Performance Evaluation of Constructed Wetland for Wastewater Treatment

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Abstract: An efficient technique to treat the municipal wastewater has been developed in this paper. It is suitable for wastewater treatment in many developed as well as developing countries. A pilot treatment plant was constructed using plots of Cynodon Dactylon grass. The grass was planted in sandy soil below which only sand was kept as a media. The wastewater was applied at the rate of 0.1 m^3/m^2/day to the plots with a ground slope of 1 in 60. The sub-surface flow through plots was monitored regularly. Wastewater samples before and after treatment were collected and tested for various water quality parameters. It was observed that removal efficiency for BOD_5 was 76 to 86 %, COD was 75 to 84 %, TDS was 29 to 35 % and TSS was 84 to 88%. The pilot project was successful in treating wastewater and bringing its basic parameters within permissible limits.
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1. Introduction

The domestic wastewater is being disposed off into natural streams without any treatment in many countries. Lombardi et al. (2010) found that untreated disposal of wastewater from Argentina into La Plata River has endangered one of the most important species of fish named Prochilodus Lineatus. During winter, the quantity of stream flow decreases and un-hygienic condition is created by an increase in the concentration of wastewater in the stream water. In summer, extreme temperature causes more problems. Thermal stratification results in improper mixing of wastewater in stream water. The level of dissolved oxygen in these streams also reduces due to high temperature, hence the stream water becomes polluted. It is needed to treat wastewater before disposal to save the aquatic life in the natural streams. Most of the countries follow conventional wastewater treatment. These include activated sludge process or anaerobic digestion and involve a lot of infrastructure. The developing countries can't afford the construction cost of wastewater treatment plant for every domestic community. A high maintenance and operational cost, coupled with technical skills, is required to run these systems. Massoud et al. (2010) evaluated the performance of wastewater treatment through activated sludge process and pond system in three villages of Lebanon. He found that treatment system is non-functional because of lack of technical and financial resources. In this research, a technique is developed to treat the domestic wastewater employing available local resources in an economical way. After implementation of research recommendations, the water quality of natural streams will be improved and the environmental impact of these streams on surrounding will be positive. This will be beneficial for agriculture, social, environment and economic sectors. The main objective of this research is to develop efficient techniques for the treatment of domestic wastewater.

In the last decade some research has been conducted on wetland treatment of wastewater. Asghar et al. (2013) performed experiments on wetland using Cyperus alternifolius plants and shrubs. He found that the wetland was efficient for COD removal. El-Khateeb et al. (2013) study recommended that subsurface flow constructed wetland is useful for treatment of sewage water. Dong et al. (2012) used aquatic plants in wetland for waste treatment and found it efficient for reducing COD. Mthembu et al (2013) found that wetland treatment of wastewater is economical. He suggested constructed wetland can be an alternative wastewater treatment technology. William (1999) suggested that artificial and natural wetlands are often the best choice to treat wastewater. High level removal of pollutants in wastewater can be achieved through wetland treatment. Tyrrel et al. (2002) studied the treatment of Leachate through sub-surface flow using clay loam soil substrate planted with grass (Agrostis Stolonifera). He worked out an empirical relation of NH3-N removal and found it was efficient to reduce contamination. Njau and Mlay (2003) carried out their study on wetland treatment on textile waste and concluded that Vetiver grass is efficient in treatment of the textile wastewater. Klomjek and Nitisoravut (2005) conducted research on artificial wetlands for removal of pollutants from saline wastewater. The research was carried out on two plants cattail (Typha Angustifolia) and Asia crabgrass (Digitaria Bicornis). The wetland vegetated with these plants was successful in reducing contamination level of BOD_5, NH_3-N, TP and Suspended Solids. Taebi and Droste (2008) suggested that overland treatment system can be economically replaced for advanced treatment and shown good result in BOD_5 removal. Chen et al. (2008) applied municipal wastewater to construct wetland vegetated with common reed (Phrugmites Australis), water bamboo (Zizania Aquatica) and cattail (Typha Latifolia). The system showed excellent results in removing BOD_5, COD, TSS, TP and NH_3-N. Kayranli et al. (2009) studied the performance of newly constructed wetlands for one year in Glaslough and five years in Dunhill for matured integrated constructed wetland. The result of the study revealed that integrated constructed wetland is efficient in removing contamination in wastewater. Andrzej et al. (2012) constructed wetland for treating leachate by planting reed and willows. The system was successful to lower total nitrogen, nitrates and chemical oxygen demand. Sarafraz et al. (2009) used the plants Phragmites Australis and Juncus Inflexus in wetland treatment of wastewater. He found that sub-surface flow through wetland can efficiently reduce contamination level of NH_3-N, TP, Zn, Pb and Cd. Borges et al. (2009) studied the removal of a pesticide Ametryn from agricultural wastewater through sub-surface flow from artificial wetland. Typha latifolia was planted in fine gravel substrate and 39% removal efficiency of Ametryn was achieved. Sohair et al. (2012) performed experiments on pilot scale vertical flow constructed wetland unit. He planted Canna, Phragmites Austrailis and Cyprus Papyrus. The quality of treated effluent proved that the unit is efficient for wastewater treatment. Abidi et al. (2009) studied the hybrid system of subsurface flow through substrate of sand and gravel, vegetated with reed (Phragmites Australis) and Typha, and found it efficient to remove contamination.

