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Bioaccumulation and Phytoremediation of Heavy Metals and Hydrocarbons by Water Hyacinth (*Eichhornia crassipes (Mart) Solms*) Exposed to Water Soluble Fractions of Petroleum Products

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Keywords

Heavy metals; Petroleum hydrocarbons; Water hyacinth; Phytoremediation; Oil spillage.

Abstract

Phytoremediation is an environmental friendly strategy of dealing with oil pollution. When oil spills occurs in aquatic environment, soluble components of spilled oil dissolves in water. This study examined the ability of *Eichhornia crassipes* to bioaccumulate and phytoremediate heavy metals and hydrocarbons in water soluble fractions (WSFs) of crude oil, diesel, gasoline and kerosene. The water soluble fractions (WSFs) were prepared using oil to deionized water ratio of 1:3. The heavy metals and total petroleum hydrocarbons (TPH) concentrations in the WSFs were determined using American Public Health Association (APHA) and American Society for Testing and Materials (ASTM) procedures. The heavy metals present in the WSFs include Fe, Mn, Cu, Pb, Zn, Cr, Cd and Ni. The TPH concentrations were crude oil (14.12 mg/L), diesel (6.34 mg/L), gasoline (4.03 mg/L) and kerosene (2.31 mg/L). The bioaccumulation factor (BCF) of heavy metals in the plants ranged from 866.63 to 3422.01 (Fe), 25.44 to 192.90 (Mn), 46.00 to 831.67(Cu), 88.00 to 1097.00 (Pb), 246.34 to 930.00 (Zn), 53.00 to 69.00 (Cr) and 111.00 to 414 (Cd). The BCF for TPH ranged between 1.37 and 41.88. The heavy metals and TPH were accumulated several times higher than their initial concentration in the WSFs thus indicating that the plant has a potential for phytoremediation.

1.0 Introduction

Internationally, water hyacinth is acknowledged as an invasive species posing a threat to the survival of aquatic organisms. Its extraction from water is typically carried out manually or physically to prevent the secondary water pollution associated with the use of chemically synthesized herbicides for its control, which leads to the generation of solid waste. In addressing this issue, scientists have suggested transforming this waste into adsorbents that can be employed for the purification of water resources. This holds particular significance, given the essential role water quality plays across all aspects of life (Moreno-Rubio et al., 2023).

Several aquatic macrophytes have been recognized to have the ability to bioaccumulate and phytoremediate contaminants in polluted ecosystems (Kuok, 2019; Anwar, 2022). Water hyacinth (*Eichornia crassipes*) is an invasive floating aquatic macrophytes that have invaded the waterways in Nigeria. The plant has been extensively studied for its ability to bioaccumulate contaminants, phytoremediate and remove organics through adsorption (Moreno-Rubio et al., 2023). Since the 1980s, water hyacinth has been recognized for its role in water pollution control (Reddy and DeBusk, 1987). Over time, the biomass of water hyacinth has been identified for its adsorptive capacity in removing metals and organics from water (Ibrahim et al., 2012). Recently, its extensive applications in the removal of organic dyes have gained attention (Wanyonyi et al., 2013). Researchers have approached this by utilizing the native form of water hyacinth in some instances, while others have opted for modified water hyacinth-based adsorbents (Kouraim et al., 2014). In certain cases, it has been reported that two weeks are sufficient for the effective treatment of domestic water using water hyacinth (Rezania et al., 2015). Consequently, several review articles have emerged in the literature, critically examining the potential and benefits of using water hyacinth in phytoremediation (Malik, 2007; Sanmuga et al., 2017).

