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Performance Studies on Wastewater Treatment Efficiency of an Artificial Wetland

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***Abstract*— One of the reasons for deterioration of quality of lakes is the discharge of wastewater into them. The Kolleru Lake is one such natural fresh water wetland in Andhra Pradesh which has International importance as it was classified under Ramsar Convention. Its water quality is deteriorating due to discharge of inflows through small streams of untreated sewage generated from the surrounding towns and human activities in Krishna-Godavari delta region. It is essential to restore the quality of lake water. Among the existing low-cost treatment option for the treatment of inflow wastewater. Artificial wetland may be considered as viable treatment option for the treatment of inflow wastewater into Kolleru Lake. Hence, in the present study a lab scale artificial wetland system is developed and used to estimate the pollutants removal efficiency from the wastewater in three different seasons. Treatment effectiveness was evaluated which indicated the percentage values of mean removal efficiencies estimated in the Winter, Summer and Monsoon seasons for the parameters viz., TDS, TSS, BOD, COD, Nitrates and Phosphates are 34.13±1.41%, 41.45±7.71% and 36.83±2.60%;46.51±2.74%, 59.76±5.88% and 52.76±3.80%; 48.85±4.38%,60.29±8.31% and 54.11±5.19%; 46.35±3.74%, 54.01±3.53% and 50±.2.3%; 47.61±3.75%, 55.23±5.43% and 52.05±4.61%;38.61±3.39%, 49.71±1.15% and 42.05±2.56% respectively. The findings indicate that artificial wetland system is effective in removing pollutants from the wastewater.**

***Keywords* — Wastewater, Kolleru Lake, drain, artificial wetland, different seasons, removal efficiency, cost effective.**

I. INTRODUCTION

Kolleru, the largest freshwater lake along the east coast of India in Andhra Pradesh (AP) had been encroached, mainly for aquaculture, to such an extent that most of the lake area was highly compartmentalized by 3–4 m high embankments of hundreds of fish tanks that had sprung up in the lake bed. The 1water in the Kolleru Lake spreads in over 901 km^2 from 0 to 10 m contour level above Mean Sea Level (MSL). The depth of the lake varies from 1 to 1.6 m and it may reach 3 to 4 m due to high flood inflows during Monsoon period. It lies between longitudes of 81^o 5' and 81^0 20' East and latitudes of 16^0 32' and 16^0 51' North in the districts of Krishna and West Godavari (Fig.1). It used to be an ideal habitat to hundreds of species of birds including the Grey or Spot-billed Pelican (Pelecanus Philippines), a migratory bird, 63 species of fishes, fresh water turtles and amphibians. Kolleru is a wetland in a low-lying deltaic setting that is acting as an important flood-balancing reservoir and a source of livelihood for traditional fishermen. However, large scale encroachments for aquaculture during recent decades, even into the core area of the lake, have disturbed the ecosystem to such an extent as to almost completely deface the lake's identity. Concerned about the situation, the AP Government in 1999 had declared the Kolleru lake area within the 5-foot ($\approx$ 1.5 m) contour above mean sea level as a wildlife sanctuary, banning all types of encroachments. The Kolleru lake area of 308 Km^2 was notified as a wildlife sanctuary in November 1999 under India's Wild Life (Protection) Act, 1972, and designated as a wetland of international importance in November 2002 under the international Ramsar Convention.

Kolleru Lake, receives runoff through 15 inflowing drains. The urbanization and transformation of hydrosphere to lithosphere changed the Euthrophic Lake from Oligotrophic due to social stress in the catchment area. The lake water quality is deteriorating due to sewage inflows from the nearby towns of Eluru, Gudivada and Vijayawada; the wastewater from the industries around, pesticides and fertilizers from the agricultural activities in Krishna-Godavari delta region.

The artificial (or constructed) wetland is a natural treatment system that may be employed to reduce Biological Oxygen Demand (Jayakumar and Dandigi, 2002, Gersberg et.al., 1986, Reed et.al., 1988, Reed et.al, 1991 U.S.EPA Manual, 2000). Hence, the present work focuses on the evaluation of sustainability of constructed wetland for the treatment of wastewater joining the Kolleru Lake through Chandraiah drain.

