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Performance Evaluation of Sub-Surface Constructed Wetland System - An Alternative Technology for Domestic Wastewater Treatment: A Case of Jimma University, Oromia Regional State, Ethiopia

Tsehay Bulti[1], Vighneswara Rao .K[2]

[1]Department of Agricultural Engineering, Faculty of Agriculture,
Wollega University, Shambu Campus, Oromia regional state, Ethiopia
biftub92[at]gmail.com

[2]Department of Chemical Engineering, Faculty of Technology,
Wollega University, Shambu Campus, Oromia regional state, Ethiopia
vignesh.che[at]gmail.com

Abstract: ***Cost-effective wastewater treatment systems are recently promoted for industries and domestic wastewaters. The aim of this study was to evaluate the performance of sub-surface constructed wetland system as an alternative eco friendly treatment technology for domestic wastewater. A Horizontal sub-surface Constructed Wetland system consists of settling tank, aeration and four horizontal sub-surface flow units has been used for the study. The treatment system was fed with raw domestic wastewater effluent collected from Jimma Institute of Technology. The wastewater treatment pilot plant was operated for four months (May 2018 to August 2018). A total of 21 triplicate samples were collected and analyzed for selected wastewater quality parameters. The removal efficiency of physico-chemical and biological parameters in the settling tank and during aeration process were EC (15% and 22%), Turbidity (42% and 15%), TDS (21% and 10.7%), TSS (43.5% and 20.4%), BOD_5 (31.25% and 19.9%), COD (53.8% and 21.9%), NO_3^--N (22.2% and 28.2%),PO_4^{3-}-P(20.6% and 29%),TC(-6.1% and 11.5%), FC(-6.4% and 23.1%)respectively. The maximum removal efficiencies for the three planted horizontal subsurface flow constructed wetlands were ranged from :(70.7% - 73.7%) EC, (61.3% - 73.3%) Turbidity, (58.5% - 68%) TDS, (78% - 83%) TSS, (75.9% - 80.5%) BOD5, (75% - 78%) COD, (69.45% - 73.5%) $NO3^-$-N, (56.25% - 78.6%) PO_4^{3-}-P, (57.6% - 69.8%) TC and (56.6% - 66.7%) FC respectively. The results of the study indicated that HSSFCW planted with Cyprus papyrus (cell 1) showed higher removal efficiency for EC (73.7%), Turbidity (73.3%), TDS (68%), TSS (83%), BOD_5 (80.5%) and COD (78%) than the other cells. Similarly wetland cell planted with Typhalatifolia (cell 2) revealed higher removal efficiency for NO_3^--N (73.5%), TC (69.8%) and FC (66.7%). Generally based on the overall results of the treatment performance of HSSFCWs, the application of constructed wetland in Ethiopia can be considered as a technically as well as economically feasible option for domestic wastewater treatment.***

Keywords: Aeration, Constructed Wetland, Domestic Wastewater, Removal Efficiency, Settling Tank, Wetland Plants

1. Introduction

Wastewater or sewage, originates from household wastes, human and animal wastes, industrial wastewaters, storm runoff and groundwater infiltration. It is 99.94 percent water by weight and the remaining 0.06 percent is material dissolved or suspended in the water (Water Pollution Control Federation, 1980). Wastewater also includes the discharges from agriculture, domestic, storm water and runoffs (USEPA, 1993). Domestic wastewater together with discharges from industry and agriculture has an impact on receiving water bodies. This is mainly because untreated wastewater usually contains among other contaminants, nutrients mainly nitrogen and phosphorus that can stimulate the growth of aquatic plants, which in turn results in eutrophication problem in rivers and coastal waters (Njau and Mlay, 2000; Muhammad et al., 2004). According to the United Nations Economic and Social Council (2005), most of the domestic wastewater generated in developing countries, including Ethiopia, is discharged into the environment without treatment, contaminating downstream water supplies used for drinking water, irrigation, fisheries, and recreational activities.

To protect human health and water quality, wastewater treatment systems must be carefully managed and properly operated. Wastewater treatment technologies are based on the combination of physical, chemical and biological mechanisms in treating wastewater and they can be classified into natural systems (wetlands and waste stabilization ponds) and conventional systems (trickling filters and activated sludge) (Pescod, 1992). Natural systems use aquatic plants and organisms at low capital cost and less sophisticated operation and maintenance (Crites and Tchobanoglous, 1998).Constructed wetlands (CWs) for wastewater treatment are potentially a good solution for treating domestic and industrial wastewaters in less-developed countries (Denny, 1997; Haberl, 1999; Kivaisi, 2001). The advantages of the CW technology are the utilization of natural processes, the high process stability and cost-effectiveness. Furthermore, the systems are simple to construct and operate which is a benefit in many developing countries.

