A Comparative Study of the Performance of Water Hyacinth (Eichhornia Crassipes) and Water Lettuce (Pistias Stratiotes) in the Remediation of Produced Water

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Abstract
The study presents the characteristics of produced water obtained from a detention pit in the Niger Delta region of Nigeria. Phytoremediation, an emerging remediation technology for contaminated soils, groundwater, surfacewater and wastewater that is both low-tech, low-cost, and environmental friendly have been employed in this study. Two aquatic macrophytes: water hyacinth (*Eichhornia crassipes*) and water lettuce (*Pistias stratiostes*) have been used to remediate this produced water harmless in the environment. The two aquatic macrophytes were comparatively studied to determine their effectiveness in remediation without the use of fertilizers to sustain their growth. Also, physico-chemical parameters were compared with standard discharge limits stipulated by the Department of Petroleum Resources (DPR). Parameters such as pH, EC, salinity, TDS, TSS, DO, BOD, COD, turbidity, sulphate, phosphate, ammonia, oil and grease, Cu, Pb, Cr, Zn, Fe, and total coliform of the produced water have been studied using standard protocol of APHA and ASTM. The physico-chemical analysis revealed that most of the parameters were above the permissible limits and that water hyacinth made a better clean up than water lettuce. One-way ANOVA analysis of variance was used to test for significant difference. Recommendations were also made for better cleanup goals and plants survivals.
Keywords: produced water, phytoremidiation, aquatic macrophytes, water lettuce, water hyacinth, contaminants.

INTRODUCTION

Water production during oil and gas extraction operations constitutes the industry's most important waste streams on the basis of volume (Reynolds Rodney R., 2003). Produced water is any water that is present is a reservoir with hydrocarbon resource and is produced to the surface with crude oil or natural gas. In Nigeria, an estimated volume of about one billion barrels of water are disposed annually from oil and gas production operations. In offshore Niger Delta, produced water are normally pumped through slotted pipelines under the surface water, while for onshore operations, produced water are stored in detention pits before being discharge into the environment. The composition of this effluent contains a significant amount of contaminants which when present in high amount may constitute environmental pollution. In the Niger Delta, before effluents are disposed, the Department of Petroleum Resources (DPR) requires the composition of produced water to be within the permissible limits depicted in Table 1. However, produced water discharge into the environment in the Niger Delta is yet to meet these pre-disposal regulatory limits. Phytotechnologies involving use of plants for pollutants removal gained importance during the last two decades. Contaminants such as petroleum hydrocarbons, heavy metals, pesticides and solvents have been rendered less harmful in phytoremediation. It is considered a natural, cost-effective and non-environmental destructive technology as opposed to conventional cleanup methods. The application of aquatic macrophytes in the remediation of these contaminants will be employed without the conventional use of fertilizers and to compare their effectiveness in the cleanup. In this study, a review of literature was conducted on the relevance of aquatic macrophytes in contaminated water remediation. After that a local survey was done and two aquatic weeds were selected for the study i.e. *Pistias stratiostes* (water lettuce) and *Eichhornia crassipes* (water hyacinth). The selected plants were free floating hydrophytes.

Table 1: Effluent Water Discharge Limits in Nigeria

Effluent Characteristics	Inland Area	Near Shore	Offshore
pH	6.5 – 8.5	6.5 – 8.5	No limit
Temperature ^{o}C	25	30	- -
Oil/Grease Content	10	20	40
Salinity	600	2,000	No limit
Turbidity	> 10	> 15	- -
Total Dissolved Solid	2,000	5,000	--
Total Suspended Solid	> 30	>50	--
CO D	10	125	--
BOD	10	125	--
Lead	0.05	No limit	--
Iron	1.0	No limit	--
Copper	1.5	No limit	--
Chromium	0.03	0.05	--
Zinc	1.0	5.0	--
Sulphide mg/l	0.2	0.2	0.2
Sulphate SO_4^- mg/l	200	200	300
Mercury mg/l	0.1	-	--
Turbidity	10 NTU	10 NTU	10 NTU

Source: DPR, 1991

PROCEDURES

Produced Water Source

The produced water was collected from one of the detention pits, onshore Niger Delta whose source is obtained from various flow stations.

