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SEASONAL STUDY AND ITS IMPACT ON SEWAGE TREATMENT IN THE ANGULAR HORIZONTAL SUBSURFACE FLOW CONSTRUCTED WETLAND USING AQUATIC MACROPHYTES

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ABSTRACT

The increasing applications of constructed wetland for sewage treatment coupled with increasingly strict water quality standards is an ever growing incentive for the development of better process design tools. This paper states the pollution removal efficiency depend on the impact of seasons on the sewage treatment. In the present study used surface and subsurface flow types constructed wetlands using free floating and emergent types of macrophytes. Surface flow e.g. *E. crassipes* and subsurface flow e.g. *Typha latifolia, Colocasia esculenta, Cana indica, Panicum maximum, Pennisetum purpureium,* and Control. Seasons are rainy, winter and summer were selected for the investigations of the impact on sewage treatment. Test samples before and after treatment were analyzed through selective parameters like pH, EC, TSS, TDS, TS, COD, BOD_5, NO_3, PO_4 and SO_4 using standard methods. Aim is to evaluate sewage treatment effectiveness and seasonal performance of the system. Present study carried for one year and samples were collected and analyzed from 2011 to 2012. Results reveal that the *E. crassipes* shows maximum pollution reduction in the type of the surface flow CW. In *E. crassipes* the maximum pollution reduction found in the rainy season and less pollution reduction found in summer season. In the subsurface flow category *Pennisetum purpureium* plant shows maximum removal efficiency in the winter season less efficiency found in the summer seasons. In *Typha latifolia* shows maximum removal of pollutants in rainy and less reduction in summer, in the *Colocasia esculenta* shows maximum removal in rainy and less removal in summer, in *Cana indica* maximum removal in winter and less removal in summer, in *Panicum maximum* shows maximum removal and in control shows maximum removal in rainy and less in removal in summer season. In the overall study maximum pollutants removal found in the rainy and winter season and seems better for the plants growth.

KEYWORDS: Seasonal Performance, Sewage Treatment, Angular Horizontal Subsurface Flow, Constructed Wetland, Aquatic Macrophytes

INTRODUCTION

Over the past two to three decades the Indian government has paid a great deal of attention to environmental protection. However, as economic development has increased, water pollution has become a major environmental issue. In India, very less amount of municipal sewage is treated. Although a few municipal sewage treatment facilities have been built in some large or metropolitan cities, sewage in smaller cities still drains directly into receiving water bodies or pure water bodies without treatment. The development of effective sewage treatment facilities is crucial; however, the economic and social effects must be carefully considered in the choice of an appropriate treatment system for growing cities in a developing country. Certain technologies such as advanced treatment technologies includes activated sludge system, membrane technology etc used widely in the treatment of municipal wastewater in developed countries. This type of treatment technologies may not be beneficial for India, especially in smaller cities, because of their high construction and operation costs (Solano et al., 2004; Song et al., 2002).

The increasing applications of constructed wetland for sewage treatment which is coupled with increasingly water quality standards is an ever growing incentive for the development of better process design tools. Constructed wetlands (CWs) have proven to be a promising treatment and alternative treatment technology for developing countries (Denny, 1997; Kivaisi, 2001; Vymazal, 2002; Kaseva, 2004; Korkusuz et al., 2005). They have low investment and operation costs, produce high quality of treated effluent with less dissipation of energy, and are relatively simple to operate (Mantovi et al., 2003; Ayaz and Akca, 2001; Song et al., 2002). Studies of constructed wetlands show that removal percentages of solids, BOD, COD and pathogens are generally high whereas removal percentages of nutrients (N and P) are often lower and more variable. Constructed wetlands are complex systems in terms of biology, hydraulics and water chemistry. However, most of the commonly available information on constructed wetland treatments has been derived from data gathered at either larger polishing wetlands or smaller constructed wetlands used for secondary treatment. There is a lack of quality data of sufficient detail, both temporally and spatially, on full-scale constructed wetlands for wastewater treatment. This has forced CW designers to derive wetland system parameters by compiling performance data from a variety of wetlands, leading to uncertainties about the validity of these parameters (EPA, 1999).

