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Performance Evaluation of Aquatic Macrophytes in a Constructed Wetland for Municipal Wastewater Treatment

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A B S T R A C T

Key words:

Phytoremediation, Constructed Wetlands, Wastewater, Commelina cyanea, Phragmites australis and Water Hyacinth (Eichhornia crassipes)

The objective of the study was to evaluate the phytoremediation potential of three aquatic macrophytes (Commelina cyanea, Phragmites australis and Water Hyacinth (Eichhornia crassipes)) for treatment of municipal wastewater collected from Federal University of Technology, Akure (Nigeria). Laboratory scale of three constructed wetlands of dimensions 0.43 m x 0.93 m x 0.36 m in width, length and depth respectively, were developed to mimic natural conditions and was operated for a single experimental run with each macrophte at different retention time of 6, 9 and 12 days. These aquatic macrophytes were planted in separate ponds. Domestic wastewater from undergraduate students' hostel was introduced to the ponds. The raw wastewater sample and treated wastewater samples were analysed using standard laboratory methods for physical (Turbidity and Dissolved solids), chemical (pH, Nitrate, Nitrite, Phosphate, Sulphate Chemical Oxygen Demand and Biochemical Oxygen Demand) and bacteriological (Coliform bacteria) parameters. Results showed substantial diminutions in all parameters treated with the phytoremediators during the course of the study. Asides the three plants effectively removing Nitrate, Nitrite, phosphate and Sulphate pollutants, Phragmites australis gave the highest removal efficiency for Phosphate (85.8%), Water hyacinth gave the highest removal efficiency for pH (11.5%), Biochemical Oxygen Demand and Coliform bacteria and Commelina cyanea gave the highest removal efficiency for turbidity (96.9%) and dissolved solids (82.9%) parameters of the domestic wastewater samples. The overall results of the phytoremediation studies indicate that the purification effectiveness of the three aquatic macrophytes were spontaneous, feasible and remarkable.

1. Introduction

Wastewater treatment is posing serious environmental problems in cities, particularly in underdeveloped countries (Ajibade et al., 2013). Wastewater management and treatment technology needs to be suitable and sustainable (Ajibade et al., 2014). It also needs to be less costly, easy to operate and maintain, and very efficient in removing both organic matter and heavy metals. The removal of wastewater constituents are achieved by different mechanisms like sedimentation, filtration, chemical precipitation, adsorption, microbial interactions, and uptake of vegetation (Hammer, 1989), among which, the most effective technology is phytoremediation strategy using Constructed Wetlands (CWs) technology. Besides water quality improvement and energy savings, CWs have other environmental protection features such as promoting biodiversity, providing habitat for wetland organisms and wildlife (e.g. birds and reptiles in large

systems). These CW systems are generally cost effective, simple, environmentally non-disruptive (Roongtanakiat et al., 2007; Wei and Zhou, 2004) ecologically sound (Xia and Ma, 2006) with low maintenance cost (Kirkpatrick, 2005) and low land requirements (Liu 2009). In developing countries, natural treatment systems are more suitable.

Natural treatment systems are considered one of the best treatment options, particularly in warm climates (Shah et al., 2014; Duenas et al., 2003). Wetlands are the systems which offer remediation in low cost and serve as an alternative technology in buffering off effluent and wastewater discharge (Md Saát and Juhari, 2015). Wetlands are among the most productive life support systems in the world and are of immense socio-economic and ecological importance to mankind (Sanyal et al., 2015). They play tremendous role in the flood control, improvement of water quality, recycling of natural ground water, acting as buffer against natural disaster, controlling of erosion, sediment's trapping, maintenance of biodiversity, waste water treatment and nutrients' recycling

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(Schuyt and Brander, 2004).

The potentials of constructed wetlands environment as a hydraulic structure for treating wastewater has been recognized globally for quite some time and by several researchers (Md Sa'at and Zaman 2017, Austin, 2014; Akinbile et al., 2012a; Aziz et al., 2010; Wojciechowska et al., 2010; Zhang et al., 2010; Katayon et al., 2008; Langergraber, 2007; Ghosh and Singh, 2005).

