Mangrove Ecosystem and Crude oil: Reactions of Mangrove Ecosystem to Acute and Chronic Crude oil Contamination

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Abstract: Oil spillages in mangrove ecosystems can be problematic hence, the need to source for bioremediation strategies from within the ecosystem. Red mangrove seedlings were carefully uprooted from mangrove soil of Ugbokodo community of Uvwie Local Government Area of Delta State, Nigeria. These acclimatized seedlings were exposed to acute treatment of one-time application of 150 ml crude oil and chronic treatment of weekly application of 20 ml crude oil. Mangrove seedlings' reactions to crude oil were investigated by observing their stem height, stem girth, numbers of leaves and leaf area fortnightly for 90 days. Also, chemical parameters (pH, heavy metals, and total petroleum hydrocarbon-TPH) were analyzed to determine the effects of the crude oil on the mangrove soils. The findings revealed notable degrees of growth in the mangrove seedlings and seedlings with chronic treatment recorded a higher increase of growth. The highest decrease in pH was observed in soil with chronic treatment (SWCT) from 5.55 at day 0 to 5.18 at day 9. The highest decrease in TPH concentration was observed in SWCT from 958.4 ppm at day 0 to 412.33 ppm at day 90. There was a decrease in the concentrations of heavy metals except for Pb in soil with acute treatment (SWAT) during the 90 days incubation period. The findings revealed that mangrove plants exposed to acute and chronic contamination both have phytoremediative abilities but seedlings with chronic treatment demonstrated greater phytoremediative capacity and acute contamination of crude oil has more adverse effect on the mangrove soil ecosystem than chronic contamination.

Key word: Acute-contamination, crude oil, chronic-contamination, phytoremediation, red-mangrove.

INTRODUCTION

Mangrove ecosystem is a type of environment which is waterlogged most of the time, but can be muddy, swampy or dry during dry seasons. Mangroves refer to as collection of different groups of plants, which have similar capability to survive and live conveniently in water environment and also salty environment (Adegbeyin, 1993; Archibong *et al*., 2024). Most plants cannot survive in water because once their roots are submerged in water, devoid of oxygen thereby die. Mangroves are able to survive in water because their unique root that grows out of under their trunks in a pitch fork like manner. Most mangroves are adapted to the water-logged environment and tend to adjust to living on lands; thus help to create new lands and environments for other inhabitants such as fishes, birds and reptiles (Aju and Aju, 2021). During the dry season, the ecosystem becomes drier with mud appearing, this leaves the environment salty, and only mangrove plants are able to filter the salt out (Adegbeyin, 1993; Hassnuddin, 2024).

Mangrove forests are quite important to the people living in the coastal region of Niger Delta because it has an active and conservative wild life. The mangrove forest provides food for its inhabitants; it also provides shelter for the inhabitants which are conservative in the ecosystem. The conservative wild life cannot live in any other ecosystem apart from mangrove ecosystem (Aju and Aju, 2021). Most of these conservative organisms include molluscs, wild fowls, fish, shell fish, crabs and so on. There are some other organisms which at one time or the other of their life time would have something to do in mangrove forest. Some organisms such as amphibians, shrimps and fishes lay their eggs and nurse their off springs in the mangrove forest before returning to water (Adegbeyin, 1993). Some birds hibernate in mangroves during migration. Organisms called manatees which are considered to be endangered because they are about to go to extinction can be found in mangrove forests (Henry, 2009).

Mangrove trees are the only trees which can grow in the harsh and unique environmental conditions of mangrove ecosystem. The leaves fall and decompose to form organic matter unlike other leaves that accumulate in soil. When the leaves fall in water they decay, microorganisms and plankton feed on them (Adegbehin, 1993). Tannin which are produced by mangroves is used in arts and design. Mangrove stems can be used in making furniture. Mangrove forests help to prevent coastal erosion from storm and water and help in land building. Mangroves help in water purification, in that there is so much disposal of waste water into the coastal environments, mangroves help to filter these waste water. Filtration occurs when the mangroves absorb nutrients and toxics in the waste water thereby reducing the content of impurity of the water. The mangroves are very effective in treating waste water in as much as the wastes are not too much or too toxic because very high toxicity can destroy the ecosystem (Archibong *et al*., 2024).