In recent years, studies on design, construction and performance of constructed wetlands in treatment of different types of wastewater, such as sewage, storm water, industrial wastewater, agricultural runoff, acid mine drainage and landfill leachate, have been conducted in worldwide. Recently, China is majorly involved in these aspects (Sun, 1997; Ji et al., 2002). However, the studies on organic mater and nutrient removal from the wastewater through constructed wetlands have been conducted mostly in short term, pilot-scale or lab-scale experiments whereas; there have been very few long-term studies of full-scale constructed wetlands. The purpose of this study is to evaluate the treatment efficiency and overall function of Angular Horizontal Subsurface flow constructed wetland system and to assess the seasonal and annual variations in removal of pH, EC, Solids, BOD_5, COD, Nitrate, Phosphates and Sulphates.

In the constructed wetlands, evapotranspiration has a substantial influence on the functioning of wetland ecosystem (Kadlec and Knight, 1996). In warm climates under tropical conditions, evapotranspiration from a CW can be considerable (Heritage et al., 1995; Lim et al., 2001; Kyambadde et al., 2005), and accordingly may have a large impact on the water balance and thereby also on outflow nutrient concentrations, and along with that treatment performance (Heritage et al., 1995; Lim et al., 2001). Therefore, as measures of the treatment efficiency of a tropical CW system, mass balance estimations are better than differences between inflow and outflow concentrations. However, some investigators assess CW efficiency based solely on differences between inflow and outflow nutrient concentrations (Juwarkar et al., 1995; Perfler et al., 1999; Tole and Khisa, 2000; Da Motta Marques et al., 2000; Meutia, 2001; Kyambadde et al., 2004, Chavan and Dhulap, 2012a, 2012b and 2012c). Furthermore, not all studies take into account the effects of evapotranspiration on pollutant mass removal rates (Sekiranda and Kiwanuka, 1998; Goulet et al., 2001; Lin et al., 2002; Jing et al., 2002; Diemont, 2006), which may lead to underestimation of the treatment results.

The objective of the present study was to examine the seasonal effect on the removal rates of some eutrophying substances, toxicants and solids (TSS) from sewage using AHSSF constructed wetlands dominated by two categories of macrophyte species in comparison with control. The mass removal rates were compared on the basis of seasonal differences. In a tropical region the rainy seasons can be heavy and affect the hydrology of AHSSF constructed wetland, which in turn can influence the treatment performance (Diemont, 2006). Also, particular attention was paid to the influence of evapotranspiration from the CW system on the mass removal rate of total phosphates. Researcher was chosen the Environmental Science Departmental laboratory of Solapur University (MH) India for fabrication and construction of pilot project, experimental sewage treatment and analysis study. The sewage was collected from Solapur city discharged by city residents.

MATERIAL AND METHODS

The constructed wetland for wastewater treatment system under investigation is situated at Environmental Science Departmental laboratory, Solapur University Solapur (MH) India. Solapur city is the head quarter of Solapur district. The city has been spread approximately between 17^0 36' to 17^0 42' N latitude and 75^0 50' to 75^0 58' E longitude (Figure 1a and b). It is the 7^{th} largest city in the state by population size heading towards 10 lakh, to be a metropolitan. Solapur city is under the arid to semi arid climatic condition and receives irregular, erratic scanty rainfall, with annual average of around 500 mm to 700 mm. It is included in rain-shadow zone and drought prone region of part of south central India. Solapur experiences relatively higher temperature throughout the year, reaching highest up to 45^0 - 47^0 in April-May months, and has relative humidity varying between 20 to 90% (S. E. Report 2007, Vadagbalkar, 2010, Chavan and Dhulap, 2013). The treatment system consisted of three types of tanks which are inlet as a holding tank for sewage, plant bed and outlet tank for collection of treated water (Figure 2 and 3). Domestic wastewater was passed into the inlet to plant bed to outlet chamber consist of surface flow and subsurface flow using free floating and emergent type plants.