The literature review shows that wastewater flow through wetland reduces BOD_5, COD, TSS, TN, TP, and turbidity in an economical way. Most of the developing countries have a large land available around urban and rural areas which may be suitable for treatment of waste water by wetland flow. The purpose of this research is to develop a guideline that is suitable for wastewater treatment for the areas where average daily temperature varies from 10^oC to 39^oC. Most of plants used for wastewater treatment in previous research need a lot of maintenance work i.e. cutting and trimming. That creates a lot of waste, which may lead to another environmental problem. Naju et al. 2003 used Vetiver Grass in his experiments. This type of grass grows naturally and gives a wild appearance. In the present research grass (Cynodon Dactylon) as shown in figure 1 is used as a plant and sandy clay as substrate. Grass is evergreen and can survive under submerged conditions. The grass plots also provide a superior look and this specie generates competitively less waste. In most of previous research tertiary treatment of wastewater is done through wetland. No data is available to use grass (Cynodon Dactylon) and sandy clay substrate for secondary treatment under continuous sub-flow throughout the year for area where average daily temperature varies from 10^oC to 39^oC. In the present research the wastewater after primary treatment applied to wetland cells. This research will provide suitable and efficient solution for wastewater treatment.

Figure 1: Grass (Cynodon Dactylon) in experimental plot

2. Materials and Methods

This study involves the construction of a model treatment facility and construction of pilot plant for the treatment of wastewater. Three wetland cells using grass (Cynodon Dactylon) vegetated in sandy clay were constructed.

A natural stream passing near University of Engineering and Technology Taxila, Pakistan was selected. The wastewater from the residential area is disposed into the stream without any kind of treatment. A manhole of wastewater near the main gate of the University was identified. All the wastewater from the University and its residential colony flows to this manhole. Untreated wastewater from this manhole is disposed directly to the stream.

The pilot plant was constructed close to this manhole to achieve real life field conditions. Three wetland cells each 2 meter long, 1 meter wide and 0.65 meter deep were constructed. The retaining walls of the cells were constructed with bricks and base with concrete. The inside walls and base were plastered with cement sand mortar of ratio 1:3. Polyethylene sheets were placed at the bottom and along the inside walls to prevent seepage. Sand layer of 150 mm thick was provided at the bottom of each plot. Locally available sandy clay layer of 0.35 m was provided over the sand. After filling and compaction of the soil in the cell, longitudinal gradient of 1:60 and cross gradient of 0% was achieved. A weir arrangement was provided at the upper edge of each cell to apply wastewater. At the lower edge of the slope a weir was also provided to collect over flow effluent. A perforated pipe was placed at the bottom of sand layer to collect seepage effluent.

These plots were initially irrigated with fresh water and allowed to consolidate for a week. Grass was planted on three plots and left for two months for complete growth and maturation. During this period the grass was daily irrigated with wastewater for two hours.

The wastewater from the manhole was pumped to storage tank of 1000-liter capacity. The tank was kept one meter above the level of grass to achieve gravity flow. A fiberglass tub with a capacity of 500-liter was used for the purpose of flow equalization and sedimentation. A wire mesh with opening size of 5mm was installed before the suction pipe of pump to screen large debris. Figure 2 shows flow diagram of the wetland cell.