Sustainable wastewater treatment is associated with low energy consumption, low capital cost, and, in some situations, low mechanical technology requirements. Therefore, wetland treatment systems could be efficient alternatives to conventional treatment systems, especially for small communities, typically rural or suburban areas, due to low treatment and maintenance costs (Soukup et al. 1994; Solano et al. 2003; Babatunde et al. 2008). Since the 1990s, wetland systems have been used for treating numerous domestic and industrial waste streams including those from tannery and textile industry, abattoirs, pulp and paper production, agriculture (animal farms and fish farm effluents), and various runoff waters (agriculture, airports, highway, and storm water; Kadlec et al. 2000; Haberl et al. 2003; Scholz 2006; Vymazal 2007; Carty et al. 2008).

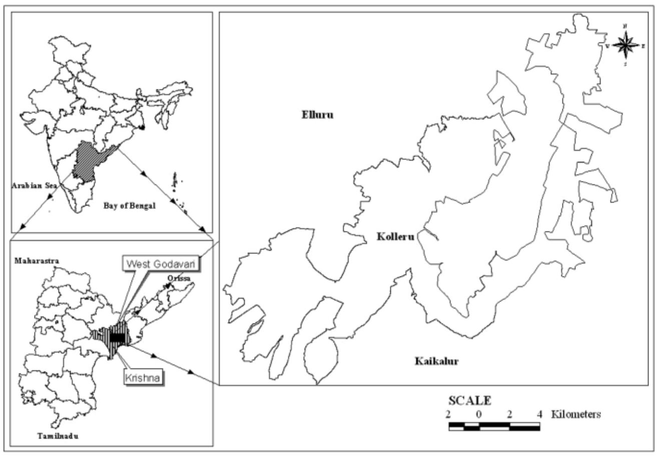


Fig. 1 Location of Kolleru Lake in India
(Marappan Jayanthi et al., 2006)

II. METHODOLOGY

A reconnaissance study was made to understand the inflows of the drains and Chandraiah Drain in the southern most tip of the Lake was found to bring industrial effluents having various pollutants. Hence, a laboratory model was constructed to study the treatability of Lake Inlet waters using artificial wetlands. All the physical parameters were minusculed and replicated the establishing condition. The artificial wetland laboratory model was fabricated for the studies in the Department of Civil Engineering, Andhra University, Visakhapatnam, Andhra Pradesh. The artificial wetland laboratory model was constructed using Perspex sheet for the designed dimensions of 1.5m length, 0.3m width and 0.6m depth (USEPA, 2000).
The model was filled with the benthic soils, flora and fauna brought from the Kolleru Lake to mimic natural characteristics of the lake and a continuous flow was maintained using a control valve that allows the flow of water through a immediate reservoir. The flow rates of wastewater are controlled and the rate of flow was fixed approximately to 1liter per hour.

However, it may be varied with reference to the desired Hydraulic Retention Time (HRT). The water brought from the Chandraiah Drain was used for the study in evaluating the treatment characteristics of constructed wetland. Floating, submerged and emergent weed vegetation obtained from Kolleru Lake were planted in the tank. As shown in the Fig 2 the system was kept open to the ambient environment.

Fig.2 The laboratory model of constructed Wetland along with constant flow rate arrangement system

The inlet and outlet wastewater samples were collected from the artificial wetland model during the Winter (November, December), Summer (May, June) and Monsoon (August, September). The wastewater samples thus collected were analyzed in the laboratory for pH, Electric Conductivity(EC), Total Dissolved Solids(TDS), Total Suspended Solids(TSS), Dissolved Oxygen (DO), Biological Oxygen Demand (BOD5) and Chemical Oxygen Demand (COD), Phosphates and Nitrates as described in Standard methods for the Examination of water and wastewater (APHA, 2005). During Winter, Summer, and Monsoon monitoring has been made for three continue fortnights for the collection of samples. For each analysis three number of replicates were used. The information collected from the analysis was used for computation of the pollutant removal efficiencies.

