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Efficiency of cattail and water hyacinth for wastewater treatment using constructed wetland

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ABSTRACT

Constructed Wetlands have emerged as a cost-effective, eco-friendly and sustainable solution to enhance water quality by effectively removing nutrients. The objective of this study is to compare water hyacinth (Eichhornia crassipes) and Cattail (Typha latifolia) as wetland plants for wastewater treatment at the National Water Resources Institute (NWRI) situated in Kaduna State, Nigeria. The percentage removal of various parameters including pH, Total Dissolved Solids (TDS), Turbidity, Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Phosphorus, Nitrate, Ammonia, Sulphate, Oil and Grease, Total Coliform, Feacal Coliform, Copper, Zinc, Iron and Lead were compared for cattail and water hyacinth. The results of the analyzed parameters were compared with the Food and Agricultural Organization of United Nations (FAO, 2015) limits for irrigation purposes. Results showed pH, TDS, Turbidity, TSS, Sulphate, Nitrate, BOD, COD, FC, and Iron, Copper, Lead and Zinc were within the permissible limit of the standard for irrigation water quality according to FAO, while EC and Total Phosphorous were above the maximum permissible limit. The result of the percentage removal efficiency showed that water hyacinth had higher performance in removing the pH (13.34%), Turbidity (97.24%), Sulphate (100%), Nitrate (18.51%), Total Phosphorous (96.34%), COD (86.21%), BOD (77.92%), Oil and Grease (73.80%), FC (78.48%), TC (36.24%), Copper (81.84%), Lead (89.69%) and Zinc (79.38%) compared to typha latifolia. Generally, water hyacinth showed higher removal efficiency. However, Typha latifolia had a higher efficiency in terms of EC, TDS, TSS and iron removal. Constructed Wetland vegetated with Eichhornia crassipes and Typha latifolia has shown potential for application in wastewater treatment.

INTRODUCTION

In Nigeria, domestic wastewater discharge lacks a complete monitoring and control system, mainly originating from poor funding. The discharged untreated or inadequately treated domestic wastewater imparts great stress to the receiving water bodies as well as to the subsurface waters, with possible public health hazards (Hankin et al., 2019). The dominant domestic wastewater treatment is using conventional treatment methods such as activated sludge for municipalities, and septic tanks and soak-away pits for rural areas.

In small communities, wastewater collection systems are much costlier than those for large communities because small populations are usually scattered over large land areas (Al-Omari and Fayyad, 2003). Regardless of these difficulties, small communities have to meet the same discharge requirements as large communities. To overcome these challenges, natural systems for wastewater treatment are adopted due to their low cost and simple technology (Al-Omari and Fayyad, 2003). The recycling and reuse of treated wastewater for non-potable purposes become important due to climate change, urbanization and industrialization (Sultana, 2019; Rahmadyanti and Wiyono, 2017).

Therefore, low-energy, low-cost, easy-to-maintain, sustainable, and reliable wastewater treatment techniques are sought. Natural treatment systems involve operations controlled by nature that exploit resources of plants, soils, and related microbial constituents to reduce or remove wastewater contaminants (Qin *et al*., 2016).

Natural Wastewater Treatment with Aquatic Plants

Aquatic plant treatment involves channelling wastewater into either swamplands or other aquatic plant ecosystems, whether natural or man-made. The removal of wastewater constituents is achieved by different mechanisms like sedimentation, filtration, chemical precipitation, adsorption, microbial interactions, and uptake of vegetation (Ajibade *et al.,* 2013). The most frequently used species in water-surface constructed wetlands is Typha latifolia (cattail) (Dierberg and DeBusk, 2008). Typha species are erect rhizomatous perennial plants with jointless stems. The plants are up to four meters tall with an extensive branching horizontal rhizome system. Leaves are flat or slightly rounded on the back, in their basal parts spongy (Sainty and Jacobs, 2003).