Experimental Set Up:

The aquatic plants which were grown in fresh water ponds were removed from the ponds; excess water was allowed to drain off and the plants were weighed. Approximately three kilograms (3kg) of each species were introduced into each experimental pond containing approximately 250 litres of the produced water, Figure 10.

Site Description:

The study was carried out at the Department of Chemical Engineering, University of Benin. The site was designed by digging two experimental pits of dimensions (40cm x 60cm x 100cm) of which 250 litres of the produced water was introduced Figure 10. The pits were cemented and secured while the control setup was a plastic bucket containing 30 litres of produced water.

METHODS

Sampling

All the collected samples were preserved in accordance with guidelines and International Standards.

All other QA/QC procedures relevant to sample collection and analyses were strictly adhered to (American Public Health Association, APHA; and American Society for Testing and Material Standard, ASTM).

Physico-Chemical and Biological Analysis of Produced Water

The following parameters were used for the analysis: pH: Glass electrode method (ASTM D 1979); Conductivity, EC: Conductivity Meter (Jackson 1967); Turbidity: Hach Turbidimeter (ASTM 1979); Salinity: Mohr's Method; Total Dissolved Solids, TDS: ASTM 1979; Total Suspended Solids, TSS: (ASTM D 1868); Dissolved Oxygen, DO: Modified Winkler's Modified (APHA 1995); Biochemical Oxygen Demand, BOD: (APHA 1995); Chemical Oxygen Demand, COD: (ASTM D 1225); Sulphate: (APHA 427 C); Phosphate: (APHA 425 C); Ammonia, NH_3:(ASTM D 3867); Oil and Grease: (ASTM D 3921); Heavy Metals: [(Iron Fe, Copper Cu, Lead Pb, Chromium Cr, Zinc Zn) (Unicam 929 Atomic Absorption Spectrometer, AAS)]; Total Coliforms: (APHA 9216C).

RESULTS AND DSCUSSION

Visual Observation:

The leaf margins of water hyacinth and water lettuce plants in the produced water started crisping and browning by the end of the first two weeks of the experiment and became necrotic before finally wilting by the end of the sixth week. These signs were first seen on the older leaves and then progressed to the younger ones.

In addition, the presence of green algae was detected in the water hyacinth and water lettuce samples. The presence of these algae in the treated samples changed the colour of the wastewater from light brown to dark green over the six weeks period. However, in the control (untreated) sample, the light brown colour of the produced water was changed to pale brown due basically to the settling of particulate matter.

Table 2: Physico-Chemical Parameters of Produced Water.

Parameters	**Control**	**Water hyacinth**	**Water lettuce**
pH --	8.45 ± 0.0000	7.61 ± 0.1500	7.60 ± 0.0550
EC (µS/cm)	1730.85 ± 3.850	1322.80 ± 5.800	1372.15 ± 3.115
TDS mg/l	866.85 ± 0.850	659.75 ± 5.450	525.65 ± 1.350
TSS mg/l	383.15 0± 1.850	348.385 ± 3.285	365.61 0± 0.030
Salinity mg/l	700.465 ± 3.3355	444.965 ± 0.9250	460.670 ± 3.950
Turbidity mg/l	0.762 ±0.0035	0.814 ± 0.2775	0.904 ± 0.3460
DO mg/l	3.63 ± 0.3495	1.23 ± 0.8650	1.44 ± 0.9800
BOD mg/l	547.41 ± 0.034	448.73 ± 43.455	454.8 0± 29.430
COD mg/l	1031.67 ± 3.930	843.21 ± 3.725	875.3 ± 8.815
Sulphate mg/l	4.4 ± 0.1670	3.1 ± 0.7225	3.4 ± 05615
Phosphate mg/l	2.32 ± 0.205	1.75 ± 0.350	2.10 ± 0.300
Ammonia mg/l	0.801 ± 0.0395	0.642 ± 0.102	0.703 ± 0.0575
Oil & Grease mg/l	0.552 ± 0.0180	0.453 ± 0.0045	0.501 ± 0.0495
Cu mg/l	0.152 ± 0.000	0.163 ± 0.0085	0.155 ± 0.0005
Pb mg/l	0.265 ± 0.0160	0.161 ±0.0110	0.236 ± 0.0395
Cr mg/l	0.262 ± 0.0085	0.204 ± 0.0425	0.236 ± 0.0135
Zn mg/l	1.39 ± 0.0815	1.46 ± 0.1978	1.36 ± 0.1797
Fe mg/l	5.697 ± 0.012	2.902 ± 0.636	3.153 ± 0.503
Total Coliform cfu/ml	255500 ± 7500	338000 ± 38000	273500 ±61500

*Note: Values are Means ± Standard Deviation.