Wetlands with macrophytes are one of the many types of natural systems that can be used for treatment of municipal wastewater. Macrophytes have been used effectively to treat different types of wastewaters due to their nutrient absorbing capacity, simplicity, low construction/operation and maintenance cost, low energy demand, process stability, potential benefits of the harvested materials. This process is called Phytoremediation. Phytoremediation is an emerging technology that uses various plants to degrade, extract and immobilize contaminants from the environment specifically soil and water (Xin et al., 2016; Prasad and Maiti 2016; Ugya et al., 2015; Ajibade et al., 2013; Gupta et al., 2012; Akinbile and Yusoff 2012; Kumar et al., 2012). The term phytoremediation is a blend of Phyto (meaning plant) from Greek word and remedium (meaning correct or remove an evil) from Latin. The phytoremediation concept was introduced by Chaney (1983) (Md Sa'at and Zaman 2017). Phytoremediation offers greater potentials to remediate contaminated water over conventional and costly methods. Several aquatic plants such as Phragmites karka and Typha latifolia, Typha latifolia, water lilies (Nymphaea spontanea), Azolla papyrus (Cyperus papyrus), Typha angustifola, Limnocharis flava, water hyacinth (Eichhornia crassipes) and water lettuce (Pistia stratiotes) have been used as wetlands plants to treat industrial wastewater with good results. All these have been widely reported by several researchers; (Rezania et al., 2016; Odukoya et al., 2015; Hadi et al., 2014; Malar et al., 2014; Syuhaida et al., 2014; Ajibade et al., 2013; Akinbile et al., 2012 a & b).

Thus, phytoremediation has also been called green remediation, botano-remediation, agro-remediation, and vegetative remediation (Kumar and Chopra, 2016). The use of aquatic plants in the treatment of wastewater stands as a very vital alternative to conventional wastewater treatment methods.

Though less expensive and requiring less skill, it is still as efficient as the conventional methods in treating wastewater. Although several studies have asserted that aquatic macrophytes are good plants for phytoremediation, none of these studies have documented the relative performance assessment of a floating plant (water hyacinth) and submerged plants (Commelina cyanea and Phragmites australis) in the treatment of wastewater for reuse and recycling. Therefore, this study thrust on the comparative studies on the purification efficacy of Commelina cyanea (Scurvy weed), Phragmites australis and Water Hyacinth (Eichorrnia crassipes) in the phytoremediation of municipal wastewater.

2. Materials and Methods

2.1 Description of the Study Site

The main (Lady Jibowu) female hostel of Federal University of Technology Akure is situated in Akure, the urban township capital of Ondo State and located in the South Western part of Nigeria. The study area lies between latitude (7°17'30"N and 7°18'30"N) and longitude (5°8'0"E and 5°9'0"E) of the Greenwich Meridian. It stands on the altitude of about 370 meters above the sea level (Adewumi and Ajibade, 2015). Akure has two seasons, a dry season from November to March and a rainy season from April to October. The mean annual temperature is 24°C - 27°C, while the annual rainfall varies between 1500 mm and 3500 mm. The mean relative humidity is over 75%. The experiments were carried out between the months of August to September (Rainy season) in 2015. This hall of residence comprises of three blocks and all the wastewater in each block were channelled with pipes from the bathrooms and kitchens into a drainage system. collection in Jibowu hostel are as shown in Plates 1a and 1b.

Plate 1a: Drainage Conveying Wastewater out of the Fence of Jibowu Hostel

Plate 1b: Point of Convergence of Wastewater Collected in Jibowu Hostel

All the drainage systems built for collection of wastewater at different strategic places around the blocks were then channelled in such a way that they will meet at a collection point, with a single drainage to channel the collected wastewater outside the fence of the hostel. Some of the network of the drainage systems built for wastewater

3.2   Methodology

3.2.1   Laboratory Scale Ponds (Constructed Wetlands)

Three plastic ponds of dimensions 0.43 m X 0.93 m X 0.36 m in width, length and depth respectively, were constructed and placed behind the engineering workshop, to mimic natural conditions as shown in Plate 2. Each pond had two parts; the larger area for the planting and the smaller area for filtering the treated wastewater sample as described by Ramprasad (2012). This is the part that led to the tap. The ponds were first filled with coarse aggregates (granite), then with sand before introducing the plants. This is illustrated in Figure 1
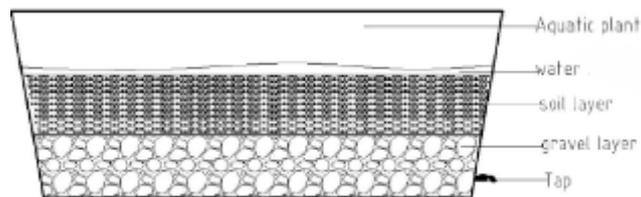
3.2.2   Selection of Species of Aquatic Plants