III.RESULTS AND DISCUSSION

Physico-chemical characteristics

The physico-chemical parameters measured from the samples collected periodically during Winter, Summer and Monsoon are presented in Table 1. Using the BOD, COD, TDS,TSS, Nitrates and Phosphates of wastewater at the inlet and outlet of the laboratory model artificial wetland, the percentage removal efficiency are computed for Winter, Summer and Monsoon seasons and are shown in Table 2.

Water Temperature is one of the important factor among the various physic-chemical parameters in any aquatic ecosystem. Temperature of water samples collected in Winter, Summer and Monsoon season the overall mean of three seasons 21.4±1.57, 28.4±1.49 and 24.6±1.46 (Table 1). In the present study specific seasonal variation in the water temperature was recorded with maximum values during Summer and the minimum in Winter.

pH is one of the important factors that serves as an index for the water pollution. The mean values of pH inlet and outlet values are 7.3±0.16 and 7.13±0.14, 7.8±0.18 and 7.49±0.14, 8±0.28 and 7.7±0.25 in Winter, Summer and Monsoon seasons (Table 1). The pH recorded is minimum during Winter and maximum in Monsoon Season, it is due to the water collected from the drain which inflows of rainwater along the drain into lake with the addition of agricultural and domestic waste. After the treatment, is a decrease in pH value in all the three seasons and reached almost to neutral level except in Monsoon. The minimum reduction of pH value in outlet sample was found in Winter and Monsoon than Summer season.

Electric Conductivity (EC) is a numerical expression of its ability to carry an electric current. The mean values of EC observed inlet and outlet water samples are 804.74±78.04 µmhos/cm and 618.90±39.22 µmhos/cm in Winter, 837.55±62.42 µmhos/cm and 605.93±17.33 µmhos/cm in Summer, 1078.78±81.9 µmhos/cm and 798.56±37.9 µmhos/cm in Monsoon season (Table 1). In the inlet samples values of EC recorded maximum during Monsoon Season this is due discharge high amount of dissolved and suspended particles along the runoff of the drain. (Narayana, 2008)

Solids in water refers to dissolved and suspended matter. Total Dissolved Solids (TDS) recorded in inlet and outlet mean values are 669±36.32 mg/l and 442±20.06 mg/l, 696±50.60 mg/l and 406±50.30 mg/l and 762±85.6 mg/l and 480±35.88 mg/l in Winter, Summer and Monsoon season (Table 1). Total Suspended Solids (TSS) is measured in inlet and outlet values are 144±37.18 mg/l and 76±16.26 mg/l in Winter,148±33.64 mg/l and 58±10.74 mg/l in Summer and 166±45.59 mg/l and 78±18.68 mg/l in Moonson season (Table 1).In Monsoon Season found high amount of TDS and TSS found in the inlet samples of wetland which are source of a drain water is due to mixing runoff rainwater which carried mud, sand, organic and inorganic matter along the drain. (Jawale and Patil, 2009) and (Salve and Hiware, 1973). In the outlet there is a higher amount of reduction of TDS and TSS in Summer than other seasons. Since, TDS and TSS concentration was reduced in the outlet samples due to filtration and microbial activity in wetland.

Disolved Oxygen (DO) in the lake water plays an important role in the metabolism of the aquatic life. The mean values of Dissolved Oxygen (DO) are 3.9±0.23 mg/l and 4.3±0.23 mg/l in Winter, 3.8±0.3 mg/l and 4.6±0.29 mg/l in Summer, 3.6±0.2 mg/l and 4.5±0.3 mg/l in Monsoon season (Table 1). Less amount of DO is observed from the inlet sample in Monsoon and Summer due to high pollution load may also decrease the DO values to a considerable level.

