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SEMI-SURFACE HORIZONTAL FLOW CONSTRUCTED WETLAND TREATMENT OF DOMESTIC SEWAGE EFFLUENT ON ITS IRRIGATION QUALITY

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ABSTRACT

An experiment was conducted at the Main Agricultural Research Station, Dharwad, Karnataka, India during January to May, 2014 to study the effect of a semi-surface horizontal flow constructed wetland system on irrigation quality of domestic sewage effluent. There was considerable reduction in pH (7.33 to 6.88), electrical conductivity (0.83 to 0.76 dS m^{-1}), sodium adsorption ratio (4.16 to 3.67), residual sodium carbonate (4.35 to 2.28 me L^{-1}), biological oxygen demand (256 to 118 mg L^{-1}) and chemical oxygen demand (410 to 251 mg L^{-1}) due to constructed wetland treatment. Further, the treatment system proved to be effective in reducing total solids, total suspended solids and total dissolved solids. Boron (2.14 to 1.00 mg L^{-1}), chlorides (7.59 to 5.60 me L^{-1}), bicarbonates (11.62 to 8.37 me L^{-1}), organic nitrogen (8.28 to 2.07 mg L^{-1}), total nitrogen (23.7 to 21.7 mg L^{-1}) and total phosphorus (7.9 to 6.0 mg L^{-1}) were also reduced due to sewage treatment compared to raw effluent. Interestingly, the treated sewage effluent had higher concentration of ammoniacal and nitrate nitrogen than untreated sewage effluent. The results revealed an improvement in the quality of sewage effluent after passing through the constructed wetland treatment system.

KEY WORDS
Domestic sewage effluent
constructed wetland treatment
Effluent quality parameters

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INTRODUCTION

Future global agricultural water consumption is estimated to increase roughly by 19 per cent by 2050 and will be even greater in the absence of any technological progress or policy interventions. In Indian context, agricultural sector alone accounts for more than 89 per cent of total water use, as against 8 per cent by domestic sector and 3 per cent by industrial sector (Paul *et al*., 2010). Declining freshwater resources and the need for safe disposal of wastewater have led to a rapid increase in wastewater reuse all over the world. Sewage irrigation is an age old agriculture practice and is being practiced over a long period in different parts of the world (Page *et al*., 1983; Pandey and Srivastava, 2009). Irrigation with sewage effluent has become a more acquainted farmers' practice as a source of irrigation water and nutrients. Farmers prefer to use sewage effluent as it contains essential nutrients and thus it reduces the costs on fertilizer inputs (Pandey and Srivastava, 2009). At the same time, it is also true that wastewater also contains broad spectrum of contaminants *viz,* biodegradable organic compounds, toxic metals, suspended solids, micro pathogens and parasites (Pedrero and Alarcon, 2009) which restrict its direct application to field. If sewage effluent can be properly treated, then the fear of toxic contaminants buildup both in soil and groundwater can be avoided.

In recent years, treated wastewater is being used in many countries like United Kingdom, United States of America, Israel, India, China, Mexico and Nairobi (Hussain *et al*., 2002) as an alternative source of irrigation with different regulations and restrictions. To alleviate hazardous contaminants, treating wastewater with proper method prior to field application attains prime importance (Dash *et al*., 2012). Use of treated wastewater offers new vistas in enhancing water availability for agricultural activities and provides a means for waste disposal (Hameed *et al*., 2010).

There are different proven conventional methods for wastewaters treatment such as active sludge process (ASP), rotating biological contactor (RBC), stabilization ponds, oxidation ditch, trickling filter (TF), sequence batch reactors (SBR), lagoons and up flow anaerobic sludge blanket (UASB), Micro-algae techniques etc.. These methods have the limitations like energy requirement, economic consideration, need for large land, complex construction and operation, sensitive to temperature and excessive sludge generation (Sayadi *et al*., 2012).

