Review of weeds with Phytoremediation potentials of Petroleum Hydrocarbon contaminated soil in the Niger–Delta states

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Abstract: Oil spillage in the Niger Delta is often as a result of petroleum exploration and exploitation activities, as well as sabotage through pipe vandalization. Most chemical and physical methods employed to clean-up the oil spill, have always come with far-reaching consequences that are more devastating to the environment than crude oil spills. Consequently, there is the need to do an environmental audit of weed species especially grasses with phytoremediation potential and their diversity in the Niger Delta, as an environmental friendly alternative. This approach will restore the ecosystem to its original status capable of supporting biological activities that will in turn support the livelihood of the communities or population that depends on it before the oil spill. Therefore, sustainable phytoremediation with weeds must explore the potentials of local and indigenous weed species with proven adaptability to the local environmental and ecosystem challenges occasioned by the peculiarity of the Niger Delta region.

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1.0 Introduction

The Niger delta (ND) is situated around the tributaries of the Niger River which drains into the Southern Atlantic Ocean and the core South-South region of Nigeria. It is the world's third largest wetland (Achebe 2012), and about 50 % the ND is made up of creeks and small islands (Francis et. al 2011). The Niger Delta region of Nigeria consists of nine core Nigerian states namely: Abia, Akwa-Ibom, Bayelsa, Cross River, Delta, Edo, Imo, Ondo and Rivers (with an area of 75,000km^2). This however, should not be confused with the southern Nigerian states (Bayelsa, Rivers, Akwa-Ibom, Cross-Rivers, Edo and Delta (BRACED) that constitutes the south-south geo-political zone:. ND has a total area of 112,000km^2 with a population of close to 32 million people (20% of the Nigerian population 2010 estimate), with over 40 different languages (Francis, *et al*., 2011). The peoples' predominant occupation include: agriculture and fishing (48%), trading (17%), services (10%), education and health (7%). Unemployment average is 24% (2006), poverty level is 43%, and infant mortality is 120 per 1000 birth (Francis, *et al*., 2011). Its ecological zone is made up of a coastal barrier sandy ridge, mangrove swamp, freshwater swamp, and lowland rainforest. Natural resource endowments include, but are not limited to petroleum, natural gas, tin, lead, coal, zinc, salt, arable land, and sea foods among others. Petroleum oil is the most abundant resources of economic importance of this region and the Nigeria nation, since the discovery, by Shell British Petroleum in 1956 at Oloibiri village in Bayelsa, one of the Niger Delta states. Crude petroleum oil is presently the mainstay of the Nigerian economy. Over 90 % of the country's revenue is generated from oil. A high percentage of the oil is drilled in very sensitive mangrove ecosystem of the Niger Delta. Unfortunately the abundance of this petroleum resource and its status in the nation's economy has not been all booms but salient bane that has triggered a lot of political conflict and interest of a global perspective. This global interest has been as a result of the ecological challenges occasioned by the activities surrounding the exploration and exploitation of the petroleum oil to the environment and the livelihood of the inhabitants thereafter.

The Niger Delta ecosystem, is fragile and highly susceptible to adverse environmental changes, resulting from climate changes, human activities, those of oil exploration and exploitation, loss of biodiversity, coastal and riverbank erosion, flooding, oil spillage, gas flaring, sewage and oil wastewater pollution, land degradation and soil fertility loss, deforestation and water hyacinth invasion, which has become recurrent and major environmental issues. The dominant and most important challenge relevant to the Niger Delta well-being and sustainable existence is that related to exploitation of petroleum oil and the attendant consequences. Over the years oil production activities have resulted to untold diverse environmental hazards and general distortions in the culture, economics and livelihood of the people due to oil spills. This paper reviews the problems associated with oil spillage in the ND and the extent of research in phytoremediation especially with weeds.