Crude oil, also known as petroleum or fossil fuel is one of the main sources of energy which sustains our modern society. Crude oil can be defined as the quantities of naturally occurring yellowish black oil extracted from the ground after the removal of inert matters and impurities (Adipah, 2019). Crude oil is a complex mixture of many compounds generally called hydrocarbons; which can be sub-divided into four major groups, the alkanes, the aromatics, the resins and the asphaltenes (Amanchukwu *et al.,* 1989). The level of biological degradation of these hydrocarbons varies; generally, resins and asphaltenes are resistant to bio-degradation, while the polycyclic aromatic hydrocarbons (PAH) are partially degradable biologically. Polycyclic aromatic hydrocarbons are of most concern because of their toxicity and ability to bioaccumulate (Amanchukwu *et al.,* 1989).

In the last century, the world's population has greatly increased therefore, leading to the increase of crude oil exploration and production activities across the globe due to the increasing demand for petroleum and its products. This has also led to the high rate of discharge of hydrocarbon waste materials into the environment. The effect of these hydrocarbon wastes has become a major environmental challenge particularly with regard to their persistence and ecotoxocity (Amanchukwu *et al.,* 1989; Adipah, 2019).

Biodegradation of toxic hydrocarbons in the soil ecosystem can occur by the activities of naturally present microorganisms through the process called microbial degradation (Okpokwasili and Okorie, 1988). Microbial degradation is one of the detoxifying mechanisms which leads to complete mineralization, another possible method of biological degradation is phytoremediation. Phytoremediation is the process through which plants remove hydrocarbons from the soil by either dissolving them in the rhizosphere or translocate them in their aerial parts (Alkorta and Garbisu, 2001; McGrath *et al*., 2002). Phytoremediation processes include phytostabilization, phytodegradation, phytovolatilization and phytoectraction (Greipsson, 2011).

Mangrove ecosystems are classified as one of the most sensitive ecosystems because mangrove represents the intertidal region between land and sea; it is physically intricate and relatively hard to access. This makes mangrove ecosystems significant places where spilled oil and associated impacts converge hence, the need to source for bioremediation strategy from within the ecosystems (Aina *et al*., 2021). Observations from many spill events around the world have shown that mangroves suffer both lethal and sublethal effects from oil exposure (Quilicit *et al*., 1995). According to rankings of the coastal areas in National Oceanic and Atmospheric Administration (NOAA)'s Environmental Sensitivity Indices, commonly are used as a tool for spill contingency planning around the world. Mangrove ecosystems are ranked as the most sensitive of tropical habitats (Snedaker, 1995). Therefore, this study sought to investigate the mangrove seedlings' reactions to crude oil, their phytoremediative abilities and the effects of the crude oil on the physiology of mangrove soil for 90 days.

MATERIALS AND METHODS

Description of study area: The mangrove ecosystem used for this research work is Ugbokodo community near Jeddo-Warri of Okpe local government area of Delta State, Nigeria. The community has one of the largest distributions of mangrove ecosystem in Delta State. Okpe is located in the area between Latitude: 5° 25' 59.99" N Longitude: 5° 56' 59.99" E.

Description of crude oil: The crude oil is Bonny light and has been reported to consist of n-alkane containing oil such as saturates (56%), aromatics (31%), polars (11%) and asphaltenes (2%). It also has 35 3° API gravity and contains 0.1% sulphur content (Qui *et al*., 2004).

Collection of soil samples: Five kilograms of wet surface soil samples (15 cm) depth was collected using a shovel during tidal recession in sterile transparent potted plastic containers (Akram, 2018).

Collection of mangrove plant: Apparently healthy and matured mangrove seedlings in good conditions were carefully uprooted using shovel and transplanted into the potted plastic containers ensuring that there was little or no root damage. These seedlings were allowed to acclimatize for 40 days and were watered daily throughout the period of acclimatization (Costa *et al*., 2020).

Determination of particle size of the soil: Fifty grams of soil sample was weighed; 5 ml of hydrogen peroxide (H_2O_2) was added to remove organic matter. The 5 ml increment of H_2O_2 was added until oxidation has been completed. The mixture was dried on hot plate and 50 ml of 5% Calgon solution was added and this was shaken on the ground shaker for 2 h. The 0.053 mm sieve was used to wash the sample into 1 litre measuring cylinder until the water coming out became clear. It is assumed that the silt and clay must have passed through the 0.05 mm sieve leaving sand fraction. The final volume in the cylinder was noted. The solution was shaken vigorously and 20 ml from the colloidal solution was taken at a certain depth, the weight of clay and silt was determined by calculation. Twenty millilitres of the solution was oven dried and the weight was noted, this is the weight of clay, the weight of silt = weight of clay and silt-weight of clay (Gray *et al*., 2010).

