Effects of crude oil treatment on the morphology and performance of water hyacinth (Eichhornia crassipes (Mart) Solms) in Niger-Delta region of Nigeria

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INTRODUCTION

Coastal marshes are important ecosystems because of their high biological productivity and role as nurseries for coastal fishes, habitat for wildlife, flood mitigation, shoreline protection from erosion, and water quality enhancement (Mitsch and Gosselink, 2007). However, these important functions are at risk in areas such as the oil-rich Niger Delta region of Nigeria, where crude oil exploration, production, transportation and refining are extensive, and the potential for oil spill is consequently high (Njoku et al., 2009). According to U.S Environmental Protection Agency (USEPA, 2007) “Oil released threaten public health and safety by contaminating drinking water, causing fire and explosion hazards, diminishing air and water quality, compromising agriculture, destroying recreational areas, and wasting non-renewable resources. Oil spills also have a severe environmental impact on ecosystems by harming or killing wildlife and plants, and destroying habitat and foods (Lijuan, 2012). They can influence an ecosystem directly or indirectly (Lijuan, 2012). The social and economic lives of people living in such communities are also affected because their rivers and other water bodies can no longer sustain aquatic life and so their primary source of livelihood is affected (Ochekwu and Madagwa, 2013). Ochekwu and Madagwa (2013) also posited that they (people in oil polluted areas) can no longer drink or swim in their river as they used to and this affect their social life.

In Nigeria, the major cause of crude oil pollution is as a result of pipeline vandalization by saboteurs (individuals and group)
seeking government attention to correct economic marginalization and ecological disaster occasioned by many years of unregulated crude oil exploration and exploitation by foreign companies (Nwilo and Badejo, 2006). This has led to loss of species diversity, loss of habitat, destruction of breeding grounds of aquatic organisms and sometimes death of organisms including man (Ndimele, 2008). Many persons/group have however faulted the claims by oil companies that most oil spill is due to sabotage (Anonymous 2014a). They rather posit that poor maintenance of oil infrastructure, equipment failure, sabotage of oil infrastructure, theft of oil and illegal refining all contributes to oil pollution in the region (Amnesty 2009; Anonymous 2014a).

The basis for the claim is the outcome of oil spill investigation in the Niger Delta region (Anonymous 2014a). The investigation process has been the subject of community complaints over many years, with allegations that the process lacks transparency, does not always comply with national law and standards and the data recorded in oil spill investigations forms are inaccurate. Conventional oil spill counter measure of physical, chemical and biological methods have been used over time (Ochekwu and Madagwa, 2013). Commonly used physical methods include booming and skimming, manual removal (wiping), mechanical removal, water flushing, sediment relocation and tilling (Ochekwu and Madagwa, 2013). Chemical methods involve the use of dispersants and this has done more damage to the aquatic ecosystem than the crude oil itself (Lin and Mendellesohn, 1998; Anukwuoruji et al., 2012; 2013; 2016). Also, biological method (Bioremediation) uses naturally occurring organisms to break down hazardous substances into less toxic or non-toxic substance (Anonymous, 2014b; Kumar et al., 2018). Some examples of bioremediation related technologies are phytoremediation, bioventing, biodeashing, landfarming, bioreactor, composting, bioaugmentation, rhizofiltration, and biostimulation. Several aquatic plants have been shown to have the ability to filter contaminants on polluted water (Brooks and Robinson, 1998; Kumar et al., 2016). Some aquatic plants accumulate metals and many species suffer phytotoxicity while others grow easily in the presence of metals (Ochekwu and Madagwa, 2013).