The selection of aquatic plants for the study was done on their availability locally as well as the environmental conditions of the area. In the process, the three aquatic plants that survived were Phragmites australis, Water Hyacinth and *Commelina cyanea.* Plates 3, 4 and 5 show the three plants in separate plastic ponds. *Phragmites australis*   and *Commelina cyanea* (emergent aquatic plants) were planted in separate ponds containing the coarse and fine aggregates, while for water hyacinth (floating aquatic plant), much water was poured to overflow on the sand. The ponds for the emergent plants were maintained by regular wetting with water and removal of weeds. *Phragmites australis*   and *Commelina cyanea* plants were planted on 3rd July, 2015 while water hyacinth was planted on 20th August, 2015. These were left to grow till 9th September, 2015 when the roots were fully established. Grey wastewater from Jibowu main hostel was then introduced to the laboratory scale ponds.

Figure 1: A section of the pond showing its constituents

Plate 2: Laboratory Scale Ponds

Plate 3: *Phragmites australis*

Plate 4: Water Hyacinth (*Eichhornia crassipes)*

Plate 5: *Commelina cyanea* (Scurvy Weed)

3.2.3   Sampling Strategy and Characterization

Grab samples of the raw wastewater obtained from the source (Jibowu Hostel) were taken with the aid of air tight sterilized bottles of 75cl capacity and kept in a cool dry place. The wastewater analysis commenced after two hours from the point of collection in the water research laboratory before it was batched into the constructed wetlands (laboratory scale ponds). Wastewater effluent samples were collected from the outlet point of the constructed wetlands containing each of the aquatic macrophytes (*Phragmites australis,* Water Hyacinth (Eichhornia crassipes) and *Commelina cyanea*) via their respective taps on the 6th, 9th and 12th days using sample bottles to determine the following parameters: pH, Turbidity, Dissolved Solids (DS), Coliform, Nitrate, Nitrite, Phosphate, Sulphate and Biochemical Oxygen Demand (BOD) were determined using standard laboratory procedures (APHA, 2012).

BOD from was determined using 5-Day BOD test by using the dissolved oxygen test kit. Chemical Oxygen Demand (COD) was measured using EPA methods 410.1. Turbidity of the sample was determined using 6850 UV Spectrophotometer at 420 μm while pH of the samples was recorded using ELICO LI 127 pH meter. Total Nitrate concentration was measured by high-performance liquid chromatography (HPLC), using a Varian Metacarb column (type 67H, 9 μm, 300 mm long, 6.5 mm internal diameter) and a mobile phase of 0.005 M sulphuric acid (H_2SO4) at 0.7mLmin−1 as adopted by Cortez et al. (2010). Standard total coliform fermentation technique (Standard methods 9221b) was used for the coliform bacteria analysis.

The experiment was monitored until excessive intake or removal of nutrients (pollutants) by the aquatic macrophytes meet the desirable limits for safe disposal of wastewater not to the extent of senescence. The values obtained were compared with the initial wastewater characteristics analysed at the point of collection and standard parameters. The treatment/removal efficiency was calculated as the percentage of removal for each parameter at the retention time of 12 days as shown in equation 1 (Bashir et al., 2010).

$$\text{Removal Efficiency (\%)} = \frac{influent\ concentration - effluent\ concentration}{influent\ concentration} \times 100 \quad (1)$$

4.   Results and Discussion

After the changes in concentration of parameters of interest in wastewater were determined, wastewater treatment efficiencies by each of the aquatic plants in the constucted wetlands were also evaluated. Table 1 shows raw wastewater characteristics of the fourteen (14) parameters taken into consideration with the characteristics of wastewater treated with Phragmites australis, Water Hyacinth (*Eichhornia crassipe*s) and Commelina cyanea. Table 2 shows the recommended standards

for permissible limits for wastewater disposal (Adam, 1989). Comparing the quality of raw wastewater with standards, it was found that the raw wastewater analysed was contaminated with varying degree of pollutants. Almost all the parameters measured exceeded the approved standards (i.e. National Agency for Food and Drug Administration and Control (NAFDAC) maximum allowed limit, Standard Organization of Nigeria (SON) standards and the World Health Organization (WHO) standards) except pH which had values within the tolerable limits. The mean microbial population in the raw wastewater and the laboratory scale CWs are shown in Table 1. The results showed that the microbial communities in the ponds are diverse with four groups of bacteria namely Escherichia coli, Klebsiella spp, Salmonella spp and Shigella spp.

