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Treatment of Brackish Water by Three Macrophytes in Constructed Wetlands

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Abstract— *Series of investigations was conducted to evaluate the feasibility of using constructed wetland to remove pollutants from saline wastewater. Three emergent plants; Pistia stratiotes, Typha orientalis and Eichhornia crassipes were planted in an experimental plot and fed with saline water diluted with distilled water to simulate a brackish water concentration of 8.7 µS/cm.*

A pilot-scale free water surface-flow constructed wetland was set up to demonstrate the performance of sand- based constructed wetland, and removal efficiency for the selected emergent plants in treating brackish water, from diluted saline water.

Treatment performances of planted units were found to be 54.5–66% for electrical conductivity, 72.4–89.4% for Chloride, 33.3–75% for Total Hardness and 66.2–95.4% for Coliform counts. The most satisfactory plant with salt removal efficiency was Pistia stratiotes though the plant growth was limited by salt concentrations. The wetland plants were non-resistant to brackish water under the tested conditions during the 20-day retention period, with notable percentage increase in concentrations of some parameters. Salt enriched wastewater inhibited nutrients flourishing, thus reduced treatment performance.

Final effluent was non-potable for human consumption, suitable for irrigation and livestock watering. Treatment system was economical and environmentally friendly, free from offensive odour and insect invasion.

Keywords— *Brackish water, Constructed wetland, Electrical conductivity, Retention period, Non- tolerant plants, Removal efficiency.*

I. INTRODUCTION

Access to fresh water is an increasingly critical national and international issue, especially since demand for fresh water in many regions of the world has already outstripped supply. Based on the latest figures from the United Nation's "World Water Development Report," more than 50% of the nations in the world will face water stress or water shortages by 2025, and by 2050, as much as 75% of the world's population could face water scarcity.

Water for human consumption and daily use comes from a variety of sources, including surface waters such as lakes, rivers and oceans, and groundwater. Most raw waters require some degree of treatment depending on their initial quality and intended application. Fresh waters typically undergo a conventional treatment process, which consists of coagulation, flocculation, sedimentation, filtration, and disinfection. In areas where fresh water supplies are limited, alternative processes can be employed for treating saline waters.

In coastal areas, salt water intrusion occurs primarily by lateral encroachment and by vertical upcoming near discharging wells. In locations where groundwater is pumped from aquifers that are in hydraulic connection with the sea, the induced gradients may cause the migration of salt water toward a well. Groundwater withdrawals also change the patterns of roundwater flow and discharge to coastal ecosystems, which may alter the nutrient concentrations and salinity of the coastal waterways and wetlands. Whether brackish waters are used for drinking or agricultural use, they need to be treated in order to alleviate health and environmental concerns.

Nigeria has a long coastline with the Atlantic Ocean. Coastal Nigeria is covered by two sedimentary basins - The Benin and the Niger Delta basins. The aquifers are sands with intervening impermeable clay layers giving rise to multi-aquifer systems. Salt water intrusion into unconfined and confined aquifers has occurred in both basins and many boreholes have been abandoned while development of potable water for the communities is hampered by salt water intrusion [1].

The Coastal region of Lagos, Nigeria has a long coastline with the Atlantic Ocean. Most of the groundwater aquifer in this region are used for irrigation purposes. However, the region is threatened by the problem of saltwater intrusion, due to high extraction rate of groundwater. The Coastal Plains Sands is the main aquifer in Lagos that is exploited through hand-dug wells and boreholes. It forms a multi-aquifer system consisting of three aquifer horizons separated by silty or clayey layers. The aquifer thickens from its outcrop area in the north of the city to the coast in the south and the sand percentage in the formation changes from north to south [2]. Coastal aquifers constitute a vital source of fresh water in these regions, and are increasingly used to meet the water supply needs [3]. There is vital need to monitor the feasible risk of saline water intrusion of the coastal aquifers because, once saline intrusion into coastal aquifer has occurred, it is extremely difficult to overcome and improve the management of the water resources based on long term strategy. Coastal aquifers in Nigeria straddling from Lagos State the west to Cross River State in the east have been reported to be affected by seawater intrusion. Some of these are presented in the works of [4], [5]. Seawater intrusion is an inevitable problem of coastal fresh water aquifer associated with urban area [6]. The challenge of saline water contamination in coastal aquifers is driven by a violation of the delicate hydrogeological balance that exists between freshwater and seawater in coastal aquifers due to large- scale groundwater abstraction occasioned by rapid urbanization [3]. Due to the proximity of Lagos to the Atlantic Ocean, the general population is faced with problems of freshwater abstraction from the subsurface.