In the majority of studies, grasses and legumes have been singled out for their potential in this regard (Qui et al., 1997; Gunther et al., 1996; Reilley et al., 1996). However, studies have shown that Eichhornia crassipes in crude oil contaminated water affects the physico-chemistry of the water thereby enhancing degradation of crude oil (Ochekwu and Madagwa, 2013). Eichhornia crassipes (Mart) Solms-Lamb (Family Pontederiacea) a monocot, commonly known as water hyacinth, is a floating aquatic plant with inflated petioles native to the Amazon basin, and it’s often considered a highly problematic invasive species outside its native range (Anonymous, 2015a; Hutchinson and Dalziel, 1968). Water hyacinth (Eichhornia crassipes) is an invasive species that has changed the functioning of the ecosystem (Tobias et al., 2019). Reports by so many scientists indicated that water hyacinth alters water quality. In tidal systems, such as the Delta, water moves back and forth through the water hyacinth patch so water quality directly outside the patch in either direction is likely to be impacted. The intricate and distinctive characteristics of water hyacinth make it one of the most ecologically resilient aquatic plants enabling it to invade major water systems (Chapungu et al., 2018). The E. crassipes was introduced into the Nigerian coastal waters in September 1984 from Port Novo creek (Benin Republic) and has continued to flourish (Inyang et al., 2015). The plant has subsequently invaded and established itself on the waterways of Niger Delta oil rich region of Nigeria (Anonymous, 2015a; Akinyemiju, 1987). Some of the fastest growing plants known, water hyacinth reproduces primarily by way of runners or stolons, which eventually form daughter plants (Anonymous, 2015a). The roots of E. crassipes naturally absorb pollutants, including lead, mercury and strontium-90, as well as some organic compounds believe to be carcinogenic, in concentrations 10,000 times that in the surrounding water (Anonymous, 2015a). Water hyacinth is sometimes cultivated for waste water treatment (Anonymous, 2015a) and has been used for environmentally sustainable phytoremediation of water, though its use has been geographically restricted (Jones et al., 2018) hence the need for this study. Also, several successful researches have been carried out to determine the potentials of E. crassipes to clean-up crude oil contaminated sites (Ochekwu and Madagwa, 2013; Udeh et al., 2013). Its phytoremediation potential therefore cannot be overemphasized.

Therefore, Eichhornia crassipes is among the plants that maintain the biological diversity of coastal areas and is useful in filtering the environment. But oil pollution seems to be negatively affecting it adversely. The aim and objective of the present study is to investigate the growth in change and performance of E. crassipes grown in crude oil contaminated environment and to determine the extent of E. crassipes tolerance to toxicity with a view to inferring their possible use in phytoremediation.

**MATERIALS AND METHODS**

**Sampling area**

Crude oil sample was collected from Shell Petroleum Development Company, Uzere flow station. The experimental plant was collected from Ase River in Ndokwa-East local Government area of Delta state, a boundary town with Uzere.

**Plant collection**

The plant was collected by hand. The study was carried out in a screen house. They were transferred into buckets filled with measured amount of water. The plant, Eichhornia crassipes (Mart) Solms-Lamb (Water hyacinth) was authenticated by a taxonomist, Prof C.U Okeke of Botany Department, Nnamdi Azikiwe University, Awka.

**Preparation of samples**

Ten litres of water from Ase River were poured into thirty different 15 litres containers. Various concentrations of crude oil were administered into the bowls. The treatment used include: 1.25%, 2.5%, 5%, 7.5% and 10%, respectively. The control, 0ml had no crude oil on it. The treatments were replicated 3 times.
The test plant, *E. crassipes* was introduced into each container a week after pollution.

**Plant performance**
The performance of the *E. crassipes* plants was measured using height, number of leaves, leaf area, fresh weight and dry weight.

**Determination of height of plants**
This was done on weekly bases. First a base marked and a string attached. Each week a metre rule was placed at the base and measurement of the plant height was taken and recorded. The height of *E. crassipes* was determined by measuring from the base level to the tip of terminal leaf (Omosun *et al.*, 2008). This was done for 8 weeks.

**Determination of leaf area**
Leaf area of *E. crassipes* plants was got by applying the tradition-al short cut field method by first getting the actual leaf area through taking the entire leaf perimeter and plotting this against leaf length × leaf breadth readings. The slope was used as the multiplying factor for subsequent leaf breadth × leaf length readings. This gave the leaf area for all leaves that sprouted (Pearce *et al.*, 1975).

**Determination of number of leaves**
On weekly bases, the numbers of leaves were counted. Careful notes were taken of new sprout and flowering.

**Determination of weight of plants**
In order to determine the fresh weight of the *E. crassipes* plant, samples were weighted on a scale with 0.0001g readability and after drying at 100°C for 24hr (till constant weight), dry weight were determined.

**Data analysis**
The data collected in this research was subjected to independent sample effect and one-way analysis of variance (ANOVA). The Duncan multiple range tests were used for means separation.