Constructed wetland was designed and constructed to utilize natural processes involving wetland vegetation, soils and the associated microbial assemblages to assist in treating wastewaters (Brix *et al*., 2011). Natural characteristics are applied to constructed wetlands with emergent macrophyte stands that duplicate the physical, chemical and biological processes of natural wetland systems. Phytoremediation is coined to be superior and efficient method of the reducing pollutants and improving the quality of waste water (Patel and Kanungo, 2010). The major nutrient removal mechanisms taking place in these treatment systems are biodegradation, precipitation and filtration (Vymazal, 2011; Dash *et al.,* 2012). The surface flow wetlands, often referred to as free water surface constructed wetlands (FWS), subsurface flow constructed wetlands, and hybrid constructed wetlands are the various types of systems tried for treating wastewaters (Vymazal, 2010).

Sayadi *et al.* (2012) reviewed the works on hybrid constructed wetlands and came out with the conclusion that the hybrid constructed wetlands ensure a more efficient and stable removal rate of pollutants from various wastewaters in comparison with other wastewaters treatment plans. However, the initial cost of erecting a constructed wetland wastewater treatment plant is enormous, but highly cost-effective in terms of operation and maintenance (Oluwole and Gbenga, 2013).

The system, already regarded as energy efficient, can be made more affordable by using local resources (Collins *et al.,* 2005). The designing of the constructed wetland and materials used may vary from place to place depending on the need and materials available. When the purpose of treatment is towards sustainable irrigation practice; lowering the load of solids and nutrients, the biological and chemical oxygen demand of the sewage effluent are the important parameters to be targeted. The present study was aimed at designing a modified surface flow system for treating the domestic sewage effluent using locally available resources to address the above concerns.

MATERIALS AND METHODS

The study was carried out at the Main Agricultural Research Station, Dharwad, Karnataka, India during January to May 2014. The domestic sewage of the University campus was collected at one point in the lower reach and used for the treatment. In the present study, the surface flow constructed wetland system (Vymazal, 2010) was slightly modified to have a semi-surface horizontal flow system with the aim of achieving higher treatment efficiency. The locally available and good adsorbents like brick pieces and charcoal were used in the shallow filer-bed systems along with sand, gravel, stone and macrophyte (*Brachiaria mutica*). The treatment system consisted of different bedding materials and the lay-out of the system is indicated in figure 1. The vegetated (*Brachiaria mutica*) channel (1.2 m width and 0.3 m depth) was horizontally and sequentially bedded with 2.0 m length strips each of big sized boulders (30-45 cm size), small sized boulders (25-30 cm size), jelly (~ 2.0 cm size), sand (0.025 cm size), broken bricks (5-10 cm size) and lastly charcoal (5-10 cm size). Each such filter strip along the grassy channel was separated by 1.0 m distance. The domestic sewage was allowed to flow through treatment channel from inlet and the treated wastewater was collected in outlet and used for irrigation. The flow rate was calculated as approximately 0.625 m^3 $hour^{-1}$ and the hydraulic retention time of around 2.5 days. The sewage effluent quality (both untreated and treated) was compared with that of ground water. All the three samples were collected periodically at 7 days interval and, the fortnight averages were calculated and compared over the period of five months.

The untreated sewage effluent (USE), treated sewage effluent (TSE) and groundwater (GW) samples were analyzed for irrigation water quality parameters *viz.*, pH, electrical conductivity (EC), biological oxygen demand (BOD), chemical oxygen demand (COD), sodium adsorption ratio (SAR), residual sodium carbonate (RSC), total suspended solids (TSS), total dissolved solids (TDS), total solids (TS), boron (B) and chloride (Cl^-) following standard procedures (Tandon, 1998 ; APHA – AWWA - WPCF, 1980). These were also analyzed for forms of N and P *viz.*, ammoniacal nitrogen (NH_4^+ -N), nitrate nitrogen (NO_3^- -N), organic nitrogen (ON), total nitrogen (TN) and total phosphorus (TP) by following the procedures as described by Tandon (1998). The sodium adsorption ratio (SAR), an indicator of likely sodium hazard in soil was calculated using the relationship between water soluble sodium and calcium + magnesium (Richards, 1954). The residual sodium carbonate (RSC), an indicator of alkalinity hazard was calculated using the values of water soluble calcium + magnesium and carbonate + bicarbonate (CSSRI, 2004).