4.1   Parameters Removal by Constructed Wetland Cultured with Aquatic Macrophytes

Turbidity concentrations of 342 NTU obtained from the raw wastewater were reduced significantly by the wetland cultured by Commelina cyanea with a removal efficiency of 96.85% as compared to Water Hyacinth and Phragmites australis cultured wetlands with 87.34% and 89.25% respectively at 12th day of the experimental study. Impressive removal rates of turbidity from wastewater was also comparable to a study carried out by Patale et al. (2010) who reported that Commelina cyanea are natural coagulants and can be used as good clarifying agents and also unveil their potential as materials for water clarification through coagulation and flocculation processes. Apart from Turbidity, Commelina cyanea did extraordinarily well by substantially reducing the initial concentration of the dissolved solids in the raw wastewater from 620 mg/L to 106 mg/L. The values obtained for water hyacinth and Phragmites australis are 307 mg/L and 504 mg/L respectively at 12 day retention time.

pH of wastewater before treatment and after treatment by Phragmite australis, Water Hyacinth and Commelina cyanea showed the pH values were in desirable limit when compared with the standards. An increase in pH was noticed in all the plants after 6 days of treatment unlike day 9 and 12 with a remarkable decrease in pH as shown in Figures 1 – 6. Figure 7 shows the percentage removal of each aquatic macrophyte where water hyacinth has proven to have the highest pH reduction efficiency of 11.54%. It may be due to plants uptake of significant amounts of sparingly soluble nutrients from the rhizosphere by acidifying the rhizosphere via excreting H+ in exchange for cations and exuding organic acids and CO_2. This is also in agreement with Mahmood *et al.,* (2005) who reported that the reduction in pH is due to absorption of nutrients or by simultaneous release of H+ ions with the uptake of metal ions.

Table 1: Characterization of Raw Wastewater and Constructed Wetlands Treated Wastewater

Parameter	Raw Wastewater	Treated Wastewater with Aquatic Macrophytes								
		Phragmites australis			Water Hyacinth			*Commelina cyanea*		
		6 days RT	9 days RT	12 days RT	6 days RT	9 days RT	12 days RT	6 days RT	9 days RT	12 days RT
Physical										
Turbidity (NTU)	342.00 ± 0.58	78.00 ± 1.15	39.48 ± 0.01	36.77 ± 0.01	80.00 ± 1.73	57.00 ± 1.16	43.30 ± 0.12	49.10 ± 0.06	21.30 ± 0.17	10.77 ± 0.13
Dissolved Solids (mg/L)	620.00 ± 0.58	618.00 ± 2.31	576.00 ± 2.31	504.00 ± 2.31	420.00 ± 3.46	400.00 ± 1.15	317.00 ± 1.73	210.00 ± 1.73	160.00 ± 2.89	106.00 ± 1.16
Chemical										
pH	7.80 ± 0.03	10.60 ± 0.06	7.40 ± 0.23	7.20 ± 0.12	10.90 ± 0.01	7.10 ± 0.00	6.90 ± 0.06	11.30 ± 0.17	7.40 ± 0.23	7.40 ± 0.17
Nitrite (mg/L)	123.00 ± 0.29	86.00 ± 1.44	35.00 ± 0.58	16.00 ± 0.29	82.00 ± 0.35	31.00 ± 0.58	10.00 ± 0.23	88.00 ± 1.15	39.00 ± 1.73	12.00 ± 0.14
Nitrate (mg/L)	14.40 ± 0.23	7.00 ± 0.09	4.40 ± 0.03	1.90 ± 0.02	6.20 ± 0.06	3.70 ± 0.02	1.00 ± 0.03	6.30 ± 0.20	4.10 ± 0.12	1.50 ± 0.12
Phosphate (mg/L)	7.75 ± 0.29	6.79 ± 0.01	3.96 ± 0.03	1.10 ± 0.23	6.88 ± 0.01	4.19 ± 0.01	1.15 ± 0.09	7.15 ± 0.01	5.50 ± 0.02	2.86 ± 0.02
Sulphate (mg/L)	16.50 ± 0.03	13.00 ± 0.29	8.60 ± 0.17	4.20 ± 0.06	11.40 ± 0.12	7.50 ± 0.12	3.30 ± 0.09	12.70 ± 0.11	8.00 ± 0.17	4.50 ± 0.23
BOD_5 (mg/L)	35.45 ± 0.03	31.65 ± 0.38	20.00 ± 0.12	13.38 ± 0.02	28.26 ± 0.01	15.75 ± 0.01	9.21 ± 0.12	28.80 ± 0.46	21.47 ± 0.02	14.94 ± 0.02
COD (mg/L)	48.67 ± 0.02	42.56 ± 0.02	34.12 ± 0.07	25.51 ± 0.02	40.48 ± 0.02	29.59 ± 0.01	14.90 ± 0.12	42.25 ± 0.14	33.66 ± 0.02	22.90 ± 0.52
Bacteriological (×)										
Escherichia coli (CFU/mL)	15 ± 0.58	4.8 ± 0.46	0.56 ± 0.01	0.36 ± 0.01	0.5 ± 0.03	0.02 ± 0.01	0.027 ± 0.00	3.8 ± 0.06	0.48 ± 0.02	0.13 ± 0.01
Klebsiella spp (CFU/mL)	10 ± 0.06	2.1 ± 0.17	0.85 ± 0.01	0.21 ± 0.01	0.93 ± 0.02	0.25 ± 0.03	0.52 ± 0.01	2.7 ± 0.06	0.89 ± 0.01	0.23 ± 0.01
Salmonella spp (CFU/mL)	8.0 ± 0.03	0.6 ± 0.02	0.12 ± 0.01	0.081 ± 0.01	0.23 ± 0.02	0.09 ± 0.01	0.0086 ± 0.00	0.64 ± 0.01	0.14 ± 0.02	0.08 ± 0.00
Shigella spp (CFU/mL)	2.4 ± 0.02	0.96 ± 0.02	0.27 ± 0.03	0.078 ± 0.01	0.42 ± 0.01	0.038 ± 0.00	0.0045 ± 0.00	0.94 ± 0.02	0.2 ± 0.06	0.069 ± 0.00