Biochemical Oxygen Demand (BOD) is an important parameter that indicates the magnitude of water pollution by oxydizable organic matter. The mean values of BOD observed are 94±13.86 mg/l and 48±4.20 mg/l in Winter, 114±4.95 mg/l and 46±8.24 mg/l in Summer, 104±12.36 mg/l and 48±2.36 mg/l in Monsoon season(Table 1).In the inlet samples the DO is higher in Winter season. The availability of oxygen to living organisms decreases with increase of BOD in water. A higher value of BOD indicates maximum consumption of oxygen and higher pollution load. Since in the present study the higher BOD was recorded during Summer in inlet samples followed by Monsoon and Winter season. In outlet samples there is huge amount of reduction recorded in Summer due to increase in temperature the microbial activities also increases (Woltemade, 2000 and Koner. et. al, 1998).

TABLE I

WASTEWATER CHARACTERISTICS AT THE INLET AND OUTLET OF THE ARTIFICIAL WETLAND (LAB SCALE) DURING DIFFERENT SEASONS.

Parameter	sample collection point	Winter	Summer	Monsoon
Temp(°C)		21.4±1.57	28.4±1.49	24.6±1.46
pH	Inlet	7.3±0.16	7.8±0.18	8±0.28
	Outlet	7.13±0.14	7.49±0.14	7.7±0.25
EC (µmhos/cm)	Inlet	804.74±78.04	837.55±62.42	1078.78±81.9
	Outlet	618.90±39.22	605.93±17.33	798.56±37.9
TDS(mg/l)	Inlet	669±36.32	696±50.60	762±85.6
	Outlet	442±20.06	406±50.30	480±35.88
TSS(mg/l)	Inlet	144±37.18	148±33.64	166±45.59
	Outlet	76±16.26	58±10.74	78±18.68
DO(mg/l)	Inlet	3.9±0.23	3.8±0.3	3.6±0.2
	Outlet	4.3±0.23	4.6±0.29	4.5±0.3
BOD(mg/l)	Inlet	94±13.86	114±4.95	104±12.36
	Outlet	48±4.20	46±8.24	48±2.36
COD(mg/l)	Inlet	176±22.86	204±22.25	182±10.03
	Outlet	94±6.94	92±5.15	90±2.85
Nitrates (mg/l)	Inlet	1.2±0.27	1.5±0.4	2.01±0.34
	Outlet	0.6±0.12	0.68±0.15	0.9±0.10
Phosphates (mg/l)	Inlet	3±0.43	2.9±0.3	3.1±0.3
	Outlet	1.8±0.21	1.45±0.16	1.8±0.18

* Values in the table are corresponding to mean values; ±, standard deviations Number of replicates = 3.

Chemical Oxygen Demand (COD) is also considered as the amount of oxygen consumed by the chemical breakdown of organic and inorganic matter and mainly serves to measure the ability of organic substances to consume oxygen in water. The mean values of COD found in inlet and outlet water samples are176±22.86 mg/l and 94±6.94 mg/l in Winter, 204±22.25 mg/l and 92±5.15 mg/l in Summer, and 182±10.03 mg/l and 90±2.85 mg/l in Monsoon season respectively (Table 1).In present findings, the value of COD was recorded in the Summer which might have been due to less water and high turbid conditions, as higher turbidity shows the presence of higher concentration of organic and non biodegrable components in the drain water which require higher amount of oxygen for their decomposition.

Nitrate is the most important nutrient in an ecosystem. The Nitrates obtained in inlet and outlet water samples with mean values are 1.2±0.27 mg/l and 0.6±0.12 mg/l in Winter, 1.5±0.4 mg/l and 0.68±0.15 mg/l in Summer, and 2.01±0.34 mg/l and 0.9±0.10 mg/l in Monsoon season (Table 1). The Concentration of Phosphates in inlet and outlet water samples with mean values of Phosphate are 3±0.43 mg/l and 1.8±0.21 mg/l in Winter, 2.9±0.3 mg/l and 1.45±0.16 mg/l in Summer, and 3.1±0.3 mg/l and 1.8±0.18 mg/l in Monsoon season (Table 1).