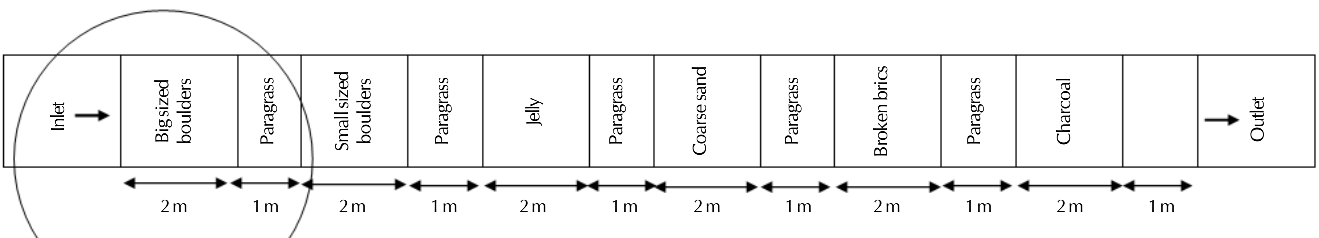
RESULTS AND DISCUSSION

All through the experimental period *i.e.,* from January to May 2014, the pH of untreated sewage effluent varied from of 6.71 to 7.86 while that of treated sewage effluent from 6.41 to 7.43 (Table 1). The mean pH of the untreated (raw) sewage effluent (7.33) was relatively more alkaline in nature compared to treated sewage effluent (6.88), which might be due to contribution from soaps and detergents present in domestic sewage effluent added through washing, bathing *etc*. The pH of treated sewage effluent which was collected from the outlet of the constructed wetland treatment system was relatively lower compared to untreated sewage effluent throughout the experimental period. The observed pH reduction was attributed to CO_2 production from decomposing plant litter and other sewage effluent components trapped in the root mat and nitrification of ammonia (Li *et al*., 2008 ; Fan *et al*., 2013). The reduction in pH of raw sewage effluent was a desirable attribute signifying lesser risk of soil sodication over a period. The mean pH of treated sewage effluent was very close to that of groundwater (6.91).

In general, the long-term irrigation with untreated wastewater under arid and semi-arid climates leads to accumulation of salts and salinity hazard (Aydin *et al*., 2015). The hope was that the treatment technique would reduce the salinity load in the treated water. In the present study, the electrical conductivity of the sewage effluent, in general, remained low, ranging from 0.69 to 0.88 dS m^{-1}. Though marginal, the electrical conductivity of the untreated sewage effluents was higher throughout the experimental period compared to the treated sewage effluent (Table 1). The overall mean electrical conductivity of untreated sewage effluent was 0.83 dS m^{-1} which reduced to 0.76 dS m^{-1} due to sewage treatment. The decrease in conductivity was attributed to uptake of micro, macro elements and ions by plants and bacteria and their removal through adsorption to plant roots, litter and settleable suspended particles (Vera *et al*. 2011 ; Arivoli and Mohanraj,