Application of crude oil: Application of crude oil commenced at the end of 40-day acclimatization period. For acute treatment 150 ml of crude oil was applied one time while, the chronic treatment consists of weekly application of smaller amount (20 ml) of crude oil (Monaghan and Koons, 1975; Proffitt *et al*., 1995.)

Observation and measurement of mangrove seedlings: The stem height, stem diameter (girth) at the first internode, number of nodes, number of leaves, and leaf area (length and width) were measured individually using measuring rule. The fate and growth of seedlings were monitored fortnightly and for 3 months (Dewayanti *et al*., 2022).

Measurement of soil pH: The electronic method using Mettler Toledo model MP126 pH meter was adapted for pH determination. This method involves the measurement of the potential between an indicator electrode and a reference electrode. The pH meter was standardized before use by calibration using pH buffers 4 and 7. Five grams of soil samples was dissolved in 5.0 ml of distilled water and strirred for 30 minutes at 5 minutes interval. After calibration, the electrode was immersed into the sample and the pH was read and recorded immediately the digits stabilized (O'Brien *et al*., 2016).

Determination of heavy metals: The soil samples were air dried, crushed and sieved. Two grams of the sieved samples were weighed; 2ml of nitric acid and sulphuric acid were added respectively. The resultant solution was heated on a hot plate until the brown fumes ceased to appear, digestion was complete. The concentration in mg/kg of the specified heavy metals in the collected samples was determined (after nitric acid digestion) by means of an atomic absorption spectrophotometer (Echem, 2014).

Determination of total petroleum hydrocarbon: Five grams of air-dried soil sieved by passing through 1.0 mm sieve was placed into a shaking bottle. For moistened soil, sodium sulphate anhydrous was added to remove water content; 1 ml of tetrachloroethylene was added to soil sample and covered with aluminium foil paper before capping it up to prevent mixture from splashing out. The mixture in the bottle was shaken for 30 minutes in a mechanical shaker at 500 rpm. The mixture was then filtered with Whatman's No. 40 filter paper, 4ml of the filtrate was taken into cuvette (cell) and ran for absorbance using Wilks Infracal TOG/TPH Spectrophotometer at 600 nm for the determination of total petroleum hydrocarbon (TPH) (Atuayan *et al*., 2013).

RESULTS

The result in Table 1 illustrated the fractional distribution of the soil particles and the soil texture was concluded to be loam sand with VCS of 11.86%, CS of 16.01%, MS of 28.45%, FS of 22.47%, VFS of 4.82%, TSA of 84% and TS of 11%.

Table 2 revealed the status of the mangrove seedlings after treatment. The mangrove seedlings acclimatized with no yellowish of leaf. The stem height, stem girth, number of leaves and leaf area (length and width) of the mangrove (*Rhizophora racemosa*) seedlings, increased comparably fortnightly in ninety days of experiment. On the 14th day after treatment, there was an increase in stem lengths, leaf area and stem diameters in all the mangrove plants. There was addition of two leaves in mangrove plant without treatment and discolouration of leaves in mangrove plants with both chronic and acute crude oil contamination.

The results also revealed that there was addition of leaves to all the mangrove seedlings during the ninety-day period of growth. Seedlings with acute and chronic treatment have six additional leaves each while seedling without treatment has four additional leaves at the end of 90 days of experiment. Table 2 also revealed that the discoloured leaves in mangrove seedling with acute treatment dried off after 14 days.

