanical aeration, odor free, low energy requirement (0.04 kWh/m^3), and green ambience.

© 2009 Elsevier B.V. All rights reserved.

1. Introduction

Several monitoring studies of water bodies reveal that the main source of pollution is the discharge of raw sewage (Belmont et al., 2004; Belmont and Metcalfe, 2002). Due to rapid economic growth and exponential population increase, Mumbai, the commercial capital of India is expected to have a population of around 26.5 million by 2025. It is expected to lead to a water demand of 18,000 million litres per day (MLD) generating almost 14,400 MLD wastewater (Perks et al., 2004). Wastewater treatment and recycling are the potential sources for addressing problems in such rapidly growing urban centres. There are various technological options available in the conventional approach for wastewater treatment. But most of the available technologies are often found to be unsuitable for applications in developing countries. One of the hurdles is the cost associated with its operation as regular supply of energy may not be available and the operating requirements are often ill matched to local skills. As a result such plants can be beyond the reach of the community (Fallowfield and Garrett, 1985; Bahgat et al., 1999). Natural systems overcome these disadvantages, viz., land treatment and wetland systems.

Land treatment has emerged as one of the promising technologies for wastewater renovation. In land treatment, wastewater is first treated by conventional physicochemical and/or biological

treatment and then allowed to infiltrate through aerated unsaturated zone wherein it gets purified through unit operations and processes such as filtration, adsorption, chemical processes and biodegradation. Land treatment system comprises of mainly Slow-Rate Irrigation System (Ou et al., 1997), Overland Flow System (Smith and Schroeder, 1985), Compact Filter System (Heistad et al., 2006), Multi Soil Layering System (Luanmanee et al. (2001), Rapid Infiltration System (Bouwer, 1985) and On Site Disposal System. Operation cost, mismatch of operating requirements with local skills and space constraint particularly in the urban sector of the developing world have limited their application to a great extent (Bahgat et al., 1999).

2. CSF system

CSF is a process developed at the Indian Institute of Technology-Bombay, India. It works with formulated soil environment wherein fundamental processes of nature, viz., respiration, mineral weathering and photosynthesis are responsible for bioconversion. Suitable mineral constitution, culture containing native microflora, geophagus worm *Pheretima elongata*, and bio-indicator plants are the key components of the media (Shankar et al., 2005). Bioconversion takes place by bacterial processing of organics and oxidizable inorganics via natural oxygen supply wherein mineral-weathering reaction serves to regulate pH while green plants serve as bio-indicators of the health of process at work. The highly oxidic potential and near neutral pH together with ecology of environment leads to significant reduction in the pathogens (Kadam et al., 2008).

* Corresponding author. Tel.: +91 22 2576 4286; fax: +91 22 2572 6895.
E-mail address: npravin@iitb.ac.in (P.D. Nemade).

Table 1
Details of laterite based constructed soil filter plant.

Site description	Values
Wastewater	Domestic + septic tank
Batch volume (V_L ; m^3)	50
Pretreatment	No
Bed	
Bed dimensions (m)	$25 \times 20 \times 0.7$
Bed surface area (m^2)	500
Upper media (v_b ; m^3)	150
Lower media (m^3)	200
Hydraulics	
Flow	Vertical
Mean hydraulic load ($m^3/m^2/h$)	0.042
Raw flow (v_r ; m^3/h)	21.6
Recycle flow (v_r ; m^3/h)	21.6
Batch time t_b ($t_r + t_r$) (h)	6.30 (2.30 + 4.0)
Plant age	2002 onwards

Site located at naval housing colony, Kanjurmarg, eastern suburb of Mumbai.

As in soils, inorganic transformations such as Fe^{2+} to Fe^{3+} and Mn^{2+} to Mn^{4+} serve as oxygen carrier (Langmuir, 1997). Predator–prey activities of geophagus worm and other macro-organisms serve to regulate bacterial work force so that the system exhibits chokeage free operation. Results of Pattanaik (2001) and Pattanaik et al. (2004) indicate that for organic loading <0.15 kg/ m^2 per day and hydraulic loading <0.05 $m^3/m^2/h$, reduction potentials >600 mV are typical. The available experimental studies on oxygen transfer show transfer coefficient in the range of 10^{-2} – 10^{-3} s^{-1} almost similar to agitated vessels. Hence aerobic oxidation is the dominant reaction at work. Because of high oxygen levels, the said CSF system finds promising in variety of applications such as water purification and sanitation. Also CSF shows oxidation of As (III) to As (V) and then co-precipitation by iron salt removes arsenic below 10 $\mu g/L$ WHO standard (Nemade et al., 2007, 2008).

The results for wastewater renovation with laterite soil based CSF also titled as *Soil Biotechnology* monitored over a period of 17 month, are presented in this paper. It is the only kind of such large-scale plant based on red soil to the knowledge of authors.

3. Materials and methods

3.1. Plant description

The facility under investigations is located in Mumbai, India. Details of the site are presented in Table 1. The plants receive unclassified, untreated raw sewage and the treated water is used

for irrigation in nearby gardens and lawns and in proximity a large urban population lives. Mumbai being a port city shows very little variation in temperature; the warmest May is $32^\circ C$ and coldest December is $24^\circ C$. It receives very heavy rainfall of about 2500 mm mostly in three to four spells over 30 days spread over June to October.

The system is constructed from RCC, stone-masonry or soil walls and consists of an impervious containment typically below ground, 0.7 m deep, with a 0.4 m of under drain layer of stone, rubble, above this a 0.3 m layer of red soil media housing culture and bio-indicator plants. Fig. 1 shows cross-sectional layout of CSF showing upper and lower media. The distribution of wastewater over the media is achieved via pumping, piping and distribution arrangements. The media consists of red soil along with suitable mineral constitution, culture containing native microflora, geophagus worm *P. elongata*, bio-indicator plants. In CSF system, geophagus worm *P. elongata* (*k*-selected organism) is engaged to maintain required soil microbial ecology. The design has suitable provision for manual removal of suspended solids from the biofilter surface.

3.2. Process description and operation

The process can be run on batch as well continuous mode. The wastewater is pumped and applied on to the top surface of the CSF system as shown in Fig. 1. Typical hydraulic loading is in the range of 0.04–0.05 $m^3/m^2/h$. A batch volume V_L of wastewater is pumped at rate v_f into the system trenches. Water first percolates through the trenches and gets collected in the collection tank. It is then pumped on to the media with the help of distribution system. The filtered water then gets collected into the collection tank and then recirculated (v_r) on to the media again. The recirculation (v_r) is continued till desired quality of water is achieved and then the water is discharged. Suspended solids are retained in trenches due to staining activity of additive material. Additives also combine with organic waste and act as primary removal of organic waste. These materials are scraped and removed periodically. The schematic details of the process operation are shown in Fig. 2.

The overall time of operation (wetting cycle) is typically 6–7 h. The bed is then rested for rest of the period (drying cycle) prior to next cycle of use. In *Soil Biotechnology* system, problem of clogging is overcome by propagating soil ecology in place, alternate wetting and drying cycles and appropriate substrate loading designs. During drying cycle, this clogging layer develops cracks due to respiration; so alternate wetting and drying is required for efficient performance. Substrate loading rate of 0.25 g/ m^2 /day is typically the design guideline for CSF with scale up factor of 1.5 for shock loading.

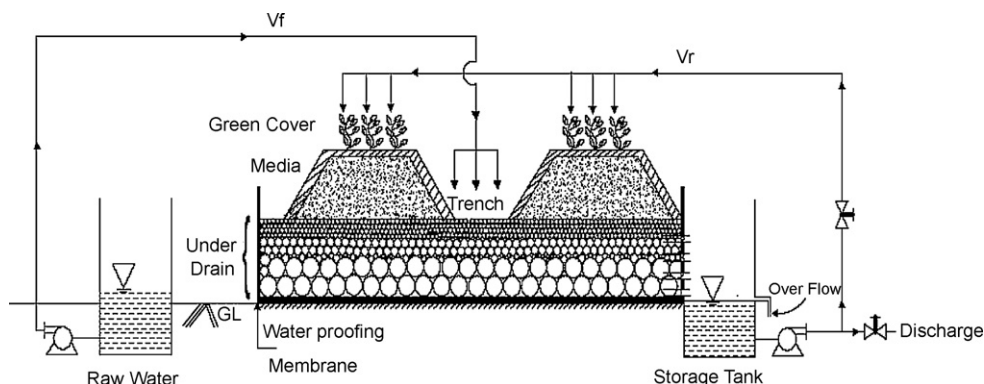


Fig. 1. Cross-sectional view and layout of CSF showing upper and lower media for processing water.

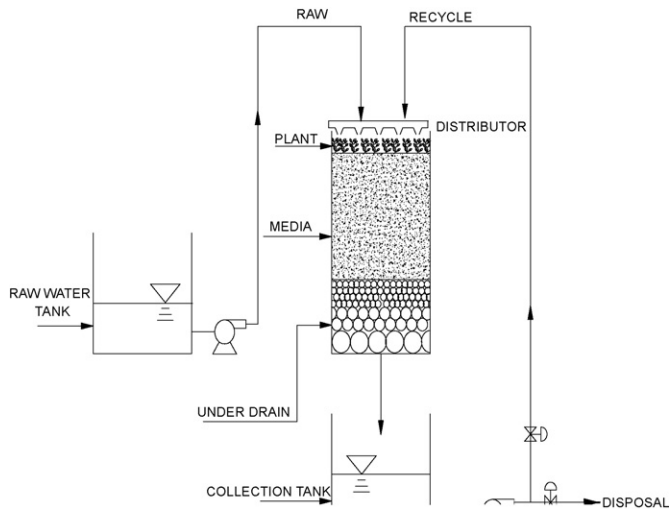


Fig. 2. Schematic of the CSF process operation.