Table 1: Temporal variations in the quality of sewage effluent

Parameters	Jan. 2014		Feb. 2014		Mar. 2014		Apr. 2014		May, 2014		Range		Mean		GW
	USE	TSE	USE	TSE	USE	TSE	USE	TSE	USE	TSE	USE	TSE	USE	TSE	
pH	7.62	7.24	6.71	6.63	7.86	7.43	7.22	6.41	7.26	6.68	6.71-7.86	6.41-7.43	7.33	6.88	6.91
EC (dS m^{-1})	0.76	0.75	0.88	0.76	0.87	0.85	0.77	0.74	0.88	0.69	0.76-0.88	0.69-0.85	0.83	0.76	0.72
Total solids (mg L^{-1})	1180	830	1220	720	870	620	860	725	1090	905	860-1220	620-905	1044	760	20
Total suspended solids (mg L^{-1})	420	290	480	230	390	250	480	270	630	350	390-630	230-350	480	278	8
Total dissolved solids (mg L^{-1})	760	540	740	490	480	370	590	480	740	630	480-760	370-630	662	446	12
BOD (mg L^{-1})	252	113	259	121	268	119	252	116	249	123	249-268	113-123	256	118	9
COD (mg L^{-1})	416	241	412	256	402	236	441	253	410	268	402-441	236-268	410	251	14
SAR ($mmol^{1/2}$ $L^{-1/2}$)	4.11	3.19	2.70	2.24	4.63	3.49	5.22	3.42	4.16	3.78	2.70-5.22	2.24-3.78	4.16	3.67	2.36
RSC (me L^{-1})	8.41	6.17	5.12	6.46	5.56	1.90	3.98	1.76	-1.34	-4.91	-1.34-8.41	-4.91-6.46	4.35	2.28	-2.70
Chlorides (me L^{-1})	9.68	6.38	10.7	7.92	6.28	3.47	5.44	4.76	5.81	5.48	5.44-10.70	3.47-7.92	7.59	5.60	5.10
Bicarbonate (me L^{-1})	15.70	11.50	12.60	11.86	12.60	8.50	10.70	7.20	6.54	2.73	6.54-15.70	2.73-11.86	11.62	8.37	2.18
Boron (mg L^{-1})	2.00	1.60	1.60	0.50	2.08	0.96	2.35	0.80	2.65	1.15	1.60-2.65	0.50-1.60	2.14	1.00	0.60
NH_4- N (mg L^{-1})	13.4	17.4	15.5	16.4	13.9	14.6	13.4	17.2	16.4	17.6	13.4-16.4	14.6-17.6	14.5	16.6	0.46
NO_3- N (mg L^{-1})	1.40	3.82	1.23	1.33	2.28	3.34	1.48	3.23	2.06	3.23	1.23-2.28	1.33-3.82	1.69	2.99	0.75
Organic nitrogen (mg L^{-1})	8.26	1.35	5.10	2.81	7.72	2.59	10.84	1.85	9.49	1.77	5.10-10.84	1.35-2.81	8.28	2.07	0.003
Total nitrogen (mg L^{-1})	23.1	22.6	21.8	20.5	23.9	20.5	25.7	22.3	23.9	22.6	21.8-25.7	20.5-22.6	23.7	21.7	1.25
Total phosphorous (mg L^{-1})	9.1	5.9	11.1	9.3	7.5	4.8	5.7	4.2	6.3	5.9	5.7-11.1	4.2-9.3	7.9	6.0	0.10



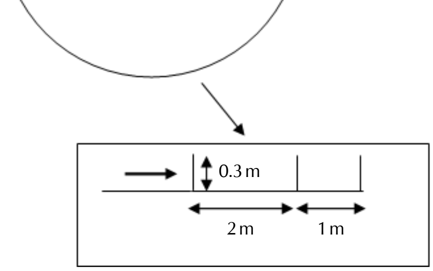


Figure 1: Lay-out of constructed wetland components

Figure 2: Mean total solids (TS), total suspended solids (TSS) and total dissolved solids of untreated (USE) and treated (TSE) sewage effluents in comparison to groundwater (GW)

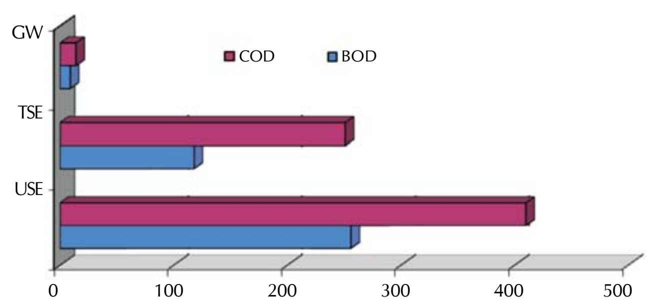


Figure 3: Mean biological oxygen demand (BOD) and chemical oxygen demand (COD) of untreated (USE) and treated (TSE) sewage effluents in comparison to groundwater (GW)

2013). The electrical conductivity of groundwater was relatively low (0.72 dS m^{-1}) compared to that of untreated sewage effluent and treated sewage effluent.