Source: Google Earth satellite image 2013

Figure 1a: Satellite Image of Sewage Discharged in Shelgi Nala at Solapur City

Figure 1b: Sewage Sample Collection Point

Figure 2: Experimental Setup of Constructed Wetland

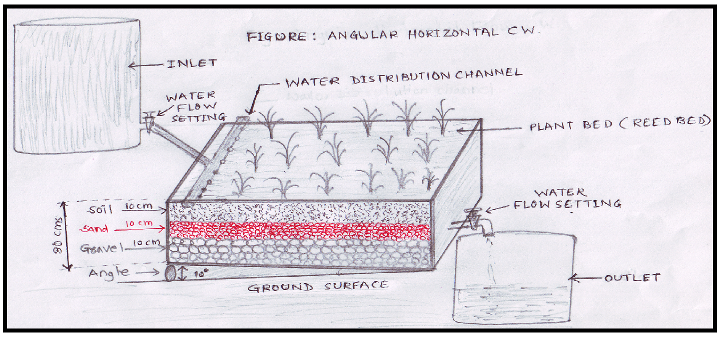

Figure 3: Design of Angular Horizontal Subsurface Flow Constructed Wetland

Firstly Inlet tank (Vertical bucket) is placed at top level than the root zone bed, which will help to adjust the flow rate of waste water sample. Secondly Tap fitted above 5 cm from the bottom of the bucket. Thirdly, plant bed (Rectangular tub) for the plant or weed bed. Fourthly, gravels, sand and soil were collected and arranged in layers which are as: (i) big size smooth gravels or pebbles (ii) sand (iii) soil. Fifthly, Plants were collected, planted and acclimatized in a test plant tub or bed for one week for the survival and to adjust the climatic conditions. Same beds were prepared each plant and for control. Sixthly, the season wise impact and their pollution removal efficiencies in each plant bed and control (without plants) were assessed. Finally the treated and untreated samples were collected at the outlet chamber (rinsed plastic cans) after 4 days hydraulic retention time. These collected samples were analyzed in the departmental laboratory (Chavan et al, 2012c, 2012d, 2013).

The present investigations were carried out at Department of Environmental Science; using AHFSS constructed wetland method and which was used for sewage treatment through various plants such as of *E. crassipes*, *Typha latifolia*, *Colocasia esculenta*, *Cana indica*, *Panicum maximum*, *Pennisetum purpureium*, and Control (Figures 2 and 3). These plants or macrophytes collection were followed by stabilization in specific environment and then by acclimatization with the minimum concentration of sewage. Here sewage samples were tested or analyzed in season wise.

Examined the impacts of different seasons on sewage treatment and calculated sewage treatment efficiencies using constructed wetlands by with or without use of plants (Control) in bed of constructed wetlands. In this method 3 seasons were preferred viz. summer, rainy (monsoon) and winter. In this seasonal study, the sewage samples were selected on the basis of their highest pollutant removal efficiency obtained (Chavan and Dhulap, 2012d). Sewage sample was tested in once in the season for all plant or macrophytes samples. Standard method of testing was carried in all seasons for all plants using 4 days (96 hrs) HRTs and calculated pollution removal efficiencies

RESULTS AND DISCUSSIONS

The list of plants which were studied under seasonal impacts on treatment of sewage using Angular Horizontal Subsurface Constructed Wetland viz. *Eichhornia crassipes, Typha latifolia, Colocasia esculenta, Cana indica, Panicum maximum, Pennisetum purpureium* and Control (Without plant).

Table 1: Percentage Wise Removal of Pollutants Using *Eichhornia crassipes* in Angular Horizontal Surface Flow Constructed Wetland

Seasons	Pollutant Removal in Percentage (%)								
	EC	TSS	TDS	TS	BOD	COD	NO_3	SO_4	PO_4
Summer	49.75	41.66	35.66	36.34	59.63	64.94	59.52	33.70	41.17
Rainy	58.11	44.24	41.90	42.17	64.63	72.34	69.23	38.93	56.52
Winter	54.31	47.66	39.50	40.43	62.88	67.14	64.58	34.37	52.63