4. Analysis

4.1. Physicochemical and microbial analysis

Samples of raw water and processed water were collected and analyzed during March 2003 to July 2004. Samples were collected in sterile 2 L plastic cans. Water temperature, conductivity and total dissolved solids (TDS) were measured using WTW (Germany) Inolab1 conductivity meter; pH and dissolved oxygen (DO) were measured using WTW (Germany) Inolab1 pH/Oxi meter. Turbidity was measured on WTW (Germany) Turb 550. Bio-chemical oxygen demand (BOD), chemical oxygen demand (COD), nitrite-N, orthophosphate, total kjeldahl nitrogen, sulphate concentration, and suspended solids were measured as per standard procedures of the American Public Health Association (APHA, 2003). Nitrate-N and $\text{NH}_4^+\text{-N}$ were measured with WTW combination electrode (Model no. NO_3^- 106674) and ELIT double junction electrode (ELIT 8051 NH_4^+ 60278), respectively.

Indicator organism's, viz., fecal coliform, total coliform and heterotrophic plate counts were enumerated as per (APHA, 2003) using membrane filtration technique. Appropriately diluted (10^{-3} – 10^{-7}) sample (100 mL in volume) volumes, in triplicate, were filtered through $0.45\ \mu\text{m}$ membrane filters supplied by PALL Life Sciences, Mumbai, and subsequently these filters were mounted on specific media supplied from Hi Media Laboratory Pvt. Ltd., India. Plates were then incubated for 24 h at 44.5°C on M-FC medium for fecal coliform, 24 h at 37°C on M-Endo agar for total coliform, and 24 h at 37°C on M-HPC agar for heterotrophic plate counts. The results are reported as number of Colony Forming Unit (CFU) per 100 mL.

4.2. Media analysis

Composite soil samples were taken randomly in May 2004. Samples were augured from two levels: one at 30–50 cm and other at 120–150 cm. Samples were air dried and mixed in equal proportion to obtain homogenous sample. Soil samples were then sub-sampled and analyzed within 5–7 days, or stored at 4°C and analyzed within 1 month. Air-dried soil was then passed through 2 mm sieve and subjected to most of the physicochemical studies except for particle size analysis. Physicochemical parameters include moisture content, specific gravity, particle size analysis, organic carbon, hydraulic conductivity, pH, cation exchange capacity, anion exchange capacity, and contact angle.

Soil pH was measured on a suspension of 10 g soil and 25 mL of 1 M KCl as well with soil paste and 1:5 soil:water suspension with glass electrode. Electrical conductivity (EC_{25}) was measured with 1:5 soil:water suspension. Soil moisture content (% MC) was measured by drying 5 g soil at $105\text{--}110^\circ\text{C}$ for 8 h and difference in weight is reported as % MC. A particle size analysis of the $<2\ \text{mm}$ fraction was carried out for each sample according to the procedure of Gee and Bauder (1986). The proportion of sand (2.0–0.05 mm) was determined by sieving, silt (0.05–0.002 mm) and clay ($<0.002\ \text{mm}$) proportions were determined by sedimentation using hygrometer method. Soil permeability was carried out as per falling-head permeability test method, adapted from Akbulut and Saglamer (2004). The hydraulic conductivity K_L was calculated by Eq. (1).

$$K_L = 2.303 \frac{aL}{At} \log \left(\frac{h_1}{h_2} \right) \quad (1)$$

where h is the head difference at any time t ; A the area of specimen; a the area of stand pipe and L is the length of specimen.

Percentage oxidizable organic matter was determined by the chromic acid method of Walkley and Black (Black, 1965). Organic carbon content was obtained by multiplying it by 1.33. Cation exchange capacity (CEC) was measured by Na saturation method (Chapman, 1965). Anion exchange capacity (AEC) was measured according to the method of Mehlich (1948). This method involves measurement of adsorbed P and extractable P separately and the summing up of these two gives AEC.

The percentage C, H, and N was determined using CHN analyzer, Thermo Finnegan-FLASHEA 1112 series, respectively. The contact angle (θ) was determined using Contact Angle Measurement Meter (GBX Instrumental Scientific). Exchangeable cations were measured as per method given by Dubbin et al. (2006). The effective cation exchange capacity (ECEC) was calculated as the sum of exchangeable cations. Each of the above analyses was performed in duplicates and mean values are reported here. Population of ammonia oxidizers and nitrite oxidizers was enumerated by the Most Probable Number (MPN) method and represented as cells/g of soil (Schmidt and Belser, 1994).

Denitrifier population was enumerated by MPN method and represented as cells/g of soil (Tiedje, 1994). Heterotrophic plate count was measured as CFU/g after incubation for 48 h with heterotrophic plate count media supplied by Hi Media Laboratory Pvt. Ltd., India. Similarly actinomycetes were measured as CFU/g of soil grown on starch casein medium (Wellington and Toth, 1994). Number of proteolytic bacteria was estimated by incubating appropriately diluted soil suspension with casein/mil powder medium for 48 h and reported as CFU/g of soil (Kern and Idler, 1999). Presence or absence of protozoan population such as flagellates, amoeba and ciliates in a mixture of soil and appropriate media incubated for 3–6 weeks were noted using $20\text{--}45\times$ magnification with phase contrast microscopy, Leica DM LS2 series and density of the protozoan was calculated in the original soil samples from MPN table (Ingham, 1994).

4.3. Enzymatic analysis of media

Enzymatic activities of dehydrogenase, acid and alkaline phosphatase, urease and β -glucosidase were determined on fresh moist sieved ($<2\ \text{mm}$) soils within 15–20 days from the collection of the samples. Control tests with autoclaved soils were carried out to evaluate the spontaneous or abiotic transformation of substrates. Dehydrogenase activity was determined as per the protocol by Tabatabai (1994) and is expressed as μmole triphenylformazan $\text{h}^{-1}\ \text{g}^{-1}$ soil. Urease activity was determined by determination of urea remaining. This method is based on the urea

remaining after incubating with soil and KCl–PMA buffer and is expressed as $\mu\text{mole urea h}^{-1} \text{g}^{-1}$ soil (Tabatabai, 1994). Acid and alkaline phosphatase was measured as per the protocol outlined by Tabatabai (1994) and expresses as $\mu\text{mole p-nitrophenol h}^{-1} \text{g}^{-1}$ soil. It is based on the estimation of p-nitrophenol formed with p-nitro phenyl phosphate as substrate in presence of MUB (Modified Universal Buffer; pH 6.5 and 11.0) buffer (Tabatabai, 1994). β -Glucosidase activity was determined according to Eivazi and Tabatabai (1977) and expressed as $\mu\text{mole p-nitrophenol h}^{-1} \text{g}^{-1}$ soil. β -Glucosidase activity measurement is based on the estimation of p-nitrophenol formed with p-nitrophenyl- β -D-glucoside (PNG) as substrate in presence of Tris hydroxymethyl amino methane (THAM, pH 12) buffer (Tabatabai, 1994). All chemical determinations and enzymatic activities were determined in triplicate and data were expressed on an oven-dry sample basis.

4.4. Mineral investigation

Trace element concentrations in the medium were determined by XRF spectroscopy on pressed powder pellets using a Philips PW 2404 instrument. Data obtained were processed using Philips SuperQ software. All the analyses were carried out in triplicates and mean with standard deviation is presented here. Mineral constitution of the medium was investigated by powder X-ray diffraction (XRD) using X'Pert Pro XRD Systems diffractometer with a curved position-sensitive detector in vertical geometry with a 2θ detection range of $3\text{--}60^\circ$. Tube operating conditions were 40 kV and 30 mA. Measurements were made in reflection geometry with the sample surface at an angle of 1° to the incident beam.

4.5. Nitrification rate

It is an indicator of activity of nitrifying bacteria in soil (Hart, 1994). Method of nitrification potential of soil medium is adapted from Zhang et al. (2005) with slight modification. Twenty gram of soil sample was incubated with 100 mL NH_4^+ -N substrate solution in a 250 mL flask and flasks were shaken at 180 rpm for 24 h at 37°C . After the incubation, soil suspension was filtered through a $0.45 \mu\text{m}$ -membrane filter for further analysis of NO_3^- -N and NO_2^- -N. The nitrification potential was calculated as:

$$\omega = \frac{(N_0 - N_t)(V_1 + V_2)}{t \cdot m(1 - w)} \quad (2)$$

where ω is the rate of nitrate-N production ($\text{mg N kg}^{-1} \text{h}^{-1}$), N_0 the initial nitrate-N concentration (mg/L) in the soil suspension, N_t the nitrate-N concentration (mg/L) after incubation for time t , V_1 the substrate solution volume (L), V_2 the water volume in the soil sample (L), m the mass of the soil sample (kg) and w is the water content ratio in the soil sample (fraction). The averages of three replicates for each sample are presented herewith.

4.6. Adsorption test for media

Batch tests for adsorption were carried out as per the method given by Zhang et al. (2005). Soil samples were dried at 105°C for constant weight and then were put in a conical flask of 250 mL and sterilized at 121°C and 1.1 MPa for 30 min. Then given volume of solutions (generally 100 mL) containing different concentrations of NH_4^+ -N, NO_3^- -N, NO_2^- -N, PO_4^{3-} -P and soil samples shaken for 24 h at 180 rpm and 37°C . Solution was then filtered through a $0.45\text{-}\mu\text{m}$ membrane filter and N, P measurement was carried out with analyte. Adsorption capacity for N or P was calculated using the

Table 2
Physicochemical performance of laterite based CSF plant.