Water hyacinth is a free-floating perennial aquatic plant (Rajendra et al., 2017) and is effective as one of the most common species used in free-water surface-constructed wetland system (Gupta et al., 2012; Rezania et al., 2015b). It is effective for the removal of heavy metals and other pollutants with a high reproduction rate, efficiency and tolerance of ecological factors (Gupta et al., 2012; Rezania et al. 2015b).

Application of Water Hyacinth for Wastewater Treatment

Use of water hyacinth has been proven viable with accomplished implementations from thousands of facilities around the globe notably India (Sung et al., 2015; Mahamadi, 2011; Priya and Selvan, 2014; Rezania et al., 2015b; Rezania et al., 2016; Jayaweera *et al.,* 2008; Xia and Ma, 2006; Mandal *et al.,* 2012; Dar et al., 2011; Lu *et al*., 2014), Nepal (Ram and Chou, 2012) and Malaysia (Rezania et al., 2015b).

A study by Rajnikant *et al.* (2021) evaluated the potential of water hyacinth for greywater treatment based on optimum growth and harvesting frequency, in Surat, Gujarat, India. Water hyacinth efficiently remediated physicochemical parameters: water temperature, pH, total dissolved solids, turbidity and chemical oxygen demand. The results also showed an average removal of ammonium–nitrogen, phosphate–phosphorous, and chemical oxygen demand of 63.26±10.47%, 61.96±12.11%, and 51.91±5.32% respectively. A 75% increase in the water hyacinth biomass was observed during the study which may be attributed to the dense roots, hyper-accumulative properties, and the rapid growth rate of water hyacinth. A harvesting interval of 15–20 days was recommended for phytoremediation of greywater for efficient treatment performance.

Water Hyacinth, *Phragmites australis and Commelina cyanea* were adopted in the treatment of wastewater at the female hostel of the Federal University of Technology Akure, Ondo State, Nigeria by Ajibade et al. (2017). The three plants effectively removed Nitrate, Nitrite, Phosphate and Sulphate pollutants. Phragmite saustralis gave the highest removal efficiency for Phosphate (85.8%) while water hyacinth gave the highest removal efficiency for pH (11.5%), Biochemical Oxygen Demand and Coliform bacteria. The highest removal efficiency for turbidity (96.9%) and dissolved solids (82.9%) was obtained from the use of *Commelina cyanea.*

In Lagos, water hyacinth was used to significantly remove nutrients from textile, metallurgical, and pharmaceutical wastewater (Ajayi and Ogunbayo, 2012). The percentage removal of BOD was in the order of metallurgical > textile > pharmaceutical wastewater, while improvement in DO was in the order of metallurgical > pharmaceutical > textile wastewater and for lowering nitrate–nitrogen was in the order of textile > metallurgical > pharmaceutical wastewater. In Kaduna, water hyacinth was applied to significantly reduce heavy metals ions (Cd, Hg, Zn, Mn, Pb, and Ag) by 90–100% and COD by 50% from the wastewater (Ugya and Imam, 2015).

Application of Typha Species for wastewater treatment

Also, application of typha species for wastewater treatment is well-established in India (Nafiya and Anitha, 2019; Panwar and Makvana, 2017; Kamal *et al.*, 2019), Pakistan (Abbas *et al.*, 2021), South Africa (Githuku et al., 2019), Malaysia (Jie-Yinn et al., 2018), USA (Meiyin Wu, 2014), Thailand (Tararag and Arunothai, 2020), Romania (Andreea et al. 2018) and Norway (Elsaesser et al., 2011).

Janyasupab *et al.* (2023) investigated the effects of longan biochar as filter materials on plant responses and wastewater treatment by cattail and assessed the growth responses of cattail in the different filter materials in Chiang Mai Province, Thailand. Results showed that the filter materials in constructed wetlands and the presence of plants interactively affect pollutant removal in the system. The presence of plants (Typha) contributed significantly to the treatment performance and was efficient in nitrogen removal, while the removed Phosphorous was bound in the biomass of the plant grown on gravel.