### RESULTS AND DISCUSSION

#### General observation
The health of *E. crassipes* was adversely affected at exposure to increasing crude oil treatments. Chlorosis of leaves, plant dehydration, stunted growth and death of the growing point was the effect of exposing *E. crassipes* to increasing concentration of crude oil. Another striking observation is the flowering of *E. crassipes* in treatment 5% at 6 weeks of planting.

#### Effect of crude oil treatment on the growth of *E. crassipes*
Results of the effect of different concentrations of crude oil on the stem height of *E. crassipes* revealed an increase in the length of control plants as well as those treated with 1.25%, 2.5% and 5% crude oil. Nevertheless, the growth rate of the control was highest (6.02±0.028 to 7.56±0.028). There was death of *E. crassipes* in 7.5% and 10.0% concentration of crude oil from the 6th week (Table 1), this agrees with the documentation of Ochekwu and Madagwa, (2013) who reported that a significant increase in the morphological parameters (plant height, number of leaves and leaf area) of *E. crassipes* was observed after 2 weeks and further increase were observed at 4 weeks. At 8 weeks and 12 weeks which the experiment lasted, the growth rate reduced greatly. Analysis of variance showed a significant (P<0.05) difference in the weekly stem height of *E. crassipes* between concentrations of crude oil (Table 1).

Results of the effect of different concentrations of crude oil on the leaf area of *E. crassipes* showed that the control and 1.25% concentrations induced a weekly increase in leaf area while concentrations of 2.5%, 5.0%, 7.5% and 10.0% showed a weekly decrease in leaf area. The control plants showed changes in leaf area from 30.10±0.007 cm² to 33.70±0.001cm² while 2.5% concentration showed decrease in leaf area from 32.35±0.015 cm² to 12.16±0.002cm². The *E. crassipes* treated with 7.5% and 10.0% crude oil concentrations died 6 weeks following treatment. Analysis of variance showed a significant (P<0.05) difference in the weekly leaf area of *E. crassipes* between concentrations of crude oil (Table 2).

### Table 1. Changes in plant height (cm) of *E. crassipes* as influenced by concentrations of crude oil.

| Crude oil concentration % | 0     | 2    | 4     | 6     | 8     |
|---------------------------|-------|------|-------|-------|-------|
| 0                         | 6.02±0.028 | 6.20±0.001 | 6.90±0.001 | 7.23±0.001 | 7.56±0.028 |
| 1.25                      | 4.32±0.021 | 4.50±0.002 | 4.86±0.000 | 5.11±0.007 | 5.22±0.007 |
| 2.5                       | 8.61±0.014 | 8.71±0.037 | 8.90±0.002 | 9.03±0.035 | 9.10±0.001 |
| 5.0                       | 10.01±0.007 | 10.20±0.004 | 10.25±0.057 | 10.30±0.001 | 10.40±0.006 |
| 7.5                       | 7.01±0.015 | 7.00±0.002 | 5.60±0.004 | -     | -     |
| 10.0                      | 8.52±0.021 | 6.70±0.006 | 6.50±0.000 | -     | -     |

Results are in Mean ± SD; **Significantly different at P<0.05 significance level.
Results of the effect of different concentrations of crude oil on the number of leaf of *E. crassipes* showed that the control plant gave the highest number of leaves as 17.00±1.414 after eight (8) weeks of growth while plants treated with 10.0% of crude oil gave the least number of leaves as 2.00±0.002 after four (4) weeks of growth. Thereafter, plants treated with 7.5% and 10.0% crude oil died so that by the 6th week they lost all their leaves. Analysis of variance showed a significant (P<0.05) difference in the weekly number of leaf of *E. crassipes* between concentrations of crude oil (Table 3).

Results of the effect of different concentrations of crude oil on the fresh weight of *E. crassipes* showed that the control plants gave the highest fresh weight from initial weight of 14.22±0.003g to 62.43±0.009g in week 8 while 10.0% concentration gave the least fresh weight increase from 17.19±0.002g initial weight to 16.28±0.011g in week 4. There was death of *E. crassipes* in 7.5% and 10.0% concentration of crude oil by the 6th week of growth. Analysis of variance showed a significant difference (P<0.05) in the weekly fresh weight of *E. crassipes* between concentrations of crude oil (Table 4).