Both the Nitrates and Phosphates are high in Monsoon Season than other seasons. Nitrate value higher during Monsoon may be due to surface run off of agricultural fields and domestic sewage

(Gohram, 1961 and Rajasekhar, 2007) and phosphates level increase in monsoon due to high runoff mixed with pesticides and fertilizers (Trivedy and Geol, 1987).Nitrate levels in surface water often show marked seasonal fluctuations with higher concentrations being found during Monsoon months compared to Summer and Winter months. During Summer months the reduction in nitrates could be due to algal assimilation and other biochemical mechanism.

The Efficiency of Constructed Wetland

The performance of removal efficiency in wetland is evaluated with respect to the physico and chemical characteristics in both influent and effluent concentrations during the monitoring period as shown in Table 2 and Fig 3 (i-vi) are Mean percentage values and the values in Parenthesis shows the Minimum and Maximum values observed from the all individual removal efficiencies in the particular month.

The TDS removal efficiency has observed the Minimum and Maximum values in Winter, Summer and Monsoon seasons are 30.83 to 36.34 %, 34.29 to 47.52 % and 32.22 to 41.55 % respectively with an Mean values after reduction are 34.13±1.41 %, 41.45±7.71 % and 36.83±2.60 % in Winter, Summer and Monsoon seasons (Table 2 and Fig 3(i)). The efficiency of TDS in wetland is evaluated by reduction of dissolved solids in the outlet versus inlet samples of the Constructed wetland.(Aditya Kishore Dash,2010).It was found that the TSS removal efficiency Minimum and Maximum in Winter, Summer and Monsoon seasons is 40.43 to 52.60 %, 43.40 to 69.88 % and 45.24 to 62.46 % respectively. The Mean values of TSS reduction are 46.51±2.74%, 59.76±5.88% and 52.76±3.80% in Winter, Summer and Monsoon seasons (Table.2 and Fig 3 (ii)). The efficiency of TSS in wetland is found by reduction of suspended particles in the outlet versus inlet samples. Suspended matter is removed primarily through the mechanism of interception, sedimentation, aggregation and settling (Kadlec, 2009).

It was determined that the BOD removal efficiency Minimum and Maximum in Winter, Summer and Monsoon seasons are 39.02-59.68 %, 47.27-70.97 % and 40.91-64.18% respectively. The mean value of percentage removal of BOD are 48.85±4.38%,60.29±8.31% and 54.11±5.19% in Winter, Summer and Monsoon seasons(Table 2 and Fig 3(iii)).The efficiency of BOD in wetland is observered by reduction of organic matter in the outlet versus inlet samples. The organic matter reduction is due to the microbial activities in the wetland (Faulwetter, 2009 and Greenway 2004).The percentage removal of COD in Winter, Summer and Monsoon seasons are computed the Minimum and Maximum values are 39.39-55.60 %, 48.00-60.44 % and 45.72-55.00% respectively. The mean values of percentage removal of COD are 46.35±3.74%, 54.01±3.53% and 50±.2.3% in Winter, Summer and Monsoon seasons (Table 2 and Fig 3(iv)). The Efficiency of wetland in reducing COD is seen in the constructed wetland which is higher in Summer and almost lesser in remaining seasons (Wijetunga, 2009).

It was found that the Minimum and maximum values of percentage removal of Nitrates in Winter, Summer and Monsoon seasons are 41.04-55.59 %, 48.10-68.25 % and 44.28-58.34 % respectively. The mean value of percentage removal of Nitrates are 47.61±3.75%, 55.23±5.43% and 52.05±4.61% in Winter, Summer and Monsoon seasons(Table 2 and Fig 3(v)).Hence, the results shows that there is better removal efficiency of Nitrates in constructed wetland. Since there is high in Summer than Winter and Monsoon (Kiwanuka et.al, 2002). The aquatic macrophyte shows nitrate removal from wastewater flows through the constructed wetland (Kutty et al., 2009).