Sub-surface flow constructed wetlands are more commonly used; they have higher treatment efficiency and need less space (Hoffmann and Platzer, 2010). Here it is better to use simple and cost-effective technologies like Sub-surface flow constructed wetlands for wastewater treatment. Sub-surface flow constructed wetlands are divided into two vertical and horizontal subsurface flow constructed wetlands (Kassa, 2013). The most common configuration to date has been a vertical flow stage followed by horizontal subsurface flow wetland cells, the vertical systems remove organics and TSS and provide nitrifying conditions while horizontal systems denitrify and further remove organics and TSS (Kadlec and Wallace, 2009). Some research studies pointed out that the performance of VSSFCWs (Vertical Sub Surface Flow Constructed Wetlands) was poor regarding denitrification (Vymazal and Kröpfelová, 2011) and clogging could be an operational issue (Du et al., 2016). In horizontal flow constructed wetlands, water flows slowly through a porous medium under the surface of the cell in a more or less horizontal path and reaches the outlet zone and is collected by an outlet device. The main significant advantages of the HSSFCWs (Horizontal Sub Surface Flow Constructed Wetlands) include the lack of odor, mosquitoes and other insect vectors and minimal risk of public exposure and contact with the water in the system (USEPA, 1993). Therefore, the study was planned to evaluate the treatment performance of Horizontal subsurface flow constructed wetlands as an alternative ecofriendly domestic wastewater treatment system.

2. Materials and Methods

2.1 Description of study area

The study was conducted at Jimma Institute of Technology, Jimma university, which is found in Oromia regional state, located 352 km southwest of Addis Ababa, the capital city of Ethiopia. The town lies between Latitude 7°39' - 7°83' North and Longitude of 36°49' - 36°61' East and with an elevation of 1700 m -1850 m above sea level. The study was carried out from May 2018 to October 2018. The study area in the form of Map shown in figure 2.1 using soft ware. .

Figure 2.1: Area Map use Arc GIS version 10.1 software

2.2 Study variables and Materials

Temperature, conductivity, pH, Dissolved Oxygen, Turbidity, BOD_5, COD, NO_3^--N, PO_4^{3-}-P, TDS, TSS, Total and Fecal Coliforms.

The materials used for the work of study and to analyze the parameters were emergent wetlands plants are Papyrus (Cyprus papyrus), Common cattail (Typhalatifolia) and Bulrush (Scirpuslacustris).

2.3 Experimental Setup

The HSSFCW system was built in Jimma Institute of Technology campus for investigation. The system consists of settling tank, aeration process, equalization tank and four analogous aligned in parallel cells of HSSFCWs, each cell was 2 m long, 0.65 m wide and 0.60 m deep with surface area of 1.3 m^2.Total area of the constructed wetland is 5.2 m^2 (length 2 m and width 2.6 m). The floor of the system has 1% slope from inlet to outlet to achieve a hydraulic head-loss.

The empty-bed volume of each HSSFCW up to the top mark of 0.5 m was filled by water approximately 0.65 m^3 (650 L), then the water filled was emptied. After that, the container was again filled with gravel size (20-30 mm at treatment zone and 40 – 60 mm at inlet and outlet zone) up to the mark of 0.5 m, approximately gives 0.423 m^3 (423 L) and finally the measured volume of water was added in the container with the gravel leveled on the top mark gives 0.227 m^3 (227 L). The percentage of the volume of water added in the container with the gravel to the water added without gravel was calculated as percentage porosity of the gravel. The porosity of the media was calculated by dividing void volume to total volume, which would give 0.35 or 35%. The void fraction, also termed media, porosity, ranges usually from 0.3 - 0.45 depending on the media material chosen (Vymazal, 1998).

Plastic membrane liner was used to prevent percolation and infiltration of some pollutants in to the groundwater. After lined plastic membrane the wetland basins were filled by gravel size of 40 mm-60 mm diameter size gravel around inlet and outlet and 20 mm-30 mm diameter size gravel around treatment zone.

The three plant species selected for this study purpose were Papyrus (Cyprus papyrus), Common cattail (Typhalatifolia) and Bulrush (Scirpuslacustris). The selection criteria for these plants were based on prior information on their use in CW, local availability, higher biomass yields, aesthetic, landscape beautification, ease of accessibility and their potential treating wastewater. The plants were picked up from Boye natural wetland and was transplant into their respective HSSFCW.

After the gravel was filled into the wetland cells, eight rhizomes of plants per square meter was planted at an interval of 25 cm between the plant and 25 cm between the rows of each plant and planted manually on April 01, 2018. The first HSSFCW cell was planted with Cyprus papyrus, second HSSFCW cell was planted with Typhalatifolia, third HSSFCW cell was planted with Scirpuslacustris and fourth HSSFCW cell was only gravel. The HSSFCW before and after plantation shown in Figure 2.3 (a) and (b).