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The treatment of saline water, referred to as desalination, utilizes membrane processes that remove excess salt and other constituents from the water. Although desalination treatment is relatively expensive, the demand for fresh water for both human consumption and agricultural purposes is increasing and designing efficient brackish water treatment processes is becoming a priority.

A constructed wetlands or known as an artificial wetland or wet park is one of the technology treatment system that have been used internationally and effectively to improve our water quality and to treat various kinds of wastewater. It is defined as engineer-made equivalent of natural wetlands, and designed to reproduce and intensify the wastewater treatment processes that occur in natural wetlands. Constructed wetlands system is widely applied for the purification of domestic wastewater, storm water runoff, and also industrial effluent. They act as biological filter which involve physical, chemical, and biological reaction which all participate in the reduction of organic, nutrient and microbiological loads [7-8].

Constructed wetlands, systems of great potential that provides effective removal of solids, organic matter and nutrients contained in many kinds of wastewater, were proposed to improve the condition of the saline wastewater. Treatment wetlands require relatively low costs for construction and operation and treat waste- water through an integration of physical, biological and chemical reactions supported by the significant wetland components [9].

Root zone technology is an emerging cleanup technology for waste water treatment, the technology can be defined as engineered use of green plants, including grasses and woody species to remove, to contain, or to render harmless the various environmental contaminants in the soil or water. [10] discussed the technology in detail. The concept of root zone technology is based upon the well-known ability of plants and their associated rhizosphere to concentrate and/or degrade highly dilute contaminants. This investigation was conducted to evaluate the feasibility of using constructed treatment wetland to remove pollutants from saline wastewater. Three emergent plants used are Pistia stratiotes, Typha orientalis and Eichhornia crassipes.

Study Area

Lagos State lies approximately between 6.45 latitude and 3.39 longitude. The southern boundary of the state lies along the Atlantic coastline while its northern and eastern boundaries are shared with Ogun State. On the western side the boundary is bordered by the republic of Benin. Its size is about 3,577 square kilometer which accommodates over nine millions of the national population (2006), Nigeria population census figures). Lagos state is the most urbanized state in Nigeria, though there are still many rural areas within the state which are still very poorly connected with urban places and thus remain undeveloped. Lagos State is located within the low lying coastal zone of south-western Nigeria [11].

Due to massive influx of people from other parts of Nigeria to Lagos metropolis, the population of Lagos has and thus an increase in the demand of water resulting in concomitant acute water shortage to meet the daily water consumption needs of the people. Most of the residents have resorted to depend on borehole water both for domestic and industrial usage [12]. Saline intrusion into coastal aquifers has become a major concern [13] because it constitutes the commonest of all the pollutants in freshwater, therefore, understanding of saline intrusion is essential for the management of coastal water resources [14]. Various workers around the world have carried out geophysical survey to demarcate the interface between freshwater and saline water. For example, [15] investigated the saltwater intrusion problem in the coastal area of South Korea, they observed that salinization of fresh groundwater is highly associated with groundwater withdrawal. [16] mapped the saltwater/freshwater interface in the geological setting of the Eastern Shore of Virginia. [17-18] showed that the deterioration of freshwater quality due to natural seawater infiltration affects the balanced life of the narrow coastal strip of Rhodes Island, USA. In- addition, [19] also observed that the discharge of a large volume of groundwater may allow saltwater intrusion into the freshwater aquifers, and this potential saltwater contamination poses a threat to the sustainable development and economic wellbeing of any coastal area. In Southeastern Nigeria, [20] delineated the depth to the top of the freshwater sands underlying the saline water sands to vary from 77 to 947 m below ground level. [14] reported that saline water intrusions into coastal aquifers have resulted in acute environmental problems in the past.