It was determined that the Minimum and Maximum of percentage removal of Phosphates in Winter, Summer and Monsoon seasons are 32.22-43.86 %, 47.34-51.84 % and 38.05-46.60 % respectively. The mean value of percentage removal of Phosphates are 38.61±3.39%, 49.71±1.15% and 42.05±2.56 % in Winter, Summer and Monsoon seasons (Table 2 and Fig 3(vi)).There is a highest removal of phosphate in Summer followed by Monsoon and Winter. The removal of phosphate is by adsorption by the supporting material such as soil in the wetland rather than by the consumption by the plants. Characteristic of soil has an important influence on the magnitude of phosphorus removal (Mustafa, 2013).

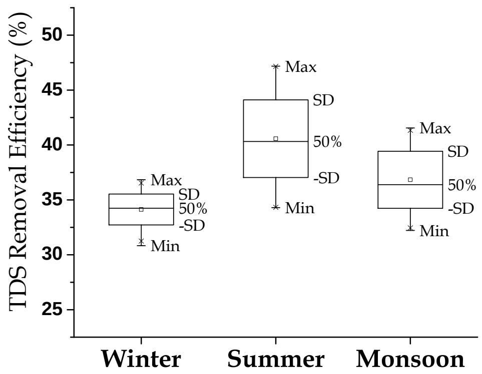
Based on the study, the artificial wetland can reduce the TDS, TSS, BOD, COD, Nitrates and Phosphates of the wastewater to a maximum extent in Summer, followed by Monsoon and Winter season. It indicates that the treatment efficiency is better during Summer than Winter season which may be due to the increase in the bacterial growth, decomposition activities with increase in temperatures. It may be adopted as a viable low cost alternative method of wastewater treatment for the treatment of the inflow wastewater joining the Kolleru lake resulting in the restoration of Kolleru lake water quality. Constructed wetlands are performances as a reliable wastewater treatment technology and represent an appropriate solution for the treatments of wastewater Constructed wetlands have shown to successfully control suspended solids, organic material and nutrients. (Greenway, 2005 and Vymazal, 2010).

TABLE II

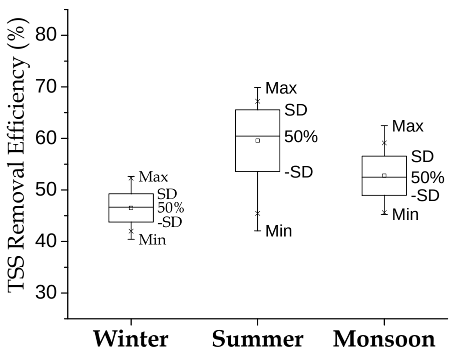
THE RANGE OF PERCENTAGE REMOVAL EFFICIENCY OF THE WASTEWATER USING ARTIFICIALWETLAND DURING WINTER, SUMMER AND MONSOON SEASONS.

	Removal Efficiency (%)		
Parameter	Winter	Summer	Monsoon
TDS	34.13±1.41* (30.83-36.34)**	41.45±7.71 (34.29-47.52)	36.83±2.60 (32.22-41.55)
TSS	46.51±2.74 (40.43-52.60)	59.76±5.88 (43.40-69.88)	52.76±3.80 (45.24-62.46)
BOD	48.85±4.38 (39.02-59.68)	60.29±8.31 (47.27-70.97)	54.11±5.19 (40.91-64.18)
COD	46.35±3.74 (39.39-55.60)	54.01±3.53 (48.00-60.44)	50±.2.3 (45.72-55.00)
Nitrates	47.61±3.75 (41.04-55.59)	55.23±5.43 (48.10-68.25)	52.05±4.61 (44.28-58.34)
Phosphates	38.61±3.39 (32.22-43.86)	49.71±1.15 (47.34-51.84)	42.05±2.56 (38.05-46.60

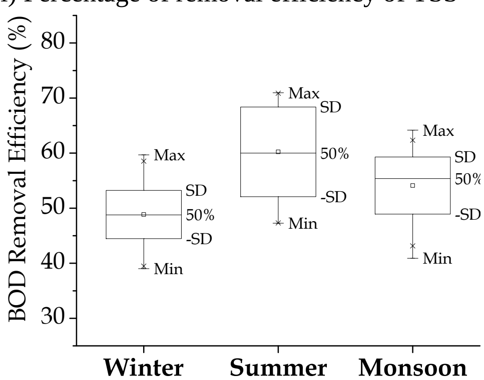
* Values in the table are corresponding to mean values; ±, standard deviations
**Values given in parenthesis are minimum and maximum values of respective parameters as compared with all individual Percentage removal efficiency in a particular season.