Figure 2.3 (a): HSSFCW Pre-plantation

Figure 2.3 (b): HSSFCW After plantation

The four HSSFCW cells, settling tank and equalization tank were connected through a single pipe using control valve. The polyvinyl chloride (PVC) pipes with 0.5inch (1.27cm) diameter were used for the supply, distribution and collection of wastewater. After the establishmentof plants HSSFCWs cells were fed only with tap water for the first two months according to Basker et al., (2009). Then after the plants reached acclimatization stage or fully grown the domestic wastewater was diluted with tap water for different percentages for one month shown in table 2.3 (a)

Table 2.3(a): Ratio of dilution of waste water with tap water

Date	Wastewater (%)	Tap water (%)
1-7/06/2018	25	75
8-14/06/2018	50	50
15-21/06/2018	75	25
21-30/06/2018	100	0

The system was designed with an average raw wastewater flow-rate of 25 L/d (0.025m^3/d) into each HSSFCW. The total average daily flow of raw wastewater into system cell was 100 L/d (0.1 m^3/d). The inflow and outflow rate was 18.1 ml/min and 15.4 ml/min. The average inflow to each cell was 25 L/d and outflow was 20 L/day. Based on the literatures hydraulic retention time of at least 6 to 8 days recommended for an adequate nitrification rate, 7 days taken as retention time and theoretical flow rate calculated by Darcy's formula (USEPA, 1993). The wastewater first settled in a settling tank and served as a primary treatment to stay 12 hours and passes on corrugated plastic sheet for aeration process and into flow equalization tank, which was used to regulate the flow rate of wastewater into the four HSSFCWs cells as shown in Figure 2.3(c).

Keys:
1. Settling tank
2. Aeration process
3. Equalization tank
4. Inlet piping
5. Constructed wetland
6. Wetland plants
7. Treated effluents
8. Dilution preventer

Figure 2.3(c): Schematic diagram of experimental setup

2.4 Sample Collection and Handling

Wastewater samples were collected from seven different points (raw wastewater, settling tank, aeration and four cells) in the interval of 7 days hydraulic retention time. Totally 21 samples were taken during the study period. Triplicate samples were taken for the analysis of each parameter. This sampling point as shown in table 2.4. Samples were taken over the period of one month after establish plants grown fully and extend from July 01, 2018 to August 01, 2018. The grab samples were taken for wastewater quality analysis every seven days (HRT=7days). The analysis was carried out within 24 hours after collection.

Table 2.4: Sampling points at study area

Sampling point	Description of sampling point
S1	The raw wastewater after fine screening
S2	The influent wastewater after settled in to settling tank
S3	The influent wastewater after aeration into flow equalization tank
S4	The effluent of HSSFCWs cell 1
S5	The effluent of HSSFCWs cell 2
S6	The effluent of HSSFCWs cell 3
S7	The effluent of HSSFCWs cell 4

2.5 Experimental Analysis and testing methods

All the parameters such as BOD_5, COD, NO_3^--N, PO_4^{3-}-P, TDS, TSS, DO, EC, pH, temperature, turbidity, Total and Fecal Coliforms were analyzed in Jimma University main campus, Environmental graduate and staff research Laboratory following according to standard methods water and wastewater (APHA, 2012).

The parameters tested and measuring methods are as follows BOD_5 - 5 day BOD test, COD - LCK114 kit method, Total dissolved and suspended solids - Gravimotric method, Ortho phosporous - LCK350 kit method, Nitrate nitrogen - LCK339 kit method, Total and Fecal coliforms - membrane filtration techniques. The standard instruments are used for measuring all the parameters.

3. Results and Discussions

The characteristics of raw domestic wastewater and the treatment efficiency of Pretreatment units (settling tank and aeration process) and the four different HSSFCWs cells with emergent plants were examined.

3.1 Characterization of raw domestic wastewater

The characteristics of raw domestic wastewater effluent from Jimma Institute of Technology and pretreated wastewater (12 hours settled effluent before applied in the HSSFCWs).

As shown by results the pH of raw domestic wastewater sample was 6.03±0.5. This result clearly shows that the domestic wastewater in the study area is slightly acidic. The pH value for raw domestic wastewater effluent was within specified limit set by EEPA (2003) standards.

The Electrical conductivity (EC) of raw waste water was observed to be 3980 ±526μS/cm. The result obtained for EC before application of the treatment exceeded EEPA (2003) maximum discharge limit due to the use of detergents and washing materials.

As it can be seen from the mean value of turbidity and DO of the raw wastewater152 ±15NTU and 0.37±0.06 mg/L respectively. The high turbidity is due to the presence of decaying organic matter in wastewater because of this DO become low.

In the current study, the TDS and TSS of raw domestic wastewater was indicated to be 1245 ±227mg/L and 1633±414mg/L respectively. The result obtained for TDS (1245 mg/L) was below the range of EEPA (2003) standard discharge limits to surface water and the value of TSS (1633 mg/L) of raw domestic wastewater was above the range of EEPA (2003) standard discharge limits to surface water.

The average concentration levels of BOD_5 and COD of raw domestic wastewater were indicated to be 2288±348 mg/L and 4039±653.6mg/L respectively. The result showed that both BOD_5 and COD of raw domestic wastewater exceeded EEPA (2003) maximum discharge standard limit.

From the results, it can be explained that the average concentration level of NO_3^- -N and PO_4^{3-} -P of raw domestic wastewater were observed to be 8.79±7.62mg/L and 19.9 ±3.4 mg/L respectively. The values of NO_3^- -Nwas above the EEPA (2003) maximum permissible limits and the value of PO_4^{3-}-P was below the EEPA (2003) discharge limits to surface water (Table 4.1). The main sources of NO_3^--N and PO_4^{3-}-P were due to anthropogenic activities like human waste, domestic wastewater, automobile emissions and decomposition of food waste.