2.0. Oil spillage and notable impacts

According to Baird, 2010, oil spills in Nigeria occur due to a number of causes that include corrosion of pipelines and storage tanks (about 50 %); sabotage (28 %); oil production operations (21%), and 1% of the spills being accounted for by inadequate or non-functional production equipment or infrastructures that are described as, very old and lack regular inspection and adequate maintenance (Nwilo and Badejo, 2001). For instance, between 1976 and 1996, a total of 4,647 oil spill incidents were recorded in Nigeria which resulted in the spill of approximately 2.3 million barr Tels of oil into the environment. Kotangora, 1991), and between 1997 and 2001, a total of 2,097 oil spill cases were also recorded, causing severe damage to soil resources and the coastal environment (Ekpebu and Ukpong 2013). Several cases of oil spillage in three States of the Niger Delta region have been documented (Table 1). The spills have caused severe damages to the soil resources of the Niger Delta, which are very important to the livelihood of the human population in the region for various reasons especially as an essential agricultural resource. This however, has impoverished the soil and made it unproductive for any meaningful agricultural activities. (Nwaugo *et al*., 2007). The reported impacts on the Niger Delta incude land degradation and arable land reduction (Wokocha et al, 2011; land productivity, Crop yield and fertility losses (Opukiri and Ibaba, 2008); loss of farm income and overall livelihood of the people (Inoni et al., 2006; Osuji and Nwoye, 2007. Opukiri and Ibaba, 2008); loss of rain and mangrove forest resources (Nwilo and Olusegun, 2007; Zabbey, 2008); invasion by water hyacinth (Fuggle, 2004) and natural gas flaring (Atevure, 2004).

Table 1. Reported Oil Polluted Sites in the Niger Delta

State	Number of communities affected	Impacted Ecological Area	Number of spill incidence
Bayelsa	9	Rainforest/Fresh water swamp and Mangrove forest	160
Delta	18	Mangrove/ Fresh water swamp forest	105
Rivers	2	Fresh water swamp	30

Source: adapted from Jemimah and Ike (2015)

1.3. **Composition of crude oil**

Crude oil, otherwise known as petroleum,, comprises of hydrocarbons, other organic compounds and small amounts of metal. Hydrocarbons are the primary component of crude oil and their composition can vary from 50-90% depending on the type of crude oil and its extraction processes. Organic compounds containig nitrogen, oxygen, and sulfur constitute between 6%-10% of crude oil while metals such as copper, nickel, vanadium and iron account for less than 1% of the total composition. These metals occur primarily as complexes such as porphyrin which are stable and can be distilled at temperatures above 500°C (Costantinides and Arich, 1967). The ecological significance of heavy metals is as a result the growing awareness of the potential toxicity due to their accumulation (Purves 1985). They are generally non-biodegradable and undergo an eco-biological cycle. The peculiarity of heavy metals lies in their ability to accumulate unnoticed to toxic levels (Wegwu and Akaninwor 2006). This, of course, is distinct from other pollutants such as petroleum hydrocarbons and litter, which may visibly build up in the environment. The toxicological action of cadmium has been attributed to its chemical similarity with zinc, as cadmium may conveniently replace zinc in some enzymes, thus altering their three–dimensional structure and impair catalytic activities (Wegwu, 1999). These attributes of crude oil is what compound the consequences and the challenges resulting from crude oil spillage. Several attempts and techniques of cleaning up or remediation of oil spills in the region have come with mixed results. These efforts range from physical, chemical to both thermal and biological methods.

2.0 **Techniques of cleaning up contaminated sites**

The common techniques for clean-up of oil spills include: physical, chemical and thermal (Frick *et al*., 1999). These techniques besides being expensive have some adverse effects on the environment (Frick *et al*., 1999; Lundstedt, 2003). Phytoremediation techniques are being evaluated for the remediation of sites contaminated with Petroleum hydrocarbons (Essien, *et al*., 2015). Today, environmental managers can choose from a variety of options to remediate petroleum-contaminated soil and groundwater. The approach or approaches chosen in such clean-ups had been those orthodox expensive and ineffective conventional practices, (e.g. pump-and-treat" and dig-and-dump" techniques), which are not environmentally friendly (as they merely transfer the pollutants from one site to another). An environmentally sound technology (EST) that addresses the inadequacies of these old remediation practices will therefore be pertinent. Here comes the natural clean-up method–phytoremediation. Phytoremediation process or method is being considered as the most environmental friendly option, which will fit into the ecosystem regulatory or control process of polluted sites or environment. Plants and weeds are naturally occurring vegetation characteristic of most of the polluted sites in the Niger Delta. Their use as potential phytoremediation tool may offer a lasting solution to clean-up. Table 2 shows how other remediation techniques compare to phytoremediation.