II. MATERIALS AND METHODS

a. *Experimental setup*

A series of investigations was set up at the Department of Civil Engineering, Ladoke Akintola University of Technology, Ogbomoso Nigeria. The experimental units were constructed with dimensions of 1800mm breadth, 900m length and 900mm depth, with the use of locally available construction materials such as medium and small grain size sand particles available within the university campus, the aquatic plant were also found near the university campus (Figure 1).

b. *Substrate Filling*

The substrates were properly washed to eliminate the undesired particles and dust, and sieved to obtain the desired grain size (granite 12 mm, coarse and fine sand and humus < 2mm). The inlet and outlet taps were covered with screen during substrate filling to prevent sand blockade. 150mm of granite column were filled at the bottom of each unit followed by 250mm of coarse sand, 300mm of fine sand and 100mm humus soil. A 100mm free board was provided.

c. *Planting of the Vegetation*

Three emergent plants, Pistia stratiotes (water lettuce), Typha orientalis (cattail), and Eichhornia crassipes (water hyacinth) were selected for investigations. Plants were collected from their natural aquatic habitat and were transplanted to the wetland setup. They were planted with a density of 8 roots per square meters and watered by irrigation until after a period of one and half months (six weeks) (Figure 2). An unplanted unit was also set as a control. After plant acclimation, all plots were fed with fresh saline water diluted with distilled water to simulate a brackish water concentration of 8.7 µS/cm electrical conductivity (EC). This range of salt concentration gives a satisfactory crop-yield for salt tolerant plants only [21]. The wastewater was maintained below the free board for a retention period of 20d, while treated effluent samples for analyses were collected at 5d intervals

d. *Sample and Data Analysis*

The macrophytes were observed throughout the experimental period for general appearance and health. Plant monitoring indicated the feasibility and efficiency of each species for employing in constructed treatment wetlands under tested conditions. During the study, wastewater samples were collected on 5 days intervals. All samples were grab samples collected at the inlet and outlet of the plots. Samples were analyzed for salinity related parameters such as for total dissolved solid (TDS), electrical conductivity (EC), Chloride (Cl), total hardness (TH), and Coliform counts, among others, according to the Standard Methods for the Examination of Water and Wastewater (APHA, 1992).

III. Results and Discussion

a. *Plant growth and Physical Appearance*

Two out of the three species, which were Pistia stratiotes (water lettuce) and Eichhornia crassipes (water hyacinth) showed injury symptoms from the combination effects of high salt concentration. They appeared burnt, withered, drying and brownish. These were observed at the tenth and fifteenth day of the brackish water feeding for Pistia stratiotes and Eichhornia crassipes, respectively. However, at the end of the experiment, the twentieth day of treatment, water plants had died though was in operational conditions (Figures 3 and 4). The two are normally aquatic plants that flourish in rivers and lake conditions, though they cannot withstand seawater intrusion. They cannot survive prolonged high saline flooding. This may be due to not being able to bear extensive plasmolysis in which water is withdrawn from their cells caused by the difference in dissolved concentrations between cell membranes. Pistia stratiotes and Eichhornia crassipes were intolerant under the tested conditions. Oxygen restriction, which is favored in prolonged retention conditions as well as in treatment systems receiving organic waste, and salt influence concurrently caused the growth of the two plants to suffer. The third specie, Typha orientalis (cattail), exhibited a stress- tolerance and could play functions for brackish water treatment. Hence, it could be utilized for prolonged treatment periods (Figures 5). Researches on the functions of wetland plants revealed that macrophytes principally create appropriate conditions for microbial activities through increasing the substrate surface area in the water column and oxygenating the sediments around root hairs for aerobic reactions. They also facilitate filtration and sedimentation by encouraging quiescent conditions. Moreover, plants also assimilate nutrients via their growth metabolism as reported in [22-25]