Data taken during six weeks of this study are presented and discussed. The variation in physico-chemical parameters of the produced water are presented in Table 2. The interpretation of data has been made with the help of Microsoft Excel statistical tools. All parameters were measured at ambient temperature of 81 ^{o}F.

pH: The pH of the produced water was as high as 8.45 before the treatment and as low as 7.60 after treatment and it was found to be within the limits of regulatory authority, (DPR) Fig.1. There was gradual reduction in pH in the sample containing water hyacinth. However, in the sample with water lettuce, there was slight increase in pH. This slight increase in pH could result from the photosynthetic activities of perphyton and phytoplankton communities or algae which depleted dissolved CO_2 from the water and raised the water pH (Reddy and DeLaune, 2008). Generally a pH range of 5.5 - 7.0 provides the most satisfactory or balanced plant nutrient levels for most plants. An optimum pH ranges of 6.5 -7.5 and 5.8 – 6.0 were reported for water hyacinth (El – Gendy et al., 2004; Hao and Shen, 2006). One-way analysis of variance ANOVA shows that a significant ($p < 0.01$) difference exist in the mean values of both samples.

Salinity: The tolerance of aquatic macrophytes to salinity will directly influence their performance in water treatment as decrease in transpiration and total dry weight will occur with increasing salinity and death at chronic salinity level (Haller et al., 1974). In this study, mean salinity values ranged from 700.5 mg/l before treatment to 405mg/l after treatment Fig. 2. ANOVA analysis revealed that the experimental machrophytes caused significant ($p < 0.0001$) decrease in both experimental pits.

Heavy Metals: Because of the great availability of soluble ferrous iron species in the anoxic conditions (Ponnanperuma, 1972) and leakage of oxygen O_2 from the roots of aquatic macrophytess (Amstrong, 1979) Fe tend to precipitate in the oxidized zone of root surface, forming Fe oxyhydroxides as coatings on roots, which is often termed iron plaque and has been widely observed in aquatic macrophytes and terrestrial plants when subjected to flooding (Crowder and St-Cyr, 1991; Hansel et al., 2001; Otte et al., 1998; Ye et al., 1997). Once formed, the large surface area of the metal plaque provides a reactive substrate to sequester metal such as Zn, Cu, Ni. In this study, the mean concentrations of the heavy metals were above DPR permissible limits. ANOVA analysis shows that there is significant ($p < 0.05$) decrease in the mean values of water hyacinth samples in all the heavy metals with the exception of zinc where there is no significant difference. Also, significant difference at ($p < 0.05$) existed in the mean values of water lettuce, Fig. 3.

Oil and Grease: Oil and grease may influence wastewater treatment systems. If present in excess amount, they may interfere with aerobic and anaerobic biological processes and lead to decrease wastewater treatment efficiency. When discharged in wastewater or treated effluents, they may cause surface films and shoreline deposits leading to environmental degradation (Greenberg et al., 1992). In the present study, mean values of oil and grease were below regulatory authority (DPR) limits. ANOVA analysis shows that significant

($p < 0.05$) difference existed in oil and grease in the sample with water hyacinth while there was no significant ($p > 0.05$) decrease in the sample with water lettuce, Fig. 4.

Dissolved Oxygen, DO: Table 2 shows the variation of DO of the produced water samples. These values were seen to be below the stipulated limits. The reason for low DO could be attributed to higher nutrient load and variations in temperature, salinity, photosynthetic activities of algae and plants, and atmospheric pressure (Chapman et al., 1992). Low level of DO is detrimental to aquatic fauna. ANOVA analysis indicated that there were no significant ($p > 0.05$) difference in the means of both experimental samples, Fig. 5.

Biochemical Oxygen Demand, BOD: For BOD5 samples were immediately processed after collection for the

determination of initial O_2 and incubated for 5 days for the determination of BOD5. Mean variations of BOD are shown in Table 2 and plotted in Fig.6. The value of BOD in the untreated effluent is however greater than the permissible discharge limits in Nigeria (DPR, 1991). The high value of BOD could be attributed to the high quantities of heavy metals, inorganic salts, oil and grease etc., all these components contribute largely towards the high BOD demand. Trevedi et al., 1986.ANOVA shows that there was no significant ($p > 0.05$) difference in BOD measured in the experimental samples.