Parameters	Influent	Effluent	% removal	K_d (h^{-1})
pH (range)	6.7–7.3	7.1–7.7	–	–
Dissolved oxygen (mg/L)	0.72 ± 1.1	4.8 ± 1.6	–	–
Total dissolved solids (mg/L)	248.5 ± 22.1	239.1 ± 25.4	3.8	–
Conductivity ($\mu\text{S/cm}$)	370.0 ± 34.2	357.1 ± 38.0	–	–
Total suspended solids (mg/L)	187.8 ± 145.3	9.1 ± 7.8	95.2	0.45
Volatile suspended solids	90.9 ± 78.5	0.2 ± 1.0	99.7	0.89
Turbidity (NTU)	96.3 ± 47.2	5.0 ± 3.4	94.8	0.44
COD (mg/L)	135.4 ± 79.4	28.8 ± 19.5	78.7	0.23
BOD (mg/L)	91.7 ± 54.7	8.6 ± 7.3	90.6	0.35
Chlorides (mg/L)	33.8 ± 8.4	32.1 ± 14.8	5.1	0.06
Sulphate (mg/L)	24.4 ± 14.4	20.2 ± 13.8	17.0	0.03
Alkalinity (mg/L)	87.9 ± 31.0	78.9 ± 30.1	10.3	0.12
Nitrogen				
Nitrate-N (mg/L)	4.3 ± 4.7	5.1 ± 6.2	–	–
Nitrite-N (mg/L)	0.4 ± 1.1	0.3 ± 0.7	–	0.06
Ammoniacal-N (mg/L)	4.3 ± 3.2	0.7 ± 0.8	82.7	0.26
TKN (mg/L)	5.9 ± 3.1	1.7 ± 0.9	71.6	0.19
Total N (mg/L)	10.8 ± 6.4	7.0 ± 6.3	34.8	0.06
O-Phosphate-P (mg/L)	1.4 ± 0.7	0.4 ± 0.2	67.3	0.17

formula given in Eq. (3).

$$q = \frac{(C_0 - C)V}{M} \quad (3)$$

where q is the adsorption capacity of soil (mg g^{-1}); C_0 the initial concentration of solute in mixed soil solution (mg/L); C the equilibrium concentration of solute in mixed soil solution (mg/L); V the volume of the solution (L) and M is the dry weight of soil (g).

5. Results

All the results are expressed as arithmetic means of triplicate analysis over the period. Standard deviations and means for all variables were performed by Statistica package for Windows (Version 5.1 Edition 98). In case of microbial population densities, data were log 10 transformed to obtain mean. First order removal rate constants were calculated as

$$K_d = \frac{V_f(C_0 - C_e)}{V_b(C_e)} \quad (4)$$

where K_d is the first order rate constant (h^{-1}), C_0 the initial concentration of the contaminant (mg/L); C_e the final concentration of the contaminant (mg/L); V_f the flow rate (m^3/min) and V_b the bed volume (m^3/min). Physicochemical contaminant removal with red soil filter is presented in Table 2. Figs. 3–7 describe the monthly pattern for physicochemical contaminant removal.

5.1. Physicochemical removal performance

In Fig. 3(a), the influent pH was found to be 7.0 ± 0.3 and effluent was found to be close to neutral (7.4 ± 0.3) showing buffering capacity of CSF environment. All effluents shows significant increase in dissolved oxygen levels and the high dissolved oxygen levels up to $4.8 \pm 1.6 \text{ mg/L}$ as shown in Fig. 3(b). This indicates water could support the oxygen requirement of the aquatic organisms (Belmont et al., 2004).

The influent BOD was found to be in the range of $91.7 \pm 54.7 \text{ mg/L}$. Effluent levels were reduced to $8.6 \pm 7.3 \text{ mg/L}$ as shown in Fig. 4(a). First order rate constants (K_d) for BOD removal was found to be 0.36 h^{-1} . In Fig. 4(b), influent COD shows wide variation as reflected in standard deviation. Mean effluent levels of COD were 28.8 mg/L registering 78.7% removal with K_d value of 0.23 h^{-1} . Considering batch volume (V_L) taken for the monitoring

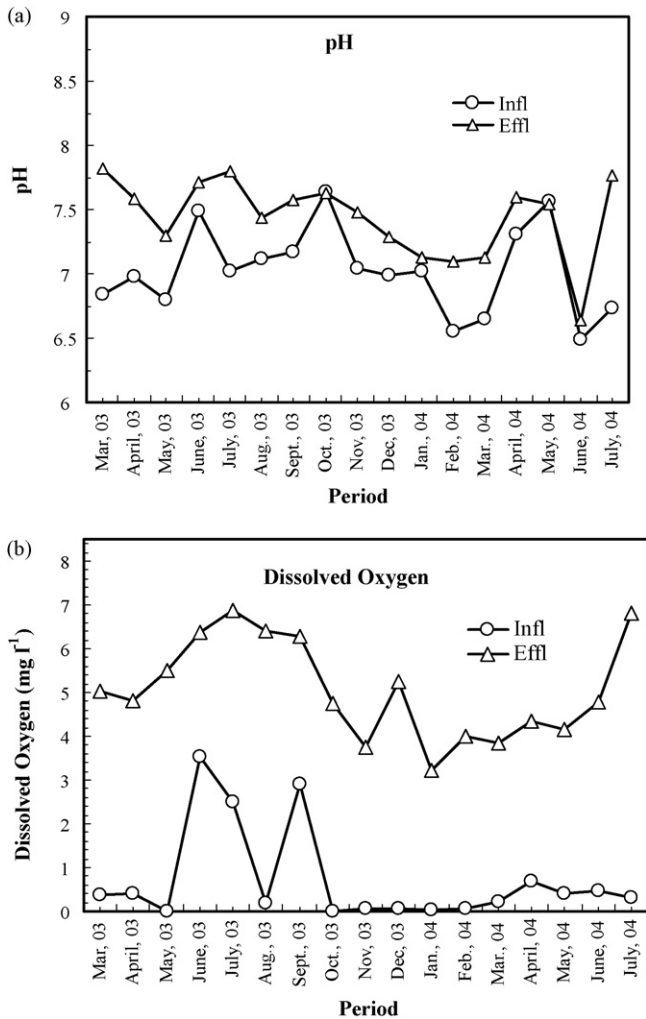


Fig. 3. Monthly monitoring of physicochemical contaminant removal of sites I and II. Profile of (a) pH and (b) dissolved oxygen.

experiment, specific mass loading for BOD₅ and COD was calculated as 9.16 and 13.5 g/m²/day. Here single batch volume per day is preferred keeping in mind the significance of alternate drying and wetting cycle.

TSS concentration in the untreated sewage was 187.8 ± 145.3, showing lot of variations as shown in Fig. 5(b). There were very large reductions of TSS to 9.1 ± 7.8 mg/L registering 95.2% removal with K_d values of 0.45 h⁻¹. It is interesting that system accounted for large fraction of TSS removal, since this is a very simple and inexpensive system. This trend was equally represented with apparent turbidity reduction to 5.0 ± 3.4.

5.2. Nutrient removal

Removal of nutrients from sewage is the challenge for protecting water bodies from eutrophication. Ortho-phosphate-P concentration in the raw sewage was 1.4 ± 0.7 mg/L. Phosphate-P levels were reduced to 0.4 ± 0.2 mg/L as shown in Fig. 7(b). Percent removals for all the time were in the range of 55–67% with K_d value of 0.17 h⁻¹.

Ammonium-N concentration in the raw sewage was 4.3 ± 3.2 mg/L as shown in Fig. 6(a). This concentration is quite low compared with values in domestic wastewater which is 12 mg/L (Metcalf & Eddy Inc., 1995). Removal was almost 80–85% for all

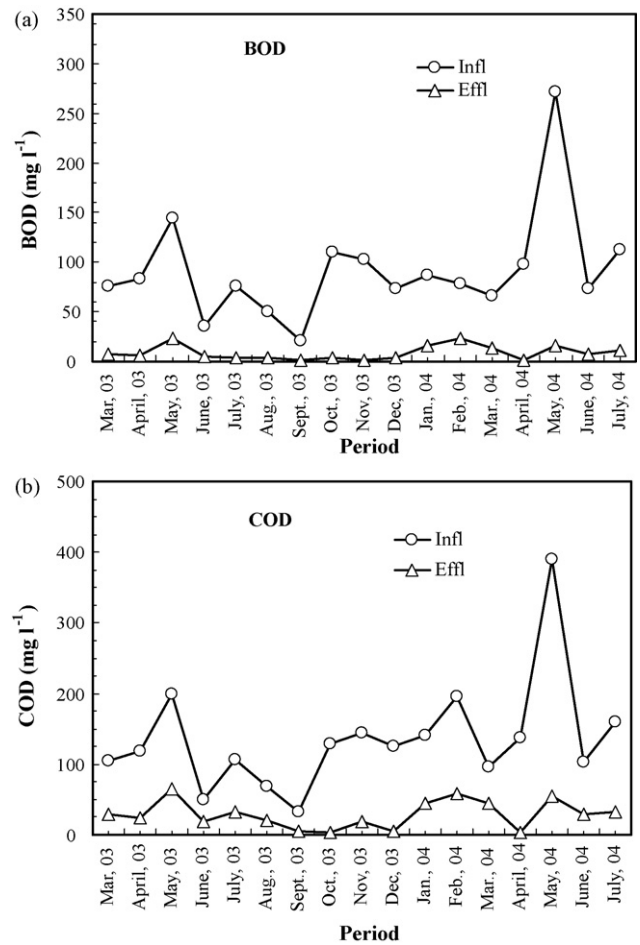


Fig. 4. Monthly monitoring of physicochemical contaminant removal of sites I and II. Profile of (a) BOD and (b) COD.

the time with 0.7 ± 0.8 mg/L in the outlet. The estimated K_d value was 0.26 h⁻¹. This was probably due to the elevated dissolved oxygen concentrations, since high oxygen promotes oxidation of ammonium to nitrate. The mean nitrate-N concentration in the raw sewage was 4.3 mg/L even though nitrate is typically absent in domestic sewage (Metcalf & Eddy Inc., 1995). Monthly variation in the influent and removal pattern for different forms of nitrogen is shown in Fig. 3.

