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Wastewater Treatment with Vertical Flow Constructed Wetland

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ABSTRACT

Water is one of the most important elements involved in the creation and development of healthy life. Haphazard disposal of untreated wastewater from households as well as institutions and industry is causing severe deterioration of water bodies in many urban areas in the developing world. There are several methods to treat the municipal wastewater for intended use. One of the methods of the treatment is constructed wetland. Constructed wetland system for wastewater treatment has been proven to be effective and sustainable alternative for conventional wastewater treatment technologies. In the present study performance of the fabricated model on which the local Amba Nala effluent characteristics like pH, DO, TS, BOD, COD with and without plant species were studied. The bed was studied for the different substrate conditions i.e. for black cotton soil, sandy soil for the detention time of 3 days, 5 days, 7 days and 9 days. It is observed that the beds with *Typha Orientalis* (macrophyte plants) produced effluents of better quality than the bed without *Typha Orientalis*. The result shows reduction of 75% in total solids, 86 % in BOD, 63% in COD using *Typha Orientalis* and on the other side without *Typha Orientalis* it was found that there is 70% reduction in total soilids, 62% in BOD and 53% in COD. The planted wetland system shows the better performance than the unplanted system. It is also found that the increasing in the detention period of the wastewater, the removal rate also increases. This study can be extended by setting pilot plant at site.

1. Introduction

Water is one of the most important elements involved in the creation and development of healthy life. The exponential growth of population and industrialization will cause a huge lack of water if we don't start to use it in a sustainable way. To achieve this, a high level of responsibility towards water usage is required, and it must be recycled according to its pollution content in order to maintain water quality and protect our environment. Many methods of water treatment have been researched and employed by responsible nations around the globe. There are various parameters that must be considered when a wastewater treatment choice is made, including level of pollution and the amount of water. to be recycled in a certain time. The use of plants for wastewater treatment is appropriate in smaller communities and agglomerations because they are easily constructed, inexpensive to maintain and very efficient. Constructed wetlands use plants which are able to cope with different concentrated pollutants in water and help bacterias to break down these substances.

Bali (2010) et al., have studied infiltration percolation technique which is capable of completely oxidizing and decontaminating wastewater Secondary effluents, intermittently applied over 100 m^2 infiltration basin, percolated through unsaturated coarse sand. Coulibaly (2008) et al., emphasis on constructed wetland planted with Amaranthus hybridus was

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developed for domestic wastewater treatment. Two beds planted with Amaranthus hybridus plants and one with unplanted bed was used to perform the experiment. Planted beds gave best COD removal than the unplanted bed. Giraldi and Iannelli (2009) have studied comparative analysis of planted and unplanted beds. They performed daily water content analyses in the interval between subsequent sludge loadings in a real scale reed bed system situated in Pisa (central Italy).Wood (2007) et al., have studied and carried out investigation to test the hypothesis that reed beds can be used to treat high-strength agricultural effluent and dairy waste of 5-d biochemical oxygen demand (BOD_5) up to 6000mg/l.

From the above literature review it can be said that the studies has been carried out for domestic sewage wastewater, industrial wastewater and other type of wastewater. The various type of combination of constructed wetland are also used. In this study, using the vertical flow system of constructed wetland the various characteristics such as BOD, COD, TS, pH, DO are studied for the municipal wastewater.

The aim of this paper is to study the wastewater characteristics of Amba Nala like BOD, COD, DO, pH and TS using constructed wetland with and without plant species.

2. Theoretical Background

2.1 Constructed Wetlands (CW)

Constructed Wetlands (CW) is a biological wastewater treatment technology designed to mimic processes found in natural wetland ecosystems. These systems use wetland plants, soils and their associated micro-organisms to remove contaminants from wastewater (Okuda and Higa, 1990). The plant within the constructed wetland is the major component for the treatment process. The type of macrophyte chosen will vastly influence the efficiency and quality of wastewater. Plants provide an environment for microbes to live, they oxygenate the wastewater, providing nutrients for the microbes to survive, they stabilize the soil and they also partake in the reduction of nutrients.

2.2 Types and classification of Constructed Wetlands

1. Surface flow treatment wetlands

Surface flow or free-water-surface wetland systems show, as the name suggests, a water flow primarily conducted aboveground and exposed to the atmosphere (free water body). Re-aeration at the surface is the major oxygen source in this wetland type. Below the free water body, the bed contains a soil layer which serves as a rooting media for the emergent vegetation. At the bottom of the wetland system, an impermeable barrier (liner or native soil) is required to avoid infiltration, and thus, contamination of groundwater.

2. Subsurface flow treatment wetlands

Subsurface flow treatment wetlands can be divided into soil and gravel based wetlands on the one hand, and into horizontal and vertical flow systems on the other hand.

3. Horizontal flow systems

The wastewater flows horizontally through a porous soil medium where the emergent plant vegetation is rooted, and is purified during the contact with the surface areas of the soil particles and the roots of the plants. This system includes an impermeable liner or native soil material at the bottom to prevent possible contamination of the groundwater.

4. Vertical flow systems

Vertical flow systems are characterized by an intermittent charging including filling and resting periods where wastewater percolates vertically through a soil layer that consists of sand, gravel or soil. The plant species primarily used in vertical flow wetlands is common reed (Phragmites australis) due to its deeply penetrating, dense root and rhizome system. Key advantage of vertical flow systems is an improved oxygen transfer into the soil layer (Melidis et al, 2010).Beside oxygen input by the plants and diffusion processes that both occur also in horizontal subsurface flow wetlands, vertical flow filter show a significant oxygen input into the soil through convection caused by the intermittent charging and drainage.Compared to horizontal subsurface flow systems, the additional aeration of the soil by convective processes allows higher nitrification capacities as well as removal of organic matter. However, denitrification that requires anoxic conditions is usually lower in vertical flow beds compared to horizontal subsurface flow beds. They are also less effective for removal of suspended solids than horizontal surface flow and subsurface flow beds.