The results in Table 2 showed that the highest increase in stem length was observed in mangrove plant with chronic treatment from 73 cm at day 0 to 93 cm at day 90. The stem length of mangrove plant with acute treatment increased from 73.5 cm at day 0 to 89 cm at day 90 and the least increase in stem length was observed in seedling without treatment from 58.8 cm at day 0 and 64.5 cm at day 90. The leaf area of all the mangrove plants also increased throughout the 90 days. The highest increase in leaf area was observed in mangrove seedling with chronic treatment, from 26 cm^2 at day 0 to 60 cm^2 at day 90. The leaf area of mangrove seedling with acute treatment increased from 29.41 cm^2 at day 0 to 57.85 cm^2 at day 90. The least increase in leaf area was observed in seedling without treatment from 24.32 cm^2 at day 0 to 30.7 cm^2. In addition, there was a slight increase in the stem diameter of all the mangrove seedlings. The highest increase was observed in seedling with acute contamination form 4 cm at day 0 to 6cm at day 90. The stem diameter of seedling without crude oil treatment increased from 5.5cm at day 0 to 6.6 cm at day 90. The least increment was observed in seedling with chronic treatment from 5cm at day 0 to 6cm at day 90. There was a gradual reduction in pH, in concentration of the TPH and heavy metals in soil with acute treatment (SWAT) and soil with chronic treatment (SWCT) except in Pb of SWAT during the ninety days of growth as shown in Figures 1-6. Figure 1 revealed a slight decrease in the pH of the treated soils containing the mangrove seedlings. The highest decrease was observed in SWCT from 5.55 to 5.18 followed by SWAT from 6.01 to 5.73. Control (CONT) 2 (Soil+ Seedling – Treatment) decreased from 6.65 ppm to 6.38 ppm but CONT. 1 (Soil- Seedling- Treatment), CONT. 3 (Soil – Seedling+

Chronic treatment) and CONT. 4 (Soil-Seedling+Acute treatment) maintained constant pH throughout the experiment. Figure 2 showed the gradual and consistent decrease in TPH concentration in all the soil samples. The decrease in TPH concentration was higher in SWCT (from 798.67 ppm to 412.33 ppm) than in SWAT (from 892.6 ppm to 539 ppm). Figure 3 revealed that CONT.1, 3 and 4 maintained a constant Pb concentration throughout the 90 days of incubation. There was a slight reduction of Pb concentration in SWCT from 0.15 ppm to 0.138 ppm and CONT. 2 from 0.40 ppm to 0.36 ppm at the end of 90 days incubation. In SWAT there was a slight increase in Pb concentration from 0.2 ppm to 0.209 ppm at the end of the incubation period.
Figure 4 showed the decrease in cadmium (Cd) concentration in SWCT, SWAT, CONT. 4 and CONT.2 (from 10.55ppm to 9.715ppm, 9.87ppm to 9.017ppm, 9.85ppm to 9.55ppm and 9.61ppm to 9.55ppm) respectively. CONT.1 and 3 maintained a constant cadmium concentration at the end of incubation period.
Figure 5 showed the decrease in chromium (Cr) concentration in the soil samples and the highest decrease was observed in SWCT from 5.39 ppm to 4.39 ppm followed by SWAT from 7.91 ppm to 7.006 ppm and CONT. 2 from 8.80 ppm to 8.76 ppm while CONT.1, CONT.3 and CONT. 4 maintained constant Cr concentration from day 0 to day 90.
Figure 6 revealed that CONT. 1, 3 and 5 maintained the same Zn concentration during the period of incubation. It also showed that there was decrease in Zn concentration, with SWCT showing the highest decrease from 29 ppm to 28.644 ppm followed by SWAT from 28.78 ppm to 28.419 ppm and CONT. 2 with the least decrease from 22.97 ppm to 22.97 ppm.

Table 1: Particles size of soil sample

VCS	CS	%MS	FS	VFS	TSA	%TOTAL SILT	TOTAL	TEXTURE
11.86	16.01	28.45	22.47	4.82	84	11	5	Loam sand

Key: VCS: very coarse sand; CS: coarse sand; MS: medium sand; FS: fine sand; VFS: very fine sand; TS: total sand; TS: total silt