Nitrate-N levels in the outlet were increased to 5.1 mg/L implying nitrification at work. These values are similar to the literature value for septic tank effluent with soil and sand filter system (Cochet et al., 1990). Very low levels of nitrite-N in the inlet (0.03–0.4 mg/L) as well outlet (0.3 mg/L) was observed. Presence of nitrite-N in the outlet, loss of ammonia-N and absence of equivalent amount of nitrate-N in the outlet implies incomplete oxidation of ammonia. Organic nitrogen was estimated by subtracting the concentration of ammonium from Total kjeldahl nitrogen. Organic nitrogen level is lower than ammonium level and is the characteristic of sewage; also implies no other source of nitrogen. Organic N levels in the raw were 1.62 ± 1.0 mg/L, and outlet shows reduction to 0.94 ± 0.5 mg/L giving percentage removal of 41.9% with K_d value of 0.08 h⁻¹ was observed as shown in Fig. 6(b). Total nitrogen (TN) concentrations in the raw sewage were 10.8 ± 6.4 mg/L. Effluent TN reduced to 7.0 ± 6.3 mg/L showing 34.8% removal with K_d value of 0.06 h⁻¹ as shown in Fig. 7(a).

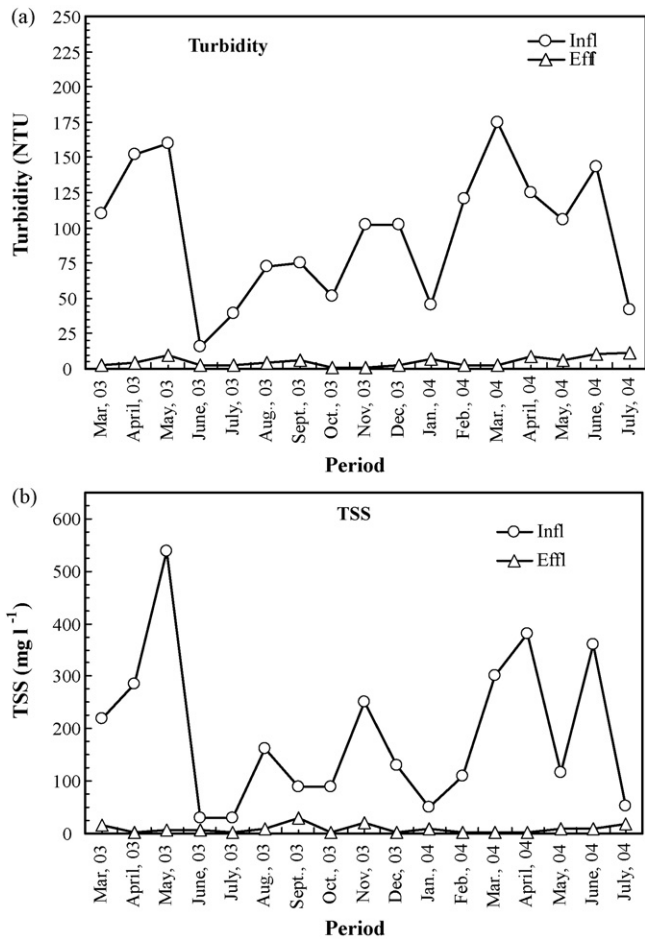


Fig. 5. Monthly monitoring of physicochemical contaminant removal of sites I and II. Profile of (a) turbidity and (b) total suspended solids.

5.3. Pathogen removal

Pathogen removal data are being classified as Summer 2003, Monsoon 2003, Post-monsoon 2003, Summer 2004 and Monsoon 2004 and presented here (Table 3). Average total coliform levels in the influent were 3.5×10^8 and reduced to 2.4×10^5 CFU/100 mL registering 3.2 log order removal with K_d value of 1.12 h^{-1} . Similarly, fecal coliform levels were reduced from 2×10^7 to 3×10^4 CFU/100 mL showing 2.8 log order removal with K_d of almost 1.0 h^{-1} as shown in Fig. 8. HPC count was reduced to 2×10^6 CFU/100 mL showing 2.85 log order removal and K_d of 1.0 h^{-1} .

5.4. Seasonal variability

The influent COD in pre-monsoon period varies in between 115 and 200 mg/L. Effluent levels reduced to 40 mg/L showing 70–80% removal. In monsoon, influent reduces to 30–106 mg/L probably due to dilution with rainwater. Outlet levels reduced to 20–30 mg/L. Removal efficiency does not show any change (68–83%). Post-monsoon shows again increase in influent COD to 125–150 mg/L with outlet values of 18 mg/L showing removal of 85–100%. Biodegradable organic loading (BOD) was in the range of 50–70 mg/L for pre-monsoon, 30–50 mg/L in monsoon again due to same dilution factor, 75–110 mg/L in post-monsoon. Effluent BOD values were in the range of 3.0–13.7 mg/L showing more than 90% removal.

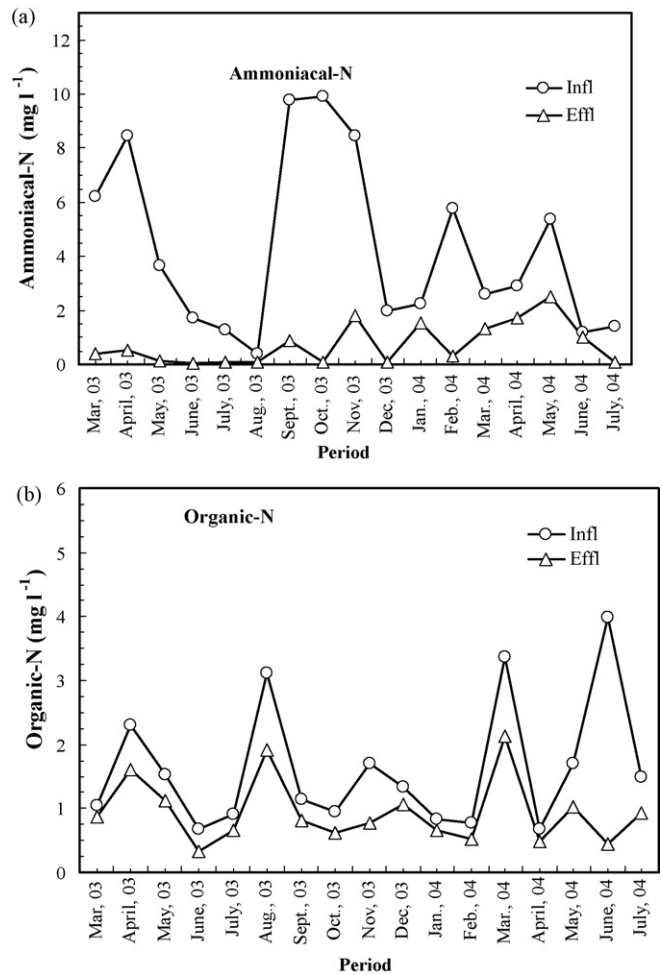


Fig. 6. Monthly monitoring of physicochemical contaminant removal of sites I and II. Profile of (a) ammoniacal-N and (b) organic-N.

Influent suspended solid load ranges from 220 to 350 mg/L in pre-monsoon, reduces to 30–100 mg/L due to monsoon factor and again increases to 90–250 mg/L. Effluent levels reduced to 4.7–8.3, 12–14 and 8–10 mg/L, respectively. Removal was found to be 92–100% except one set showing 80% removal. Similarly, turbidity in the incoming wastewater also ranges from 120 to 60 NTU in pre-monsoon, lowers to 40–75 NTU during monsoon and as expected rises to 52–102 NTU. Effluent values were 5.0 NTU, 4–11 NTU and 3–5 NTU, respectively. Overall turbidity removal was 91–99%. Monthly variation of physicochemical parameters such as pH, DO, BOD and COD is depicted in Figs. 3 through 7.

Ammoniacal-N loading in the influent varies from 3.0 to 6.0 mg/L in pre-monsoon lowers to 0.4–1.2 mg/L in monsoon and show increase to 2–10 during post-monsoon. Outlet levels show 0.3–0.4, 0.3–1.5 and 0.9 mg/L, respectively. Overall it shows 90–100% removal. Nitrite-N, which is the intermediate in the nitrification process, varies from 0.12 to 0.18 mg/L in pre-monsoon influent and 0.48–4.8 mg/L in the monsoon influent and again drops to 0.02–0.1 mg/L in post-monsoon. Outlet shows 0.07 mg/L, 0.05–0.13 and 1.0 mg/L, respectively. But removal was found to be stable at 75–90%. Nitrate-N shows many variations in the influent as well in the effluent. During pre-monsoon, its concentration in the influent was found to be 0–3.0 mg/L and in the effluent it shows removal as well accumulation. Still removal was very negligible, i.e. 10%. In the monsoon, it varies in the influent from 3.97 to 16 mg/L and removal also varied from as low as 44% to as high as 94%.

Table 3
 Microbial performance of the laterite based constructed soil filter plant.