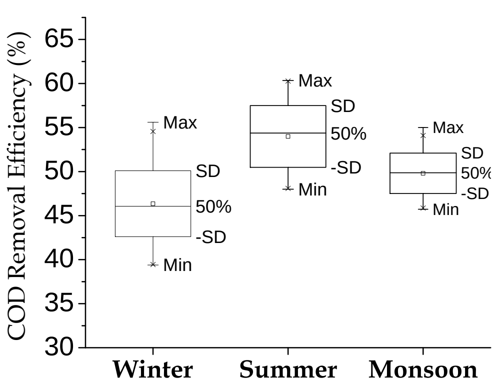
(i) Percentage of removal efficiency of TDS



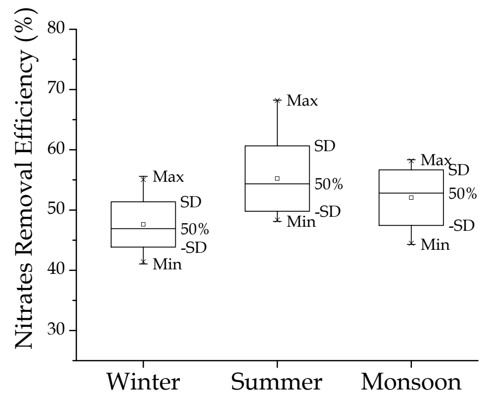
(ii) Percentage of removal efficiency of TSS



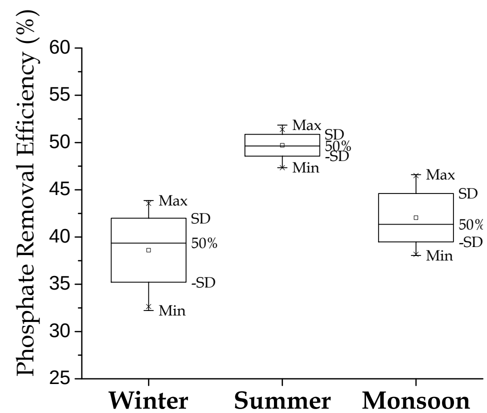
(iii) Percentage of removal efficiency of BOD



(iv) Percentage of removal efficiency of COD



(v) Percentage of removal efficiency of Nitrate



(vi) Percentage of removal efficiency of Phosphates

Fig.3 Graphs showing the % removal efficiency from the wastewater samples values of TDS,TSS,BOD,COD,Nitrates and Phosphates values (i to vi) in Winter,Summer and Monsoon seasons.

Seasonal trends were analyzed graphically by inspection of Box and Whisker plots (Figure 3). The central "box" horizontal line inside the box is the Mean, the top and bottom of the box are the Standard deviation "+" and "-".The whiskers extend above and below the box are Minimum and Maximum values

III. CONCLUSIONS

The Constructed wetland can reduce organic compounds and Nutrients such as BOD, COD, TDS, TSS, Nitrates and Phosphates in wastewater. Based on the results obtained in this study, it appears that microbial activities and vegetation in wastewater play a vital role in the treatment of wastewater by utilizing the organic compounds for their growth and development. Eventually, the dissociated organic products are used by the aquatic plant which acts as bio-filter media. Therefore, it can be concluded that microbes as well as aquatic plants, together, performs great role to purify the polluted wastewater. Since the low cost, environment friendly and simple technology, the use of constructed wetland for the remediation of wastewater is a technology which could be adopted by the developing countries where limited resources are available for the installation of high tech treatment plants.

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