5. Hybrid systems (Combine System)

In these systems the advantages and disadvantages of horizontal flow and vertical flow can be combined to complement each other. Some design approaches have been made using such combinations. The treatment processes are numerous and differ according to the type of flow (surface flow, subsurface vertical flow, and subsurface horizontal flow), species of plant, conception of the system (dimensions and number of beds) and structure of substratum (soil or gravel) An increasing interest could be noticed in the last years for systems combining vertical and horizontal flows, and have gained increased attention since 1990. The idea was to combine the advantages of vertical flow with those of the horizontal flow..

3. Materials and Methods

3.1 Experimental set up and operation conditions of wetlands

Vertical flow constructed wetland system similar to vertical subsurface flow wetland systems were constructed and located at the Institute Environmental Engineering Laboratory. The constructed wetland systems, including *Typha orientalis* without vegetation and with vegetation, were operated in continuous flow mode alternately. The raw wastewater was sampled from the local Amba nala. The constructed wetland lab model made up of plastic. The raw wastewater and treated wastewater container have dimension of 23cm × 20cm × 38 cm and bed assembly is in cylindrical shape having diameter 23 cm and height 45 cm. The inlet unit is provided with a PVC pipe along with a calibration knob. The calibration knob has been such adjusted that it will work for different detention period. The inlet chamber is there with a scale and it shows a marking of one litre so that the volume of waste water in the inlet and outlet chamber can be measured. The water which will percolate through the bed assembly will come out from the PVC pipe attached at the bottom and from there it will be collected in the outlet chamber. The required plant species, *Typha orientali*s is collected from a local stream. The schematic of the wetland modules with out *Typha orientalis* is shown in Figure.1 and with *Typha orientalis* is shown in figure 2.

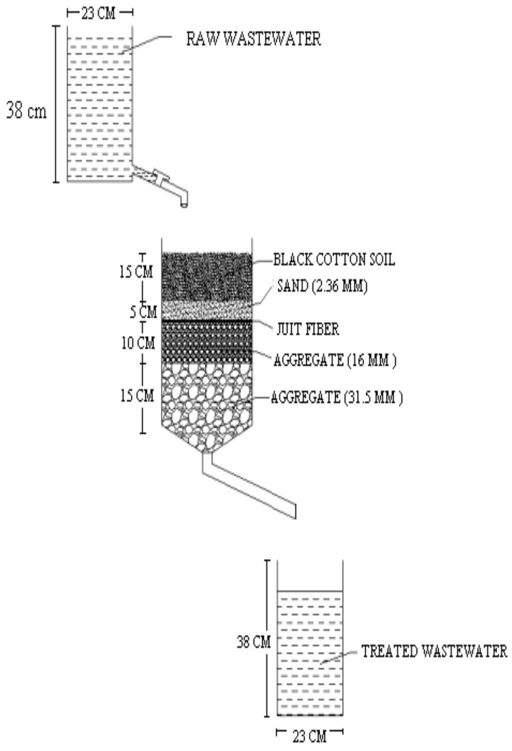

Figure 1: Laboratory setup for constructed wetland without Typha orientalis.

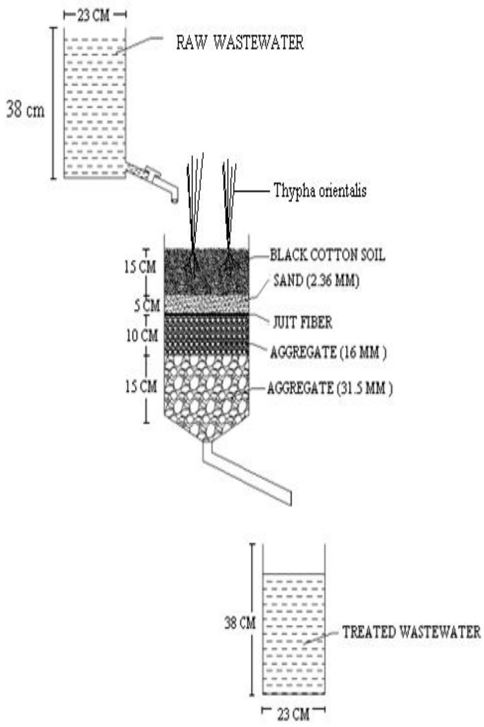

Figure 2: Laboratory setup for constructed wetland with Typha Orientalis.

3.2 Preparation of Bed

The constructed wetland having narrow bottom with the height of 45cm.Top layer consist of substrate (soil media), the Black cotton soil, Sandy soil use as the substrate for different wetland bed conditions. Before placing the soil in the bed, it was be cleaned and was ensured to free from the impurity. The soil media have the depth of 15 cm, below the soil layer the sand is placed, the depth of sand layer is 5cm.The mean grain size of sand is 2.36 mm, below the sand the jute fibers are placed. Before placing the sand, it was cleaned and washed with the clean water, so as to remove the dust over it. The bottom of wetland unit is filled aggregate having size 16 mm & 31.5 mm respectively. The 16 mm aggregate have the depth of 10 cm and the 31.5 mm aggregate have the depth 15 cm. Aggregate must be wash with the clean water and dried so as to remove the impurity over the surface of it. The unplanted and planted wetland system has the same assembly, the only difference in case of planted wetland system is that it has the macrophyte plant also in the assembly. Constructed wetland technology is based upon the treatment power of three main mechanisms: micro-organisms colonizing the system, the physical and chemical properties of the bed media , and finally the plants themselves. The laboratory scale model calibrated for the various discharge like 3-days,5-days,7-days and 9-days

3.3 Starting of Experiment

After the preparation of the bed for the constructed wetland the actual performance of the bed was started. The raw wastewater from the local Amba nala is collected and screened through fine mesh, before putting the wastewater in the influent container. The raw wastewater characteristics like pH, DO, BOD, COD, and TS were determined using procedure mentioned in standard methods. The screened wastewater was put into the influent container; the container provided with the calibration knob, the knob calibrated for the varying detention time i.e for 3, 5, 7 and 9 days. After the calibration the wastewater was allowed to pass over the surface of the bed, as the time progress the percolation of wastewater start into the bed. Percolated water from the bed collected in the outlet tank. The purified wastewater characteristics also studied by using standard methods. The same procedure was adopted for the planted constructed wetland. The comparative study between the unplanted and planted wetland was done.