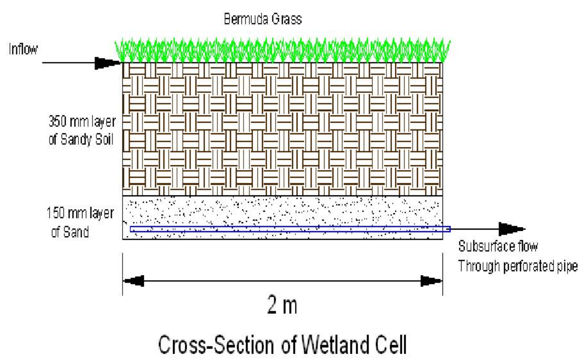

Figure 2: Cross-section

2.1 Hydraulic loading rate

After maturation period the grass was trimmed and wastewater was applied to the cell for 24 hours every day. Hydraulic loading rates were observed within the range of 0.05 to 0.12 m^3/m^2 per day. It was observed that application of maximum hydraulic rate of 0.1 m^3/m^2 per day was suitable to achieve maximum subsurface flow, because over-flow occurred beyond this value. It is assumed that the loss in flow is because of evapotranspiration.

2.2 Sampling and analysis

Wastewater was daily pumped into the storage tank. An operation of 24 hour application of wastewater to each cell was maintained for a period of one year. Standard method of wastewater sampling was adopted every month as per standard procedure recommended by American Public Health Association, American Water Works Association and Water Environment Federation (Eaton et al. 2005). The samples were transported for analysis to the laboratory of Institute of Environmental Sciences and Engineering, National University of Sciences and Technology, Rawalpindi, Pakistan. The tests were performed monthly for a period of one year. The grass was trimmed every month after each sampling.

Performance of the model wastewater treatment plant was analysed using standard methods of testing for wastewater analysis. PH, Conductivity, BOD_5, COD, TDS and TSS were tested in the laboratory. Standard methods for the examination of water and wastewater recommended by American Public Health Association, American Water Works Association and Water Environment Federation were followed (Eaton et al. 2005). pH was measured with electrometric method No. 4500-H^+B, Electronic conductivity (EC) measured with conductivity cell Method No. 2510 B, BOD_5 was tested with method No. 5210 B 5 Days BOD_5 Test, COD of the samples was measured as per Open Reflux Method No. 5220 B, TDS was measured with Gravitational Method No. 2540C and Total Suspended Solids of the wastewater were measured as per method described in Part No. 2540-D (Eaton et al. 2005). The atmospheric temperature during the test was recorded every month.

3. Result and discussion

Three samples of the wastewater were taken before the start of the study in December 2007. Figure 3 shows the average results of the tested parameters. These results of waste water parameters were compared with those of National Environmental Quality Standards (NEQS) for Municipal and industrial Effluents (The Gazette of Pakistan, 2000). It was observed that the pH is within the range of NEQS i.e. 6 to 10. According to NEQS the 80 mg/L is the limit of BOD_5 for disposal of wastewater into inland water. The wastewater has 382 mg/L of BOD_5 which is above the allowable limit. NEQS specify a disposal limit of COD to be 150 mg/L but in present study a value of 519 mg/L was observed which is non-conformance with the permissible value. Allowable limit for TDS is 3500 mg/L and the wastewater under consideration has 580 mg/L, which is within limits. Further 263 mg/L of TSS is also not acceptable as NEQS specify a limit of 200 mg/L. No limit is mentioned in NEQS about Electronic conductivity and its value of 1398 µS/cm was observed. These results show the wastewater is highly polluted and it must be treated before disposal to natural stream.

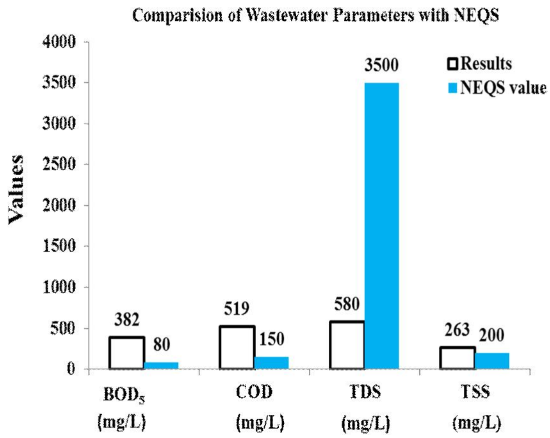

Figure 3: Average results of parameters of three samples of wastewater tested in December 2007.