Again the results revealed that the dry weight of *E. crassipes* of the control plant was the highest with a value 9.62±0.002g after 4 weeks of growth while crude oil treatment, 10%, gave 3.46±0.006g dry weight after 4 weeks of growth. Thereafter, plants treated with 7.5% and 10% died. The control plant increased its dry weight to 12.49±0.006g by the 8th week of growth. Analysis of variance showed a significant difference (P<0.05) in the weekly dry weight of *E. crassipes* between concentrations of crude oil (Table 5).

Table 2. Changes in leaf area (cm²) of *E. crassipes* as influenced by varying concentrations of crude oil.

| Crude oil concentration % | Leaf area (cm²) per age (Weeks) |
|---------------------------|---------------------------------|
|                           | 0     | 2     | 4     | 6     | 8     |
| 0                         | 30.10±0.007 | 32.53±0.009 | 33.56±0.001 | 33.60±0.006 | 33.70±0.001 |
| 1.25                      | 12.21±0.008 | 12.24±0.005 | 12.28±0.008 | 12.29±0.001 | 12.38±0.007 |
| 2.5                       | 32.35±0.015 | 12.81±0.013 | 12.16±0.013 | 12.16±0.012 | 12.16±0.002 |
| 5.0                       | 59.82±0.003 | 59.80±0.011 | 50.47±0.003 | 33.72±0.004 | 32.48±0.001 |
| 7.5                       | 25.43±0.014 | 22.33±0.008 | 20.33±0.012 |           |           |
| 10.0                      | 24.77±0.005 | 21.67±0.012 | 18.06±0.001 |           |           |

Results are in Mean ± SD; **Significantly different at P<0.05 significance level.

Table 4. Changes in fresh weight (g) of *E. crassipes* as influenced by concentrations of crude oil treatment.

| Crude oil concentration % | Fresh weight (g) per age (Weeks) |
|---------------------------|---------------------------------|
|                           | 0     | 2     | 4     | 6     | 8     |
| 0                         | 14.22±0.003 | 33.05±0.004 | 48.09±0.001 | 60.37±0.008 | 62.43±0.009 |
| 1.25                      | 17.53±0.012 | 28.99±0.006 | 40.06±0.002 | 52.38±0.012 | 54.25±0.005 |
| 2.5                       | 19.34±0.001 | 42.66±0.000 | 45.03±0.009 | 47.07±0.001 | 48.88±0.013 |
| 5.0                       | 15.51±0.006 | 37.00±0.001 | 38.59±0.005 | 39.95±0.002 | 40.66±0.011 |
| 7.5                       | 18.22±0.001 | 18.11±0.007 | 18.10±0.013 |           |           |
| 10.0                      | 17.19±0.002 | 19.13±0.002 | 16.28±0.011 |           |           |

Results are in Mean ± SD; **Significantly different at P<0.05 significance level.

Table 5. Changes in dry weight (g) of *Eichhornia crassipes* as influenced by crude oil concentrations during growth.

| Crude oil concentration % | Dry weight (g) per age (Weeks) |
|---------------------------|--------------------------------|
|                           | 0     | 2     | 4     | 6     | 8     |
| 0                         | 2.84±0.001 | 6.61±0.006 | 9.62±0.002 | 12.07±0.002 | 12.49±0.006 |
| 1.25                      | 3.51±0.006 | 5.80±0.002 | 6.02±0.006 | 6.48±0.003 | 6.85±0.003 |
| 2.5                       | 3.87±0.004 | 8.53±0.000 | 11.00±0.001 | 11.41±0.003 | 11.77±0.000 |
| 5.0                       | 3.10±0.002 | 7.40±0.004 | 7.72±0.002 | 7.99±0.001 | 8.14±0.012 |
| 7.5                       | 3.65±0.009 | 6.60±0.006 | 5.43±0.000 |           |           |
| 10.0                      | 3.43±0.003 | 3.43±0.003 | 3.46±0.006 |           |           |

Results are in Mean ± SD; **Significantly different at P<0.05 significance level.
The response of E. crassipes to crude oil contamination showed a reduced plant height, leaf area, number of leaves, fresh weight and dry weight as the concentration (treatment) increased. These results are in line with the report of Bailey and McGill (1999) who stated that plants tolerate increased exposure to crude oil and creosote-contaminated soil with minimal growth rate. Crude oil spills affect plants adversely by creating conditions that make essential nutrients like nitrogen and oxygen needed for plant growth unavailable to them (Wright et al., 1997). According to Erute et al. (2009), oil contamination causes slow rate of germination in plants. Adam and Duncan (1999) reported that this effect could be due to the oil which acts as a physical barrier (hydrophobic layer), preventing or reducing access of the seeds to water and oxygen.