4. Results and Discussion

4.1 Raw Wastewater Characteristics

The raw wastewater collected from different location of Amba Nala was studied in the laboratory. The various tests were conducted on the raw wastewater like pH, DO, BOD, COD, T.S, Phosphorus, Chloride, Nitrate, Sulphate and hardness, as per procedure laid down in standard methods. The results are enlisted in Table.1. From the table it is observed that the waste is moderate in strength and needs the treatment before discharging into stream.

Table 1: Raw wastewater characteristics of Amba Nala

Parameter	Rukhamini Nagar	Asiad Colony	Prashant Nagar	H.V.P.M.
pH	7.54	7.56	7.62	7.63
Conductivity (ds/m)	146	149	148	148
Calcium (mg/l)	26	28	27	26
Magnesium (mg/l)	34	37	36	36
Chloride (mg/l)	64	67	65	67
Sulphate (mg/l)	19	17	19	19
Nitrate (mg/l)	4.4	4.8	4.7	4.5
Phosphate (mg/l)	0.14	0.136	0.138	0.135

4.2. Black Cotton Soil as a Substrate

The performance of model was studied for the two main conditions i.e. for planted and unplanted wetland. The constructed wetland bed studied for the black cotton soil, the bed studied for the different detention period i.e for the 3, 5, 7, and 9 days.

For the detention time of 3 days without typha it was found that, the % removal for the total solids was in the range of 71%, for BOD maximum % removal was 36%, for COD it is 21%. Whereas for the planted wetland system with 3 days detention time, % removal for total solids was in the range of 72%, for BOD maximum % removal was 47%, for COD it is 35%. Figure 3, 4, 5 shows the percentage removal of total solids, B.O.D. and C.O.D. using black cotton soil for the detention time of 3 days. For the detention time of 5 days without typha it was found that, the % removal for the total solids was in the range of 74%, for BOD maximum % removal was 48%, for COD it is 42%. Whereas for the planted wetland system with 5 days detention time, % removal for total solids was in the range of 74 %, for BOD maximum % removal was 45%, for COD it is 43%. Figure 6, 7, 8 shows the percentage removal of total solids, B.O.D. and C.O.D. using black cotton soil for the detention time of 5 days. For the detention time of 7 days without typha it was found that, the % removal for the total solids was in the range of 72%, for BOD maximum % removal was 53%, for COD it is

42%. Whereas for the planted wetland system with 7 days detention time, % removal for total solids was in the range of 71%, for BOD maximum % removal was 86%, for COD it is 66%. Figure 9, 10, 11 shows the percentage removal of total solids, B.O.D. and C.O.D. using black cotton soil for the detention time of 7 days. For the detention time of 9 days without typha it was found that, the % removal for the total solids was in the range of 75%, for BOD maximum % removal was 63%, for COD it is 55%. Whereas for the planted wetland system with 9 days detention time, % removal for total solids was in the range of 75%, for BOD maximum % removal was 88%, for COD it is 65%. Figure 12, 13, 14 shows the percentage removal of total solids, B.O.D. and C.O.D. using black cotton soil for the detention time of 9 days. The Fabio Masi and Nicola Martinuzzi performed the test over the constructed wetland using *phragmites australis* as macrophyte plant they found the 95% removal in BOD and 94% removal in COD and 84% removal in total solids.

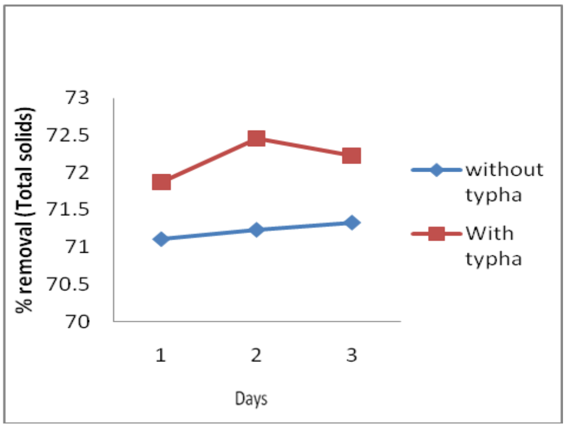

Figure 3: % Removal of Total Solids for Detention Time 3 days using Black cotton soil