The Niger Delta in Nigeria is one of the most polluted region in the world, primarily due to crude oil exploration and production activities (Kadafa, 2012; Raji and Abejide, 2013). The causes of this high level of pollution include vandalization of pipelines by oil thieves, sabotage by host communities, accidents and poor maintenance of oil facilities and equipments (Egbe and Thompson, 2010; Oyebamiji and Mba, 2014). According to Oyem and Oyem (2013), over 6000 spills were recorded in 40 years of oil exploration in Nigeria with an average of 150 spills per annum and between 1976 and 1996 about two million barrels of oil was released into the environment. In addition to crude oil, refined petroleum products such as diesel, gasoline and kerosene are also spilled into the environment mainly due to activities of vandals (Okpo and Eze, 2012). Most oil spills in the Niger-Delta occur in aquatic ecosystems leading to pollution of streams and rivers and the need to develop remediation strategies and options. These options include physical control of oil spread, chemical agents or dispersants and bioremediation, which involves the use of living organisms (Zhu et al. 2001; Dave and Ghaly, 2011).

The term water soluble fractions (WSFs) describes the degree of solubility of petroleum components. The solubility of oil in water is extremely low and depends on the composition of the oil, temperature, oil to water ratio and duration of oil to water contact. The constituents of water soluble fractions of oil include cations, anions, heavy metals and low molecular weight hydrocarbons and heavy metals detected in Nigerian blends of crude oil includes Zn, Cu, Pb, Fe, Mn, Cd, Cr, Ni, and V. (Edema et al. 2008; Edema and Okoloko, 2008). This shows that crude oil spills are likely sources of heavy metals pollution in the environment (Akpoveta and Osakwe, 2014; Dickson and Udoessien, 2012). The low molecular weight hydrocarbon found in WSF of petroleum include Benzene, Toluene, Ethylbenzene and Xylene (BTEX). Others include naphthalene and methylated naphthalenes.

Phytoremediation is a plant-based technique employed for the removal or recovery of excess nutrients in contaminated environments. The use of aquatic plants in wastewater phytoremediation proves highly efficient, given their significant capacity for assimilating and degrading contaminants such as nitrates, phosphates, and heavy metals. While phytoremediation is a relatively recent technology acknowledged for its operational efficiency and environmentally friendly nature, it remains in the early stages of development and optimization. Its widespread application is still limited at present. It is crucial to emphasize the need for a clear vision of this innovation, accompanied by the availability of accurate data to the public, as this would enhance its effectiveness as a viable solution on a global scale. Furthermore, phytoremediation has been assessed as a distinct low-tech and environmentally friendly alternative when compared to existing technologies (Mohebi and Nazari, 2021).

The continuous release of heavy metal-contaminated wastewater into the environment poses a serious threat to human health. The utilization of plants for the removal of heavy metals and as bio-sorbents represents a cost-effective, efficient, and environmentally friendly technology. Phytoremediation becomes particularly advantageous when a plant can extract and accumulate specific metal elements from contaminated wastewater. Notably, plant roots play a crucial role in absorbing pollutants, especially heavy metals, leading to an enhancement in water quality (Mohebi and Nazari, 2021).

The effectiveness of the aquatic plant Hyacinth in removing mercury from wastewater has been evaluated (Mohebi and Nazari, 2021). Park et al. (2010) categorized bio-sorbents used for heavy metal removal from wastewater into seven groups: fungi, bacteria, industrial waste, algae, natural residues, agricultural waste, and other biological materials. This underscores the diverse approaches and sources involved in utilizing bio-sorbents for mitigating heavy metal contamination in wastewater. The characteristics of bioaccumulation is very important in phytoremediation of polluted ecosystems by plants. This study investigated the ability of *Eichhornia crassipes* to bioaccumulate and phytoremediate heavy metals and hydrocarbons in water soluble fractions of crude oil, diesel, gasoline and kerosene.

2.0 Materials and Methods

2.1 Study site and materials collection.

The study was carried out at Delta State polytechnic, Otefe-Oghara, Nigeria. *Eichhornia crassipes* (Mart) Solms was collected from streams near river Ethiope in Sapele. Crude oil was collected from Okporhuru oil well in Jesse, Delta state. Diesel, gasoline and kerosene were bought from Total Petrol Station, Sapele.