A significant increase in the morphological parameters (plant height, number of leaves, leaf area, fresh weight and dry weight) as observed after two weeks of planting in treated with 1.25%, 2.5%, and 5% agrees with the work done by Ochekwu and Madagwa (2013) on phytoremediation potentials of water hyacinth in crude oil polluted water. Also, the findings that after 6 weeks of growth, E. crassipes treated with 7% and 10% crude oil died is in consonance with Ochekwu and Madagwa (2013) report that in their experiment to determine the phytoremediation potentials of E. crassipes; at 8 and 12 weeks, the growth rate reduced greatly indicating that E. crassipes can hardly tolerate crude oil with time. Frick et al. (1999) had stated that phytoremediation of petroleum hydrocarbons may be ineffective, if concentrations of the contaminants are either too high (causing toxicity) or too low (resulting in poor bioavailability). This statement therefore implies that there is a limit of sustenance of petroleum hydrocarbon pollution for every plant above which toxicity will apply.

The findings that the morphological nature of these plants were tortured especially by loss of chlorophyll and clear chlorosis immediately following crude oil pollution is in line with the general physiology of plants since nutrients absorption such as nitrogen uptake cannot be achieved smoothly. Such minerals are needed for chlorophyll synthesis. This corresponds with Brooks and Robinson (1998) work on aquatic phytoremediation by accumulator plants. Ochekwu and Madagwa (2013) had posited that chlorosis of the leaves may be an implication of the persistent organic compound and heavy metals absorbed by the plant. Pezeszki and Delaune (1992), however, stated that the effect of crude oil on plants could be short term under field conditions, since plants would likely recover once residual oil is removed by rainfall. The observation that E. crassipes plants started flowering 6 weeks at treatment 5% could have been exploited as normal point reaction to stress. According to Kaede and Kiyotoshi (2010), many plant species can be induced to flower by responding to stress factors.

Conclusion

It is evident from the study that E. crassipes have demonstrated promising potential to phytoremediate petroleum hydrocarbons. At a very low concentrations E. crassipes survived for a long period of time, however, high concentration decreases the morphology of the test plant. The ability of the plant to tolerate different levels of petroleum hydrocarbons was also proved in the study. The study however advocates the use of alternative clean-up method in cases of excessively high concentrations of crude oil concentrations before reclaiming with the plant. This also suggests that the test plant can be used in cases with low to moderate crude oil contamination. It also proposes the use of the plant as possible bio-indicator for the detection of crude oil using the plant growth at lower doses as markers. Further assessment of the plant in field situation would be useful.

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REFERENCES

Adam, G.L. and Duncan, H. (1999). Effect of Diesel on growth of selected plant species. Environmental Geochemistry and Health, 21: 353-357.

Akinremi, O.A. (1987). Invasion of Nigerian waters by water hyacinth. Journal of Aquatic Plant Management, 25: 24-26.

Amnesty International (2009). Oil Spill investigation in the Niger Delta. Amnesty International memorandum. http://web.amnesty.org.oilspill. (Cited 20th September 2014).

Anonymous (2014a). Oil Spill. Wikipedia, the free encyclopedia. http://en.wikipedia.org/wiki/oilspill. (Cited 20th November, 2014).

Anonymous (2014b). Bioremediation. Wikipedia, the free encyclopedia. http://en.wikipedia.org/wiki/bioremediation. (Cited 20th November, 2014).

Anonymous (2015a). Eichhornia crassipes. Wikipedia, the free encyclopedia. http://en.wikipedia.org/wiki/Eichhornia_craspides. (Cited 5th January, 2015). Antimicrobial effects of four plant extracts against post harvest spoilage fungi of yam (Dioscorea rotundata Poir). International Journal of Plant and Soil Science, 12 (3): 1-10.