Tararag and Arunothai (2020) investigated the growth and eco-physiological responses of Typha angustifolia to different concentrations of anaerobic digester effluent from a swine farm and assessed their influence on wastewater treatment effectiveness. High removal efficiency for electrical conductivity (73%), total dissolved solids (70%), total suspended solids (93%), biochemical oxygen demand (99%), chemical oxygen demand (82%,), ammonium nitrogen (99%) and orthophosphate (80%) was found. The dissolved oxygen concentration in the anaerobic digester effluent increased over time because of the released root oxygen.

Application of Cattail and Water Hyacinth

Vivien *et al.* (2023) carried out a study on comparative analysis of greywater pollutant removal efficiency with horizontal free water surface flow wetland with other wetland technologies in Kaduna, Nigeria. Incorporating water Hyacinth *(Eichhornia crassipes)* with horizontal free water surface flow wetland technology demonstrated the highest efficacy in removing various pollutants adopting a retention time of four months. This combination outperformed other wetland technologies in effectively removing pollutants, including ammonia (60%), oil and grease (78.46%), COD (85%), TP (37.04%), FC (75%), and TC (79.59%), representing significant progress in greywater treatment.

The effectiveness of macrophytes in wastewater treatment was also examined by Abbas et al. (2021) in Lahore, Pakistan. The study demonstrates the phytoremediation perspective of *Typhala latifolia* and water Hyacinth in industrial wastewater treatment. The *Typha latifolia* was found to be efficient in the removal of Turbidity (Tu), Electrical conductivity (EC), Color (Col), iron (Fe) and copper

(Cu) from industrial wastewater employing 16 days retention time. Results also showed that the maximum percentage removal of selected heavy metals by *Typha latifolia* follows the order Fe > Cu > Zn from 20% industrial wastewater. *Typha latifolia* was not very effective for zinc removal as compared to iron and copper from industrial wastewater.

The objective of the study is to compare the efficacy of water hyacinth (*Eichhornia crassipes*) and cattail (*Typha latifolia*) in treating combined domestic and agricultural wastewater in a constructed wetland system in Kaduna, Nigeria.

METHODOLOGY

Overview of the Observational Set-Up For The Wetland

Each cell of the constructed wetland had a volume of 12m in length, 1m in width and 1m in depth. It was constructed with hollow sandcrete blocks, sand, gravel, and cement and properly lined to reduce the pores and minimize excessive loss of water. Based on existing literature and field procedures, the wetland was constructed to simulate horizontal free water surface flow (HFWSF).

Observational Procedure

The wastewater(s) was collected from households (domestic) and demonstration farms (agriculture) and channelled through a central pipe to the detention basin. The wastewater flows into each constructed wetland via their respective pipes and is channelled to the plants, where it undergoes removal processes such as absorption, filtration, sedimentation, reduction, oxidation, and precipitation. The inlet pipes served as the entry point for the wastewater, while the outlet pipes facilitated the discharge of the effluent. The flow of wastewater from the detention basin was controlled using stop valves on the inlet pipes.

Sample Collection/Analysis

Wastewater samples of the influent and effluent were collected from the constructed wetland and analyzed. The samples were collected from each cell vegetated with water hyacinth (Eichhornia crassipes) and cattail (Typha latifolia) in a sterilized four-litre plastic container for evaluation. A retention time of four weeks was adopted. American Public Health Association's standard method for water and wastewater examination was adopted (APHA, 2012). The values of the removal efficiency were calculated using Equation 1. Table 1 outlines the analytical methods and instruments used to analyze each parameter in this study. The Removal Efficiency (R.E) is given as:

R.E. (%) = (Cin-Cout)/Cin ×100 **(1)**

Where Cin is the influent concentration and Cout is the effluent concentration, in mg/L.

RESULTS AND DISCUSSION

pH and Electrical conductivity (EC)

The pH of the untreated wastewater was 8.35. After remediation with *Eichornia crassipes* and *Tyha latifolia*, the pH became 7.23 and 7.62 with a removal efficiency of 13.34% and 8.67% respectively. This reduction in pH is associated with the absorption of pollutants by the plant (Dipu et al., 2010). The pH is within the FAO (2015) limit specified.