Note: RT, mg/L, CFU/ml and NTU stand for Retention Time, milligram per Litre, Coliform Forming Unit per millilitre and Nephelometric Turbidity Unit respectively and data are presented as mean ± standard error (n = 3).

Table 2: Recommended Standards for safe Disposal of Treated Wastewater

Parameter	NAFDAC Maximum Allowed Limits	SON Standards Maximum Allowed Limits	WHO Standards	
			Highest Desirable	Maximum Permissible
pH at 20^{0}C	6.5-8.5	6.5-8.5	7.0-8.9	6.5-9.5
Turbidity	5.0 NTU	5.0 NTU	5.0 NTU	5.0 NTU
Nitrate (mg/L)	10	10	10	50
Nitrite (mg/L)	0.02	0.02	0.2	3
Sulphate (mg/L)	100	100	250	500
Odour	Unobjectionable	Unobjectionable	Unobjectionable	Unobjectionable
Taste	Unobjectionable	Unobjectionable	Unobjectionable	Unobjectionable

Source: Adams, 1989

Note: NAFDAC, SON, WHO, and NTU stand for *National Agency for Food and Drug Administration and Control,* Standard Organization of Nigeria, World Health Organization, and Nephelometric Turbidity Unit respectively

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pH of wastewater before treatment and after treatment by *phragmite australis*, Water Hyacinth and *Commelina cyanea* showed the pH values were in desirable limit when compared with the standards. An increase in pH was noticed in all the plants after 6 days of treatment unlike day 9 and 12 with a remarkable decrease in pH as shown in Figures 1 – 6. Figure 7 shows the percentage removal of each aquatic macrophyte where water hyacinth has proven to have the highest pH reduction efficiency of 11.54%. It may be due to plants uptake of significant amounts of sparingly soluble nutrients from the rhizosphere by acidifying the

rhizosphere via excreting H+in exchange for cations and exuding organic acids and CO_2. This is also in agreement with Mahmood *et al.,* (2005) who reported that the reduction in pH is due to absorption of nutrients or by simultaneous release of H+ ions with the uptake of metal ions.

It was observed that the three aquatic plants used did remarkably well in removing nitrate and nitrite from the wastewater. Nitrite was reduced from 123 mg/L to 16 mg/L, 10 mg/L and 12 mg/L in the laboratory scale ponds cultured with Phragmite australis, Water Hyacinth and *Commelina cyanea* respectively at day 12 retention time while nitrate was reduced from 14.4 to 1.9 mg/L, 1.0 mg/L and1.5 mg/L in the three constructed wetlands treated with Phragmite australis, Water Hyacinth and *Commelina cyanea* respectively. Figures 1 - 6 explain the reduction progress. Ammonia (a major component of food, water and urine) in wastes is oxidized to nitrate and nitrite. The nitrate is taken up by plants for plant growth and used in the synthesis of organic nitrogenous compounds