Anukworji, C.A., Putheti, R.B. and Okibgo, R.N. (2012). Isolation of fungi causing rot of cocoyam (Colocasia esculenta (L.) Schott) and control with plant extracts: (Allium sativum, L., Garcinia kola, heckel, Azadirachta indica, L. and Carica papaya, L.). Global Advanced Research Journal of Agricultural Science, 1(1): 33-47.

Anukwuorji, C.A., Anuagasi, C.L. and Okibgo, R.N. (2013). Occurrence and control of fungal pathogens of potato (Ipomea batatas L. Lam) with plant extracts. Journal of Advanced Pharmaceutical Technology & Research, 2(3): 273-289.

Anukwuorji, C.A., Obianuju, C.M., Ezebo, R.O. and Anuagasi, C.L. (2016). Antimicrobial effects of four plant extracts against post harvest spoilage fungi of yam (Dioscorea rotundata Poir). International Journal of Plant and Soil Science, 12(3): 1-10.

Bailey, V.L. and McGill, W.B. (1999). Assessment of the role of plants in the bioremediation of two hydrocarbon-contaminated soils. Proceedings of the phytoremediation Technical Seminar. Environment Canada: Ottawa. 2:87-97.

Brooks, R.R. and Robinson, B.H. (1998). Aquatic phytoremediation by accumulator plants. CAB International, Oxon UK. 226pp.

Chapungu, L., Mudzengi, B. and Mudzengi, L. (2018). Socio-ecological Impacts of Water Hyacinth (Eichhornia Crassipes) Under Dry Climatic Conditions: The Case of Shagashe River in Masvingo, Zimbabwe. International Journal of Environmental Science and Public Health, 2(1): 36-52.

Erute, M.O., Zibigha M. and Odogu. G. (2009). The effect of crude oil on growth of the weed (Passalum scrobiculatum L.) phytoremediation potential of the plant. African Journal of Environmental Science and Technology, 3(9): 229-233.
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Mitsch, W.J. and Gosselink, J.G. (2007). Wetlands. Van Nostrands Renhold, New York. 566p.

Lin, Q. and Mendelssohn, I.A. (1998). The combined effects of phytoremediation and biostimulation in enhancing habitat restoration and oil degradation of petroleum contaminated wetlands. Ecological Engineering, 10: 263-274.

Mitsch, W.J. and Gosselink, J.G. (2007). Wetlands. Van Nostrands Renhold, New York. 566p.

Ndimele, P.E. (2008). Evaluation of phytoremediative properties of water Hyacinth and Biostimulants in Restoration of Oil polluted wetland in the Niger Delta. PhD Thesis, University of Ibadan, Nigeria.

Njoku, K.L., Akinona, M.O and Ojoh, B.O. (2009). Phytoremediation of crude oil contaminated soil: The effect of growth of Glycine max on the physico-chemistry and crude oil contents of soil. Nature and Science, 7(10): 79-87.

Omosun, G., Markson A.A. and Mbanasor, O. (2008). Growth and anatomy of Amaranthus hybridus affected by different crude oil concentration. American Journal of Science Research, 3(1): 70-74.

Pearce, R.B., Mock, J.J. and Bailey, T.B. (1975). Rapid Method for Estimating Leaf Area Per Plant in Maize. Crop Science, 15(3): 691-694.

Pezeshki, S.R. and Delaune, R.D. (1992). Effect of crude oil on gas exchange functions of Juncus roemerianus and S. alterniflora. Water Air and Soil pollution, 68: 461-468.

Quié, X., Leland, T.W., Shah, S.I., Sorenson D.L. and Kendall E.W. (1997). Field study: Grass remediation for clay soil contaminated with polycyclic aromatic hydrocarbons. Phytoremediation of soil and water contaminants. American Chemical Society, 664: 186-199.

Reilley, K.A., Banks, M.K. and Schwab, A.P. (1996). Organic chemicals in the environment: dissipation of polycyclic aromatic hydrocarbons in the rhizosphere. Journal of Environmental Quality, 25: 212-219.

Tobias, V.D., Conrad, J.L. and Mahardja, B. (2019). Impacts of water hyacinth treatment on water quality in a tidal estuarine environment. Biological Invasions, 21: 3479–3490.

Udeh, N.U., Nwaoguzie, I.L. and Momoh, Y. (2013). Bio-remediation of a crude oil contaminated soil using water hyacinth (Eichhornia crassipes) Advances in Applied Science Research, (2): 362-369.