As mentioned earlier the wastewater was applied to the grass plots at a hydraulic application rate of 0.1 m^3/m^2 /day. Figure 4 shows the average atmospheric temperature at the time of testing. Performance evaluation of sub-surface flow through grass plots was observed over a period of one year from March 2008 to February 2009. The average values of the parameters tested for the samples from three plots is represented by figures 4 to 8.

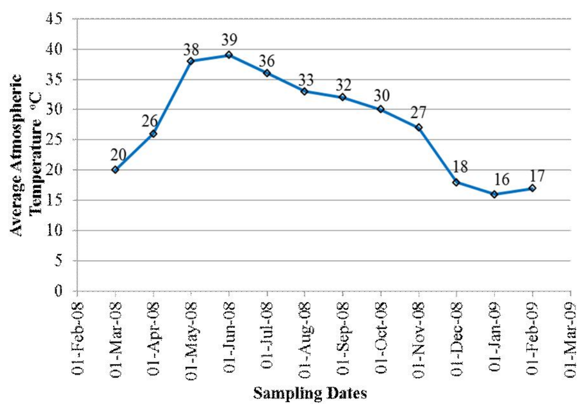

Figure 4: Average Atmospheric Temperature (^{o} C) over the year at the time of sampling.

Figure 4 represent the average atmospheric temperature at the time of sampling. The temperature varied to a minimum value of 16^{o}C to a maximum value of 39^{o}C. It was observed that grass remained green all over the year and was continuously growing 100 mm to 150 mm. It was trimmed every month after the test samples were taken.

According to NEQS the permissible value of pH of the treated wastewater before disposal to inland water is between 6.0 and 9.0. Figure 5 shows that pH of the influent wastewater varied from 6.78 to 6.86. Although the pH of the wastewater was already within permissible limit and after sub-surface flow though grass plot a change of 2.64% to 3.24% was observed. PH of the effluent waste water is between 6.65 to 6.58 which is also within NEQS limit. According to Metcalf & Eddy (2003) pH values is a key factor for the growth of organisms. Most bacteria cannot survive above 9.5 and below 4.0.

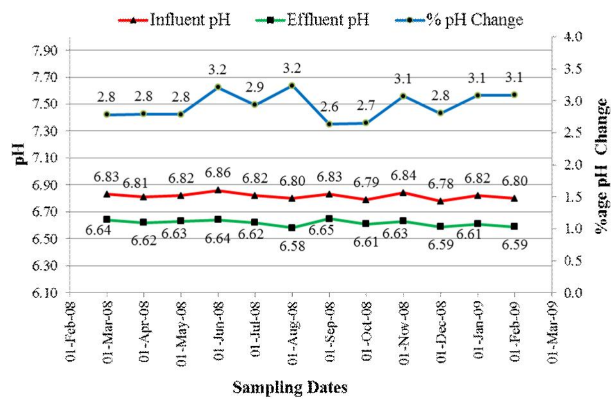

Figure 5: pH Reduction efficiency of gross plots.

There is no limit of electronic conductivity (EC) mentioned in the NEQS. According to Metcalf & Eddy (2003) the electrical conductivity of wastewater is used as a surrogate measure of total dissolved solids concentration. Results mentioned in figure 6 shows that EC of the influent wastewater varied from 1379 µS/cm to 1437 µS/cm. After treatment it reduced by 14% to 22%. The EC of the effluent wastewater was observed from 1082 µS/cm to 1227 µS/cm.

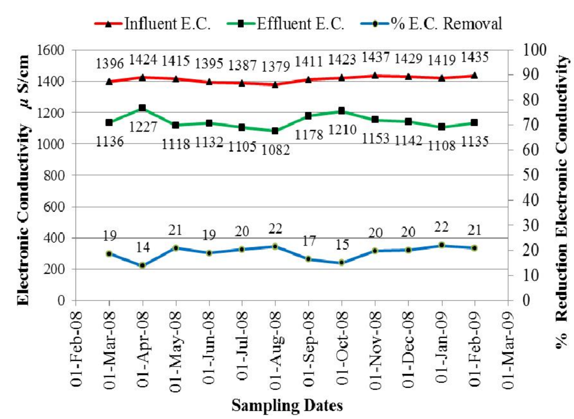

Figure 6: Electronic conductivity reduction efficiency of gross plots over the year