The data pertaining to temporal variations in total solids, total suspended solids and total dissolved solids are presented in table 1. Throughout the study period, the untreated sewage effluent had higher contents of total solids, total suspended solids and total dissolved solids. The mean total solids were relatively higher in the raw sewage effluent (1044 mg L^{-1}) which reduced (760 mg L^{-1}) due to effluent treatment (Fig.2). Continuous irrigation with untreated wastewater was reported to decrease the saturated hydraulic conductivity due to suspended solids including organic matter (Abedi-Koupai *et al*., 2006). However, due to sequential filter beds adopted in the present study, the mean total suspended solids were greatly reduced from 480 to 278 mg L^{-1} indicating lesser risk of filling of soil pores and maintaining the soil water conductivity. Efficiency of turbidity removal is reported to depend largely on the size sand/ bedding particles and the depth of the bed (Jing *et al.,* 2001). Zurita *et al*. (2009) and Vera *et al*. (2011) also attributed the reduction in total solids, total suspended solids and total dissolved solids to the mechanical and biological filtering action of constructed wetland system. Groundwater showed the lowest values of total solids, total

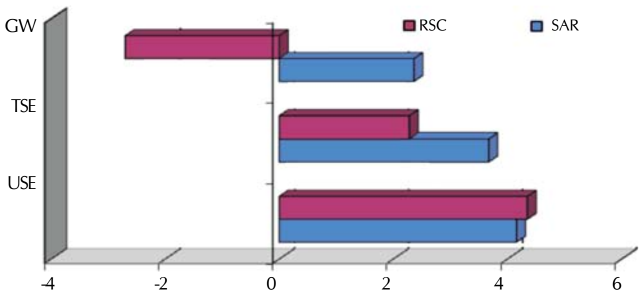


Figure 4: Mean residual sodium carbonate (RSC) and sodium adsorption ratio (SAR) of untreated (USE) and treated (TSE) sewage effluents in comparison to groundwater (GW)

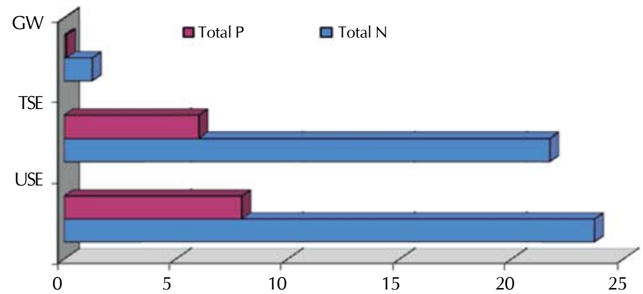


Figure 5: Mean total N and total P of untreated (USE) and treated (TSE) sewage effluents in comparison to groundwater (GW)

suspended solids and total dissolved solids (20, 8 and 12 mg L^{-1}, respectively).