Apart from general appearance, relative growth rate can be employed to confirm the health of plants. Pistia stratiotes and Eichhornia crassipes died before the end of the experiment (Figures 3 and 4). The continuous growth of Typha orientalis in the present experiment resembled those of halophyte species such as Suaeda esteroa, Salicornia bigelovii and Atriplex barclayana when they were irrigated with aquaculture effluent at 35ppt of salinity, according to [26]. Nevertheless, these halophytes provided higher RGR values when they were fed with wastewater at 10ppt of salt. This indicated that Typha orientalis have a higher potential for growing in saline conditions. The observation was also close to that reported for constructed wetlands located in tropical zones receiving municipal wastewater [27]. This indicated the capability of Typha orientalis for acclimatization and growth in a treatment wetland receiving municipal wastewater in a saline condition.

b. *Saline water Treatment*

The concentrations of various characteristics of brackish water parameters during treatment in comparison with the national standards for drinking water quality and Irrigation Water Standards are shown in Table 1. The parameters of the fresh saline water diluted with distilled water to simulate a brackish water (raw) concentration of 8.7 µS/cm were below the recommended limit, except E.coli that was too numerous to count.

Table 2 summarizes the treatment performance of the wetland plants compared to the unplanted with the salinity related parameters. Above 50% reduction were recorded by control (unplanted) for E.C, TDS, and chloride. Water lettuce reduced over 60% of E.C and TDS at day 5 retention. The average reductions in Chloride were 89.4% @ day 15, 78% @ day 10 and 83% @ day 10 by Water lettuce, Water hyacinth and Typha orientalis, respectively. Total hardness was reduced by 75% @ day 15 by Water lettuce.

The percentage reduction in chloride concentrations during the retention days were displayed in Table 3. The average reduction in chloride ranged from 76.4%- 89% with water lettuce, 74% - 78% in Water hyacinth, and 72.4% - 83% by Typha orientalis (Figure 6).

High salt concentration is a major factor causing unexpected poor treatment performance. High strength salinity either limited plant growth or introduced open water areas that promoted the production of excessive amounts of algae and SS resuspension as reported by [27]. The effect of dissolved solids (TDS) on the growth of plants, is an aspect of agricultural concerns. Dissolved salts increase the osmotic potential of soil water and an increase in osmotic pressure of the soil solution increases the amount of energy which plants must expend to take up water from the soil. As a result, respiration is increased and the growth and yield of most plants decline progressively as osmotic pressure increases. Although most plants respond to salinity as a function of the total osmotic potential of soil water, some plants are susceptible to specific ion toxicity.

(a)

(b)

(c)

Fig. 1. Wetland Units Construction: During, after and vegetation growth in constructed wetland.

(a)

(b)

(c)

Fig. 2. Vegetation growth before treatment: a. twelfth day after planting; b and c. week six after planting.

Day 6

Day 10

Day 15

Day 20

Fig. 3. Pistia stratiotes (water lettuce) decomposing with increasing treatment periods (Days 6-20).


Day5


Day 10


Day15


Day20

Fig. 4. Eichhornia crassipes (water hyacinth) withering and drying with increasing treatment periods (Days 5-20).


Fully grown Typha plant


Day 5


Day 10

Fig. 5. Typha orientalis (cattail) exhibiting a stress- tolerance functions with increasing treatment periods.

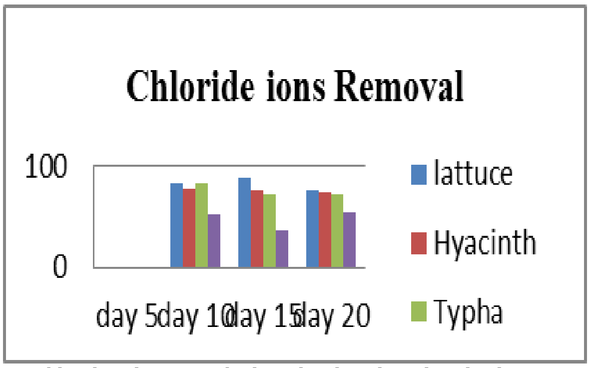

Fig. 6. Chloride reduction with planted and unplanted wetland systems with increasing treatment periods.