Bio-chemical oxygen demand is one of the most critical parameter as far as the performance evaluation of a treatment facility is concerned. NEQS specify a limit of 80mg/L for BOD_5 for safe disposal of treated wastewater into land stream. Figure 7 shows that BOD_5 of influent domestic wastewater at the time of application varied from 321mg/L to 389mg/L, which is much more than the NEQs limit. After base flow through grass plots the BOD_5 reduced from 52 mg/L to 78 mg/L indicating a considerable reduction of 76% to 86% which is below the NEQS. Vymazal and Masa (2003) archived 53% removal of BOD_5 by applying wastewater sub-surface flow through gravel substrate vegetated with Phalaris Arundinacea and Phragmites Australis at Dolni Mesto (Czech Republic). Gikas et al. (2007) applied subsurface flow through granular base vegetated with Phragmites Australis in North Greece and observed the reduction of BOD_5 by 91%. Phragmites Australis is easily available in many countries but its look is not as pleasant as that created by grass used in present paper. Abidi et al. (2009) applied vertical subsurface flow through substrate of sand and gravel and vegetated with reed (Phragmites Australis) and Typha and which found 61% removal efficiency for BOD_5.

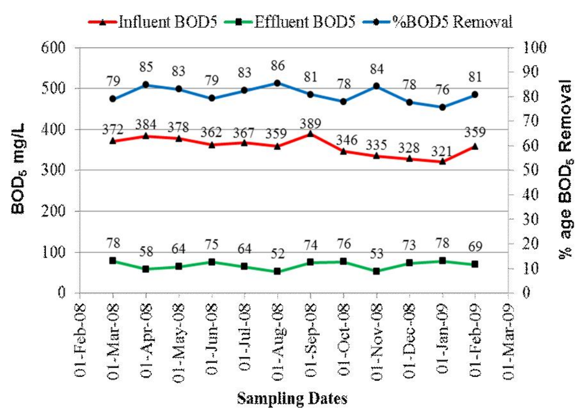

Figure 7: BOD_5 removal efficiency of gross plots over the year.

Chemical oxidization of compounds is more than biological oxidization for various types of wastewater. The COD of a wastewater in general is higher than the BOD_5. According to NEQS the COD limit is 400 mg/L. Figure 8 shows that COD of the influent wastewater ranged from 571 mg/L to 684 mg/L. After subsurface flow through grass plots it is reduced in the range of 98 mg/L to 161 mg/L and a removal efficiency of 75% to 84% is achieved. Vymazal and Masa (2003) archived 30% removal of COD by applying wastewater sub-surface flow to vegetated beds at Dolni Mesto (Czech Republic). Njau et al. (2003) achieved 46.2%removals of COD when wastewater was applied to constructed wetlands planted with vetiver grass. Gikas et al. (2007) applied subsurface flow and achieved COD removal efficiency of 80.3%. Kayranli et al. (2009) achieved COD removal of 89.1% through sub-surface flow. Asghar et al. (2013) performed experiments on wetland using Cyperus Alternifolius plant and found 75% COD is removed.

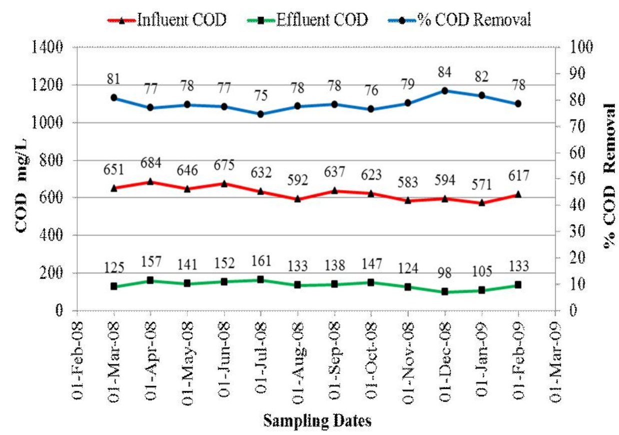

Figure 8: COD removal efficiency of gross plots over the year.

TDS removal efficiency of 29% to 35% is achieved with sub-surface flow of wastewater through grass plots. Figure 9 shows that TDS of influent wastewater varied from 598mg/L to 658 mg/L. The TDS of effluent wastewater was observed in a range 407mg/L to 452mg/L. NEQS limit of TDS is 3500 mg/L for safe disposal of domestic wastewater. TDS of the influent and effluent wastewater is less than NEQS limit. So TDS is not the deciding factor for finding out the wastewater treatment efficiency of wetland treatment using grass.