2.2 Preparation of water soluble fractions (WSFs) of crude oil, diesel, gasoline and kerosene.

Water soluble fractions was prepared using oil to deionized water ratio of 1:3. The mixture was stirred for 24 hours using a magnetic stirrer and then allowed to stand for 3 hours to obtain clear layers of water and oil. The oil was discarded and the remaining mixture poured in a separating funnel and allowed to stand overnight before draining the WSFs into brown capped bottles to serve as 100% WSF. This was diluted with deionized water to give 6.25, 12.50, 25.0% and 50% WSF concentrations.

2.3 Experimental setup.

Five hundred milliters of WSFs of each petroleum product was poured into plastic containers measuring 12cm in height and 9cm in diameter before the plants were introduced. Treatments were in three replicates with deionized water as control. The experiment was observed for 15 days.

2.4 Analysis of Heavy metals.

Samples were digested using a mixture of perchloric, nitric and sulphuric acids in the ratio of 1:2:2 and analysed using Perkins Elmer Atomic Absorption Spectrophotometer (AAS) according to APHA (2011).

2.5 Determination of Total petroleum Hydrocarbon (TPH).

Total petroleum hydrocarbons was extracted from sample using 50:50 solvent mix of acetone and methylene chloride and dried using anhydrous sodium sulphate before subjecting to Spectrophotometer calibrated at 410nm (ASTM, 2010).

2.6 Determination of Bioconcentration Factor (BCF) and Translocation Factor (TF).

BCF and TF were calculated according to Singh *et al.* (2017).

$$BCF = \frac{\text{Concentration of metals/TP in plant}}{\text{Initial concentration of metal/TPH in WSF}} \quad (1)$$

$$TF = \frac{\text{Concentration of metal/TPH in shoot}}{\text{Concentration of metals/TPH in root}} \quad (2)$$

3.0 Results

The heavy metals found in the WSFs are shown in Table 1. The concentrations of heavy metals in WSFs of crude oil are Fe (0.11mgL^{-1}), Zn (0.09 mgL^{-1}), Cu (0.04 mgL^{-1}), Mn (0.12 mgL^{-1}), Cd (0.01 mgL^{-1}), Pb (0.02 mgL^{-1}), and Ni (0.11 mgL^{-1}). Manganese (Mn) had the highest while Cd had the least concentration in WSF of crude oil. The concentrations of heavy metals in WSF of diesel are Fe (0.08 mgL^{-1}), Zn (0.07 mgL^{-1}), Cu (0.02 mgL^{-1}), Mn (0.16 mgL^{-1}), Cr (0.01 mgL^{-1}), Cd (0.01 mgL^{-1}), Pb (0.01 mgL^{-1}) and Ni (0.1 mgL^{-1}). The concentrations of Fe, Zn, Cu, Mn, Cr, Pb, and Ni in WSF of gasoline are 0.08, 0.08, 0.03, 0.28, 0.01 and 0.10 mgL^{-1} respectively. Similarly the concentrations of Fe, Zn, Cu, Mn, Cr, Pb, and Ni in WSF of kerosene are 0.04, 0.06, 0.02, 0.17, 0.01 and 0.11 mgL^{-1} respectively. The concentration of Mn was highest in all WSFs while Cr and Cd had the lowest concentrations, vanadium was not detected in any of the WSFs. The concentration of total petroleum, hydrocarbons (TPH) in the WSFs are crude oil (14.12 mgL^{-1}) diesel (6.34 mgL^{-1}) gasoline (4.03 mgL^{-1}) and kerosene (2.31 mgL^{-1}) (Table 1).

Table 1. Heavy metal and total petroleum hydrocarbon (TPH) content (mgL^{-1}) of WSFs of crude oil, diesel, gasoline and kerosene.