Table 2: Other Remediation Technique compared to Phytoremediation

Remediation Techniques	Advantages over Phytoremediation	Disadvantages over Phytoremediation
Solidification / Stabilization	Not seasonally dependent. It is a rapid process and simple to apply and operate	Site is not restored to original form; leaching of the contaminant is a risk; can result in a significant increase in volume of contact.
Soil Flushing / Soil Washing	Not seasonally dependent, except in cold climates; methods well established for much site remediation of contaminants	Change; additional treatment steps and chemical handling add complexity and cost; possible lengthy period of treatment.
Bioremediation method of remediation	Established and accepted, a bioreactor can be utilized for existing work; it may be faster than phytoremediation.	Requires nutrient addition at a much greater level than phytoremediation; applicable to organics only.
Electro kinetics	Not seasonally dependent; can be used in conjunction with phytoremediation to enhance rhizosphere biodegradation.	Useful for soil only, not wetlands; uniformity of soil conditions is required.
Chemical Reduction / Oxidation	Not seasonally dependent; relatively short treatment time frame; usually off site.	Requires excavation; uses chemical additives; fertility of the soil after treatment may be damaged.

Source: adapted from (2003)

2.1 Phytoremediation

The term phytoremediation (phyto meaning plants and the Latin suffix remedium meaning to clean or restore) refers to a diverse collection of plant–based technologies that use either naturally occurring, or genetically engineered, plants to clean contaminated environments (Flathman and Lanza, 1998).Thus, Phyto remediation –is the use of plants or existing vegetation to clean up soil and water. It can be used to detoxify sites containing heavy metals, pesticides, explosives, crude oil hydrocarbons and land fill leachates. The process explores the unique and selective ability of plants to absorb, accumulate and degrade contaminants that are present in polluted soil and water resources (Mbhele, 2007). The technology is ecologically friendly, solar-energy driven, and is based on the concept of using "nature to cleanse nature" (Osam *et al*., 2013). Phytoremediation technology has been proved to be a successful method of treating contaminated soils to levels below the maximum permissible level of the contaminants. Phytoremediation is characterized by the use of vegetative species for *in situ* treatment of land areas polluted by a variety of hazardous substances (Sykes *et.al.,* 1999). Plants are especially useful in the process of decontamination because they prevent erosion and leaching which can spread the toxic substances to surrounding areas (USEPA, 2001).

2.2 Types of phytoremediation technology

There are four different plant–based technologies being used today; each having a different mechanism of action for remediating contaminants (Bentjen, 2002).These includes:

- **Phytoextraction:** which relies upon a plant's natural ability to take up certain substances (such as heavy metals) from the environment and sequester them in their cells until the plant can be harvested.
- **Phytodegradation:** a means by which plants convert organic pollutants into a non-toxic form.
- **Phytostabilization:** a form of "Allelochemical mediation, where a plant releases certain chemicals that bind to the contaminant to make it less bioavailable and less mobile in the surrounding environment.
- **Phytovolitization**: a process through which plants extract pollutants from the soil and then convert them into a gas that can be safely released into the atmosphere.

Comparison of these processes is presented in Table 3.

Table 3. Comparison between phytoremediation technologies

Phytoremediation technologies	Action on contaminant	Main types of contaminants	Vegetation
Phytostabilization	Retained *in situ*	Organics and metals	Cover maintained
Phytodegradation	Attenuated *in situ*	Organics	Cover maintained
Phytovolatilization	Removed	Organics and metals	Cover maintained
Phytoextraction	Removed	Metals	Harvested repeatedly

Source: adapted from Greipsson (2011)

More research needs to be carried out to identified weeds that have these characteristics in the Niger Delta, in order to determine their suitability and potentials.