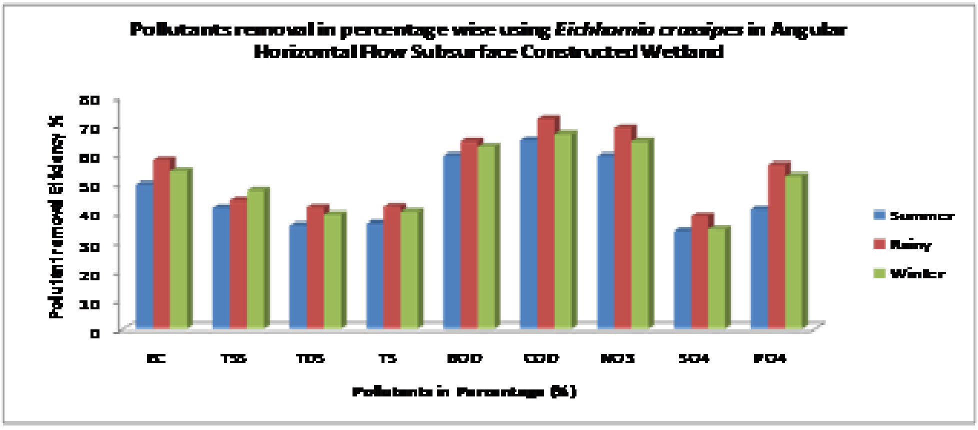

Figure 4: Percentage Wise Removal of Pollutants Using *Eichhornia crassipes* in Angular Horizontal Surface Flow Constructed Wetland

Table 2: Percentage Wise Removal of Pollutants Using *Typha latifolia* in Angular Horizontal Subsurface Flow Constructed Wetland

Seasons	Pollutant Removal in Percentage (%)								
	EC	TSS	TDS	TS	BOD	COD	NO_3	SO_4	PO_4
Summer	48.76	37.25	33.58	34.00	43.11	59.27	54.76	25.84	35.29
Rainy	56.22	42.47	39.83	40.14	52.00	63.29	58.97	32.74	47.82
Winter	53.01	40.18	38.84	39.00	44.00	60.95	56.25	28.12	42.10

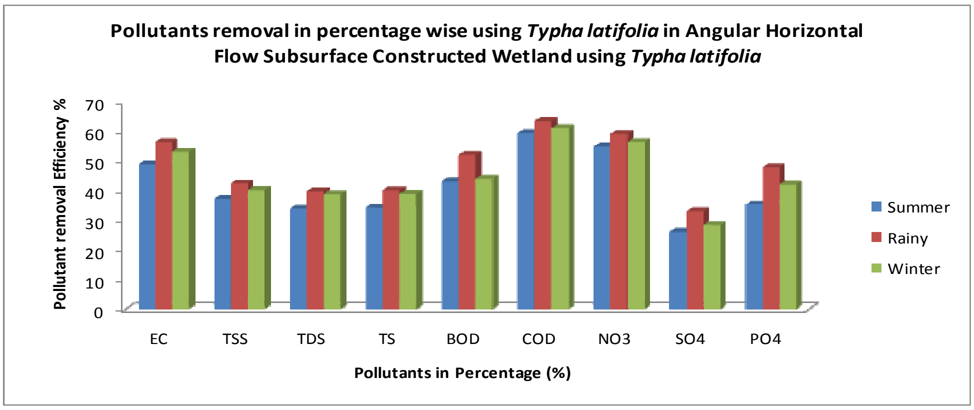

Figure 5: Percentage Wise Removal of Pollutants Using *Typha latifolia* in Angular Horizontal Subsurface Flow Constructed Wetland

Table 3: Percentage Wise Removal of Pollutants Using *Colocasia esculenta* in Angular Horizontal Subsurface Flow Constructed Wetland

Seasons	Pollutant Removal in Percentage (%)								
	EC	TSS	TDS	TS	BOD	COD	NO_3	SO_4	PO_4
Summer	45.32	35.29	33.08	33.33	38.53	55.15	40.47	23.59	35.29
Rainy	53.58	40.70	39.49	39.63	46.34	60.63	51.28	30.08	39.13
Winter	50.86	40.65	37.82	38.15	40.20	57.61	45.83	26.04	36.84