Parameter	Crude oil	Diesel	Gasoline	Kerosene
Fe (mg L^{-1})	0.11	0.08	0.08	0.04
Zn (mg L^{-1})	0.09	0.07	0.08	0.06
Cu (mg L^{-1})	0.04	0.02	0.03	0.02
Mn (mg L^{-1})	0.12	0.16	0.28	0.17
Cr (mg L^{-1})	nd	0.01	0.01	nd
Cd (mg L^{-1})	0.01	0.01	nd	nd
Pb (mg L^{-1})	0.02	0.01	0.01	0.01
Ni (mg L^{-1})	0.11	0.10	0.10	0.11
V (mg L^{-1})	nd	nd	nd	nd
TPH (mgL^{-1})	14.12	6.34	4.03	2.31

Key: nd – not detected.

The bioconcentration factor (BCF) of heavy metals in *Eichhornia crassipes* exposed to 100 % WSFs of crude oil, diesel, kerosene and gasoline are shown in Table 2. The BCF indicate the number of times the concentration of metal accumulated in the plant is higher than the initial concentration of metal in the WSFs. The BCF of Fe, Mn, Cu and Zn in all WSFs ranged from 866.63 to 3422.01, 25.44 to 192.90, 46.00 to 831.67 and 246.34 to 930.00 respectively. The BCF of the metals Fe, Mn, Cu and Zn were higher in roots than in shoots. The BCF of Pb, Cr, Cd and Ni ranged from 88 to 1097.00, 53.00 to 163, 111 to 414 and 0.30 to 15.84 respectively. The BCF of the metals Pb, Cr, Cd and Ni were higher in the shoots than in roots.

Table 2. Bioconcentration factor (BCF) of heavy metal in *Eichhornia crassipes* exposed to 100 % WSF of crude oil, diesel, kerosene and gasoline.

Heavy metal	**Plant Organ**	**BCF**			
		Crude oil	Diesel	Kerosene	Gasoline
Fe	shoot	1197.36	359.00	730.00	923.63
	root	2224.64	507.63	966.75	1408.50
	Total	**3422.00**	**866.63**	**1696.75**	**2332.13**
Mn	shoot	78.40	6.56	11.53	14.25
	root	114.50	18.88	18.18	24.50
	Total	**192.90**	**25.44**	**29.71**	**38.75**
Cu	shoot	46.25	29.50	14.00	289.00
	root	86.50	41.00	32.00	542.67
	Total	**132.75**	**70.50**	**46.00**	**831.67**
Pb	shoot	416.00	68.00	129.00	812.00
	root	223.00	20.00	98.00	285.00
	Total	**639.00**	**88.00**	**227.00**	**1097.00**
Zn	shoot	325.67	97.14	98.17	183.13
	root	604.33	153.14	148.17	334.13
	Total	**930.00**	**250.28**	**246.34**	**517.26**
Cr	shoot	bdl	91.00	bdl	36.00
	root	bdl	72.00	bdl	17.00
	Total	**0.00**	**163.00**	**0.00**	**53.00**
Cd	shoot	327.00	69.00	bdl	bdl
	Root	87.00	42.00	bdl	Bdl
	Total	**414.00**	**111.00**	**0.00**	**0.00**
Ni	shoot	8.42	0.20	0.40	8.70
	Root	7.42	0.10	0.18	4.50
	Total	**15.84**	**0.30**	**0.58**	**13.20**

bdl: below detection level in WSF

Table 3 show the translocation factors (TF) of heavy metals in *Eichhornia crassipes* exposed to WSF of crude oil, diesel, kerosene and gasoline. The TF indicate the proportion of metal accumulated in the shoots compared to the roots. The TF of Fe, Mn, Cu and Zn were below 1 ranging from 0.54 to 0.76, 35 to 68, 0.44 to 0.72 and 0.54 to 0.66 respectively while TF for Pb, Cr, Cd and Ni were above 1 ranging from 1.32 to 3.40, 1.02 to 3.16, 1.64 to 3.76 and 1.13 to 2.22 respectively.

Table 3. Translocation factor (TF) of heavy metal in *Eichhornia crassipes* exposed to 100 % WSFs of crude oil, diesel, kerosene and gasoline.