Phosphate was found to be present in the untreated wastewater in quantity of 7.75 mg/L but was reduced drastically to 1.10 mg/L (*Phragmites australis*), 1.15 mg/L (Water hyacinth) and 2.86 mg/L (*Commelina cyanea)*. Figures 1 - 6 show the reduction progress. El-khatib et al. (2004) and Majeed *et al. (*2012) suggested that Phragmites australis uptake capacity of nutrients (Phosphorus) as compared to other macrophytes may be due to cell elongation in rhizomes and shoot and better water absorption. Phosphorus (P) removal in this system is primarily by plant uptake, microbial immobilization with plant detritus, adsorption to the benthic

sediments, and precipitation within the water column (Bruce, 1992). Kamaruddin *et al.* (2013) remarked that reduction in total phosphorus might be due to variation in the substrate as the effectiveness of wetlands in Phosphorus reduction is a function of adsorption capacity of substrate. This claim was also supported by Akinbile et al. (2015). Sim et al. (2008) suggested that removal may be due to P intake by the plant which according to Kropfelova *et al.* (2009) create the platform for biological activity in a biofilm while also contributing to nutrient uptake and aesthetic benefits.

The sulphate in the raw wastewater was tested to be 16.5 mg/L and by the end of the twelfth day it has greatly decline. This diminution was to 4.2 mg/L, 3.3 mg/L and 4.5 mg/L respectively in the wetlands cultured with *Phragmite australis*, Water Hyacinth and Commelina cyanea. This shows the purification efficiencies of the three aquatic plants in the removal of sulphate in wastewater is highly commendable (Figures 1 – 6). It is noted that the Water Hyacinth cultured wetlands consumes more as a result of its vigorous growth and metabolic activities on the wastewater which confirms the previous findings as reported by Ajibade et al. (2013). Major processes involved in the removal of sulphate may include microbial and plant uptake, adsorption and precipitation.

The measured value of the BOD_5 in the raw wastwater was 35.45 mg/L. Figures 1 – 6 show the great decrease in the BOD_5 content as treated with aquatic macrophytes cultured in wetlands. Water hyacinth did incredibly well (9.21 mg/L) in the purification process of BOD in the wastewater in contrast with

Commelina cyanea (14.94 mg/L) and Phragmites australis (13.38 mg/L) at day 12 of the experimental study. The Chemical Oxygen Demand (COD) content was measured to be 48.67 mg/L at the point of collection before it was batched in the constructed wetlands cultured with the aquatic macrophytes. This gradually dropped to 25.21 mg/L, 14.29 mg/L and 22.90 mg/L on the 12th day of the experiment   in the cultured wetlands with *Phragmite australis,* Water Hyacinth and *Commelina cyanea* respectively. According to Ajibade et al. (2013) and Vymazal (2007), plant root system acts as proper media for microbial growth providing oxygenic condition in the rhizosphere for microbial degradation of organic pollutants as also reported by Valipour et al. (2015) and Shah et al. (2010). The main mechanisms of COD removal by wetland plants may involve aerobic and anaerobic degradation processes, sedimentation and filtration (Bulc et al., 2006).

The coliform bacteria removal efficiency of Water Hyacinth after day 12 retention time was found to be prominent and spontaneous compared to Commelina cyanea and Phragmites australis cultured wetlands which were considerably effective (Table 1). The high removal of total coliform bacteria in the constructed wetland with Water Hyacinth could be from their receiving direct sunlight and their high wastewater pH. Also, seasonal fluctuations in environmental characteristics influence plant growth and bacterial respiration, factors that in turn influence contaminant removal in Water Hyacinth systems.
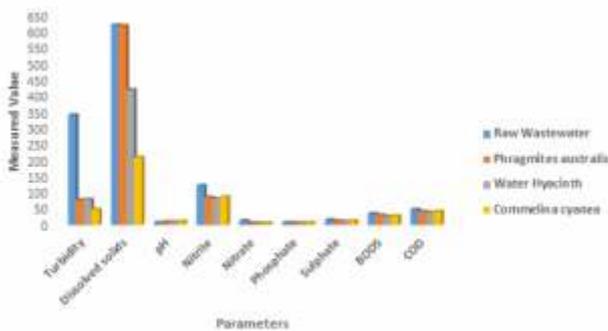