These factors encouraged organic matter distribution, high oxygen consumption and eventually water deterioration. Extreme salt concentrations normally affect the function of biota such as plants and microorganisms. As observed in this study, high salt concentrations led to plant stress which reduced suitable areas for microorganism support. Also, it could have an effect on the metabolism function of the organism. Hence, the effectiveness of the treatment processes by the organism namely aerobic, anaerobic and facultative bacteria as well as others could not be achieved. Furthermore, improper SS removal and high SS in effluent indicated that sedimentation and filtration, significant processes for SS removal promoted by plants, did not succeed. These faults, caused by high salinity interfering with the treatment function of significant wetland components limited the removal efficiency [9]

TABLE 1. Concentrations of various characteristics of brackish water parameters during treatment.

	Raw	Water Lettuce (retention days)				Water Hyacinth (retention days)				Typha Orientalis (retention days)				Unplanted (retention days)				NSDWQ (2007)	Irrigation Water Standards (Ayers and Westcot, 1994)
		5	10	15	20	5	10	15	20	5	10	15	20	5	10	15	20		
Temperature	28.5	28.7	27.1	29.7	26.3	28.3	27.0	29.7	26.4	28.6	27.4	28.2	26.2	28.7	27.6	27.7	26.5	ambient	ambient
pH	7.2	7.5	7.2	7.5	7.0	7.5	7.9	6.8	7.1	7.8	7.4	7.2	7.4	6.69	6.72	6.6	7.1	6.5-8.5	6.5
Turbidity	2.0	34	54	38	12.5	42	92	105	120	8	44	105	115	190	210	280	255	5	-
D.O	5.9	4.6	4.5	4.9	5.3	3.1	5.0	5.0	6.0	3.3	4.7	5.3	5.0	1.3	4.2	5.7	5.6	8	-
E.C (µS/cm)	8.7	2.93	3.96	4490	5580	647	981	1720	2370	1371	1792	2310	2810	4.12	6.76	6740	7110	1000	3000
TDS	4.35	1.48	1.98	2245	3555	232.5	490.3	860	1185	685.5	896	1155	1405	2.06	3.38	3370	3555	500	2000
Chloride	5.0	27	0.85	0.53	1.18	48	1.10	1.16	1.30	15	0.85	1.38	1.38	155	2.37	3.20	2.30	250	1065
Tot. Hardness	60	105	100	15	95	150	65	70	100	115	40	100	65	330	300	-	230	150	-
E.Coli ($x10^3$)	TNTC	TNTC	TNTC	3.5	9.0	TNTC	TNTC	32.5	1.5	TNTC	TNTC	11	TNTC	TNTC	NG	NG	NG	1	-

TNTC- Too Numerous To Count
NG- No Growth

TABLE 2. Treatment performance of planted and unplanted wetland systems in the salinity- related parameters.

Salinity Related Parameters	Water Lettuce	Water Hyacinth	Typha Orientalis	Unplanted
E.C (µS/cm)	66.32% @ day 5	-	-	52.64% @ day 5
TDS	66% @ day 5	-	-	52.64% @ day 5
Chloride	89.4% @ day15	78% @ day 10	83% @ day 10	54% @ day 20
Tot. Hardness	75% @ day 15	-	33% @ day 10	-

TABLE 3. Percentage reduction of chloride during the retention days in planted and unplanted wetland systems.

Wetland Plants/Unplanted	% Removal Day 5	% Removal Day 10	% Removal Day 15	% Removal Day 20
Water Lettuce	-	83	89	76.4
Water Hyacinth	-	78	76.8	74
Typha Orientalis	-	83	72.4	72.4
Unplanted	-	52.6	36	54

IV. CONCLUSION

These investigations demonstrated that constructed wetlands were an option for improving the quality of saline wastewater. Typha orientalis could survive and facilitate the various treatment processes for saline wastewater treatment; in a low cost and environmental friendly technique, though the treated effluent is suitable for non-drinking purposes such as irrigation and fishing. However, Water lettuce and water hyacinth were intolerant and terminated during the period of study, the results showed that Typha orientalis was clearly superior for salinity removal. When used for purification of saline wastewater, Typha orientalis, Water lettuce and water hyacinth seemed to have best removal performance at day 10 retention.

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