Heavy metal	TF			
	Crude oil	**Diesel**	**Kerosene**	**Gasoline**
Fe	0.54	0.71	0.76	0.66
Mn	0.68	0.35	0.63	0.58
Cu	0.53	0.72	0.44	0.53
Pb	1.87	3.40	1.32	2.85
Zn	0.54	0.63	0.66	0.55
Cr	3.16	1.26	1.02	2.11
Cd	3.76	1.64	2.00	2.83
Ni	1.13	2.00	2.22	1.93

Table 4 show the bioconcentration factor (BCF) of TPH in ***Eichhornia crassipes*** exposed to WSFs of crude oil, diesel, kerosene and gasoline. BCF of TPH in WSF of crude oil, diesel, kerosene and gasoline ranged between 8.12 and 34.16, 1.90 and 10.80, 5.86 and 22.18 and 1.37 to 13.69 respectively. The BCF of TPH is higher in roots than in shoots and BCF was greater than 1.

Table 4. Bioconcentration factor (BCF) of Total Petroleum Hydrocarbon (TPH) in *Eichhornia crassipes* exposed to WSF of crude oil, diesel, kerosene and gasoline for 15 days.

WSF (%)	BCF			
	Crude oil	**Diesel**	**Kerosene**	**Gasoline**
6.25	34.16	6.67	20.53	13.69
12.50	41.88	10.80	17.84	8.42
25.00	33.70	6.86	22.18	5.94
50.00	15.43	3.80	9.51	3.00
100.00	8.12	1.90	5.86	1.37

The TF of TPH in *Eichhornia crassipes* ranged from **0.33 to 0.51, 0.39 to 0.57, 0.50 to 0.65 and 0.42 to 0.75** for WSF of crude oil, diesel, kerosene and gasoline respectively. The TF of TPH in *Eichhornia crassipes* was less than one (Table 5).

Table 5. Translocation factor (TF) of Total Petroleum Hydrocarbon in *Eichhornia crassipes* exposed to WSF of crude oil, diesel, kerosene and gasoline for 15 days.

WSF (%)	TF			
	Crude oil	**Diesel**	**Kerosene**	**Gasoline**
6.25	0.51	0.57	0.65	0.59
12.50	0.43	0.52	0.52	0.75
25.00	0.38	0.39	0.50	0.79
50.00	0.33	0.51	0.53	0.42
100.00	0.35	0.47	0.60	0.52

4.0 Discussion

The results of this study showed that heavy metals are present in the WSFs and were absorbed by the aquatic macrophyte. The presence of heavy metals in crude oil and refined petroleum products have been confirmed by several studies. This can reveal the source rock of the petroleum. Heavy metals also enter petroleum during storage and transportation (Akpoveta and Osakwe, 2014). The heavy metals bioaccumulated include Fe, Mn, Zn, Cu, Cd, Pb, V and Cr, even when some of the metals were below detection level in the water soluble fractions. The heavy metals were also translocated from the roots to the shoots. This findings are consistent with other studies. The ability of aquatic macrophytes to absorb and translocate heavy metals has been demonstrated by several studies. Victor et al. (2016) demonstrated the ability of *Eichhornia crassipes* and *P. stratiotes* to bioaccumulate Pb, Zn, Cd, Cu and Cr from waste waters. Yabanli et al. (2014) reported the ability of the submerged aquatic macrophyte *Myriophyllum spicatum* to bioaccumulate Pb, Cr, As, Hg and Cadmium. The ability of *Ceratophyllum demersum* to bioaccumulate nickel has also been shown (Chorom et al. 2012). Akapo et al. (2011) also showed that *P. stratiotes* bioaccumulated Mn and Pb when exposed to crude oil. There are very few studies of bioaccumulation of heavy metals using WSFs of petroleum products. The available studies focused on WSFs of crude oil (Edema et al. 2008; Edema and Okoloko, 2008).