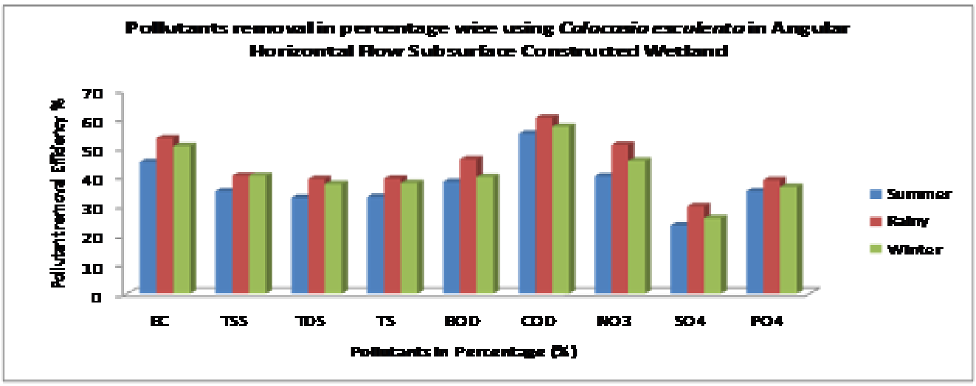

Figure 6: Percentage Wise Removal of Pollutants Using *Colocasia esculenta* in Angular Horizontal Subsurface Flow Constructed Wetland

Table 4: Percentage Wise Removal of Pollutants Using *Cana indica* in Angular Horizontal Subsurface Flow Constructed Wetland

Seasons	Pollutant Removal in Percentage (%)								
	EC	TSS	TDS	TS	BOD	COD	NO_3	SO_4	PO_4
Summer	44.82	55.88	34.34	36.79	41.28	53.09	45.23	29.21	29.41
Rainy	50.56	49.11	38.74	39.93	50.00	59.57	48.71	31.85	39.13
Winter	53.01	57.94	39.32	41.44	56.70	62.38	56.25	35.41	42.10

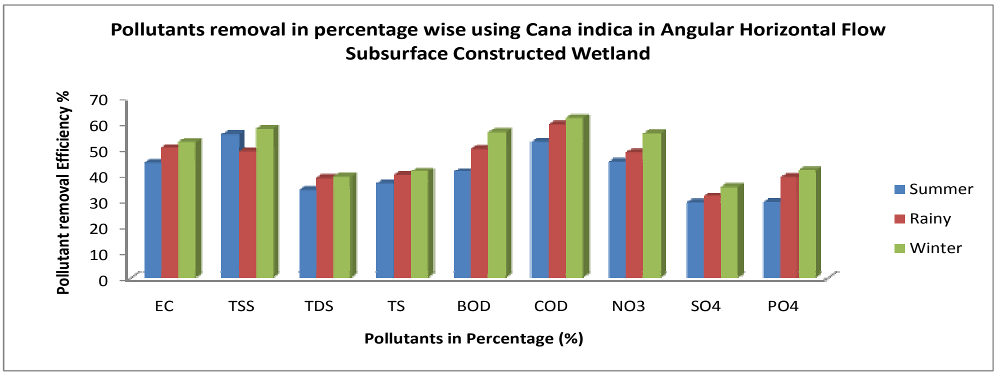

Figure 7: Percentage Wise Removal of Pollutants Using *Cana indica* in Angular Horizontal Subsurface Flow Constructed Wetland

Table 5: Percentage Wise Removal of Pollutants Using *Pannicum maximum* in Angular Horizontal Subsurface Flow Constructed Wetland

Seasons	Pollutant Removal in Percentage (%)								
	EC	TSS	TDS	TS	BOD	COD	NO_3	SO_4	PO_4
Summer	46.30	55.88	34.59	37.01	43.11	54.63	52.38	32.58	29.41
Rainy	52.07	48.67	39.03	40.14	52.43	60.63	53.84	34.51	34.78
Winter	54.31	53.27	40.52	42.50	57.73	63.80	60.41	38.54	47.36