EC significantly decreased from 1546.67µS/cm for the untreated effluent to 269.00µS/cm with treatment by *Typha latifolia* and 297.00µS/cm by *Eichornia crassipes (*water hyacinth). However, EC of treated effluent was not within the acceptable range specified by the Food and Agriculture Organization for Irrigation (FAO, 2015). This stray from the optimal range can lead to nutrient imbalance, osmotic stress and even plant death (Patricia et al., 2023). This is approximately 82.61%

removal efficiency by *typha latifolia* and 80.80% by water hyacinth.

Total Dissolved Solid (TDS), Turbidity and Total Suspended Solid (TSS)

The TDS levels for the untreated, *typha latifolia* and *Eichornia crassipes* treated effluent were established at 744.67mg/L, 133.33mg/L and 147.33mg/L respectively below the limit specified by FAO (2015). The removal efficiency of 82.09% by cattail *(typha latifolia)* and 80.21% by water hyacinth *(Eichornia crassipes)* were observed. Turbidity decreased significantly from 344.33NTU to 11.67NTU for the cattail *(typha latifolia)* treated effluent and 9.51NTU for the water hyacinth with removal efficiency of 96.61% and 97.24% by water hyacinth *(Eichornia crassipes)* respectively.

TSS results showed a significant reduction from 230.67mg/L of the influent to 12.67mg/L for the cattail *(typha latifolia)* treated effluent (94.51% removal efficiency) and 18.67mg/L for the water hyacinth *(Eichornia crassipes)* treated effluent (91.91% removal efficiency).

Oil and Grease and Ammonia

The concentrations of oil and grease in the influent were 780mg/L, 280mg/L for the *Typha latifolia* treated effluent and 204.3mg/L for the *Eichornia crassipes* with removal efficiency of 64.10% and 73.80% respectively. Ammonia (NH_3) decreased from 68.67mg/L to 0.04mg/L and 0.33mg/l for the effluent treated with the *typha latifolia* and *Eichornia crassipes* respectively. Removal efficiency by *typha latifolia* and *Eichornia crassipes* were established at 99.94% and 99.52% respectively.

Sulphate, Nitrate and Total Phosphorus

Sulphate concentrations were within the safe limit for irrigation agriculture in irrigation water recommended by FAO of 0-20mg/L at 32.33mg/L. Both aquatic plants considerably reduced the sulphate concentration to 1.33mg/L and 0.00mg/L under *typha latifolia* and *Eichornia crassipes* respectively with 95.88% and 100% removal efficiency. The nitrate concentrations in the wastewater complied with the limit specified by FAO (2015), reduced from 1.21mg/L to 1.20mg/L and 0.98mg/L in the *typha latifolia* and *Eichornia crassipes* treated effluents respectively and resulting in 0.28% and 18.51% removal efficiency.

The total phosphorus levels had a concentration of 58.08mg/l for the untreated wastewater. After treatment, 8.22mg/l and 2.12 mg/l were established for *typha latifolia* and *Eichornia crassipes* treated effluents respectively exceeding the limit established by the FAO (2015) regulations despite high removal efficiency of 85.84% by *Typha latifolia* and 96.34% by water hyacinth *(Eichornia crassipes)*. An excess of total phosphorous commonly result in stunted growth of plants, reduced crop yield and quality (Fahad et al., 2023).

BOD, COD and Feacal Coliform (FC)

The BOD of 40.33mg/l for the raw effluent was mitigated to 24mg/L with *Typha latifolia* treatment and 8.91mg/l with water hyacinth*(Eichornia crassipes)* treatment with removal efficiency of 40.50% and 77.92% respectively. The BOD reduction may be due to the consumption of organic matter by microorganisms in the vicinity of plant roots for their growth and multiplication (Ghulam *et al.,* 2014). However, only water hyacinth-treated effluent fell below the FAO (2015) limit. This is consistent with the findings of Ani and Eugenia (2017) who reported 77.24% treatment using water Hyacinth and Panwar and Makvana (2017) who reported 47.3% for cattail.