This study also observed differences in bioaccumulation of heavy metals between plant root and shoot in *Eichhornia crassipes*. The heavy metals Fe, Mn, Cu and Zn were accumulated more in the roots of *Eichhornia crassipes* than in the shoots while the concentrations of Cd, Pb, and Cr where higher in *Eichhornia crassipes* shoots than in the roots when the plant was exposed to WSF of crude oil, diesel, kerosene and gasoline. This differential accumulation has been reported in some studies. Singh *et al.* (2017) reported higher Cd, Mn and Pb accumulation in shoot than root of *Eichhornia crassipes* harvested from Kanji wetland, India, while Co, Cr, Cu, Fe and Zn accumulated more in the roots than shoots. A study on ability of *Eichhornia crassipes* to absorb and translocate Cd, Pb, Cu, Zn and Ni in wetlands showed that all five metals were bioaccumulated 3 to 5 times higher in roots that in the shoots (Ndeda and Manohar, 2014). The metals Cr and Cd that were not detected in WSFs of crude oil, kerosene and gasoline and V which was not detected in any of the WSFs were bioconcentrated in the aquatic macrophyte *Eichhornia crassipes*. Translocation of heavy metals from roots to shoots depends on plant species, presence of carriers and channels, availability of binding sites, energy, pH, photosynthesis, temperature and metabolic levels (Ndeda and Manohar, 2014; Nwoko, 2010).

The BCF and TF of heavy metals are used to estimate the phytoremediation potential of a plant. While BCF is ratio of metal concentration in the shoots or roots to medium, TF is ratio of metal concentration in the shoots to the roots (Ndeda and Manohar, 2014; Victor et al. 2016). In the present study, maximum BCF in all WSFs concentrations for *Eichhornia crassipes* were Fe (4664.25), Mn (192.90), Cu (1247.50), Pb (1097.00) and Zn (930.00). The maximum TF for *Eichhornia crassipes* were Fe (0.76), Mn (0.68), Cu (0.72), Pb (3.40) and Zn (0.66) Bioconcentration factor for (Fe), Copper (Cu) and Lead (Pb) are above 1000 while only Pb, Cr and Ni had TF above 1. The BCF for *Eichhornia crassipes* was in the order Fe > Cu > Pb > Zn > Mn while TF was in the order Pb > Fe > Cu > Mn > Zn.

The uptake and accumulation of total petroleum hydrocarbon (TPH) from WSFs of crude oil, diesel, kerosene and gasoline by the macrophyte was also investigated. The BCF of TPH was concentration dependent. It was high at low medium concentrations and low at high WSF concentrations. It ranged between 8.12 and 34.16 (Crude oil), 1.90 and 10.80 (Diesel), 5.86 and 22.8 (Kerosene) and 1.37 to 13.69 (Gasoline).

The findings of this study show that *E. crassipes* has potential for phytoremediation of heavy metals and soluble petroleum hydrocarbons. According to Singh et al. (2017), plants with BCF and TF greater than 1 have potential to act as hyper-accumulators. Aisien et al. (2010) observed that BCF values over 1000are generally considered evidence of a plant's potential for phytoremediation. Plant species with high BCF and low TF are suitable for phytostabilization. Phytostabilization immobilizes pollutants through absorption and accumulation by roots, adsorption onto roots surfaces and precipitation within rhizophere and via roots excidates (Ikhajiagbe and Anoliefo, 2012).

Conclusion

When oil spills occur in aquatic ecosystems, heavy metals and low molecular weight hydrocarbons dissolve into the water body. Some of the heavy metals like Cadmium, Chromium and Lead and the light molecular weight hydrocarbons such as Benzene, Toluene, Ethylbenzene and Xylene (BTEX) are toxic to living organism. They are capable of being accumulated and bioconcentrated along the food chain to dangerously high levels that are toxic to organisms at the top trophic levels including man. The ability of aquatic plants to accumulate the pollutants can also play important role in phytoremediation of polluted water. Early response to pollution is necessary to protect the ecosystem from soluble petroleum constituents.