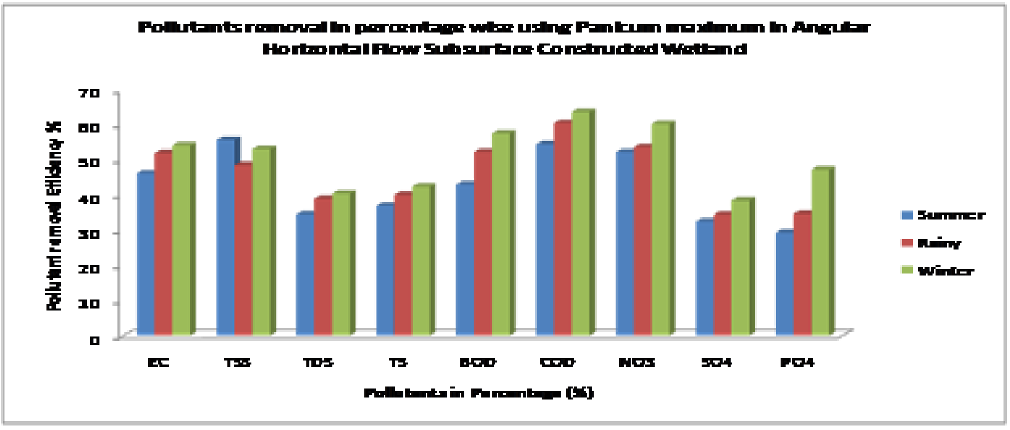

Figure 8: Percentage Wise Removal of Pollutants Using *Pannicum maximum* in Angular Horizontal Subsurface Flow Constructed Wetland

Table 6: Percentage Wise Removal of Pollutants Using *Pennisetum purpureium* in Angular Horizontal Subsurface Flow Constructed Wetland

Seasons	Pollutant Removal in Percentage (%)								
	EC	TSS	TDS	TS	BOD	COD	NO_3	SO_4	PO_4
Summer	47.78	54.90	35.66	37.85	45.87	57.21	54.76	37.07	47.05
Rainy	53.58	48.67	40.12	41.10	56.09	63.29	61.53	39.82	52.17
Winter	56.03	59.34	41.12	43.19	59.79	65.71	64.58	41.66	57.89

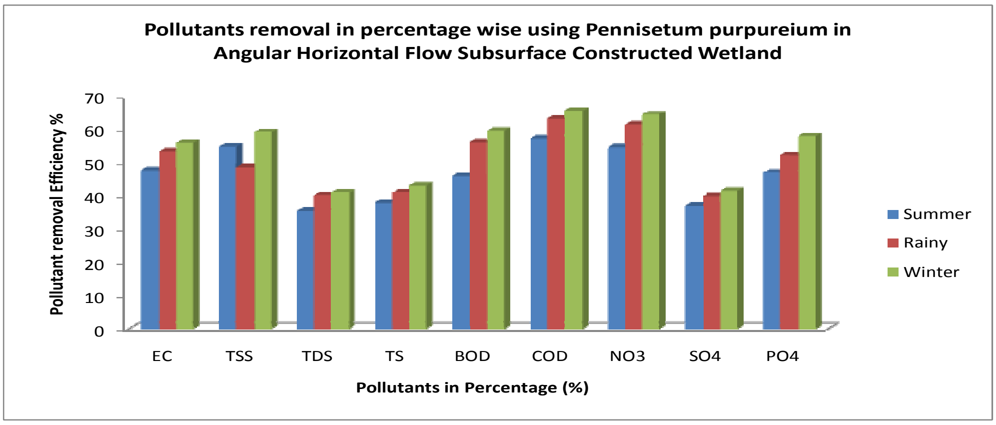

Figure 9: Percentage Wise Removal of Pollutants Using *Pennisetum purpureium* in Angular Horizontal Subsurface Flow Constructed Wetland

Table 7: Percentage Wise Removal of Pollutants without Using Plants Bed i.e. Control in Angular Horizontal Subsurface Flow Constructed Wetland

Seasons	Pollutant Removal in Percentage (%)								
	EC	TSS	TDS	TS	BOD	COD	NO_3	SO_4	PO_4
Summer	30.04	40.19	30.87	31.93	29.35	31.95	26.19	21.34	23.52
Rainy	38.49	50.44	35.36	37.09	35.36	37.76	33.33	27.43	30.43
Winter	34.48	44.85	34.65	35.81	30.92	32.38	29.16	22.91	26.31