2.3 Limitation of phytoremediation

The limitation to phytoremediation in soil includes:

- The depth of the treatment zone is determined by plants used in phytoremediation. In most cases, it is limited to shallow soil
- High concentrations of hazardous materials can be toxic to the plants.
- It involves the same mass transfer limitations as other bio treatments.
- It may be seasonal, depending on location
- It can transfer contamination across media, e.g., from soil to air.
- It is not effective for strongly adsorbed e.g. polychlorinated biphenyls (PCBs) and weakly adsorbed contaminants
- The toxicity and bioavailability of biodegradation products is not always known
- Products may be mobilized into ground water or bio accumulated in animals.
- It is still in the demonstration stage.
- It is unfamiliar to regulators.

2.4 Criteria for selecting candidate phytoremediation weeds

The nature of site contamination is an important factor in the selection of species for phytoremediation. There are several approaches employed in the selection of candidate weed or plant for the phytoremediation of soil contaminated with organic pollutants. These have been generally based on rooting depth of species, regional climate, and nature of the conterminal soil (Bakers *et al* 2003; Kirk *et al*., 2002). However, some important criteria in selecting plant species for phytoremediation are listed below:

- The level of tolerance with respect to existing metal at the site;
- The level of accumulation, translocation and uptake potentials of the compounds;
- High growth rate and biomass yield;
- Tolerance to waterlogging and extreme drought conditions;
- Availability, habit preference e.g. terrestrial, aquatic and semi aquatic etc.
- Tolerance to high pH and salinity; and
- Root characteristics and depth of the root zone.

3.0 Weeds implicated in the Niger Delta Environment

Most studies on phytoremediation of polluted environment have employed broadleaved weeds and grasses, as well as legumes. However, researchers who have compared weed types and grouping have come to the conclusion that grasses and legumes are the best suitable for phytoremediation due to their multiple and ramified root systems (Adam and Duncan, 1999; Merkl *et al.,* 2004).

Classification of weeds on the basis of where they are found (habitat) is widely used by agriculturists Akobundu (1987) as cited by Soladoye *et al. (*2010). This method of classification groups weeds into upland (terrestrial) weeds, aquatic weeds, arable crop weeds, weeds of plantation crops etc. Table 4 shows some weeds implicated as aquatic and non-aquatic (terrestrial) respectively in the Niger Delta.

4.0 Weeds species reported for phytoremediation of hydrocarbon pollutant and heavy metals in the Niger–Delta.

Out of the nineteen weed families that are reported or found in the Niger Delta region, about 40 % of these weed families have been reported for the remediation of organic pollutants and heavy metal in various location by different researchers (Table 5). What is not clear in most of the efforts in phytoremediation is whether researchers explored the habitat relationships of studied species or their niches in terms of ecosystem disruption and stabilization. Reports from various workers suggest that a lot of research needs to be conducted at the site of the spillage to really tap into the potentials of the reported weed species. Most of these weed species reported belong to the Poaceae family (Table 5), meaning that they are the species with greater potential when compared to their broad-leafed species. This confirms the reports of Adam and Duncan, 1996; Merki et al., 2004, that popular and best species for phytoremediation are grasses and legumes.

Table 4. Some common weed families found and have been researched on in the Niger Delta