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References

Aisien, F. A., Faleye, O., & Aisien, E. T. (2010). Phytoremediation of heavy metals in aqueous solutions. Leonardo Journal of Sciences, 17(4), 37-46.

Akapo, A.A., Omidiji, S.O. and Otitologu, A.A. (2011). Morphological and anatomical effects of crude oil on *Pistia stratiotes*. The Environmentalist, 31(3):288– 298.

Akpoveta, O.V. and Osakwe, S. A. (2014). Determination of heavy mental contents in refined petroleum products. Journal of Applied Chemistry, 7 (6): 1 – 2.

Anwar, A. (2022). Phytoremediation of heavy metals and total petroleum hydrocarbons and nutrient enhancement of *Typha Latifolia* in petroleum secondary effluent for biomass growth. Environmental Science and Pollution Research. 29:5777 – 5786.

APHA (2011). Standard methods for the examination of water and wastewater. American Public Health Association, Washington D.C. USA, 20 edition.

ASTM (2010). Petroleum products, lubricants and fossil fuel. American Society for Testing and Materials. 5(3):D4420-84

Chorom, M., Parnian, A. and Jaafarzadeh, N. (2012). Nickel removal by the aquatic plant *Ceretophyllum demersum* L. International Journal of Environmental Science and Development, 3(4):372.

Dave, D. A. E. G., & Ghaly, A. E. (2011). Remediation technologies for marine oil spills: A critical review and comparative analysis. American Journal of Environmental Sciences, 7(5), 423.

Dickson, U.J. and Udoessien E.I. (2012). Physico-chemical studies of Nigerian oil blends. Petroleum and Coal. 54(3):243-251.

Edema N., Okoloko, E.G. and Agbogidi, O.M. (2008). Physical and ionic characteristics in water soluble fraction (wsf) of Olomoro well-head crude oil before and after exposure to Azolla Africana desv. African Journal of Biotechnology, 7(1).

Edema, N.E. and Okoloko, G.E. (2008). Composition of the water soluble fraction (WSF) of Amukpe Well-head crude oil before and after exposure to *Pistia stratiotes* L. Research Journal of Applied Sciences 3 (2): 143 – 146.

Egbe, R.E. and Thompson, D. (2010). Environmental challenges of oil spillage for families in oil producing communities of the Niger-Delta region. Journal of Human and Environmental Research, 13: 24 – 34.

Ibrahim, H. S., Ammar, N. S., Soylak, M., and Ibrahim, M. (2012). Removal of Cd (II) and Pb (II) from aqueous solution using dried water hyacinth as a biosorbent. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 96, 413-420.

Ikhajiagbe, B., & Anoliefo, G. O. (2012). Phytoassessment of a 5-month old waste engine oil polluted soil after augmentation with *Pleurotus tuberregium*. Current Research Journal of Biological Sciences, 4(1), 10-16.

Kadafa, A. A. (2012). Oil exploration and spillage in the Niger Delta of Nigeria. Civil and Environmental Research, 2(3), 38-51.

Kuok, H.D.T. (2019). Phytoremediation of soil contaminated with petroleum hydrocarbons: A review of recent literature. Global Journal of Civil and Environmental Engineering. 1:33 – 42.

M. N. Kouraim, N. M. Farag, S. A. Sadeak, M. A. Gado (2014). Extraction of uranium using impregnated hydrophobic water hyacinth roots. International Journal of Chemical Studies; 2(4): 10-19

Malik, A. (2007). Environmental challenge vis a vis opportunity: the case of water hyacinth. Environment international, 33(1), 122-138.

Moreno-Rubio, N., Ortega-Villamizar, D., Marimon-Bolívar, W. et al. Potential of Lemna minor and *Eichhornia crassipes* for the phytoremediation of water contaminated with Nickel (II). Environ Monit Assess 195, 119 (2023). https://doi.org/10.1007/s10661-022-10688-3.