Organism	Symbol	Summer 2003		Monsoon 2003		Post-monsoon 2003		Summer 2004		Monsoon 2004		Average	
		Infl	Effl	Infl	Effl	Infl	Effl	Infl	Effl	Infl	Effl	Infl	Effl
TC ^a	avg	1.15 × 10 ⁸	1.0 × 10 ³	4.6 × 10 ⁸	9.8 × 10 ⁴	8.4 × 10 ⁷	8.5 × 10 ⁴	8.5 × 10 ⁸	8.1 × 10 ⁵	3.5 × 10 ⁸	1.9 × 10 ⁵	3.5 × 10 ⁸	2.4 × 10 ⁵
	K		5.06		3.67		2.99		3.02		3.13		3.17
	K _d ^b		1.79		1.30		1.06		1.07		1.16		1.12
FC ^a	avg	1.5 × 10 ⁵	1.0 × 10 ³	2.0 × 10 ⁷	2.7 × 10 ⁴	5.1 × 10 ⁶	2.4 × 10 ⁴	5.3 × 10 ⁷	3.8 × 10 ⁴	2.0 × 10 ⁷	6.6 × 10 ⁴	2 × 10 ⁷	3.1 × 10 ⁴
	K		2.18		2.86		2.32		3.15		2.49		2.79
	K _d ^b		0.77		1.01		0.82		1.11		1.87		0.99
HPC ^a	avg	5.1 × 10 ⁸	1.2 × 10 ⁴	1.5 × 10 ⁹	5.1 × 10 ⁵	6.3 × 10 ⁸	2.3 × 10 ⁶	3.0 × 10 ⁹	6.5 × 10 ⁶	1.4 × 10 ⁹	8.7 × 10 ⁵	1.4 × 10 ⁹	2.0 × 10 ⁶
	K		4.63		3.47		2.43		2.66		3.25		2.85
	K _d ^b		1.64		1.23		0.86		0.94		1.13		1.01

TC: total coliform; FC: fecal coliform; HPC: heterotrophic plate count; $K = \log(N_0/N)$; $K_d (h^{-1}) = \{\ln(N_0/N)\}/t_b$, where K is log removal; K_d is pathogen removal rate constants (h^{-1}), stdev = standard deviation.

^a Colony Forming Unit (CFU)/100 mL.

^b h^{-1} .

Sulphate concentration in the influent varies from 17 to 24 mg/L in all three season and outlet shows 17–20 mg/L showing removal as low as 12% during monsoon. Effluent levels were reduced to 14–21 mg/L showing 43–47% removal in rest of the season. Phosphate-P concentration in the influent shows variation from 0.3 to 2.0 mg/L. Outlet levels of phosphate-P were reduced to 0.3–0.6 mg/L, showing removal of 11–80%.

Summer 2003 has shown better K and K_d compared to Summer 2004 for all three indicator organisms. In fact, highest log removal for total coliform and HPC were reported during Summer 2003 (5.06 and 4.63, respectively). But FC log removal was better during Summer 2004 (3.15 log removal with K_d of 1.11 h^{-1}) than Summer

2003. Dilution effects on the influent levels as well as wash out effect on effluent levels were not seen during two monsoon seasons as apprehended; except for fecal coliform levels during Monsoon 2004 decreased marginally.

This is important as hydraulic loading is generally overburdened with monsoon precipitation during monsoon season and apprehension was that it will affect the performance. Fig. 8 shows the pattern of seasonal variation for pathogen removal.

5.5. Media characteristics

5.5.1. Physicochemical

Tables 4 and 5 summarize physicochemical characteristics of the media which houses the ecology of selected bacteria, geophagus worms *P. elongata* and bio-indicator green plants. Moisture content in the range of $24.6 \pm 2.3\%$ shows that, media drains rapidly this is

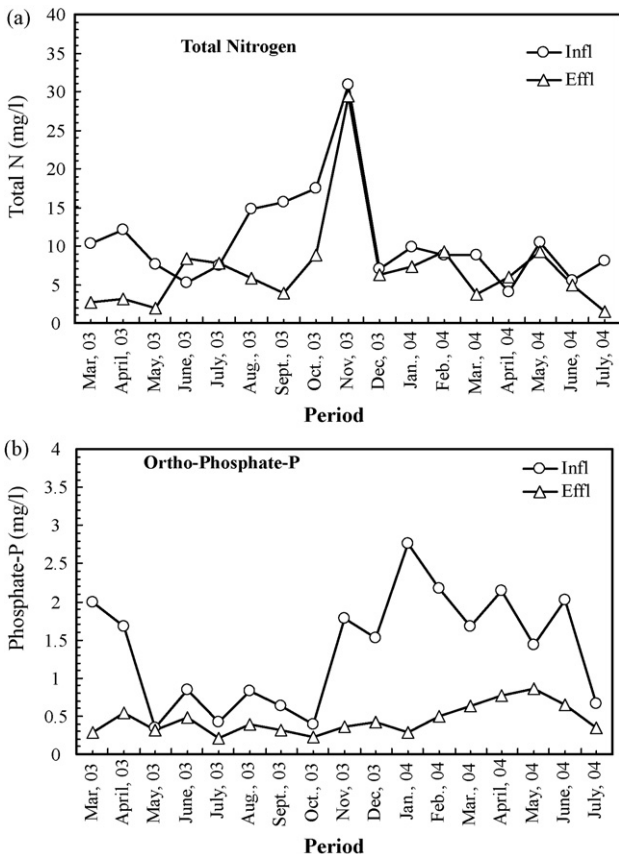


Fig. 7. Monthly monitoring of physicochemical contaminant removal of sites I and II. Profile of (a) total-N and (b) orthophosphate-P.

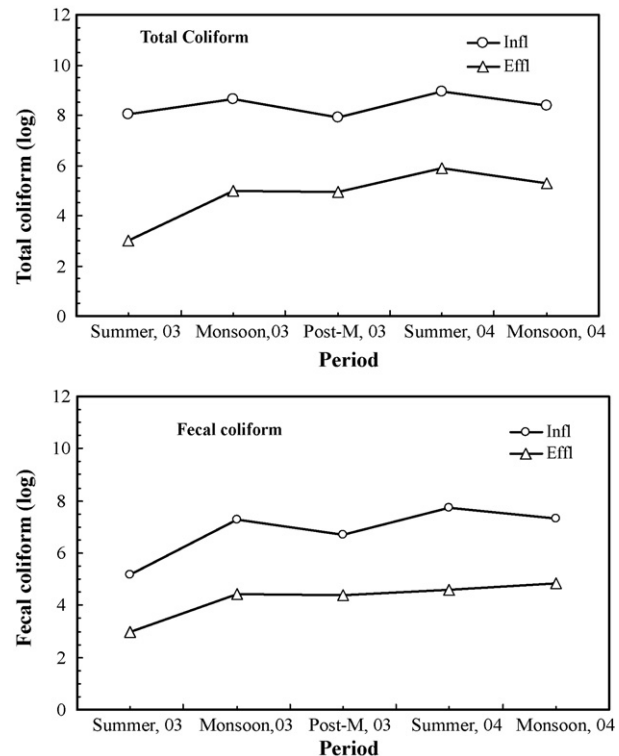


Fig. 8. Seasonal performance for total coliform and fecal coliform.

Table 4
Physical properties of the laterite soil medium.

Parameters	Values
Moisture content (%)	24.6 ± 2.3
Conductivity (μS/cm)	319 ± 17
TDS (mg/L)	214 ± 11.4
Salinity (ppt)	0
Temperature (°C)	26 ± 0.3
Specific gravity	2.78 ± 0.19
Particle size distribution	
Clay (g/kg)	160 ± 9
Silt (g/kg)	420 ± 19
Sand (g/kg)	360 ± 16
Gravel (g/kg)	60 ± 4
Soil texture (USDA Scheme)	Loam
Bulk density (g cm ⁻³)	1.43
Hydraulic conductivity, K_L (m/s)	4.41 × 10 ⁻⁵

±Standard deviation.

so even after several years after setting up the facility. The hydraulic conductivity K_L values (10⁻⁵ m/s) reported in Table 4 are based on a measurement technique wherein the media is compacted physically prior to measurement and found to be low compared to 10⁻⁴ to 10⁻⁵ m/s observed in the field scale studies.

pH of the medium was found to be slightly acidic. High values of organic matter, total carbon and nitrogen content, CEC, AEC are in consistent with reported value for soils irrigated with municipal wastewater for prolonged period (Fuentes et al., 2002). In comparison to other natural soils such as Tanzanian pumice and Japanese granite, this medium has 2–7 times more specific surface area and hundred times more pore volume. Specific surface area is an indicator of adsorptive surface area (Njau et al., 2003).

5.5.2. Microbial

Table 6 shows that microbial ecology in place is quite rich in terms of ammonia oxidizers, nitrifiers as whole, denitrifiers, proteolytic bacteria, actinomycetes, heterotrophic and predator population (protozoa and geophagus worm *P. elongata*). These values far exceed the values reported in the literature (McCarthy, 1987).

5.5.3. Enzymatic

Soil enzymes' activities have been suggested as suitable indicators of soil quality because: (a) they are a measure of the soil microbial activity and therefore they are strictly related to the nutrient cycles and transformations; (b) they may rapidly respond to

Table 5
Chemical properties of laterite soil medium.

Parameters	Values
pH	
Soil suspension (1:5)	6.5 ± 0.1
Soil paste	6.6 ± 0.1
Soil-KCl	5.8 ± 0.2
Oxidizable organic matter (g C/kg)	6.0 ± 0.3
Total organic carbon (g C/kg)	8 ± 0.4
Organic matter (g C/kg)	12 ± 0.6
Carbon (g/kg)	15.5 ± 1.9
Hydrogen (g/kg)	9.4 ± 0.2
Nitrogen (g/kg)	3.0 ± 0.1
C/N	5.11 ± 0.42
CEC (cmole _c kg ⁻¹)	38.9 ± 6.0
AEC (cmole _c kg ⁻¹)	2.03 ± 0.3
Contact angle (θ)	76.9 ± 4.1
BET surface area (m ² /g)	28.8 ± 1.5
Pore volume (m ³)	25.3 ± 1.7
Nitrification potential (mg N kg ⁻¹ h ⁻¹)	1.92 ± 0.03

±Standard deviation.

Table 6
Microbial properties of laterite soil medium.