Table 4.1 shows that the average concentrations of TC and FC from raw wastewater were 4.9 x 10^4 ±0.5 x 10^4cfu/100mL and 3.7 x 10^4 ±0.4 x 10^4cfu/100mL respectively. The values of TC and FC were above the EEPA (2003) maximum permissible limits to surface water. Fecal coliform showed a positive relationship with BOD and negative correlation with DO. When bacterial count is high, the greater will be the BOD and the lesser they DO (MDNR, 2011). Coliforms also had a positive relationship with conductivity and salinity mainly because inorganic dissolved solids are essential ingredients for aquatic life. A negative relationship existed between nitrate concentration and coliform levels. As coliform levels become high, nitrate concentration tends to decrease due to uptake (Eukeneet al., 2016).

3.2 Performance of pretreatment units

It is not recommendable that the direct discharge of raw domestic wastewater into the Constructed wetland system, it needs some stages of pretreatment units to reduce the level of pollutant concentration, protect treatment units from damage and to aid in their efficient operation.

3.2.1 Settling tank

A settling tank was used prior to the wetland system to remove larger sediment and avoid clogging in the wetland (Sa'at, 2006).The raw wastewater settled in the settling tank for twelve hours, then after aerated, it transferred to equalization tank, finally the incoming inflow distributed into the four different constructed wetland cells.

As shown by the result revealed that the average measure of EC reduced after pretreatment in settling tank from 3980 ±526μS/cm to 3380 ±375μS/cm. The results showed that settling tank has an average EC (Electrical Conductivity) removal efficiency of 15 % shown in figure 3.2.

Analytical results revealed that from settling tank the mean concentration of TDS (Total Dissolved Solids) and TSS (Total Suspended Solids) reduced from 1245 ±227mg/L to 982 ±145 mg/L for TDS and 1633±414 mg/Lto 923 ±198mg/L for TSS. The result showed that the removal efficiency of settling tank was 21 % and 43.5% for TDS and TSS respectively. The TDS average concentration in settling tank was 982 ±145 mg/L comply with the EEPA (2003) standard limit of 3000 mg/L. The mean concentration of TSS in settling tank 923 ±198 mg/L explained that did not comply with the EEPA (2003) standard limit of 150 mg/L.

As it can be seen the mean concentration of the organic matter BOD_5 (Biological Oxygen Demand) reduced from 2288 ±348 mg/L to 1573 ±295 mg/L in settling tank. The result indicated that the removal efficiency ofBOD_5 was31.25 %. The COD (Chemical Oxygen Demand) value of the settling tank was 4039±653.6 mg/L to 1864 ±408mg/L. This result indicated that the settling tank had COD removal efficiency of 53.8 %.The result shows that the NO_3^--N (Nitrate - Nitrogen) mean value from pretreatment of settling tank was minimized from 8.79±7.62mg/L to 6.84±6.1mg/L. The mean concentration of (PO_4^{3-} -P) in settling tank was reduced from 19.9±3.4mg/L to 15.8±3.3mg/L. The result indicated the sedimentation tank has an average NO_3^- -N andPO_4^{3-} -P removal efficiency of 22.2 % and 20.6 %.

From the results it was observed that the TC showed an increased in concentration during settling tank that was from 4.9 x10^4 ± 0.5 x 10^4 cfu/100 mL to 5.2x 10^4 ± 0.4 x 10^4cfu/100mL.The mean FC concentration in tank was increased of 3.7 x 10^4 ± 0.4 x 10^4 cfu/100 mL to 3.9 x 10^4 ± 0.4 x 10^4cfu/100mL.The result showed that the fresh wastewater contains less coliform than after settled in settling tank. This was due to microorganism's starts to growth in the settled wastewater of the settling tank.

3.2.2 Aeration system (Influent for HSSFCWs)

Results shows the average measure of EC reduced after aeration process 3380 ±375µS/cm to 2636 ±434 µS/cm. The results indicated that aeration process has an average EC removal efficiency of 22 % (figure 3.2).Thus, the average EC value from settling tank and aeration process effluents does not meets the EEPA (2003) standard maximum discharging limit, it needs further treatment.

The results revealed that mean concentration of TDS and TSS reduced from 982 ±145 mg/L to 877±156 mg/L for TDS and 923 ±198 mg/L to 735±64 mg/L for TSS after aeration process. Thus, the aeration process had 10.7 % for TDS and 20.4 % for TSS removal.

TDS average concentration after aeration process (877±156 mg/L) comply with EEPA (2003) standards of 3000 mg/L. The mean concentration of TSS was 735±64 mg/L explained that did not comply with EEPA (2003) standard of 150 mg/L. Most of the suspended matter in raw wastewater are settle-able but very small suspended solids needed more settling time to be removed. Thus, further treatment in constructed wetlands was required to meet the maximum allowable limit.