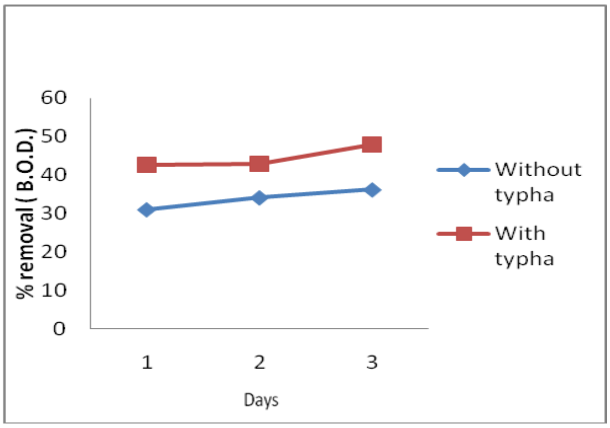

Figure 4: % Removal of B.O.D. for Detention Time 3 days using Black cotton soil

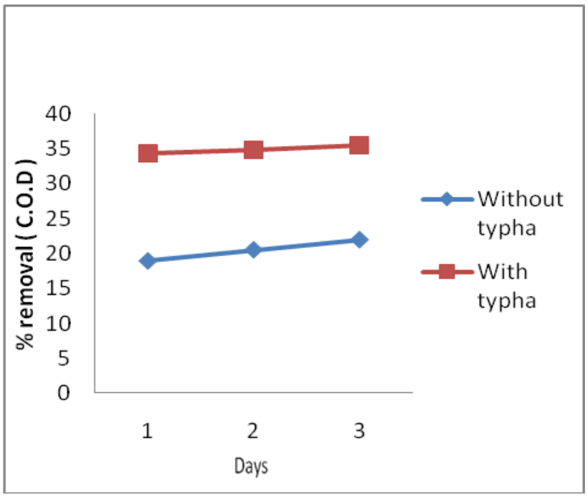

Figure 5: % Removal of C.O.D. for Detention Time 3 days using Black cotton soil

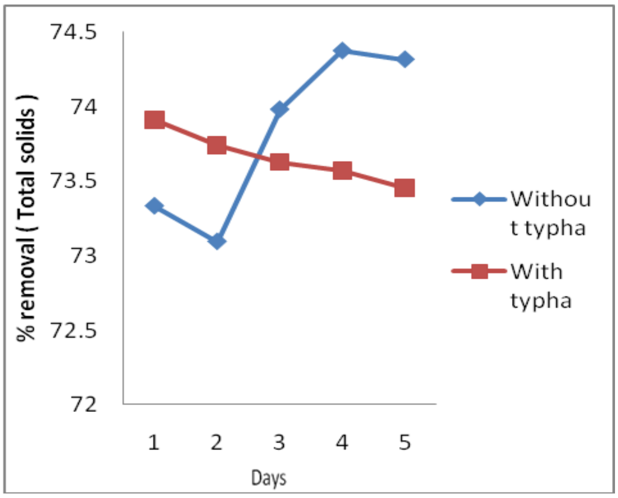

Figure 6: % Removal of Total Solids for Detention Time 5 days using Black cotton soil

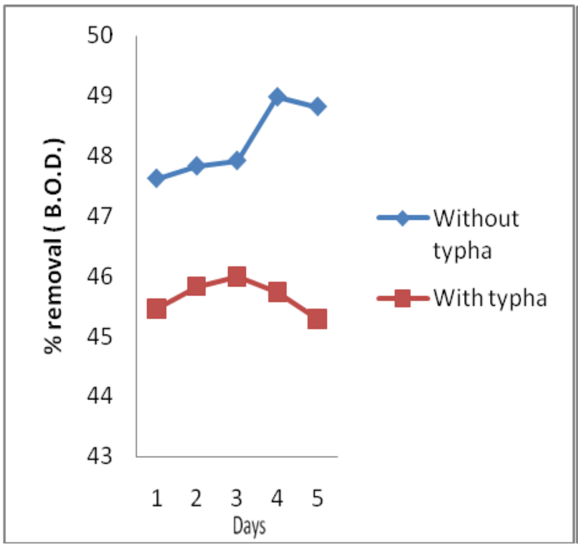

Figure7: % Removal of B.O.D. for Detention Time 5 days using Black cotton soil

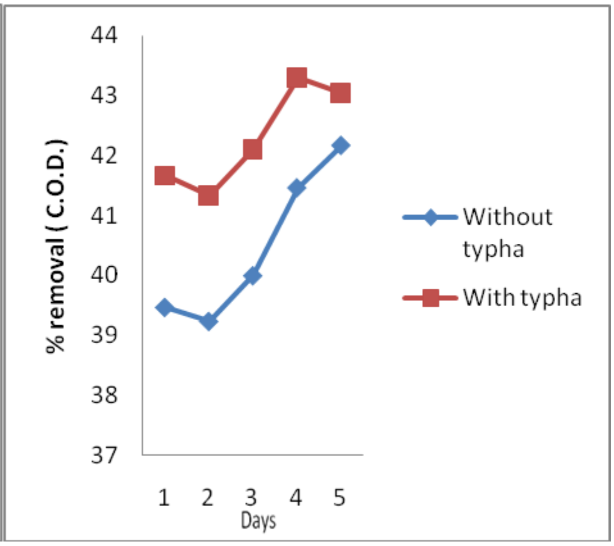

Figure 8 % Removal of C.O.D. for Detention Time 5 days using Black cotton soil

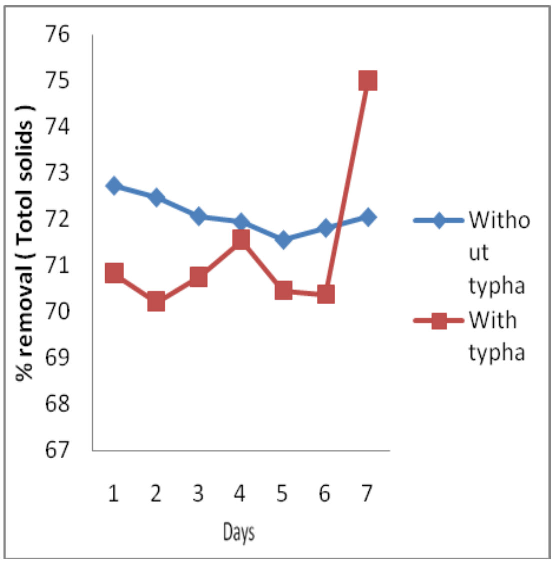

Figure 9: % Removal of Total solids for Detention Time 7 days using Black Cotton soil