The temporal variability in biological oxygen demand and chemical oxygen demand over the period revealed much higher values of these in untreated sewage effluent compared to treated sewage effluent (Table 1). During the monitoring period, the biological oxygen demand of untreated sewage effluent ranged from 249 to 268 mg L^{-1} which reduced to 113-123 mg L^{-1}, considered nearer to the permissible level. Similar trend was observed with chemical oxygen demand also. This suggested an improvement in biological oxygen demand and chemical oxygen demand due to constructed wetland treatment. The mean biological oxygen demand of 256 mg L^{-1} in untreated sewage effluent was reduced to 118 mg L^{-1} after the treatment (Fig.3). These trends are in agreement with the findings of Zurita *et al.* (2009) who reported a considerable reduction in biological oxygen demand due to constructed wetland system. The groundwater recorded the lowest biological oxygen demand (9 mg L^{-1}) and chemical oxygen demand (14 mg L^{-1}) compared to untreated and treated sewage effluents. The presence of macrophytes as a bio-filter is reported to provide a more effective distribution of the roots and a more propitious habitat encouraging the development of a great diversity of microbial communities. Higher biological oxygen demand and chemical oxygen demand removal efficiencies were reported due to increased retention time and higher rhizhosphere oxidation caused by diversity of roots.

The residual sodium carbonate and sodium adsorption ratio are considered as indicators of likely sodium and alkalinity hazard in soil, respectively. Across sources of irrigation water, the residual sodium carbonate varied between 8.41 and -4.91 during the period from January to May 2014 indicating larger natural variability (Table 1). The residual sodium carbonate values were higher in the beginning and decreased over time in both untreated and treated sewage effluents. The overall mean residual sodium carbonate values of different sources of irrigation water indicated higher values for untreated sewage effluent (4.35 me L^{-1}) followed by treated sewage effluent (2.28 me L^{-1}) and least in groundwater (-2.70 me L^{-1}) (Fig. 4). Unlike in case of residual sodium carbonate, lesser variations were observed in sodium adsorption ratio during the period and among untreated and treated sewage effluents. The overall mean sodium adsorption ratio values indicated higher values for untreated sewage effluent (4.16 $mmol^{1/2}$ $L^{-1/2}$) followed by treated sewage effluent (3.67 $mmol^{1/2}$ $L^{-1/2}$) and least in groundwater (2.36 $mmol^{1/2}$ $L^{-1/2}$). The sodium adsorption ratio values did not vary much during the period of study. The reduction in ionic concentrations therein affecting lower residual sodium carbonate and sodium adsorption ratio of treated sewage effluent was attributed to the processes like sedimentation, filtration, decomposition, adsorption and plant uptake (Vymazal, 2011). The overall reduction in residual sodium carbonate and sodium adsorption ratio in treated sewage effluent indicated less alkalinity and sodicity hazard due to its irrigation.

Wide variations in chloride concentrations were observed in case of untreated sewage effluent, which ranged from 5.44 to 10.70 me L^{-1} (Table 1) whereas in case of treated sewage effluent, the chloride concentration varied from 3.47 to 7.92 me L^{-1}. The overall mean chloride concentration of the untreated sewage effluent during the experimental period was 7.59 me L^{-1}, which reduced to 5.60 me L^{-1} due to constructed wetland treatment. Similar to chloride concentration, the bicarbonate content of untreated sewage effluent also varied considerably from 6.54 to 15.70 me L^{-1} with the mean value of 11.62 me L^{-1}. Similarly, bicarbonate content in the treated sewage effluent varied to a greater extent from 2.73 to 11.86 me L^{-1}. However, the least mean bicarbonate content was observed in groundwater (2.18 me L^{-1}). The reduction in the concentration of these specific ions meant an improvement in the irrigation quality of the effluent as higher contents of these are known to cause specific ion toxicity in plants. The drop in chloride and bicarbonate levels of treated water can be attributed to the processes listed above under SAR and RSC.

In general, the untreated sewage effluent had higher boron concentration than the treated sewage effluent. The boron concentration ranged between 1.60 to 2.65 mg L^{-1} and 0.50 to 1.60 mg L^{-1}, respectively for untreated sewage effluent and treated sewage effluent samples (Table 1). The mean boron concentration of treated sewage effluent was 2.14 mg L^{-1}. The boron content of groundwater was fairly low at 0.60 mg L^{-1}. Though, a notable fall in boron concentration of treated sewage effluent was observed, most of the times it was well above the safe limit. This aspect emphasized the need for further improvement in the filtration system to lower the boron level in the effluent. Filtration, adsorption and plant uptake might have contributed for the reduction of B in the treated sewage effluent (Vymazal, 2011).