S/no	Botanical Family	Common weed species or regular species reported	Habitat	Referenced work
1	Asteraceae	*Acanthospermum hispidium, Ageratum conyzoides, Aspilia africana, Bidens pilosa, Chromolaena odorata Emilia coccinea, Emilia praetermissa Synedrella nodiflora, Tridax procumbens, Tithonia diversifolia Vernonia cinerea Erigeron floribundus*	Terrestrial	Aiyesanmi *et al.*(2012), Ikhajiabe and Anoliefo (2012), Ikhajiagbe *et al.;(2013)* Obadoni, *et al.(*2009), Soladoye *et al.* (2010), Udo-Inyang *et al.* (2013)
2	Araceae	*Pistia stratiotes*	Aquatic	NIFFR (2002)
3		*Alternanthera pungens, Alternanthera sessilis. Amaranthus hybridus, Amaranthus spinosus Amaranthus viridis, Gomphrena celosioides*	Terrestrial	Ikhajiagbe *et al; (*2013), Ogbo *et al.* (2009), Soladoye *et al. (*2010) Wiberforce (2015)
4	Aizollaceae	*Azolla pinnata*	Aquatic	Asimiea and Omokhua, (2013)
5	Capparaceae	*Cleome viscose*		Soladoye *et al. (*2010)
6	Combretaceae	*Combretum hispidum*	Terrestrial	Soladoye *et al. (*2010)
7	Commelinaceae	*Commelina diffusa, Commelina benghalensis, Aneilema beniniense, Commelina* erecta	Aquatic/ Terrestrial	Soladoye *et al. (*2010) NIFFR (2002), Dienye (2015)
8	Connaraceae	*Cnestis ferruginea*	Aquatic/Terrestrial	Soladoye *et al.(*2010)
9	Convolvulaceae	*Ipomoea involucrata*, *Ipomoea triloba*	Terrestrial	Ikhajiagbe *et al.* (2013*)*
10	Crassulaceae	*Bryophyllum pinnatum*	Terrestrial	Soladoye *et al.(*2010)
11	Cucurbitaceae	*Momordica charantia*	Terrestrial	Soladoye *et al.(*2010)
12	Cyperaceae	*Cyperus esculentus*, *Cyperus rotundus, Kyllinga erecta Mariscus alternifolius*, *Rhynchospora corymbosa*	Aquatic/Terrestrial	Efe and Elenwo (2014), Efe and Okpali (2012) NIFFR (2002), Ogbo *et al.* (2009), Soladoye *et al. (*2010)
13	Euphorbiaceae	*Acalypha cilata, Acalypha fimbriata Euphorbia heterophylla, Euphorbia hirta, Manniophyton fulvum*, *Phyllanthus amarus*	Terrestrial	Ikhajiagbe *et al.* (2013) Ogbo *et al.* (2009), Soladoye *et al. (*2010), Wilberforce (2015)
14	Fabaceae	*Calopogonium mucunoides, Centrosema pubescens, Pueraria phaseoloides*	Terrestrial	Edu *et al*(2015) Ikechukwu and Ndukwu (2014) Nwaichi Onyeike, (2011) and Obua *et al.* (2012), Okonwu *et al* (2014)
15	Ficoidaceae	*Trianthema portulacastrum*	Terrestrial	Soladoye *et al.(*2010))
16	Lamiaceae	*Solenostemon monostachyus,Plastostoma africanum Hyptis lanceolata*	Terrestrial	Soladoye *et al. (*2010), Ogbo *et al.*2009), Dienye (2015)
17	Malvaceae,	*Sida rhombifolia*	Terrestrial	Ogbo *et al.*(2009)
18	Poaceae	*Axonopus compressus, Eleusine indica, Panicum maximum, Paspalum scrobiculatum, Pennisetum purpureum, Phragmitis australis, Vetiveria nigritana*	Terrestrial	Ayotamuno *et al.*(2006), Efe and Elenwo (2014) Efe and Okpali (2012), Essien *et al* (2015), Odokuma and Ubogu (2014), Ogbo *et al.*(2009), Udo-Inyang *et al.*(2013) Uwagboe (2008), Wilberforce (2015)
19	Portulacaceae	*Talinum triangulare*	Terrestrial	Uwagboe (2008)

Table 5. Samples of weed species studied for phytoremediation in Niger–Delta States