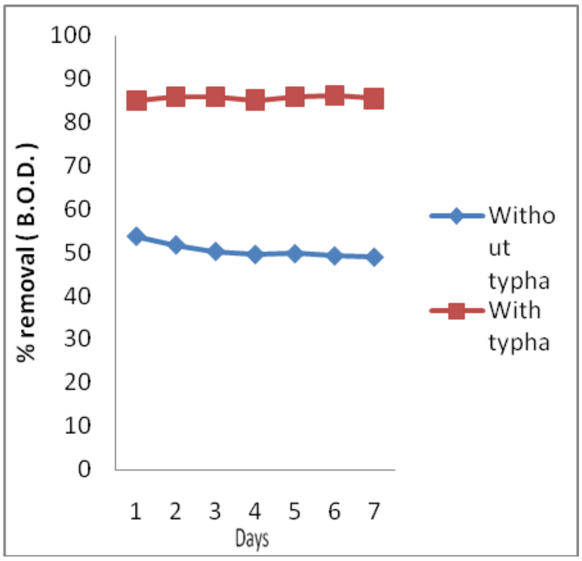

Figure 10: % Removal of B.O.D. for Detention Time 7 days using Black Cotton soil

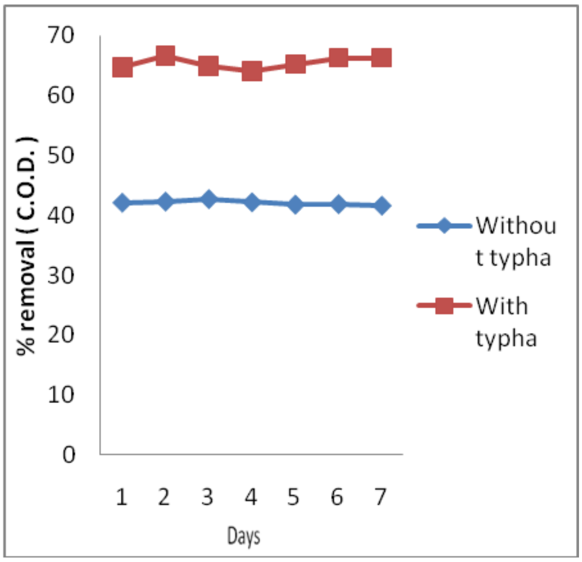

Figure 11: % Removal of C.O.D. for Detention Time 7 days using Black Cotton soil

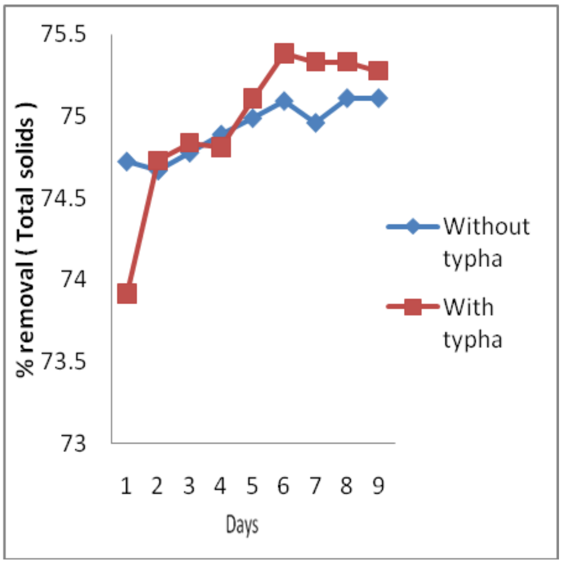

Figure 12: % Removal of Total solids for Detention Time 9 days using Black cotton soil

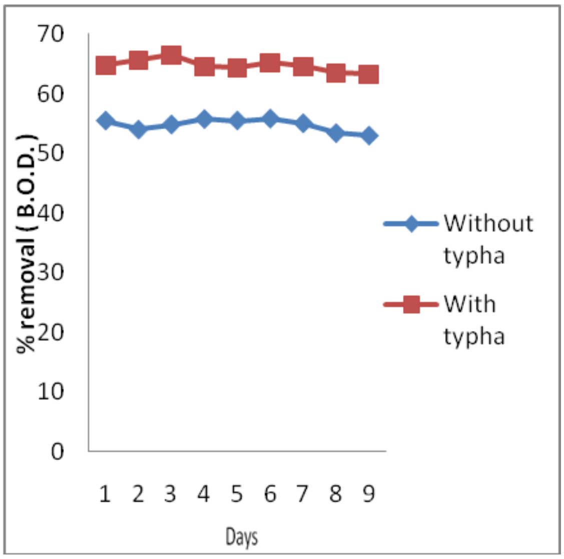

Figure 13: % Removal of B.O.D. for Detention Time 9 days using Black Cotton soil

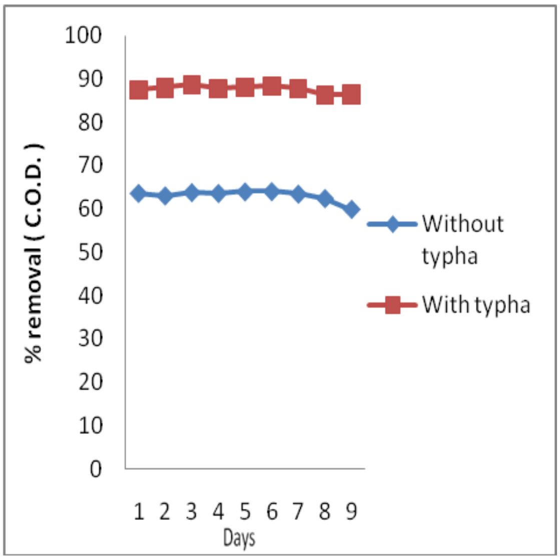

Figure 14: % Removal of C.O.D. for Detention Time 9 days using Black cotton soil

4.3 Sandy Soil as a Substrate

After completion of the various testing over the black cotton soil the substrate layer change to the sandy soil. The bed was studied for the two main conditions i.e. for planted and unplanted wetland. The constructed wetland bed studied for the black cotton soil, the bed studied for the different detention period i.e for the 3, 5, 7, and 9 days.