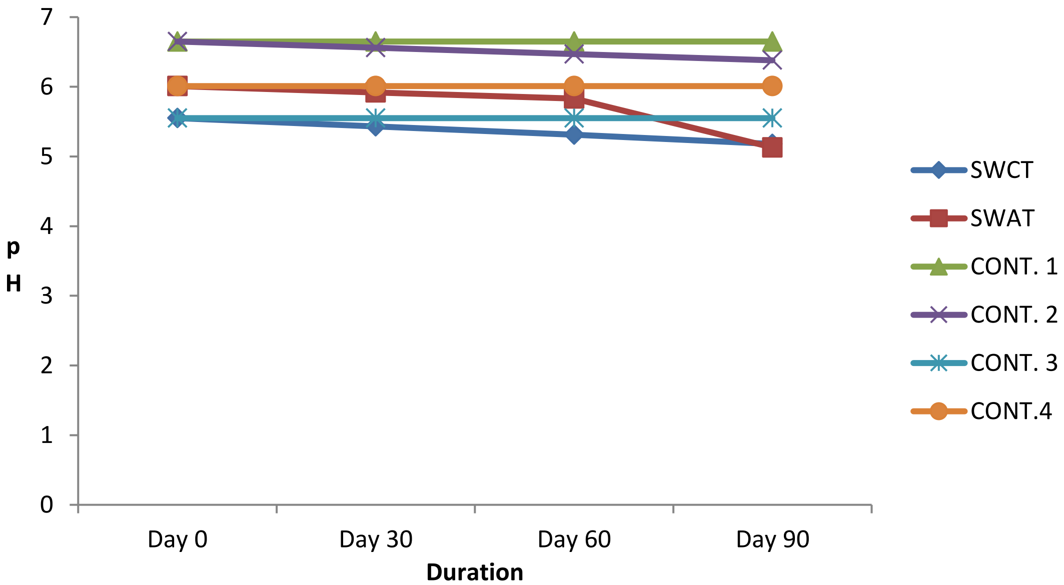

Figure 1: pH of soils over 90 days period of incubation

Keys: SWCT: Soil with chronic treatment, SWAT: Soil with acute treatment, CONT. 1: Soil-Seedling-Treatment, CONT2: Soil+Seedling-Treatment, CONT. 3: Soil–Seedling+Chronic treatment, CONT. 4: Soil-Seedling+Acute Treatment.

Table 2: Status of mangrove seedlings after treatment

Day	Sample	Stem length (cm)	Leaf area (cm^2)	Stem diameter (cm)	Fate and growth of seedlings and soil
	Chronic treatment (soil + seedling)	73	26	5	Acclimatized with no yellowish leaf
0	Acute treatment (soil + seedling)	73.5	29.41	4	Acclimatized with no yellowish leaf
	Control (soil+seedling –treatment)	58.8	24.32	5.5	Acclimatized with no yellowish leaf
	Chronic treatment (soil + seedling)	74	26	5	Discoloration of one leaf
14	Acute treatment (soil + seedling)	74	36.75	5	Yellowish colouration of leaves Notable quantity of crude oil on the soil surface
	Control (soil+seedling –treatment)	59	24.35	6.25	Addition of two leaves; No yellowish leaf
	Chronic treatment (soil + seedling)	77	26.9	5.25	Discolouration of one leaf
28	Acute treatment (soil + seedling)	77	36.78	5.25	Coloured leaves dried off Reduced quantity of crude oil observed on the soil surface
	Control (soil+seedling –treatment)	59	25.39	6.25	Addition of two leaves. No yellowish leaf
	Chronic treatment (soil + seedling)	80	38.4	5.5	Addition of two leaves
42	Acute treatment (soil + seedling)	80	46.12	5.5	Addition of two leaves Small quantity of crude oil on the surface of the soil
	Control (soil+seedling –treatment)	61	29.7	6.25	Addition of two leaves. No discolouration of leaf
56	Chronic treatment (soil + seedling)	83.5	40.8	5.5	Crude oil observed on the soil surface No addition of leaf
	Acute treatment (soil + seedling)	82	47.12	6	No discolouration of leaf
	Control (soil+seedling –treatment)	64	30.7	6.5	Addition of two leaves No discolouration
70	Chronic treatment (soil + seedling)	86.5	52.27	5.65	Small amount of crude observed on the soil surface. Addition of two leaves
	Acute treatment (soil + seedling)	86	56.5	6	No discolouration
	Control (soil+seedling –treatment)	64.5	36.7	6.58	
90	Chronic treatment (soil + seedling)	93	60	6	Small amount of crude oil observed on the soil surface. Addition of six leaves observed.
	Acute treatment (soil + seedling)	89	57.85	6	No discoloration of leaves. Addition of six leaves.
	Control (soil+seedling –treatment)	64.5	30.7	6.6	Additional of four leaves. No discolouration