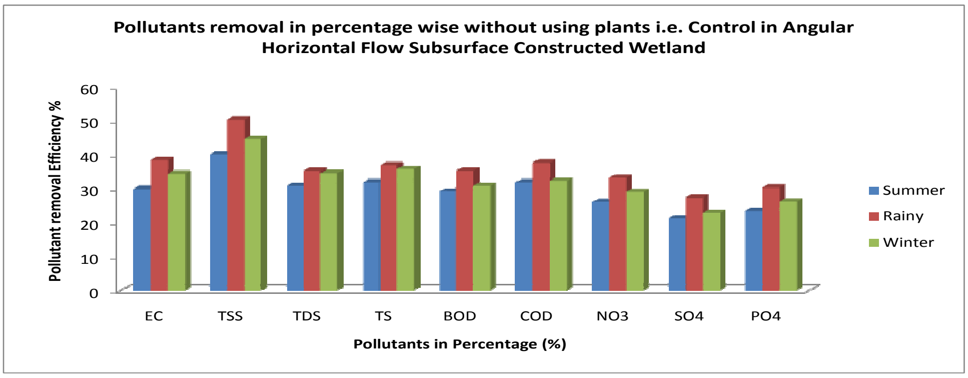

Figure 10: Percentage Wise Removal of Pollutants without Using Plants Bed i.e. Control in Angular Horizontal Subsurface Flow Constructed Wetland

- **Plant Growth**

All of these test plant species showed positive growth in the sewage water without obvious symptoms of toxicity or nutrient deficiency. After 365 days (1 year) growth of plant species were increased up to 6 to 8 feet (Figures 4-9). *Eichhornia crassipes, Cana indica, Pennisetum purpureium, Panicum maximum and Typha latifolia* shows maximum growth and increased their total biomass. However, in association with observations made during final sampling, researcher suggested relatively deeper root penetration for *Pennisetum purpureium and Panicum maximum* than that of the other test plant species. Plant productivity and resource allocation varied widely for the 6 test plant species grown in the same sewage and culture conditions. Observations during plant establishment showed that new growth initially emerged mainly from rhizomes or rootstocks, with old shoots generally dying back during the first few weeks of growth.

- **Plants Uptakes Nutrients**

The nutrients such as Nitrogen and Phosphorus which is largely present in the sewage. In the constructed wetland treatment these nutrients were absorbed by plants through phytoremediation process. The free floating plant *E. crassipes* and emergent plants *Pennisetum purpureium, Panicum maximum and Cana indica* removed maximum nutrients in winter and rainy season from the sewage than the control bed. Actually plant uptake rates during the period that treatment was monitored (near the end of the trial) were not specifically measured and may have differed significantly from these values. The differences in N removal associated with plant biomass could also have been due in part, to indirect stimulation of nitrification through root-zone oxygen release, with subsequent gaseous loss via denitrification (Reddy et al., 1989a, b).

- **Sewage Treatment Performance**

In the study of seasonal impact on sewage treatment, studied treatment performances in the seasons using various plants in the constructed wetland. In the *E. crassipes* maximum pollutant removed in rainy season and minimum in summer, *Typha latifolia maximum* pollutant removed in rainy season and minimum in summer, *Colocasia esculenta* maximum pollutant removed in rainy season and minimum in summer, *Cana indica* maximum pollutant removed in winter season and minimum in summer, *Panicum maximum* pollutant removed maximum in winter season and minimum in summer, *Pennisetum purpureium* maximum pollutant removed in winter season and minimum in summer and in the control (without plant) maximum pollutant removed in rainy season and minimum in summer (Table 1 to 7).

In the *E. crassipes* plant, all the pollution parameters show maximum removal in rainy and less removal in summer. TS removed in the rainy season by 42.17%, winter season removed by 40.43% and in summer 36.34%. BOD removed in the rainy season by 64.63%, winter season removed by 63.88% and in summer 59.63%. COD removed in the rainy season by 72.34%, winter season removed by 67.14% and in summer 64.94%. NO_3 removed in the rainy season by 69.23%, winter season removed by 64.58% and in summer 59.52%. PO_4 removed in the rainy season by 56.52%, winter season removed by 52.63% and in summer 41.17% respectively (Figure 4). The *E.crassipes* growing in the experimental tanks this reaches to the flowering stage.

In *Typha latifolia* plant all the pollution parameters show maximum removal in rainy and less removal in summer. TS removed in the rainy season by 40.14%, winter season removed by 39% and in summer 34%. BOD removed in the rainy season by 52%, winter season removed by 44% and in summer 43%. COD removed in the rainy season by 63.29%, winter season removed by 60.95% and in summer 59.27%. NO_3 removed in the rainy season by 58.97%, winter season removed by 56.25% and in summer 54.76%. PO_4 removed in the rainy season by 47.82%, winter season removed by 42.10% and in summer 35.29% respectively (Figure 5). This plant growing in the experimental bed and it reaches to the flowering stage.