The bed with sandy soil as substrate studied for different detention time and with and without plant species, for the detention time of 3 days without typha it was found that, the % removal for the total solids was in the range of 71%, for BOD maximum % removal was 31%, for COD it is 18%. Whereas for the planted wetland system with 3 days detention time, %

removal for total solids was in the range of 73%, for BOD maximum % removal was 34%, for COD it is 19%. Figure 15, 16, 17 shows the percentage removal of total solids, B.O.D. and C.O.D. using sandy soil for the detention time of 3 days. For the detention time of 5 days without typha it was found that, the % removal for the total solids was in the range of 71%, for BOD maximum % removal was 39%, for COD it is 29%. Whereas for the planted wetland system with 5 days detention time, % removal for total solids was in the range of 74%, for BOD maximum % removal was 44%, for COD it is 34 %. Figure 18, 19, 20 shows the percentage removal of total solids, B.O.D. and C.O.D. using sandy soil for the detention time of 5 days. For the detention time of 7 days without typha it was found that, the % removal for the total solids was in the range of 73%, for BOD maximum % removal was 46 %, for COD it is 45%. Whereas for the planted wetland system with 7 days detention time, % removal for total solids was in the range of 74%, for BOD maximum % removal was 57%, for COD it is 52%. Figure 21, 22, 23 shows the percentage removal of total solids, B.O.D. and C.O.D. using sandy soil for the detention time of 7 days. For the detention time of 9 days without typha it was found that, the % removal for the total solids was in the range of 75%, for BOD maximum % removal was 61%, for COD it is 52%. Whereas for the planted wetland system with 9 days detention time, % removal for total solids was in the range of 76 %, for BOD maximum % removal was 74%, for COD it is 61%. Figure 24, 25, 26 shows the percentage removal of total solids, B.O.D. and C.O.D. using sandy soil for the detention time of 9 days. C.Smeal et al., when performed used the soil based reed bed system for the treatment of effluent at Gelita, Australia they had study for the gravel soil, sandy soil and black cracking clay in that case they have found that the sandy soil have the less hydraulic conductivity than the gravel soil.