Parameters	Values
Ammonia oxidizers (cells/g)	8.9 × 10 ⁷
Nitrifiers (cells/g)	1.4 × 10 ⁶
Denitrifiers (cells/g)	2.2 × 10 ⁶
Proteolytic bacteria (cells/g)	1.4 × 10 ⁹
Actinomycetes (cells/g)	2.4 × 10 ⁸
Heterotrophic plate count (cells/g)	2.8 × 10 ¹²
Protozoa	
Naked amoebae (cells/g)	1.01 × 10 ⁸
Flagellates (cells/g)	8.33 × 10 ⁴
Ciliates (cells/g)	8.33 × 10 ⁴

±Standard deviation.

the changes caused by both natural and anthropogenic factors; (c) they are easy to measure (Gianfreda and Bollag, 1996; Drijber et al., 2000; Calderon et al., 2000; Colombo et al., 2002; Nannipieri et al., 2002). Moreover, as claimed by several authors (Dick and Tabatabai, 1993; Dick, 1997; Van Beelan and Doelman, 1997; Trasar-Cepeda et al., 2000), soil enzymes activities may be considered early and sensitive indicators to measure the degree of soil degradation in both natural and agro-ecosystems.

Enzymatic activities are presented in Table 7. Except for phosphatase all enzymes are positively correlated with soil pH and are in good agreement with Gianfreda et al. (2005) for non-polluted soils. Gianfreda et al. (2005) also negatively correlates enzymatic activity with organic pollution and even mentioned that all enzymatic activity particularly dehydrogenase (DH) and urease activity falls completely due to organic pollution. Present site is almost 2–3 years old and DH and Urease activity is comparable with non-polluted soil (Caravaca et al., 2005). Phosphatase activity can be correlated with increase phosphate-P removal rate constant. Phosphate-P removal rate constant (0.17 h⁻¹) can be correlated with acid and alkaline phosphatase activity (0.88 and 1.33 μmole PNP/g soil h⁻¹, respectively) confirming their involvement in the P cycle. Phosphatase activity of Kanjur site is almost 2 times than normal soils. β-Glycosidase activity was slightly higher than non-polluted soils. Again one major distinction here is that sites reported by Gianfreda et al. (2005) received Polyhydroxy Aromatic Hydrocarbon (PAH) as the source of organic pollution which is a known recalcitrant whereas the sites reported in this study mostly receives simple organics in the form of domestic sewage.

5.5.4. Mineralogy

X-ray diffraction of (XRD) analysis of the medium has shown the presence of quartz (SiO₂), montmorillonite clay {MgO·Al₂O₃·5SiO₂·(H₂O)_x}, albite (NaAlSi₃O₈) and hematite (Fig. 9). Presence of hematite (Fe₂O₃) has given the medium its characteristic red color. Table 8 shows the composition of medium as determined by XRF. This has been compared with Japanese

Table 7
Enzymatic properties of laterite soil medium.

Parameters	Values
Beta glucosidase (μmole PNP/g soil h)	0.53 ± 0.02
Acid phosphatases (μmole PNP/g soil h)	C: 4 × 10 ⁻⁴
Alkaline phosphatases (μmole PNP/g soil h)	0.88 ± 0.05
Dehydrogenase (μmole TPF/g soil h)	C: 0.05
Urea hydrolysed (μmole urea/g soil h)	1.33 ± 0.17
	C: 0.04
	1.15 ± 0.11
	C: 3 × 10 ⁻⁵
	6.55 ± 0.11
	C: 4 × 10 ⁻³

±Standard deviation.

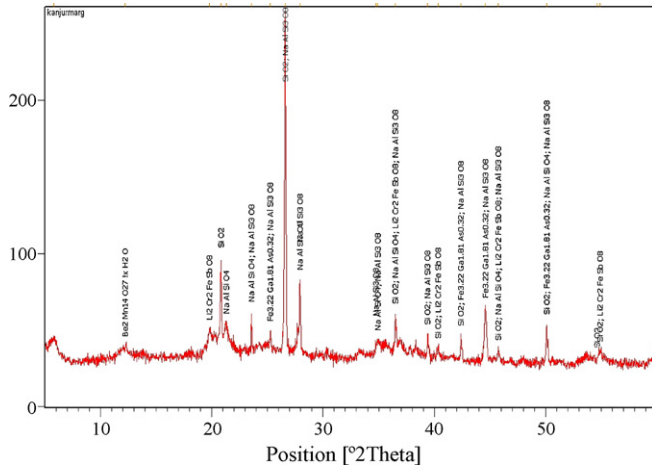


Fig. 9. XRD of laterite soil medium.

granite and Tanzanian pumice soil. As can be seen from Table 8, laterite soil medium has low Ca, Mg, and Al in comparison with others. But has more Fe content than granite even though not more than pumice. Values for granite and laterite medium are of the same order of magnitude except for Fe, Ti, and Mn.

5.5.5. Nitrification rate

Results of the nitrification potential measurement are given in Table 5. A soil nitrification potential as high as $1.92 \pm 0.03 \text{ mg N kg}^{-1} \text{ h}^{-1}$ was observed. This high value could be attributed to high ammonia oxidizer population in the medium and also to the mode of operation, i.e. intermittent application (alternate drying and wetting cycle) and is in agreement with the reported values in the literature (Zhang et al., 2005). But this high value of nitrification potential is at least 80–85 times less than its estimated nitrification values.

5.5.6. Adsorption studies: phosphorus removal

Laterite soil medium was tested for phosphate-P adsorption isotherm, which was compared to those of pure red clay, red soil, and anion exchanger resin. Data in Fig. 10 indicated high phosphorus (PO_4^{3-}) adsorption capacity of Kanjur medium and is comparable with pure red soil and resin. This could be attributed to high specific area, Al and Fe content of the medium. Langmuir's isotherm model was applied to analyze the adsorption characteristics of the medium according to the following equation

$$\frac{C}{q} = \frac{C}{q_{\max}} + \frac{1}{Kq_{\max}} \quad (5)$$

where q is the adsorption capacity of medium (mg P g^{-1}), q_{\max} the maximum adsorption capacity of soil (mg P g^{-1}), C the equilibrium concentration of phosphorus (mg PL^{-1}) and K is the adsorption coefficient (L mg^{-1}). Eq. (5) was applied to the data shown in Fig. 10 and a linear regression analysis of C/q and C was performed and accordingly, from the value of slope ($1/q_{\max}$) and intercept ($1/(Kq_{\max})$), q_{\max} and K were calculated and reported in Table 9.

Table 8
 Mineral investigation of laterite soil media.

Material	Al ₂ O ₃ (%)	CaO (%)	K ₂ O (%)	MgO (%)	SiO ₂ (%)	Fe ₂ O ₃ (%)	Na ₂ O (%)	TiO ₂ (%)	MnO (%)	P ₂ O ₅ (%)
Granite ^a	19.2	1.3	3.6	0.7	62.0	5.1	3.01	0.5	0.0	0.0
Pumice ^a	13.7	12.7	3.5	7.3	35.4	18.2	2.1	4.9	0.0	0.0
Laterite soil medium	12.3 ± 0.1	1.42 ± 0.01	0.02 ± 0.003	1.3 ± 0.01	37.0 ± 0.53	16.3 ± 0.01	0.3 ± 0.001	2.1 ± 0.02	0.2 ± 0.004	0.13 ± 0.001

±Standard deviation.

^a Njau et al. (2003).

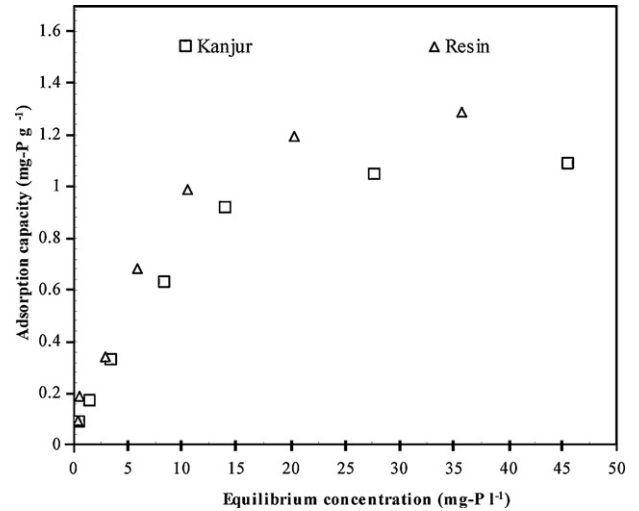


Fig. 10. Phosphorus (PO_4^{3-} -P) adsorption isotherm of different materials.

Table 9
 Regression analysis results of phosphorus and nitrogen adsorption isotherm.

Adsorption target	Items	Kanjur	Resin	Red clay ^a
Phosphorus	q_{\max} ($\text{mg PO}_4^{3-}\text{-P g}^{-1}$)	1.338	1.53	2.06
	K (L mg^{-1})	0.111	0.154	0.56
Ammoniacal-N	q_{\max} ($\text{mg NH}_4^+\text{-N g}^{-1}$)	0.654	0.59	NA
	K (L mg^{-1})	0.167	0.016	NA

^a Zhang et al. (2005); NA: not available.

Saturation time for phosphorus adsorption was calculated as per the approach given by Zhang et al. (2005). Assuming the phosphorus concentration in the influent as 3 mg PL^{-1} , bulk density of medium as 1.43 g cm^{-3} and hydraulic loading of 4 cm h^{-1} for 2.5 h of operation per day, saturation time was estimated to be about 5.24 years according to the adsorption parameters shown in Table 9. Considering the age of the plant (Table 7), its threshold point is yet to arrive as per as its saturation time is considered.

5.5.7. Adsorption studies: nitrogen removal

Adsorption isotherms of laterite medium to $\text{NH}_4^+\text{-N}$, $\text{NO}_3^-\text{-N}$, $\text{NO}_2^-\text{-N}$ were investigated (Fig. 11). Material has little adsorption capacity for $\text{NO}_3^-\text{-N}$, and $\text{NO}_2^-\text{-N}$. This is possibly due to the negative charge of the soil. From all the above forms of nitrogen, $\text{NH}_4^+\text{-N}$ shows adsorption pattern due to positive charge. Similar regression analysis was performed by applying the same equation of Langmuir's isotherm to the data shown in Fig. 11 and values of q_{\max} and K are given in Table 9.