Colocasia esculenta all the pollution parameters show maximum removal in rainy and less removal in summer. TS removed in the rainy season by 39.63%, winter season removed by 38.15% and in summer 33.33%. BOD removed in the rainy season by 46.34%, winter season removed by 40.20% and in summer 38.53%. COD removed in the rainy season by 60.63%, winter season removed by 57.61% and in summer 55.15%. NO_3 removed in the rainy season by 51.28%, winter season removed by 45.83% and in summer 40.47%. PO_4 removed in the rainy season by 39.13%, winter season removed by 36.84% and in summer 35.29% respectively (Figure 6).

Cana indica all the pollution parameters show maximum removal in winter and less removal in summer. TS removed in the rainy season by 39.93%, winter season removed by 41.44% and in summer 36.79%. BOD removed in the rainy season by 50 %, winter season removed by 56.70% and in summer 41.28%. COD removed in the rainy season by 59.57%, winter season removed by 62.38% and in summer 53.09%. NO_3 removed in the rainy season by 48.71%, winter season removed by 56.25% and in summer 45.23%. PO_4 removed in the rainy season by 39.13%, winter season removed by 42.10% and in summer 29.41% respectively (Figure 7). This plant growing in the experimental bed of constructed wetland and finally it reaches to the flowering stage.

Panicum maximum all the pollution parameters show maximum removal in winter and less removal in summer. TS removed in the rainy season by 40.14%, winter season removed by 42.50% and in summer 37.01%. BOD removed in the rainy season by 52.43 %, winter season removed by 57.73% and in summer 43.11%. COD removed in the rainy season by 60.63%, winter season removed by 63.80% and in summer 54.63%. NO_3 removed in the rainy season by 53.84%, winter season removed by 60.41% and in summer 52.38%. PO_4 removed in the rainy season by 34.78%, winter season removed by 47.36% and in summer 29.41% respectively (Figure 8).

Pennisetum purpureium all the pollution parameters show maximum removal in winter and less removal in summer. TS removed in the rainy season by 41.10%, winter season removed by 43.19% and in summer 37.85%. BOD removed in the rainy season by 56.09 %, winter season removed by 59.79% and in summer 45.87%. COD removed in the rainy season by 63.29%, winter season removed by 65.71% and in summer 57.21%. NO_3 removed in the rainy season by 61.53%, winter season removed by 64.58% and in summer 54.76%. PO_4 removed in the rainy season by 52.17%, winter season removed by 57.89% and in summer 47.05% respectively (Figure 9). This plant growing in the experimental bed of constructed wetland and finally it reaches to the flowering stage.

In the control (without plant) bed, all the pollution parameters show maximum removal in rainy and less removal in summer. TS removed in the rainy season by 37.09%, winter season removed by 35.81% and in summer 31.93%. BOD removed in the rainy season by 35.36%, winter season removed by 30.92% and in summer 29.35%. COD removed in the rainy season by 37.76%, winter season removed by 32.38% and in summer 31.95%. NO_3 removed in the rainy season by 33.33%, winter season removed by 29.16% and in summer 26.19%. PO_4 removed in the rainy season by 30.43%, winter season removed by 26.31% and in summer 23.52% respectively (Figure 10)

In the overall observational study the *Pennisetum purpureium* and *E. crassipes* shows maximum pollution removal efficiency than the other plant beds and control bed in all the three seasons.

CONCLUSIONS

Analysis of the constructed wetland database indicates that domestic constructed wetland systems can greatly improve water quality. In this study, work carried on impact of seasons on the treatment of sewage through angular horizontal subsurface constructed wetland using aquatic plants. The maximum pollutants removal and pollution removal efficiency found 99.7% in *Pennisetum purpureium* as compare to control and other plant beds used in the constructed wetland study. This plant shows maximum removal of pollutants in winter and less removal in summer. TS removed by 43.19%, and BOD removed by 59.79%, COD removed by 65.71%, NO_3 removed by 64.58%, PO_4 removed by 57.89% and SO_4 removed by 41.66% respectively. There is a significantly seasonal factor to this wetland for BOD_5, COD, Nitrate and Phosphates when measured on a percentage reduction basis. BOD_5, COD, nitrate, phosphates, and Sulphates removal efficiencies displayed seasonal variations compared with the control and which removals being more efficient in winter and rainy compared to those in summer.

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