From results mean concentration of organic matter BOD_5 reduced from 1573 ±295 mg/L to 1260 ±237 mg/L after aeration process. The result indicated that removal efficiency of BOD_5after aeration process was 19.9 %. The COD value 1864 ±408mg/L to 1456±365 mg/L, this result indicated that the aeration process had COD removal efficiency of 21.9 %. However, the BOD_5 and COD values achieved from settling tank and aeration process did not meet with the EEPA (2003) discharge standard limit, it needed further treatment. TheNO_3^- -N mean value from pretreatment of aeration process was minimized from 6.84±6.1mg/L to 4.91±5 mg/L. This result showed that the NO_3^- -N value was within the standard limits of EEPA (2003).

The mean concentration of Orthophosphate (PO_4^{3-}-P) after aeration process was reduced from 15.8±3.3 mg/L to 11.2 ±2.8mg/L. When the PO_4^{3-}-P value from settling tank and aeration process compared with provisional discharge limits set by NEQ Standard for wastewater effluent (EEPA, 2003), it did not comply standard limit of 5 mg/L. Thus, further treatment using the constructed wetlands was another option to meet the standard limits.

The results indicate that TC concentration decreased after aeration process from 5.2x 10^4 ± 0.4 x 10^4 cfu/100 mL to 4.6x 10^4 ± 0.4 x 10^4cfu/100 mL. The mean FC concentration reduced from 3.9 x 10^4 ± 0.4 x 10^4 cfu/100 mLto 3.0 x 10^4 ± 3.6 x 10^4cfu/100 mL.

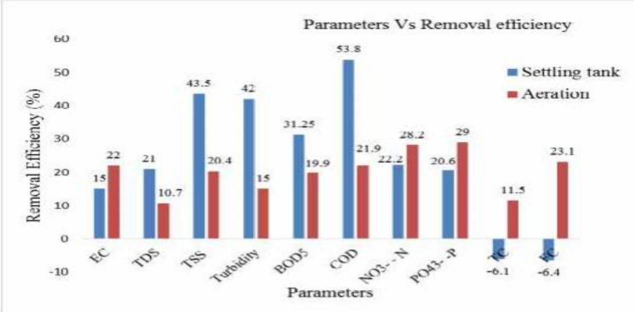

Figure 3.2: Performance of settling tank and areation

3.3 Performance of the Four Different cells of HSSFCW

3.3.1 pH and Temperature

The pH values in the effluent was variable among the four cells. The average value of pH of influent was5.5±0.31. In the effluents of planted cells, the pH value with an average of 6.9± 0.06(cell 1), 7 ±0.1 (cell 2), 7.1 ±0.15 (cell 3) while in unplanted (cell 4) with a mean of 6.4±0.9.These ranges are suitable for high microbial activities as they are within the optimal values of 5.5 to 9 for pH (EEPA, 2003).

The average temperature values during study period in the influent was with an average of 24.4±1.8^{o}C and did not vary between influent and effluents of different cells (24.2±1.8, 24.2±1.94, 24.3±1.4 and 24.6 ±2.1^{o}C) respectively. These ranges are suitable for high microbial activities as they are within the optimal values of < 37^{0}C for temperature (EEPA, 2003). The temperature did not vary might be explained by no differences of weather during sampling days.

3.3.2 Electrical Conductivity (EC) and Turbidity

As revealed the results of EC, the influent wastewater was observed to be 2636 ±434µS/cm. The effluents from the planted HSSFCWs had a mean EC of 694±21µS/cm (cell 1), 756±41µS/cm (cell 2), 773±43µS/cm (cell 3) and unplanted (control) cell had a mean EC of 897 ±74µS/cm (cell 4).The observed removal efficiency of the constructed wetland system was 73.7 %(cell 1), 71.3%(cell 2), 70.7 % (cell 3)and 66 % (cell 4).The significant decrease in EC despite significant water losses is might be due to uptake of micro and macro nutrients and ions by plants and bacteria, and their removal through adsorption to plant roots, litter and settleable suspended particles. The value of the provisional EC discharge limit of domestic effluent to environment set by EEPA (2003) was 1000 µS/cm. It could be seen that the HSSFCWs satisfying EC value in the domestic wastewater quality to meet the standard limit.

The turbidity of influent sample was indicated to be 75 ±3 NTU. The effluents from the planted HSSFCWs had a mean turbidity of 20 ±2NTU (cell 1), 29 ± 3NTU (cell 2), 28 ±2 NTU (cell 3) and unplanted (control) bed had a mean Turbidity of 38 ±2NTU (cell 4). Results indicated that the turbidity removal efficiency of HSSFCWs were73.3 %(cell 1), 61.3% (cell 2), 62.7 % (cell 3) and 49.3 % (cell 4).Efficiency of constructed wetland in the removal of turbidity may depend on the gravel size and depth of the cell (Prasad et al., 2006). HSSFCW system acted as a mechanical and biological filter and removed suspended particles from the water and thus decreased turbidity as (Matagiet al., 1998). the results shown in figure3.3.2.