A similar approach as in case of $\text{PO}_4^{3-}\text{-P}$ was adopted for saturation time of $\text{NH}_4^+\text{-N}$ adsorption. Assuming the $\text{NH}_4^+\text{-N}$ concentration in the influent as 8 mg N L^{-1} , bulk density of medium as 1.43 g cm^{-3} and hydraulic loading of 4 cm h^{-1} for 2.5 h of operation per day, saturation time was estimated to be about 0.96 years according to the adsorption parameters shown in Table 9. Here bio-

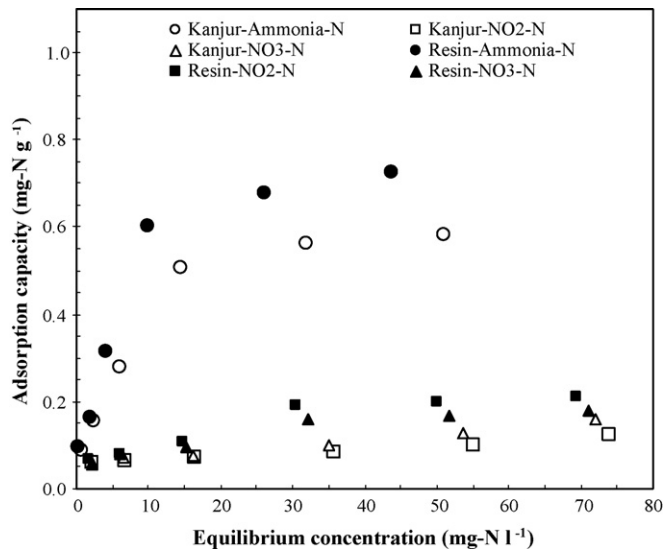


Fig. 11. N adsorption isotherm.

conversion of ammonia-N is not considered even though it is likely to be decomposed to nitrate nitrogen due to aerobic environment and microbial ecology in place. We have monitored the site for almost 1.5 year, i.e. more than the saturation time and have not found saturation for NH_4^+ -N removal confirms that bioconversion do take place making available adsorption sites for further treatment of water and wastewater. Also the facility is quite older than its saturation period (Table 1) and continues to function implying that adsorptive sites are rejuvenating. Nitrate nitrogen as seen earlier is unlikely to be retained in the bed due to negative charge of soil based medium and will be restored for successive adsorption of ammonia nitrogen.

6. Discussion

pH of the effluent was found to be in the neutral range. Additives, which are primary rock powder added in the media, probably get subjected to mineral weathering and control the pH. This can also be evident from marginal increase in conductivity and total dissolve solids in the effluent. Suspended solid and turbidity removal was almost 90–100% even for low (monsoon) as well during high loading (pre- and post-monsoon). This could be attributed to filtration capacity of soil bed.

COD loading variation with respect to seasonal change was expected and low loading in monsoon is probably due to rain-water dilution factor. The K_d values for BOD and COD (0.35 and 0.23 h^{-1} , respectively) are many folds higher than the reported values for planted soil filter (0.26 and 0.16 day^{-1}). The organic removal could be attributed to physicochemical and microbial properties of the media. The present system was designed for organic load of 53.6 kg/day and the actual substrate load was found to be 4.58 kg/day . It implies that the present load is 8.5% of the actual capacity of the bed. Hydraulics, distribution system efficiency and inevitability of alternate drying and wetting cycle could be the accounting factors for this under utilization of the bed.

Rate of nitrification based on nitrification potential was estimated to be 3.45 kg/day whereas the actual nitrification rate was found to be 40 gN/day . These values are at least 85 times less suggesting only 1.2% nitrification than its estimated potential. Loss of ammoniacal-N via volatilization can be ruled out as the pH of the medium is slight acidic. Ammonium can also be lost through nitrification–denitrification reaction. Unsatura-

tion (via drying cycle) tends to fill the soil pores with air and thereby enhances oxygen rich atmosphere in soil medium. Organic carbon source contained in the effluent are primarily susceptible to oxidation than ammonia due to best bacterial affinity and adsorption (Cochet et al., 1990). Hence, denitrification seems to be least predominant mechanism for N removal here. Adsorbed ammonia is available for uptake by micro-organisms and by vegetation, or for conversion to nitrate N through nitrification. But absence of equivalent amount of nitrate and/or nitrite nitrification in most of the effluent samples confirms the incomplete nitrification. Missing nitrogen can be accounted through bioassimilation via sorption by soil microflora and/or plants. Overall, TN reduction could be attributed to removal of ammonium and organic N compensating for the nitrate-N formation. Nitrogen removal mechanism could be soil fixation, ammonia volatilization, plant uptake and nitrification–denitrification.

Removal of anions is the critical constraint for most of the soil based natural systems for wastewater purification. Attachment of anions on to the soil is very weak (due to weak van der Waal's force of attraction) as soil is negatively charged due to silicates. This charge repulsion is the major barrier in the anionic adsorption onto soil. This was also observed for N and S removal in CSF soil filter. Sulphate removal was as low as 10% during monsoon and rest of the time 17%.

There are two aspects of pathogen removal in CSF: (i) property of media to retain pathogens in first phase of filtration, i.e. bacterial adhesion, and (ii) predation of these pathogens to regenerate bed for further adhesion. The high values of K_d observed is a measure of bacterial removal power of the system resulting due to high population of predators such as coliphage, protozoa, and earthworm of which coliphage and protozoa were measured and reported to be high as mentioned earlier. Physicochemical environment such as pH, moisture content, types of soil, clay content, organic matter content, CEC, AEC; hydrodynamic properties such as oxygen concentration, residence time in filter and microbial niche are some of the factors controlling the fate of microbes when applied on to the soil (Ellis and McCalla, 1976; Crane and Moore, 1984; Krone, 1968; Reddy et al., 1981).

Measurement of soil hydrolases activity such as urease, protease, acid phosphatase and β -glucosidase are related to the N, P and C mineralisation. Urease and protease activity are associated with hydrolysis of organic nitrogen to inorganic nitrogen, phosphatase activity is an indicator of hydrolysis of organic phosphorus compounds to phosphates and β -glucosidase hydrolyses β -glucosides in soil or in decomposing plant residue (Caravaca et al., 2005; Ceccanti and García, 1994). Microbial ecology of the media and its characteristic enzymatic activity has reflected into the removal of C, N and P compounds from wastewater.

7. Conclusions

CSF with laterite soil medium facility shows high-degree removal of COD, BOD, ammoniacal-N, nitrite-N, suspended solids and turbidity thereby imparting crystal clearness to water, color as well odor removal and total green ambience. Due to its low energy, green ambience, production of soil and fertilizers, chemical contaminants and pathogen removal, CSF is only one of its kind which proves a better option to treat, recycle and reuse wastewater for non-potable water as from gardens, washing roads, floors, cars and side drains, for cleaning toilets, and for construction.

Acknowledgements

The authors wish to register their sincere acknowledgement to the staff of Naval Dockyard Housing Colony, Mumbai for their

help in construction, operation, maintenance and monitoring of the plant. We would like to extend our sincere thanks to Sophisticated Analytical Instrumentation Facility (SAIF), Indian Institute of Technology-Bombay, Mumbai for their assistance during the analysis of samples.