S/no	Botanical Family	Common or regular weed species reported	Type of contaminant remediated	Level of success	References
1	Asteraceae	*Chromolaena odorata*	Heavy metals	Accumulation of heavy metals such as Cd, Cr, Cu, Mn, Ni, Pb and Zn	Aiyesanmi *et al*. (2012), Wilberforce (2015)
		Synedrella nodiflora	Heavy metal	Accumulation of heavy metals such as Pb	Aiyesanmi *et al*. (2012)
		Tithonia diversifolia	crude oil	Reduced the total hydrocarbon (THC) content of the soil by 25 %	Udo-Inyang *et al*. (2013)
2	Cyperaceae	*Cyperus rotundus*	Petroleum hydrocarbon (PHC)	48% reduction in THC after 3 months	Efe and Elenwo (2014), Efe and Okpali (2012)
		Mariscus alternifolius	PHC	Removal of over 30 % of saturated hydrocarbons (SHC) in spent lubricating oil contaminated soils	Ogbo *et al*. (2009)
3	Euphorbiaceace	*Phyllantus amarus*	PHC	Removed 45.89 % of the SHC in spent lubricating oil contaminated soils	Ogbo *et al*.(2009)
	Fabaceae	*Centrosema pubescen*	crude oil	Significant reduction of large amounts of heavy metal contaminants (i.e. Cd, Cu and Fe) in a relatively short time.	Nwaichi and Onyeike (2011)
5	Lamiaceae	*Hyptis spicigera*	PHC	Removed 30 % SHCs in spent lubricating oil contaminated soils	Ogbo *et al*. (2009)
6	Malvaceae,	*Sida rhombifolia*	PHC	*S. rhombifolia* removed over 80 % of the SHCs in spent lubricating oil contaminated soils	Ogbo *et al*. (2009)
7	Poaceae	*Axonopus compressus*	PHC	47% reduction in THC after 3 months	Efe and Elenwo (2014) Efe and Okpali (2012)
	Poaceae	*Eleusine indica*	heavy metals	Reduce the quantity of PAH and heavy metals e.g., Pb, Cd in the soil. Accumulation of heavy metals such as Cd, Cr, Cu, Mn, Ni, Pb and Zn	Essien *et al* (2015), Wiberforce (2015)
		Panicum maximum	crude oil	considerable reduction in the total petroleum hydrocarbon (TPH)	Uwagboe (2008)
		Paspalum scrobiculatum	crude oil	The different levels of crude oil contamination. Caused significant reduction in the growth of the plant using plant height, fresh weight and leaf area. The contamination did not cause significant reduction in the dry weights of the plant	Ogbo *et al*.(2009)
		Pennisetum purpureum	petroleum hydrocarbon	Reported hydrocarbon losses 83%, which decreased to and 55% after the six-week remediation period.	Ayotamuno *et al*.(2006)
		Phragmitis australis	crude oil	The plant recorded 100 % germination in all crude oil concentrations including control. plant height decreased with increased concentrations of crude oil	Odokuma and Ubogu (2014)
		Vetiveria nigritana	crude oil	reduced the total hydrocarbon content in the soils by efficiency greater than 41%	Udo-Inyang *et al*.(2013)
8	Portulacaceae	*Talinum triangulare*	crude oil	considerable reduction in the total petroleum hydrocarbon (TPH) of 2.8%	Uwagboe (2008)

Conclusion

Huge amount of money is being spent in Nigeria on importing sophisticated technologies for the clean-up of crude oil contaminated soil. This review has shown the potential of some indigenous weeds species especially grasses in the phytoremediation of crude oil contamination. Most weed species studied have been for the remediation of spill oil of various grades and quality, including waste engine oil, spent lubricating oil, crude oil, etc. There have been mixed results ranging from 5% to >40% remediation by various weed species studied. However, most of the research works and successes reported were limited to pot and laboratory experiments. Many more trials especially field research is needed to authenticate the findings of these laboratory and potted experiments and their limitations. Weed flora and species diversity audit of the Niger Delta environment is a necessary tool towards the recruitment of candidate weed species for phytoremediation of pullulated sites. The data from such activity will be necessary to determine surviving species and their diversity, as well as the subsequent weed species colonization, and their relationships with the soil physical and chemical properties of the polluted site. Therefore, sustainable phytoremediation with weeds must explore the potentials of local and indigenous weed species with proven adaptability to the local environmental and ecosystem challenges occasioned peculiarity of the Niger Delta region. Such environmental friendly approach or alternative for the treatment of crude oil contamination would save the region and the country a lot of foreign exchange spending.

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