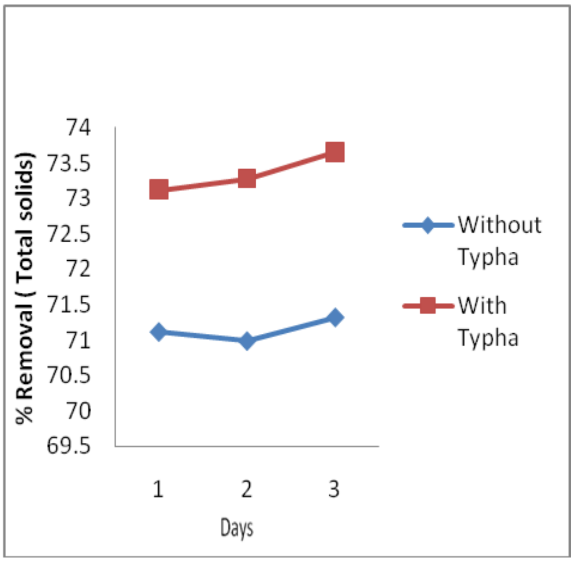

Figure 15: % Removal of Total solids for Detention Time 3 days using Sandy soil

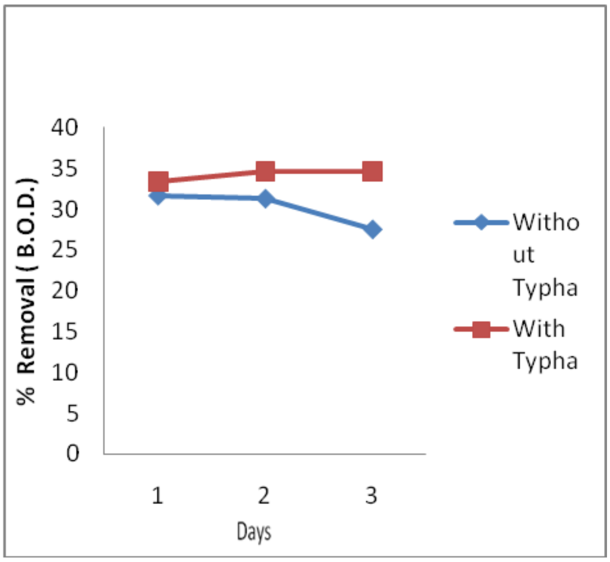

Figure 16: % Removal of B.O.D. for Detention Time 3 days using Sandy soil

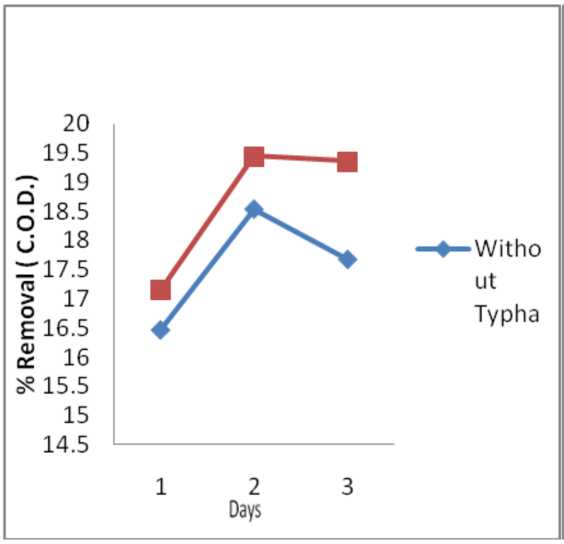

Figure 17: % Removal of C.O.D. for Detention Time 3 days using Sandy soil

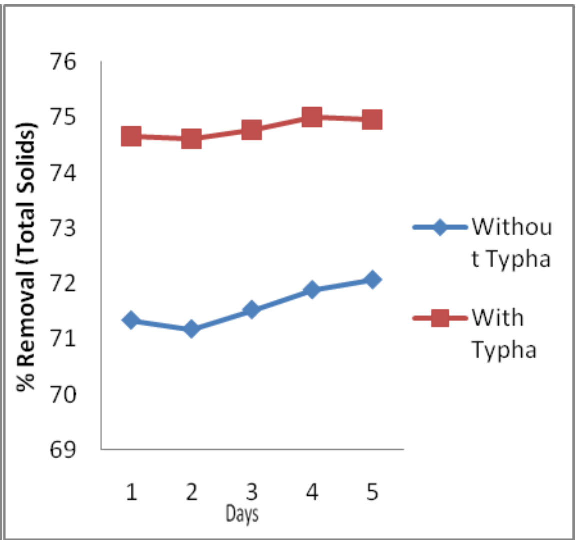

Figure 18: % Removal of Total solids for Detention Time 5 days using Sandy soil

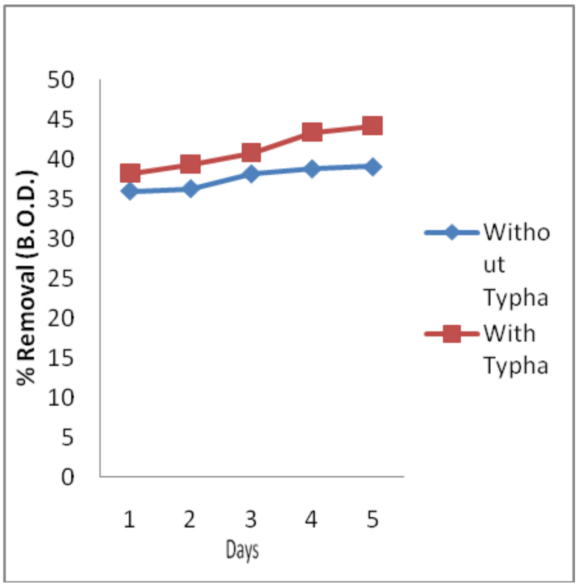

Figure 19: % Removal of B.O.D. for Detention Time 5 days using Sandy soil

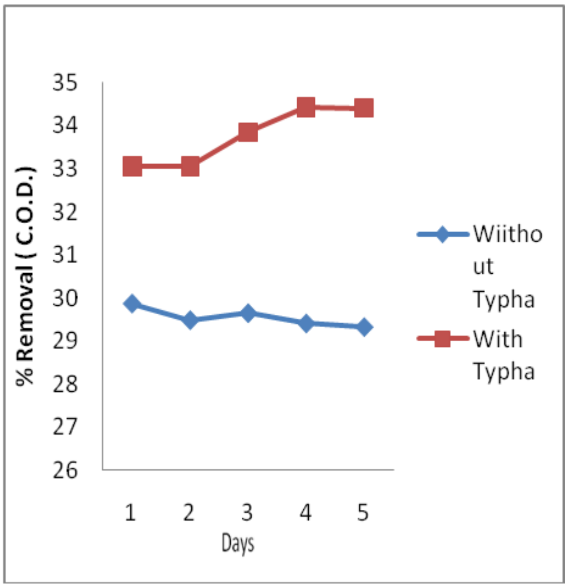

Figure 20: % Removal of C.O.D. for Detention Time 5 days using Sandy soil

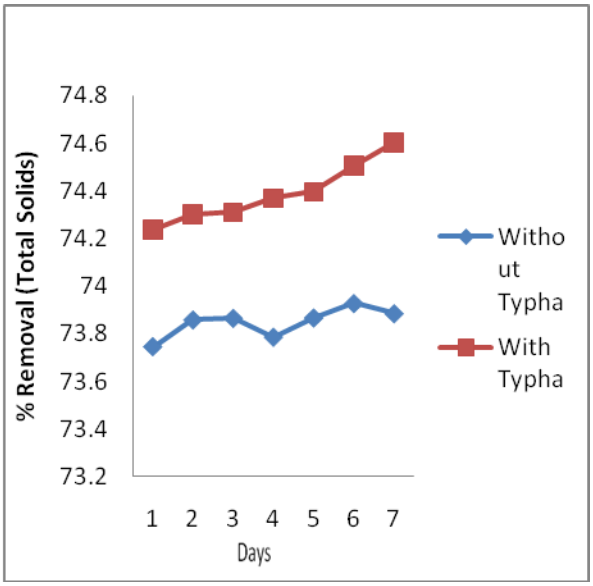

Figure 21: % Removal of Total solids for Detention Time 7 days using Sandy soil

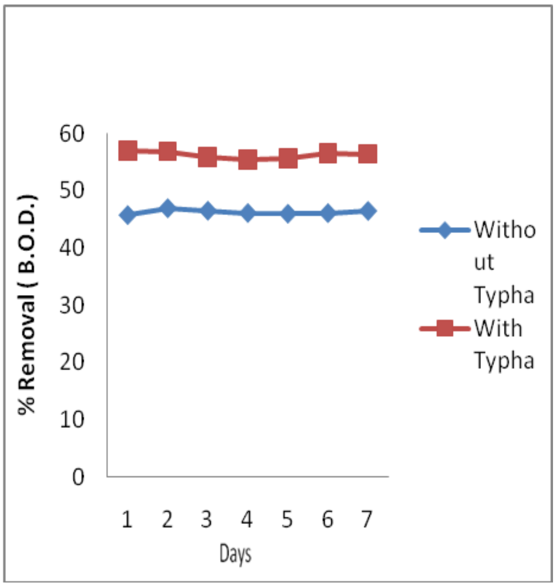

Figure 22: % Removal of B.O.D. for Detention Time 7 days using Sandy soil

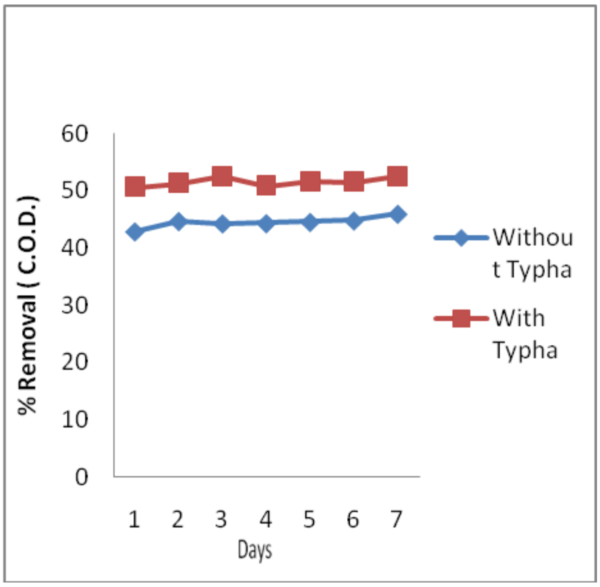

Figure 23: % Removal of C.O.D. for Detention Time 7 days using Sandy soil

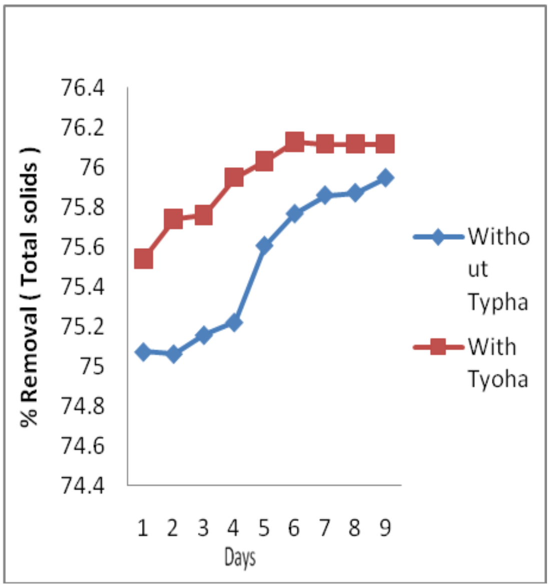

Figure 24: % Removal of Total Solids for Detention Time 9 days using Sandy soil

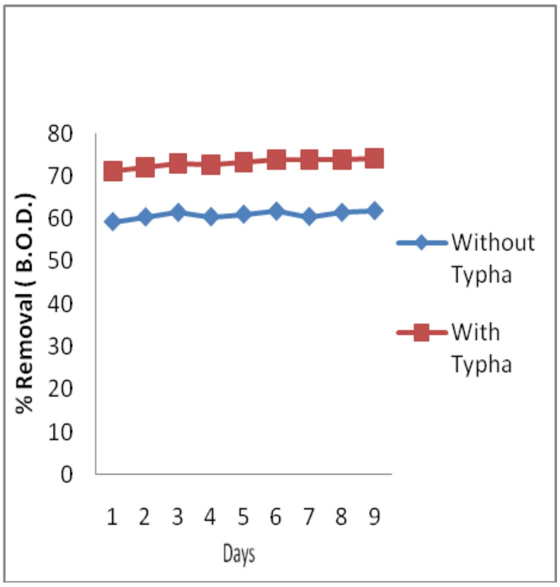

Figure 25: % Removal of B.O.D. for Detention Time 9 days using Sandy soil

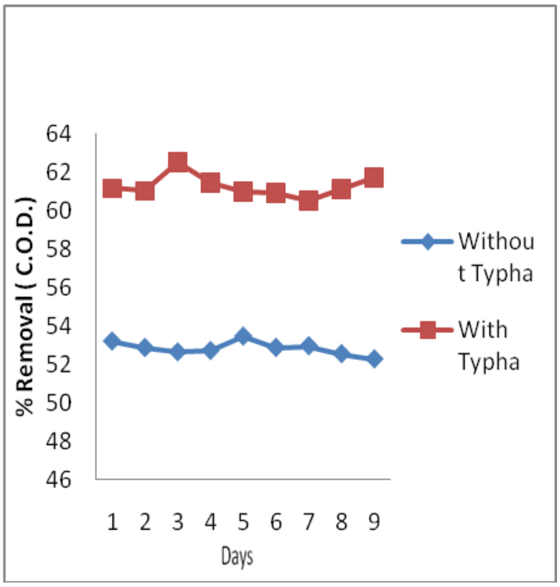

Figure 26: % Removal of C.O.D. for Detention Time 9 days using Sandy soil

5. Discussion

In case of black cotton soil as substrate it was found that the percentage removal of pollutant in case of the planted wetland was more than the unplanted constructed wetland it is because of the oxygen diffusion from roots of the typha and the nutrient uptake and insulation of the bed surface. It is also observed that increases in the detention time increase the % removal of the pollutant as the black cotton soil has good water holding capacity. The % removal for increasing detention time was not linear but for the detention time of 7 days it was found that the overall percentage removal of all pollutant was best. In case of sandy soil the percentage removal of pollutant was less as compare to the black cotton soil as the sandy soil has the less water holding capacity than the black cotton soil. It was found that the percentage removal of pollutant in case of the planted wetland was more