Chemical Oxygen Demand, COD: Variation of COD is shown in Table 2. The mean value however was greater than the minimum stipulated limits of effluent discharge in Nigeria, (DPR, 1991). ANOVA reveals that significant ($p < 0.01$) decrease in COD was noticed in the mean values of the experimental samples Fig.7.

Total Suspended Solids, TSS: Suspended solids do not mean that they are floating matters and remain on top of the produced water layer. They are under suspension and remain in water sample. TSS plays an important role in water and waste water treatment. Their presence in water samples cause depletion of O_2 level. In this study, TSS values were greater than regulatory authority in Nigeria. The values of TSS are shown in Table2 and plotted in Fig.8. ANOVA analysis of variance shows that there was significant difference in both experimental samples at ($p < 0.01$). TSS is important in an important parameter for designing wastewater treatment plant and the length of time for which wastewater should be retained for primary treatment.

Total Dissolved Solids, TDS: Total dissolved solids TDS, are the solids contained in the filtrate that passes through a filter with a normal pore size of 2 micrometer or less. Wastewater contains high fraction of dissolved solids. The size of colloidal particles in waste water is typically in the range from 0.01 to 1.0 micrometer, (APHA, 2005). In the present study, TDS values were below regulatory limits in Nigeria Table 2. Mean values of TDS are plotted in Fig. 9 and ANOVA shows that that there were significant difference in both water hyacinth and water lettuce at ($p < 0.01$). *Electrical Conductivity, EC:* The electrical conductivity of water is a measure of a solution to conduct electric current. The conductivity of water is one of the important parameter used to determine the suitability of water for irrigation. It is useful indicator for water salinity or total salt content of wastewater. In this study, the variations of mean conductivity values for the three samples are shown in Table 2. Maximum value of EC was 1730 ± 3.850µS/cm in the control. This value was reduced by water hyacinth and water lettuce to 1322 ± 5.800 and 1372 ± 3.115 respectively. There is a relationship between the variables and conductivity which might be due to leaching of secondary salts and dissolved elements in the produced water (Onojake, 2011). Analysis of variance shows that significant difference at ($p < 0.01$) existed in the means of both aquatic macrophytes.

Turbidity: Turbidity values were seen to increase. This may be due to suspended solids and green algae present in the treatment ponds. Knowledge of turbidity variation in water measurement is of prime importance to water treatment operation because it is in conjunction with other information to determine whether a supply requires special treatment by chemical coagulation and filtration before it may be used for public purpose (Clair N.S, et al., 1992). Turbidity is also delirious to aquatic organisms and may cause anaerobic conditions. It can interfere with respiration in aquatic fauna and also screen out light hindering photosynthesis and natural aquatic life. ANOVA analysis of variance reveals that there was no significant ($P > 0.05$) difference in the means of both aquatic macrophytes.

Analysis of Sulphate: Sulphate (SO_4^{2-}), is one of the major cation occurring in natural water. Sulphate being a stable, highly oxidized, soluble form of sulphur and which is generally present in natural surface and ground waters. Sulphate itself has never been a limiting factor in aquatic systems. The normal levels of sulphate are more than adequate to meet plant needs. When water is loaded with organic waste to point that oxygen is removed then sulphate as electron acceptor is often used for breakdown of organic matter to produce H_2S and produce rotten egg smell (Welch, 1980). In the present study, the mean value of sulphate in the untreated effluent was 4.4 ± 0.167 mg/l and that of treated effluent for water hyacinth and water lettuce was 3.1 ± 0.7225 mg/l and 3.4 ± 0.5615 mg/l respectively and the values were all within the permissible limits of 10 mg/l according to DPR, 1991. ANOVA analysis shows that there was no significant difference ($p > 0.05$) in sulphate for both water lettuce and water hyacinth.