Table 1 - Analytical methods and instruments

Parameters	Unit	Method	Equipment/Instrument
Ph		pH meter	Palintest pH meter
Temperature	°C	Thermometer	Palintest Thermometer
Electrical Conductivity	(µS/cm)	Conductivity meter	Palintest Conductivity meter
Total Dissolve Solid	ppm/mg/L	Conductivity meter/ TDS	Palintest TDS meter
Turbidity	NTU	Turbidimeter	Palintest turbidimeter
TSS	mg/L	Turbidimeter method	Palintest turbidimeter
Biochemical Oxygen Demand (BOD)	mg/L	Empirical analysis using 5 days incubator at 20°C (BOD bottle method)	BOD bottles, incubator, water bath
Chemical Oxygen Demand (COD)	mg/L	Close reflux method (Dichromate method)	Spectrophotometer, Regents
Total Phosphorus	mg/L	Spectrophotometer method	Spectrophotometer, Regents
Nitrate	mg/L	Spectrophotometer method	Spectrophotometer, Regents
Ammonia	mg/L	Spectrophotometer method	Spectrophotometer, Regents
Sulphate	mg/L	Spectrophotometer method	Spectrophotometer, Regents
Oil and grease	mg/L	Gravimetric method or Solvent extraction method	Analytical balance, Separatory funnel, Solvent
Lead (Pb)	mg/L	ASS (Atomic absorption Spectrophotometer) method	ASS
Copper (Cu)	mg/L	ASS (Atomic absorption Spectrophotometer) method	ASS
Iron (Fe)	mg/L	ASS (Atomic absorption Spectrophotometer) method	ASS
Zinc (Zn)	mg/L	ASS (Atomic absorption Spectrophotometer) method	ASS
Total / Feacal coliform	CFU/100Ml	Membrane filtration method	Membrane filtration setup (0.45 mm pore size membrane filter paper, filtration flask, *m*-Endo agar, TC and FC, incubator 37 °C and 44 °C).

COD was mitigated from 580mg/L to *Typha Latifolia* treated effluent of 100.33mg/L and 80.00mg/L for water hyacinth*(Eichornia crassipes)* with a removal efficiency of 82.70and 86.21 respectively. A reduction in BOD indicates a reduction in Faecal coliform (FC) (Ram et al., 2012). FC of 509.67CFU/100mL was reduced to 123.67CFU/100mL and 109.67CFU/100mL by *Typha latifolia* and *Eichornia crassipes* treatments with 75.74% and 78.48% removal efficiency respectively.

Iron (Fe), Copper (Cu), Lead (Pb) and Zinc (Sn)

Iron of 29.97mg/L was found for the raw effluent. 0.81mg/L and 1.06mg/L iron concentrations were recorded for *Typha latifolia* and *Eichornia crassipes* treated effluent with a removal efficiency of 97.31% and 96.45% respectively. The results showed that the iron values were within the permissible limit with respect to FAO (2015) standard for irrigation water. The study found a high removal efficiency for Fe by *Typha latifolia* which is consistent with previous reports of up to 92.01% (Abbas et al., 2021).

The concentration of Copper was mitigated from 0.40mg/L to 0.08mg/L and 0.07mg/L for *Typha latifolia* and water hyacinth-treated effluent with a percentage removal efficiency of 79.25% and 81.84% respectively. Both were within the permissible limit of the FAO (2015) standard for irrigation water.