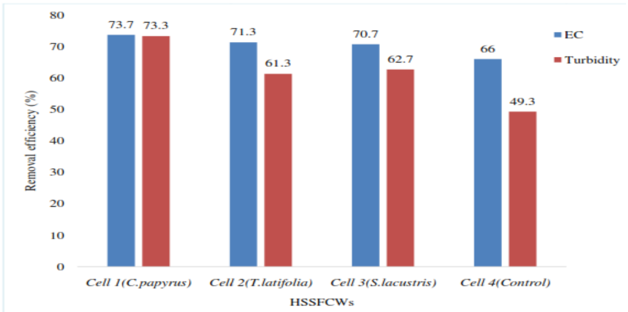

Figure 3.3.2: Removal Efficiencies of EC and turbidity

3.3.3 TDS and TSS removal

The mean influent values for TDS and TSS prior to HSSFCWs were 877 ±156 mg/L and735 ±64mg/L respectively, which was equivalent to the mean daily loading rate of 24 g/m^2/day for TDS and 31g/m^2/day for TSS. The mean effluent concentration of all the four HSSFCWs cells for TDS were 281 ±32mg/L (cell 1), 320±30mg/L (cell2), 364 ±44mg/L(cell 3), 422 ±37.4mg/L(cell 4) and TSS were 124.7 ±20.2mg/L (cell 1), 149±30.6mg/L (cell2), 147.3±34 mg/L(cell 3), 211 ±34mg/L(cell 4).The obtained effluent concentration values were below the standard limit values, indicating the effectiveness of the constructed wetland in fulfilling the regulatory limit values to discharge the effluent into surface and inland water bodies. The average removal efficiency of each wetland cells were 68%, 63.5%, 58.5%, 51.9% for TDS and 83%, 79.7%, 78%, 71.3% for TSS with their respective cells (Figure 3.3.3).

The better removal efficiency for both TDS (68%) and TSS (83%) was recorded by Cell 1 planted with Cyperuspapyrus followed by Typhalatifoliafor both TDS (63.5%) and TSS (79.7%), Scirpuslacustries for TDS (58.5%) and for TSS (78%). Whereas, the minimum observed in unplanted Cell 4 was TDS (51.9%) and TSS (71.3%).

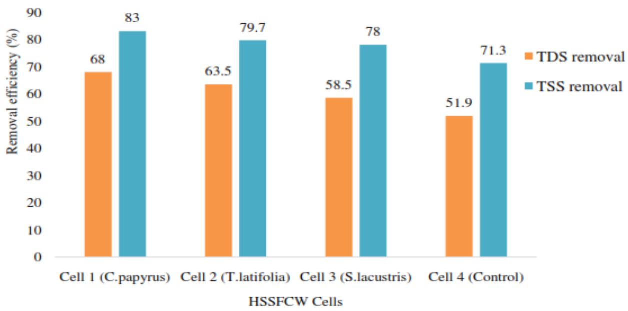

Figure 3.3.3: Removal efficiencies of TDS and TSS

3.3.4 BOD_5 and COD removal

In the influent, BOD_5 level with an average of 1260 ± 237 mg/L. Effluent mean concentration BOD_5 of three cells was 246 ±44 mg/L (cell 1), 304±7.4mg/L (cell 2), 289±12mg/L (cell 3) while in unplanted (cell 4), BOD_5 concentration with an average of 389±18.4mg/L in outlet sample. The result indicated that BOD_5 removal efficiency of HSSFCWs were with planted cells 80.5% (cell 1), 75.9 % (cell 2), 77 % (cell 3) and unplanted 69% (cell 4). The maximum BOD_5 removal efficiency was observed in the Cell 1 planted with Cyperus papyrus (80.5%) followed by Scirpuslacustris (77%) and Typhalatifolia (75.9%).

It was observed that the influent COD was1456 ±365mg/L. Average concentrations of effluent samples from each HSSFCWs were 320 ±32mg/L (cell 1), 364±38mg/L(cell 2), 355±28mg/L (cell 3) and 497±14mg/L (cell 4). From this result BOD_5 and COD effluents from the HSSFCWs, did not meet the discharge limits set by the EEPA (2003) for wastewater. This might be due to the fact that organic loading rate used in this study was 44 g/m^2.d BOD_5 and 78 g/m^2.d COD, which was higher than the recommended value. The maximum recommended organic loading rates for wastewater treatment by constructed wetlands is 11 g /m^2.d BOD_5 and 20 g /m^2.d COD, this may decreases the removal efficiency of the CWs (USEPA, 1998). The average removal efficiency of each wetland cells for COD were 78%, 75%, 75.6% and 65.9%with their respective cells (Figure 3.3.4).