Phosphate (PO_4^{3-}): Phosphate occurs in natural waters in low quality as many aquatic plants absorb and store phosphate many times their actual immediate needs. Low concentration of phosphate affects the growth of aquatic flora as it is very essential plant nutrient. The amount of phosphate is probably due to the presence and decomposition of aquatic vegetation releases phosphate. In the present study, the mean values of phosphate for untreated produced water was 2.32 ± 0.205 mg/l while for the treated produced water containing water hyacinth and water lettuce were 2.10 ± 0.350 mg/l and 1.75 ± 0.300 mg/l respectively. ANOVA analysis shows that there was no significant difference ($p > 0.05$) for both water lettuce and water hyacinth. Also these values were within the permissible limits of 5 mg/l according to DPR, 1991.

Ammonia (NH_3): Ammonia reaches reservoir through diverse sources, major contributor being domestic waste. Ammonia is very important parameter because its final biochemical oxidation gives rise to nitrates, which is again important in drinking water supply for health in humans and animals. In the present comparative study, the mean values of ammonia in untreated produced water was 0.801 ± 0.0395 while for the treated water containing water hyacinth and water lettuce were 0.642 ± 0.102 and 0.703 ± 0.0575 respectively Table 2. ANOVA analysis however reveals that there was no significant difference ($p > 0.05$) in the analysis of variance.

Total Coliform: The luxurious growth of bacterial population during summer and monsoon months is the outcome of the influx of washed organic matter in the produced water reservoir from the surround forest areas. It is natural that the incoming nutrient load finds its way first to the surface, thereby encouraging bacterial proliferation during summer. Collins (1963) has suggested that rains bringing in particulate matter, which serves as sites of adsorption for bacteria, thereby, increasing the bacterial load. In the present study, the mean number of total coliform bacterial for the untreated produced water was 255, 000 $\pm$7,500 cfu/ml while for the treated samples containing water lettuce and water hyacinth were 273, 500 $\pm$61500 cfu/ml and 338, 000$\pm$38000 cfu/ml respectively. The increased total coliform in both treated samples may be due to dead organic matter and green algae. Analysis of variance, ANOVA shows that there was significant difference at ($p > 0.05$) of total coliform in the mean of water lettuce. However, water hyacinth made a significant ($p < 0.001$) decrease in total coliform.

CONCLUSION

In this comparative study, two aquatic macrophytes- water hyacinth (*Eichhornia crassipes*) and water lettuce (*Pistias stratiostes*) were avaluated for their effectiveness. The produced water used in this study is yet to meet standard regulatory authority. Data obtained from this six weeks study shows that using water hyacinth and water lettuce improved water quality by decreasing total solids. However water turbidity value increased due to deposition of dead organic matter and growth of algae. Growth of water hyacinth and water lettuce was limited. High salinity levels appear to be the principal reason for inhibited growth, along with the presence of uncharacterized soluble compounds making up a significant fraction of the produced water soluble chemical oxygen demand (SCOD).In terms of physical cal parameters such as EC, turbidity, TDS, TSS and oil and grease, water hyacinth made a better reduction than water lettuce. Comparing the chemical parameters like pH, alkalinity, DO, COD, BOD, ammoniacal nitrogen, phosphate, sulphate, and heavy metals, again, water hyacinth displayed better absorption. Microbial parameters such as coliform (total and feacal) however, were seen to increase in values. This can be attributed to deposition of dead organic matter. These dead organic matters encourage the proliferation of fungal, bacterial and algal population. It is worthy however to note that among the nineteen parameters analyzed in this study, water hyacinth was able to reduce fourteen parameters while water lettuce reduced three parameters. The above comparative study has led to the conclusion that water hyacinth is a better candidate than water lettuce in the remediation of produced water.

Constructive Recommendations: For efficient produced water remediation,

- Aquatic macrophytes should be supplemented with fertilizers such as NPK.
- Grown-up plants and dead plant biomass must be removed in order to keep an optimum plant density and to prevent the return of contaminants into the produced water sample due to decomposition processes (Brix, 1997).
- In the alternative to using fertilizers, partially dead plants and grown-up plants can be removed and replaced with new and younger plants since these aquatic macrophytes are relatively abundant in our coastal waters until desirable clean-up is achieved.