The lead (Pb) concentration of 0.34mg/L was observed for the influent. The treated effluents by Typha latifolia and water hyacinth were recorded at 0.04mg/L and 0.03mg/L, where removal efficiency was established at 88.11% and 89.69% respectively. 88.11% is consistent with the findings of Morari et al. (2015) who reported a removal efficacy of 88% for (Pb) by Typha latifolia. Zinc had a value of 0.346mg/L in the raw effluent, 0.073mg/L for Typha latifolia treated effluent and 0.071mg/L for the water hyacinth treated effluent with removal efficiencies of 78.90% and 79.47% respectively. Table 2 summarizes the key findings discussed earlier.

CONCLUSIONS

In this study, the treatment efficiency of two macrophytes (*Eichornia crassipes* and *Typha latifolia*) in artificially constructed wetlands was assessed and compared to the quality standards of the Food and Agricultural Organization of the United Nations. The physicochemical, biological, and heavy metal quality of the wastewater (domestic and aquaculture) was evaluated. The pollutant removal efficiency of water hyacinth *(Eichornia crassipes)* and cattail *(Typha latifolia)* in treating wastewater showed that water hyacinth*(Eichornia crassipes)* and cattail *(Typha latifolia)* were both effective in improving wastewater quality. The result showed that the physicochemical characteristics of the wastewater: pH, TDS, Turbidity, TSS, Sulphate, Nitrate, BOD, COD, biological characteristics; FC, and heavy metals: Iron, Copper, Lead and Zinc were within the allowable range/limit to the standard for irrigation water quality according to FAO (2015). EC and Total Phosphorous were above the maximum permissible limit with respect to the standard. In comparison, the efficiency of water hyacinth recorded for parameters like pH, Turbidity, Sulphate, Nitrate, Total Phosphorous, COD, BOD, Oil and Grease, FC, TC, Copper, Lead and Zinc was higher than that of *Typha latifolia*. *Typha latifolia* has a higher efficiency in terms of EC, TDS, TSS, and iron removal. A constructed wetland system containing macrophytes has shown potential for nutrient removal/treatment in wastewater within four weeks.

Table 2 - Summary of Findings

Parameters	Units	Influent	Effluent for TL	PTL	Effluent for WH	PWH	FAO Limit
pH		8.35	7.62	8.67%	7.23	13.34%	6.50 - 8.50
EC	µS/m	1546.67	269.00	82.61%	297.00	80.80%	3
TDS	mg/L	744.67	133.33	82.09%	147.33	80.21%	2000
Turbidity	NTU	344.33	11.67	96.61%	9.51	97.24%	35
TSS	mg/L	230.67	12.67	94.51%	18.67	91.91%	50 - 100
Ammonia	mg/L	68.67	0.04	99.94%	0.33	99.52%	***
Sulphate	mg/L	32.33	1.33	95.88%	0.00	100.00%	1000
Nitrate	mg/L	1.21	1.20	0.28%	0.98	18.51%	0 - 10
T. Phosphorous	mg/L	58.08	8.22	85.84%	2.12	96.34%	<2
Bod	mg/L	40.33	24.00	40.50%	8.91	77.92%	10
Cod	mg/L	580.00	100.33	82.70%	80.00	86.21%	0 - 150
Oil/grease	mg/L	780.00	280.00	64.10%	204.33	73.80%	***
FC	CFU/100 mL	509.67	123.67	75.74%	109.67	78.48%	<200
TC	CFU/100 mL	910.67	587.67	35.47%	580.67	36.24%	***
Iron	mg/L	29.97	0.81	97.31%	1.06	96.45%	5
Copper	mg/L	0.40	0.08	79.25%	0.07	81.84%	0.10 - 0.20
Lead	mg/L	0.34	0.04	88.11%	0.03	89.69%	2
Zinc	mg/L	0.35	0.07	78.81%	0.07	79.38%	2

EC: Electrical conductivity, TSS: Total suspended solids, TDS: Total dissolved solid, TC: Total Coliform, FC: Feacal coliform, BOD: Biological oxygen demand, COD: Chemical oxygen demand, ***: Not available, PTL: removal efficiency (*Typha latifolia*), TL: *Typha latifolia*, WH: Water Hyacinth, PWH: removal efficiency (water hyacinth)

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