Ndeda, L.A. and Manohar, S. (2014). Bioconcentration factor and translocation ability of heavy metals within different habitat of hydrophytes in Nairobi dam, Kenya. Journal of Environmental Science, Toxicology and Food Technology, 8 (4): 42 – 45.

Nwoko, C.O. (2010). Trends in phytoremediation of toxic elemental and organic pollutants. African Journal of Biotechnology. 9(37):6010-6016.

Okpo, O.C. and Eze, R. (2012). Vandalization of oil pipelines in the Niger Delta region of Nigeria and poverty: An Overview, Studies of Sociology of Science, 3(2):13 – 21.

Oyebamiji, M., & Mba, C. (2014). Effects of oil spillage on community development in the Niger Delta region: Implications for the eradication of poverty and hunger (Millennium Development Goal One) in Nigeria. World, 1(1), 27-36.

Oyem, I.L.R. and Oyem, I.L. (2013). Effects of crude oil spillage on soil physico-chemical properties in Ugborodo Community. International Journal of Modern Engineering Research, 3(6):3336 – 3342.

Park, D., Yun, Y. S., & Park, J. M. (2010). The past, present, and future trends of biosorption. Biotechnology and Bioprocess Engineering, 15, 86-102.

Priya, E. Sanmuga, and P. Senthamil Selvan. "Water hyacinth (*Eichhornia crassipes*)–An efficient and economic adsorbent for textile effluent treatment–A review." Arabian Journal of Chemistry 10 (2017): S3548-S3558.

Raji, A. O. Y., & Abejide, T. S. (2013). An assessment of environmental problems associated with oil pollution and gas flaring in the Niger Delta region Nigeria, C. 1960s-2000. Arabian Journal of Business and Management Review (OMAN Chapter), 3(3), 48.

Reddy, K.R. and DeBusk, W.F. (1987) Nutrient Storage Capabilities of Aquatic and Wetland Plants. In: Reddy, K.R. and Smith, W.H., Eds., Aquatic Plants for Water Treatment and Resource Recovery, Magnolia Publishing, Orlando, 337-357.

Rezania, S., Ponraj, M., Talaiekhozani, A., Mohamad, S. E., Din, M. F. M., Taib, S. M., ... & Sairan, F. M. (2015). Perspectives of phytoremediation using water hyacinth for removal of heavy metals, organic and inorganic pollutants in wastewater. Journal of environmental management, 163: 125-133.

Singh, N. Kaur, M. and Katnoria, J.K. (2017). Analysis on bioaccumulation of metals in aquatic environment of Beas river basin: A case study from Kanji wetland. GeoHealth, 1: 93 – 105.

Victor, K.K., Ladji, M., Adjiri, A.O., Cyrille, Y.D.A. and Sanogo, T.A. (2016). Bioaccumulation of heavy metals from wastewaters (pb, zn, cd, cu and cr) in water hyacinth (Eichhornia crassipes) and water lettuce (*Pistia stratiotes*). International Journal of Chem Tech Research. 9(2):189-195.

Wanyonyi, W. C., Onyari, J. M., & Shiundu, P. M. (2014). Adsorption of Congo red dye from aqueous solutions using roots of *Eichhornia crassipes*: kinetic and equilibrium studies. Energy Procedia, 50, 862-869.

Yabanli, M., Yozukmaz, A. and Sel, F. (2014). Heavy metal accumulation in the leaves, stem and root of invasive submerged macrophyte *Myriophyllum spicatum* L. (Haloragaceae), Brazillian Achives of Biology and Technology, 57 (3): 434 – 440.

Z. Mohebi, M. Nazari, Phytoremediation of wastewater using aquatic plants, A review, Journal of Applied Research in Water and Wastewater, 8 (1), 2021, 50-58.

Zhu, Y. G., Smith, S. E., & Smith, F. A. (2001). Zinc (Zn)-phosphorus (P) interactions in two cultivars of spring wheat (*Triticum aestivum* L.) differing in P uptake efficiency. Annals of Botany, 88(5), 941-945.

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