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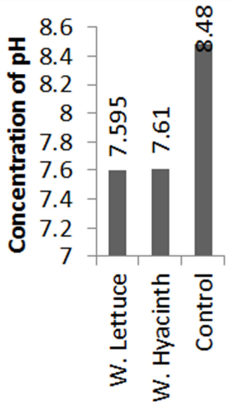

Fig. 1 pH

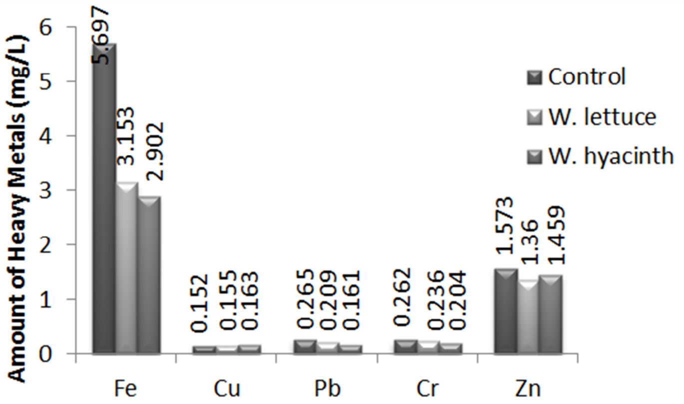

Fig. 3 Heavy Metals Removal

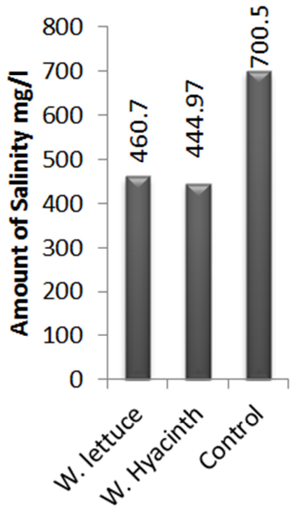

Fig.2 Salinity

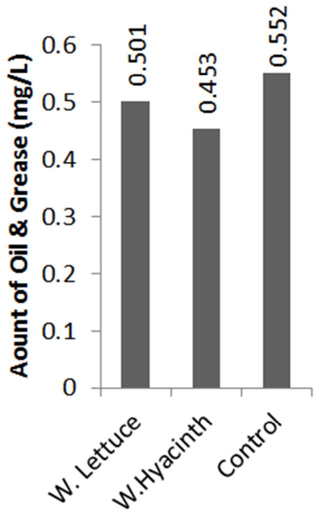

Fig.4 Oil and Grease

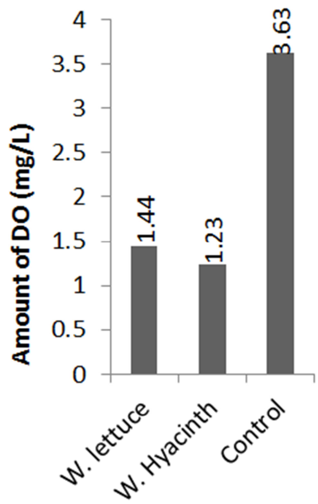

Fig.5 Dissolved Oxygen

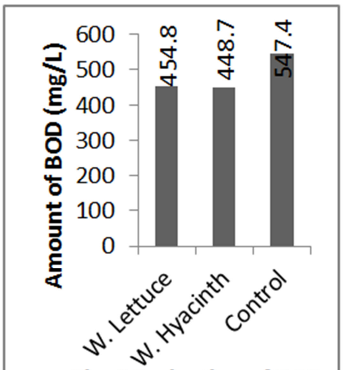

Fig. 6 Reduction of BOD

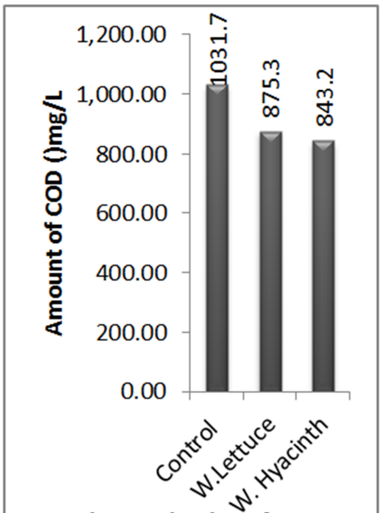

Fig.7 Reduction of COD

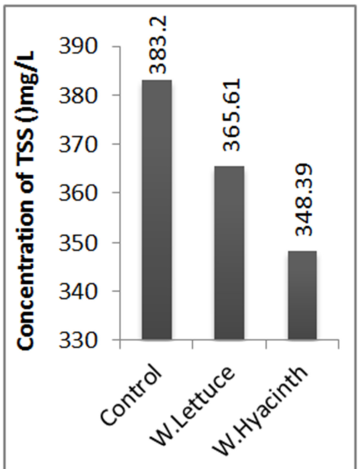

Fig.8 Reduction of TSS

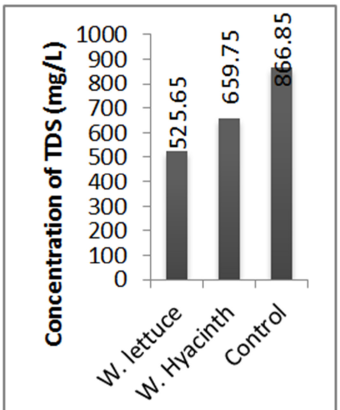

Fig.9 Reduction of TDS

(A) (B) (C)

Fig.10 Experimental Set Up: A: Control; B: Water Hyacinth; C: Water Lettuce

REFERENCES

APHA, American Public Health Association. 1999. *Standard Methods for the Examination of Water and Wastewater.*

ASTM, *Annual Book of America Society for Testing and Materials Standards*. (1979) 1527, Philadelphia.

Brix, H., 1997. Do Macrophytes Play a Role in Constructed Treatment Wetlands. *Water Sci. Tech* 35(5):11 - 17.

Chapman D., Kimstach V. (1992). The Selection of Water Quality Assessment (Chapman, D. Ed.) Chapman and Hall Ltd., London pp. 51-119.

Clair, N.S., Perry L.M., and Gene F.P. (1998) Chemistry of Environmental Engineering and Science. 5th ed. McGraw-Hill Companies Inc.

Collins V.G. (1963) The Distribution and Ecology of Bacteria in Fresh Water. *Proc. Soc. Wat. Treat. Exam.* 12:40-73.

Crowder, A. and L. St-Cyr. (1991) Iron Oxides Plaques on Wetland Roots. *Trends in Soil Sci*. 1:315-329.

DPR. Department of Petroleum Resources, (1991) Environmental Guidelines and Standards for the Petroleum Industry in Nigeria. Production and Terminal Operations. Department of Petroleum Resources, Ministry of Petroleum Resources, Lagos.