References

- Akbulut, S., Saglam, A., 2004. Modification of hydraulic conductivity in granular soils using waste materials. *Waste Manage.* 24 (5), 494–499.
- American Public Health Association (APHA), 2003. Standard Methods for the Examination of Water and Wastewater. American Public Health Association, American Water Works Association and Water Pollution Control Federation, Washington, DC.
- Bahgat, M., Dewedar, M.A., Zayed, A., 1999. Sand-filters used for wastewater treatment: buildup and distribution of microorganisms. *Water Res.* 33 (8), 1949–1955.
- Belmont, M.A., Metcalfe, C.D., 2002. Contaminacion del agua en la cuenca del rio Texcoco. In: Proceedings of the International Conference: AMBAKUCHA 2002. The first Intercultural Conference on the Integrated Management of Human Settlements within Watersheds, Otavalo, Ecuador, May 28–31, 2002.
- Belmont, M.A., Cantellano, E., Thompson, S., Williamson, M., Sanchez, Abel, Chris, D., Metcalfe, C.D., 2004. Treatment of domestic wastewater in a pilot scale natural treatment system in central Mexico. *Ecol. Eng.* 23, 299–311.
- Black, C.A. (Ed.), 1965. Methods of Soil Analysis, Part 2. Chemical and Microbiological Properties. American Society of Agronomy, Madison.
- Bouwer, H., 1985. Renovation of wastewater with rapid infiltration land treatment systems. In: Asano, T. (Ed.), *Artificial Recharge of Groundwater*. Butterworth, Boston, MA, pp. 249–282.
- Calderon, J.F., Jackson, L.E., Scow, K.M., Rolston, D.E., 2000. Microbial responses to simulated tillage in cultivated and uncultivated soils. *Soil Biol. Biochem.* 32, 1547–1549.
- Caravaca, F., Alguacil, M.M., Torres, P., Roldan, A., 2005. Plant type mediates rhizospheric microbial activities and soil aggregation in a semiarid Mediterranean salt marsh. *Geoderma* 124 (3/4), 375–382.
- Ceccanti, B., Garcia, C., 1994. Coupled chemical and biochemical methodologies to characterize a composting process and the humic substances. In: Senesi, N., Miano, T. (Eds.), *Humic Substances in the Global Environment and Its Implication on Human Health*. Elsevier, New York, pp. 1279–1285.
- Chapman, H.D., 1965. Cation exchange capacity. In: Black, C.A., et al. (Eds.), *Methods of Soil Analysis*. Agronomy 9. American Society of Agronomy, Madison, pp. 891–901.
- Cochet, C., Derangere, D., Rousselle, T., 1990. Soil absorption systems and nitrogen removal. *Water Sci. Technol.* 22 (3/4), 109–116.
- Colombo, C., Palumbo, G., Sannino, F., Gianfreda, L., 2002. Chemical and biochemical indicators of managed agricultural soils. In: 17th World Congress of Soil Science, Bangkok, Thailand, 1740####, pp. 1–9.
- Crane, S.R., Moore, J.A., 1984. Bacterial pollution of groundwater: a review. *Water Air Soil Pollut.* 22, 67–83.
- Dick, R.P., 1997. Soil enzyme activities as integrative indicators of soil health. In: Pankhurst, C.E., Doube, B.M., Gupta, V.V.S.R. (Eds.), *Biological Indicators of Soil Health*. CAB International, Wallingford, USA, pp. 121–156.
- Dick, W.A., Tabatabai, M.A., 1993. Significance and potential uses of soil enzymes. In: Metting, F.B. (Ed.), *Soil Microbial Ecology: Application in Agricultural and Environmental Management*. Marcel Dekker, New York, pp. 95–125.
- Drijber, R.A., Doran, J.W., Parkhurst, A.M., Lyon, D.J., 2000. Changes in soil microbial community structure with tillage under long-term wheat-fallow management. *Soil Biol. Biochem.* 32, 1419–1430.
- Dubbin, W.E., Penn, M.G., Hodson, M.E., 2006. Edaphic influences on plant community adaptation in the Chiquibul forest of Belize. *Geoderma* 131, 76–88.
- Eivazi, F., Tabatabai, M.A., 1977. Phosphatases in soils. *Soil Biol. Biochem.* 9, 167–172.
- Ellis, J.R., McCalla, T.M., 1976. Fate of pathogens in soils receiving animal wastes—a review. ASAE Paper No. 762560. ASAE, St. Joseph, MI.
- Fallowfield, H.J., Garrett, M.K., 1985. The treatment of wastes by algal culture. *J. Appl. Bact. Symp. Suppl.*, 1875–2055.
- Fuentes, E.R., Constantino, C.L., Silva, E.E., Dendooven, L., 2002. Characteristics and carbon and nitrogen dynamics in soil irrigated with wastewater for different lengths of time. *Bioresour. Technol.* 85, 179–187.
- Gee, G.W., Bauder, J.W., 1986. Particle size analysis. In: Klute, A. (Ed.), *Methods of Soil Analysis, Part I*. Agron. Monogr. 9, 2nd ed. ASA and SSSA, Madison, WI, pp. 383–411.
- Gianfreda, L., Bollag, J.M., 1996. Influence of natural and anthropogenic factors on enzyme activity in soil. In: Stotzky, G., Bollag, J.M. (Eds.), *Soil Biochemistry*, vol. 9. Marcel Dekker, New York, pp. 123–194.
- Gianfreda, L., Rao, M.A., Piotrowska, A., Palumbo, G., Colombo, C., 2005. Soil enzyme activities as affected by anthropogenic alterations: intensive agricultural practices and organic pollution. *Sci. Total Environ.* 341, 265–279.
- Hart, S.C., Stark, J.M., Davidson, E.A., Firestone, M.K., 1994. Nitrogen mineralization immobilization and nitrification. In: Weaver, R.W., et al. (Eds.), *Methods of Soil Analysis. Part 2: Storage for Short Periods at Room Temperature*. SSSA Book Ser. 5. SSSA, Madison, WI, pp. 985–1018.
- Heistad, A., Paruch, A.M., Vråle, L., Ádám, K., Jenssen, P.D., 2006. A high-performance compact filter system treating domestic wastewater. *Ecol. Eng.* 28 (4), 374–379.
- Ingham, E.R., 1994. Protozoa. In: Mickelson, S.H., Bigham, J.E. (Eds.), *Methods of Soil Analysis. Part 2: Microbial and Biochemical Properties*. Soil Science Society of America, Madison, WI, pp. 491–515.
- Kadam, A.M., Oza, G.H., Nemade, P.D., Shankar, H.S., 2008. Pathogen removal from municipal wastewater in constructed soil filter. *Ecol. Eng.* 33, 37–44.
- Kern, J., Idler, C., 1999. Treatment of domestic and agricultural wastewater by reed systems. *Ecol. Eng.* 12, 13–25.
- Krone, R.B., 1968. In: Wilson, C.W., Beckett, F.E. (Eds.), *Municipal Sewage Effluent for Irrigation*. Louisiana Tech. Alumni Fndtn., Ruston, LA, pp. 75.
- Langmuir, D., 1997. *Aqueous Environmental Geochemistry*. Published by Prentice-Hall, Inc., New Jersey, USA, pp. 403–430.
- Luanmanee, S., Attanandana, T., Masunaga, T., Wakatsuki, T., 2001. The efficiency of a multi-soil-layering system on domestic wastewater treatment during the ninth and tenth years of operation. *Ecol. Eng.* 18, 185–199.
- McCarthy, A.J.M., 1987. Lignocellulose-degrading actinomycetes. *FEMS Microbiol. Rev.* 46, 145–163.
- Mehlich, A., 1948. Determination of cation and anion exchange properties of cells. *Soil Sci.* 66, 429–445.
- Metcalfe & Eddy Inc., 1995. *Wastewater Engineering: Treatment, Disposal and Reuse*. Revised by Tchobanoglous G., Burton, F., 3rd edn., Tata McGraw-Hill Publishing Co., New Delhi.
- Nannipieri, P., Kandeler, E., Ruggiero, P., 2002. Enzyme activities and microbiological and biochemical processes in soil. In: Burns, R.P., Dick, R.P. (Eds.), *Enzymes in the Environmental Activity, Ecology and Applications*. Marcel Dekker, New York, pp. 1–33.
- Nemade, P.D., Kadam, A.M., Oza, G.H., Dutta, S.M., Shankar, H.S., 2007. Adsorption of arsenite As (III) by soil biotechnology and hydrous ferric oxide. In: International Conference on Water Management and Technology Applications in Developing Countries, Kuala Lumpur, Malaysia, 14–16 May 2007.
- Nemade, P.D., Kadam, A.M., Shankar, H.S., 2008. Arsenic and iron removal from water using constructed soil filter—a novel approach. *Asia-Pac. J. Chem. Eng.* 3, 497–502.
- Njau, K.N., Minja, R.J.A., Katima, J.H.Y., 2003. Pumice soil: a potential wetland substrate for treatment of domestic wastewater. *Water Sci. Technol.* 48 (5), 85–92.
- Ou, Z., Sun, T., Li, P., Yediler, A., Yang, G., Kettrup, A., 1997. A production-scale ecological engineering forest system for the treatment and reutilization of municipal wastewater in the Inner Mongolia, China. *Ecol. Eng.* 9 (1/2), 71–88.
- Pattanaik, B.R., 2001. Studies in waste water processing in biofilters. Ph.D. Thesis. Chemical Engineering Department, Indian Institute of Technology-Bombay, India.
- Pattanaik, B.R., Gupta, A., Shankar, H.S., 2004. Residence time distribution model for soil filters. *Water Environ. Res.* 76, 168–174.
- Perks, A.R., Bauer, G.A., Devnani, S., Bhmbane, E., 2004. Wastewater flow monitoring for Mumbai, India. Internal Report for R.V. Anderson Associates Ltd., Ottawa, Canada, pp. 1–6.
- Reddy, K.R., Khaled, R., Overcash, M.R., 1981. Behavior and transport of microbial pathogens and indicator organisms in soils treated with organic wastes. *J. Environ. Qual.* 10, 255–266.
- Schmidt, E.L., Belsler, L.W., 1994. Autotrophic nitrifying bacteria. In: Mickelson, S.H., Bigham, J.E. (Eds.), *Methods of Soil Analysis. Part 2: Microbial and Biochemical Properties*. Soil Science Society of America, Madison, WI, pp. 159–177.
- Smith, R.G., Schroeder, E.D., 1985. Field studies of the overland flow process for the treatment of raw and primary treated municipal wastewater. *J. Water Pollut. Control Federation* 57 (7), 785–794.
- Shankar, H.S., Bhawalkar, U.S., Pattanaik, B.R., 2005. US Patent: Process for Treatment of Organic Wastes. US Patent No.: 6890438, www.uspto.gov (issue date: 10 May 2005).
- Tabatabai, M.A., 1994. Soil enzymes. In: Mickelson, S.H., Bigham, J.E. (Eds.), *Methods of Soil Analysis. Part 2: Microbial and Biochemical Properties*. Soil Science Society of America, Madison, WI, pp. 775–826.
- Tiedje, J.M., 1994. Denitrifier. In: Mickelson, S.H., Bigham, J.E. (Eds.), *Methods of Soil Analysis. Part 2: Microbial and Biochemical Properties*. Soil Science Society of America, Madison, WI, pp. 245–267.
- Trasar-Cepeda, C., Leiros, M.C., Seoane, S., Gil-Sotres, F., 2000. Limitation of soil enzymes as indicators of soil pollution. *Soil Biol. Biochem.* 32, 1867–1875.
- Van Beelan, P.V., Doelman, P., 1997. Significance and application of microbial toxicity tests in assessing ecotoxicological risks of contaminants in soil and sediments. *Chemosphere* 43, 455–499.
- Wellington, E.M.H., Toth, I.K., 1994. Actinomycetes. In: Mickelson, S.H., Bigham, J.E. (Eds.), *Methods of Soil Analysis. Part 2: Microbial and Biochemical Properties*. Soil Science Society of America, Madison, WI, pp. 269–290.
- Zhang, J., Huang, C., Shi, H., Hu, H., 2005. Nitrogen removal enhanced by intermittent operation in a subsurface wastewater infiltration system. *Ecol. Eng.* 25, 419–428.