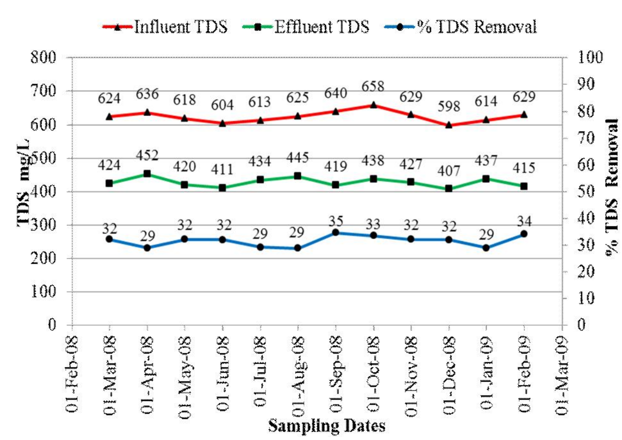

Figure 9: TDS removal efficiency of gross plots over the year.

TSS removal efficiency of subsurface flow through grass plots is observed in a range of 84% to 88%. Figure 10 shows TSS value between 225mg/L to 271mg/L of influent wastewater is reduced to a range between 32 mg/L and 36mg/L. The limit of NEQS of TSS of wastewater disposal is 200mg/L. Naju et al.

(2003) achieved the removal of TSS by 46.2% when textile wastewater was overflowed through vetiver grass. Vymazal and Masa 2003 archived removal of TSS by 33 % by applying wastewater sub-surface flow through gravel substrate vegetated with Phalaris Arundinacea and Phragmites Australis at Dolni Mesto (Czech Republic). Gikas et al. (2007) applied subsurface flow through granular base vegetated with Phragmites Australis in North Greece and observed the reduction of TSS by 99.9%. Abidi et al. (2009) vertical subsurface flow through substrate of sand and gravel vegetated with reed (Phragmites Australis) and Typha. He found 56% removal efficiency TSS.

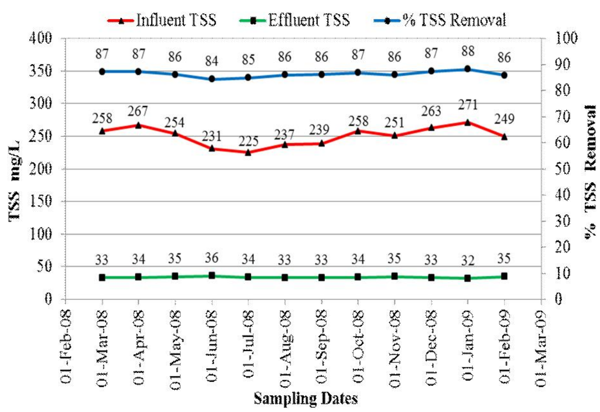

Figure 10: TSS removal efficiency of gross plots over the year.

4. Conclusions

The research work was focused to treat the wastewater through subsurface through sandy soil with sand as filter media at the bottom vegetated with grass (Cynodon Dactylon). The basic parameters of wastewater and stream water quality were tested in the laboratory. These are pH, EC, BOD_5, COD TDS and TSS.

After detailed literature review and experiments it was evaluated that land based wastewater treatment through subsurface flow is the most effective and cost efficient method under the present circumstances. Cynodon Dactylon grass was selected because it remains green all over the year and grows in all seasons. It can also survive under submerged conditions. Additionally it gives a pleasant look.

After detail experimental analysis it has been evaluated that the wetland cells planted with grass have shown excellent results with a ground slope of 1 in 60 and with a hydraulic loading rate of $0.1m^3/m^2$/day The removal efficiency of BOD5 was 76 to 86 %, COD was 75 to 84 %, TDS was 29 to 35 % and TSS was 84 to 88 %.

The results obtained during the performance evaluation of model wastewater treatment plant through constructed wetland cells indicated that this method has shown excellent results in removing different type of contaminants and reducing them to a permissible level.

5. Recommendations

Untreated Domestic wastewater discharge should be treated through wetland using grass before disposal to streams. It is recommended that this practice should be used on mega scale especially in urban as well as in rural areas where a large land is available.

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