Greenberg, A. E., Clesceri L. S. and Eaton A. D. (1992) Oil and Grease 5520 *Standard Examination of Water and Wastewater, pp 5/24ff. Aerican Public Health Association, American Water Works Association, Water Environmental Federation.* Washington D.C.

Haller, W. T., D.L. Sutton, and W. C. Balowe, (1974) Effects of Salinity on Growth of Growth of Several aquatic Macrophytes. *Ecology* 55: 891-894.

Hansel, C.M., S. Fendersf, S. Sutton, and M. Newville. (2001) Characterization of Iron Plaque and Associated Metals in the roots of Mine-Waste Impacted Aquatic Plants. *Environ. Sci. Technol*. 35:3863-3868.

Onojake, M. C., 2011. J. Water Qual. Expo Health 3:91-99

Otte, M.L., J. Rozema, L. Koster, M.S. Haarsma, and R.A.Brockman. (1989) Iron Plaque in Roots of Aster tripolium L.: Interaction with Zinc Uptake. *New Phytol*. 111:309-317.

Reddy, K.R., and R.D. DeLaune, (2008) Biochemistry of Wetlands, *Science and Applications*. CRC Press Boca

Raton.

Reynolds, R.R., and R. D. Kiker, (2003) Produced Water and Associated Issues- A Manual for the Independent Operator, *Okclahoma Geological Survey Open File Report 6-200;* Prepared for the South Midcontinent Region of the Petroleum technology Transfer Council.

Trivedi, R. K., Khatarker S. B., Goel P. K., (1986) Characterization, Treatment and Disposal of Wastewater in a Textile Industry. *Ind. Poll. Cont*. 2(1): 1-12

Ye, Z.H., A.J.M. Baker, M.H. Wong, and A.J. Yang, G.C. Chen, P.J. Steffela, and C.A. Powell. (2008) Temporal and Spartial Variations of Nutrients in the Ten Mile Creek of South Florida, USA and Effects of Phytoplankton Biomass. *Journal of Environmental Monitoring* 10: 508-516.