In contrast to other parameters, the mean NH_4^+-N concentration in the untreated sewage effluent was less (14.5 mg L^{-1}) than that in the treated sewage effluent (16.6 mg L^{-1}) throughout the experimental period (Table 1). The NH_4^+ -N concentrations in the untreated sewage effluent ranged from 13.4 to 16.4 mg L^{-1} while that in treated sewage effluent varied between 14.6 and 17.6 mg L^{-1}. The mean values over the period also revealed the similar trend. The results obtained were found contrasting to the findings of Arivoli and Mohanraj (2013), Vera *et al*. (2011) and Jing *et al*. (2001). But, Vymazal (2011) reported that removal of ammonia-N is limited by lack of dissolved oxygen in filtration beds caused by permanent saturation. Presence of higher contents of organic nitrogenous fractions in domestic sewage effluent might enhance bacterial activity in the constructed wetland leading to conversion of the organic nitrogen into ammoniacal nitrogen. Ammoniacal-N is known to get adsorbed onto active sites of the bed matrix. Since it is a reversible process, as the cation exchange site of matrix is saturated, NH_4^+ -N will be released back into the water system. The higher NO_3^- -N content in the treated water might be because of the enhanced rhizosphere microbial activity under the plant species in the wetland treatment unit.

The untreated sewage effluent recorded higher organic and total nitrogen concentration compared to treated sewage effluent during the monitoring period (Table 1). The mean organic nitrogen was considerably reduced in treated sewage effluent (2.07 mg L^{-1}) compared to untreated sewage effluent (8.28 mg L^{-1}). Accelerated bacterial action taking place in the constructed wetland might have reduced the organic nitrogen levels in the treated sewage effluent. The mean total nitrogen was relatively higher at 23.7 mg L^{-1} in untreated sewage effluent which reduced to 21.7 mg L^{-1} due to passing through constructed wetland while, groundwater registered the lowest total nitrogen content (1.25 mg L^{-1}) (Fig.5). The results were in agreement with the findings of Healy and Cawley (2002) and Kelvin and Tole (2011). The vegetated channel with paragrass (*Brachiaria mutica*) looked efficient in nitrogen removal through uptake.

The total phosphorous concentration in untreated sewage effluent varied greatly between 5.7 and 11.1 mg L^{-1} (Table 1) with the mean value of 7.9 mg L^{-1} (Fig.5). Similarly, the total phosphorus content varied from 4.2 to 9.3 mg L^{-1} with the mean value of 6.0 mg L^{-1} in treated sewage effluent. The total phosphorus concentration in the groundwater was very less (0.10 mg L^{-1}). The processes like precipitation, plant uptake and adsorption taking place in the constructed wetland treatment system might be responsible for the reduction in total phosphorus in the treated sewage effluent (Vera *et al*., 2011; Arivoli and Mohanraj, 2013).

On the basis of present findings, it can be concluded that the modified semi-surface horizontal flow constructed wetland system improved the quality of sewage effluent with significant reduction in pH, EC, sodium adsorption ratio, residual sodium carbonate, biological oxygen demand and chemical oxygen demand. Considerable reduction was also observed in other ancillary quality parameters such as total solids, total suspended solids, total dissolved solids, boron, chlorides, bicarbonates, total carbon, organic nitrogen, total nitrogen and total phosphorus were also improved in the treated sewage effluent compared to raw effluent. However, the treated sewage effluent had higher concentration of ammoniacal and nitrate nitrogen than untreated sewage effluent. Evidencing the beneficial effect of the treatment system, further, it is desired to standardize the components (length, breadth and depth) of the filterbed, the flow rate and other design parameters to arrive at desired irrigation quality for safe and sustained use of domestic sewage effluent in crop production.

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