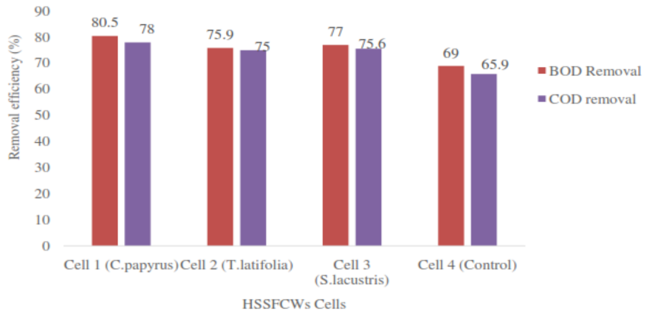

Figure 3.3.4: Removal efficiencies of BOD5 and COD

3.3.5. (NO_3^--N) and (PO_4^{3-}-P) Removal

As per results the average nitrate and orthophosphate concentrations in the influent were4.91±5mg/L and 11.2 ±2.8mg/L respectively, which was equivalent to the mean influent daily loading rate of 0.2 g/m^2/day forNO_3^--N and 0.4 g/m^2/day for PO_4^{3-}-P. The observed effluents of nitrate and orthophosphate concentrations in a HSSFCWs were 1.5 ±1.1mg/L(cell 1), 1.3±1.0mg/L (cell2), 1.5±0.25mg/L (cell 3), 1.8±0.32mg/L (cell 4) and 4.9 ±2.2mg/L (cell 1), 4.5±1.3mg/L (cell 2), 2.4±0.69mg/L (cell 3), 7.1±1.3mg/L (cell 4) respectively. The values of the provisional nitrate and orthophosphate discharge limit of effluent to environment set by EEPA (2003) were 20 mg/L and 5 mg/L respectively.

The result shows that NO_3^--N and PO_4^{3-}-P removal efficiency of four HSSFCWs cells were 69.45% (cell 1), 73.5% (cell 2), 69.45 (cell 3), 63.3% (cell 4) and 56.25% (cell 1), 59.8 (cell 2), 78.6% (cell 3), 36.6 (cell 4) respectively (Figure 3.3.5).

The maximum NO_3^--N removal was observed in Cell 2 planted with Typhalatifolia (73.5%) followed by both Cyperus papyrus and Scirpuslacustries (69.45%) and Cell 4 unplanted (63.3%).The better removal efficiency of PO_4^{3-}-P was observed in Cell 3 with Scirpuslacustries (78.6%) followed by Cell 2 with Typhalatifolia (59.8%), Cyperus papyrus Cell 1(56.25%) and Cell 4 unplanted (36.6%).

The result of this study,NO_3^--N removal of HSSFCWs were higher than those found by other authors for example, a removal rates of 55%, 62% and 49.3% were recorded by Pucciet al., (2000), Vipat et al., (2008) and Zuritaet al., (2009)respectively. The constructed wetland showed a good potential for the reduction of nitrate nitrogen.

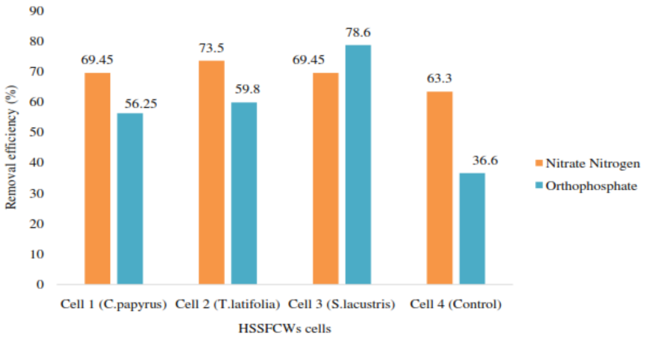

Figure 3.3.5: Removal efficiencies (NO_3^--N) and (PO_4^{3-}-P)

3.3.6 TC and FC Removal

As per results, the influent coliform concentration was $4.6x10^4 \pm 0.4x10^4$cfu/100mL for Total Coliform (TC) and $3.0x10^4 \pm 0.36x10^4$cfu/100mL for Fecal Coliform (FC). The effluent TC concentration of each cells were: $1.8x10^4 \pm 0.2x10^4$ cfu/100mL (cell 1), $1.4x10^4 \pm 0.1x10^4$ cfu/100mL (cell 2), $1.9x10^4 \pm 0.15x10^4$ cfu/100mL (cell 3) and $2.4x10^4 \pm 0.3x10^4$ cfu/100mL (cell 4) while for FC it was $1.2x10^4 \pm 0.2x10^4$ cfu/100mL (cell 1), $1.0x\ 10^4 \pm 0.2x\ 10^4$ cfu/100mL (cell 2),$1.3x10^4 \pm 0.25x10^4$ cfu/100mL (cell 3) and $1.5x\ 10^4 \pm 0.3x\ 10^4$cfu/100mL (cell 4)respectively.

Total Coliform removal efficiency of each constructed wetland cells was: 61% (cell 1), 69.8% (cell 2), 57.6% (cell 3) and 48.2% (cell 4) while for FC it was 60%, 66.7%, 56.6% and 50%, respectively (Figure 3.36). As can be seen from Figure 3.3.6, in the case of total and fecal coliforms, the best removal efficiencies were found in the Cell 2 planted with Typhalatifolia followed by both Cyperus papyrus (cell 1) and Scirpuslacustries (Cell 3). These results are also found within the range of removals reported for constructed wetlands treating domestic wastewater in similar conditions, Kaseva (2003) obtained 43% - 72% TC and FC removal efficiency. However, Mantoviet al., (2003) recorded total number of coliform bacteria reduction by more than 99%.