than the unplanted constructed wetland it is because of the oxygen diffusion from roots of the typha and the nutrient uptake and insulation of the bed surface. It is also observed that increases in the detention time increase the % removal of the pollutant. The % removal for increasing detention time was not linear but for the detention time of 7 days it was found that the overall percentage removal of all pollutant was best.

6. Conclusions

Following conclusion are drawn by using laboratory scale model on different soil substrate condition and using with and without plant species for different detention time.

1. The raw wastewater characteristics of Amba Nala was determined and found that waste is moderate in strength and needs treatment.
2. Using black cotton soil as substrate, it is found that BOD, COD removal 59 % and 53 % for unplanted constructed wetland whereas for planted constructed wetland it was 86% and 63%. In case of sandy soil BOD, COD removal 61 % and 51 % for unplanted constructed wetland whereas for planted constructed wetland it was 74% and 61%.

3. It was found that the overall percentage removal of all pollutants were better for the detention time of 7 days as compare to the other detention time.
4. During hydraulic retention study, it was found that the BOD, COD was best removed in planted wetland than unplanted wetland. It is because of the oxygen diffusion from roots of the typha and the nutrient uptake and insulation of the bed surface.
5. It was found that there is an increase in the pH of the treated wastewater for each case which is because of the presences of the jute fiber in the bed assembly.
6. At all soil substrate conditions, it was found that that percentage removal for planted was 76% and for unplanted constructed wetland in the average range of 74%, which shows slightly improvement of total solids using planted condition.
7. The planted wetland system shows the better performance than the unplanted system. It is also found that the increases in the detention period of the wastewater the removal rate also increases.
8. The removal rate was found better for the black cotton soil than the sandy soil, as black cotton soil having good water holding capacity found to the best for the pollutant removal in the wastewater.

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