Figure 1: Comparison of Values of Parameters after 6 days retention time
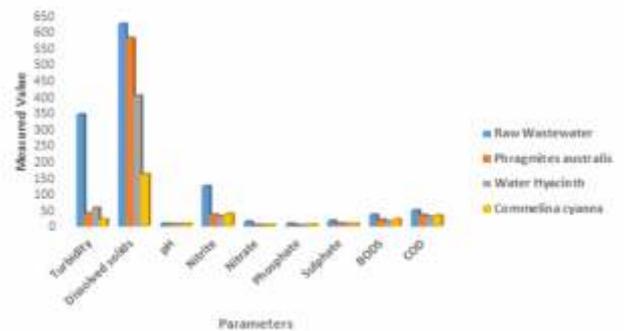

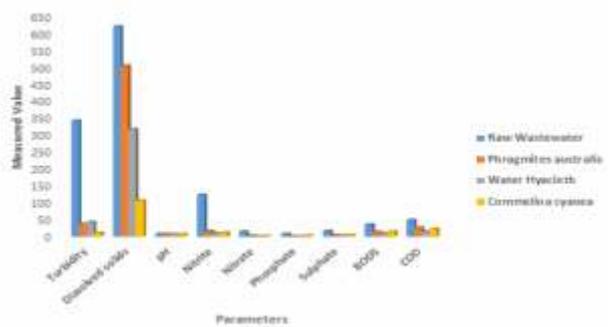Figure 2: Comparison of Values of Parameters after 9 days retention time

Figure 3: Comparison of Values of Parameters after 12 days retention time
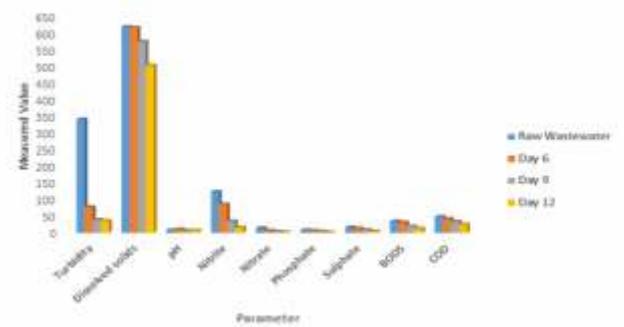

Figure 4: Comparison of Values of Parameters for Phragmites australis at Different Retention Times
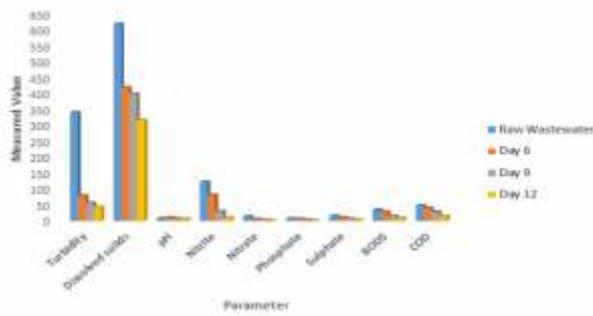
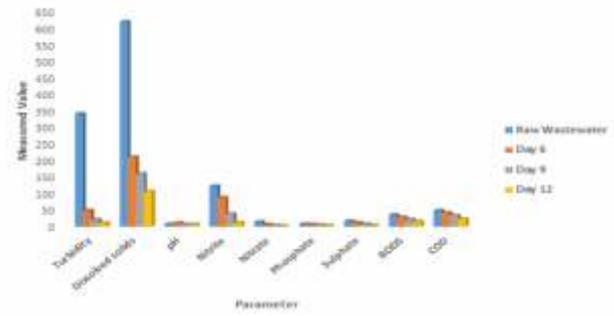Figure 5: Comparison of Values of Parameters for Water Hyacinth at Different Retention Times

Figure 6: Comparison of Values of Parameters for *Commelina cyanea* at Different Retention Times

4.3   Removal Efficiency of the Three Aquatic Macrophytes Plants after 12 days Retention Time

Of all tested parameters, turbidity was removed most efficiently (over 87% in all the samples obtained in the laboratory scale pond cultured with different aquatic macrophytes) and the treatment efficiency reached highest in the pond cultured with Commelina cyanea (96.85%). Phragmites australis gave the highest reduction in Phosphate, Water Hyacinth gave the best purification efficiency in most of the parameters namely pH, Nitrite, Nitrate, Sulphate, Biochemical Oxygen Demand, Chemical Oxygen Demand with 11.54%, 91.87%, 93.06%, 80%, 74.02 and 63.39% removal efficiencies respectively. Also, Water Hyacinth treatment capacity was far better in the bacteriological parameters except for Klebsiella spp which was treated better by the Phragmites australis.   Commelina cyanea gave the highest reduction in turbidity and dissolved solid parameters of the domestic

wastewater sample. Figure 7 show the clear distinctions in the removal efficiency or treatment capacity of the aquatic macrophytes.