The performance efficiency results indicated that this wetland system achieved poor results regarding Total and Fecal coliform removal capability. This means that the removal in this parameter was mainly due to physical processes (sedimentation and filtration) rather than biological processes and lack of long HRT which is required for a more effective wastewater treatment. The mean final effluent concentration of TC and FC were above the National Effluent Emission Standard limit values (3000 cfu/100ml) set by EEPA (2003).

The presence of coliform bacteria in wastewater effluent above the emission standard makes the receiving water unsuitable for direct contact recreational use.. However, one strong advantage of using constructed wetlands to treat wastewater over natural wetlands is that the final effluent can be easily chlorinated. In addition to fulfilling the National Emission Standards of EEPA (2003), chlorine disinfection of constructed wetland effluent can produce waters suitable for unrestricted use (USEPA, 1998).

Therefore, the HSSFCWs should disinfect its effluent before being discharged into the receiving water bodies to fulfill the discharge limit values set by EEPA (2003) for domestic wastewater effluent as well as to recycle the wastewater to use for different purposes.

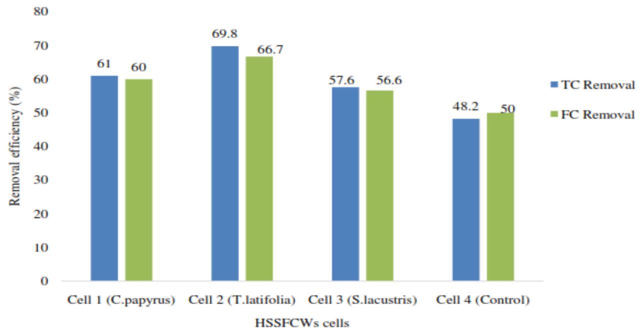

Figure 3.3.6: Removal efficiencies of TC and FC

4. Conclusions

From the present study, it can be concluded that the characteristics of raw domestic wastewater, pretreatment units (settling tank and aeration process) and treatment performance of HSSFCWs for the treatment of domestic wastewater in the study area for physical, chemical and biological parameters were analyzed. The results compared with EEPA (2003) Standard limit values to discharge the domestic wastewater effluent into the environment.

The experimental results of raw domestic wastewater and in pretreatment units (settling tank and aeration process) prior discharged to HSSFCWs cells were not within acceptable limits. The discharging of raw domestic wastewater into water bodies without treatment is very disastrous to public health as well as to the environment. Thus, further treatment using the constructed wetlands was another option to meet the standard limits.

The potential of HSSFCW was found to be efficient for the effluent concentration removal of EC, TDS, TSS, NO_3^--N, PO_4^{3-}-P from domestic wastewater when compared with the EEPA (2003) standard limit. However, it was not observed to be reduced effluent concentration below the standard limit for the treatment of BOD_5, COD, TC and FC. The maximum removal efficiency was observed in Cell 1 planted with Cyperus papyrus for EC (73.7%), Turbidity (73.3%), TDS (68%), TSS (83%), BOD_5 (80.5%) and COD (78%) relatively showed good removal efficiency than the rest three HSSFCWs (cell 2, cell 3 and cell 4). The better removal efficiency for NO_3^--N (73.5%), TC (69.8%) and FC (66.7%) was recorded by Cell 2 planted with Typhalatifolia and Orthophosphate (78.6%) was recorded by cell 3 planted with Scirpuslacustris. The average removal efficiency of the three-planted HSSFCWs was much higher than unplanted (control) HSSFCW. This means vegetated plants has an essential element to increase the performance of the HSSFCW. Therefore, findings from this study indicated that HSSFCWs using selected plant species, could achieve a level of clean up, cost effective and environmentally friendly for low-level income countries to protect their environment.

5. Recommendations

Based on the results of this study, Ethiopia country can use this technology as an alternative wastewater treatment. The following points are recommended:

❖ The HSSFCWs should consist of more than one cells in series and all the cells should be planted with different plant species for increasing performance.
❖ The HSSFCWs should a combination of more than one different substrate media to improve the removal efficiency of the system.
❖ Various alternatives for design and operation parameters should be examined and their effects to improve the pollutant removal efficiency should be investigated.
❖ Government regulations and legislations need to be enforced to ensure that polluters meet environmental standards of effluent discharge into water bodies and natural wetlands found in different parts of the country.

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Author Profile

Tsehay Bulti received the B.Sc in Bioprocess and Agricultural Engineering from Ambo University in 2015 and M.Sc in Environmental Engineering from Jimma University, Ethiopia in 2018. she stayed in Ethiopia, Wollega University, Shambu Campus, Dept. of Agricultural Engineering and working as an Assistant Professor. Her research areas include

Environmental Engineering , Bio Process Engineering and Energy and fuels.

Vighneswara Rao. K received the Ph.D in Chemical Engineering from Jawaharlal Nehru Technological University Hyderabad, India in 2015. he stayed in Ethiopia and working as an Assistant Professor in Dept. of Chemical Engg., Wollega University, Sambu Campus. He is focusing on the research areas of Cyclone Separators, powder properties and powder characterization, bulk solids materials handling, Particle Technology, Environmental Engineering and Safety Hazards & Management.