4.4   Comparison of Values of Parameters for 12 Days Retention Time with Standard Parameter

Comparing the result of the effluent with the WHO standard for permissible quality of water that can be disposed to the environment, it was observed that all the parameters of the treated water are within the provided range. Table 2 shows the recommended standards. Comparing the values under the treated wastewater by the aquatic macrophytes after 12 days in Table 1 and Table 2, the treated wastewater is fit to be disposed to the environment for specific purposes such as flushing of toilets, Irrigation of lawns and farmlands.
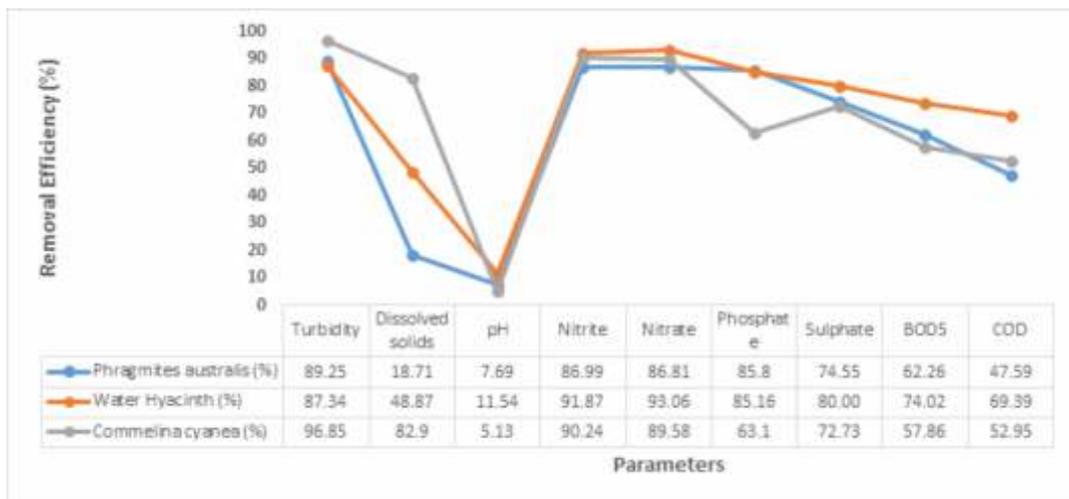

Parameters	Turbidity	Dissolved solids	pH	Nitrite	Nitrate	Phosphate	Sulphate	BOD5	COD
Phragmites australis (%)	89.25	18.71	7.69	86.99	86.81	85.8	74.55	62.26	47.59
Water Hyacinth (%)	87.34	48.87	11.54	91.87	93.06	85.16	80.00	74.02	69.39
Commelina cyanea (%)	96.85	82.9	5.13	90.24	89.58	63.1	72.73	57.86	52.95

Figure 7: Removal Efficiency of Aquatic Macrophytes after 12 days Retention Time

5.   Conclusion

The study has revealed that macrophytes have a pivotal function in relation to wastewater purification by providing a surface area for attached microorganisms, pollutant uptake, enhancing filtration and releasing oxygen. Significant removal was found in the three constructed wetland systems with aquatic macrophytes. In this study, the comparison between the three aquatic macrophytes have shown obvious difference in the bacteriological parameters removal efficiencies indicating the positive role of Water Hyacinth in the process of phytoremediation. The treatment efficiency was found to be higher in the wetland with Water Hyacinth compared to the two aquatic macrophytes because water hyacinth can proffer more oxic conditions which accelerate aerobic processes in the putrefaction of organic matters and other nutrients. The floating plant used (Water Hyacinth) showed the highest removal of nutrients (pH, Nitrite, Nitrate, Sulphate, COD and BOD) while Phragmites australis did outstandingly in removing phosphate to the barest minimum in the wastewater. Commelina cyanea was unarguably the best among the aquatic macrophytes in the purification of wastewater from turbidity and dissolved solids. The results proved that aquatic macrophytes are effective in domestic wastewater treatment and the removal efficiency of all parameters was highly related to optimum plant growth rate in different conditions which implies that they can be used for phytoremediation of polluted wetlands through proper management strategies.

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