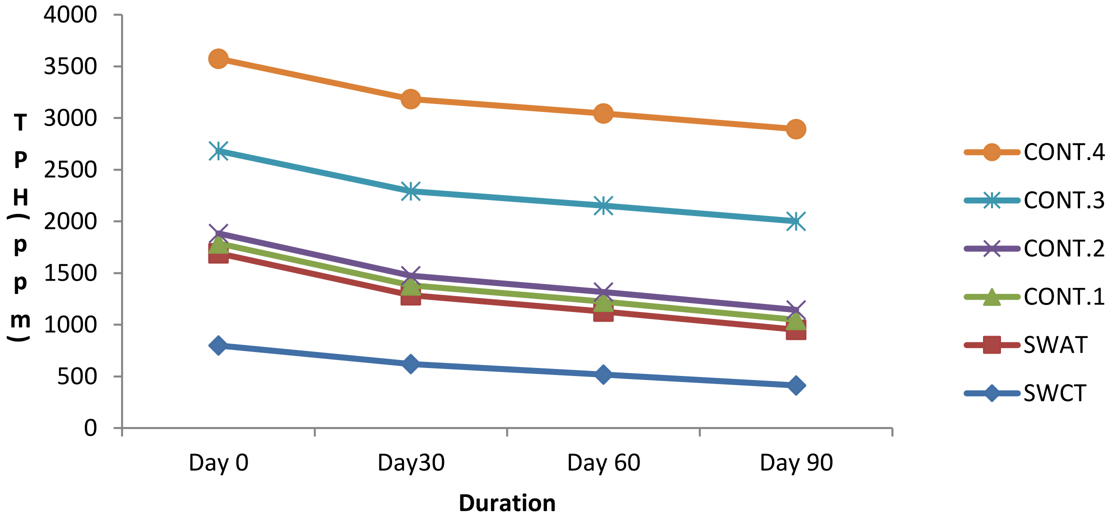

Figure 2: Total petroleum hydrocarbon (TPH) content of soils over 90 daysperiod of incubation

Keys: SWCT: Soil with chronic treatment, SWAT: Soil with acute treatment, CONT. 1: Soil-Seedling-Treatment, CONT2: Soil+Seedling-Treatment, CONT. 3:Soil-Seedling+Chronic treatment, CONT. 4: Soil-Seedling+Acute Treatment.

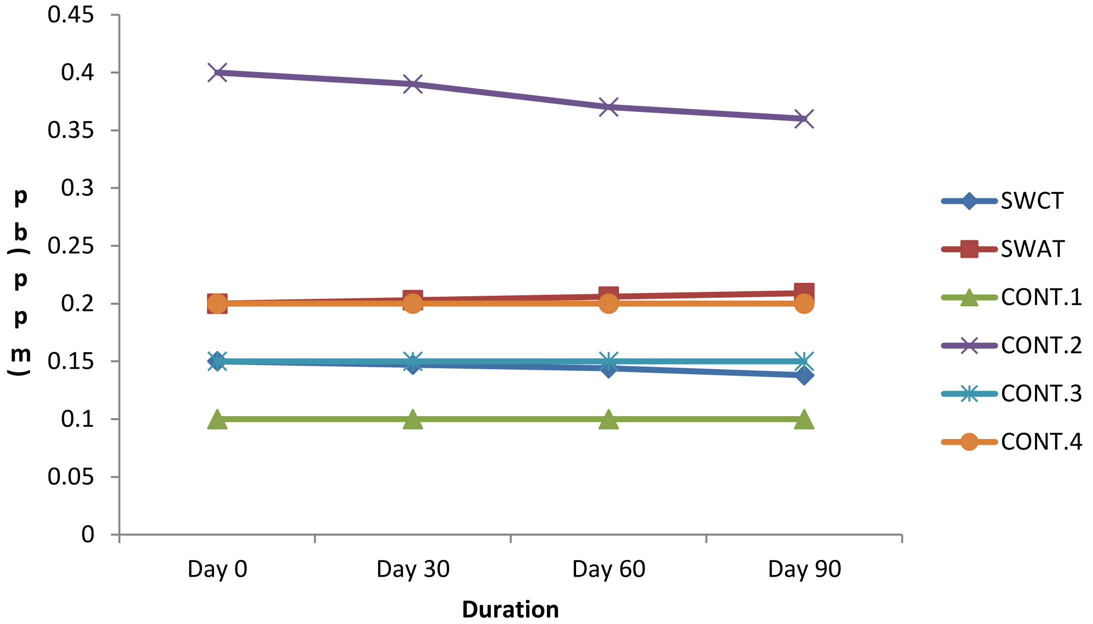

Figure 3: Lead (Pb) content of soils over 90 days period of incubation

Keys: SWCT: Soil with chronic treatment, SWAT: Soil with acute treatment, CONT. 1: Soil-Seedling-Treatment, CONT2: Soil+Seedling-Treatment, CONT. 3: Soil – Seedling+Chronic treatment, CONT. 4: Soil-Seedling+Acute Treatment.

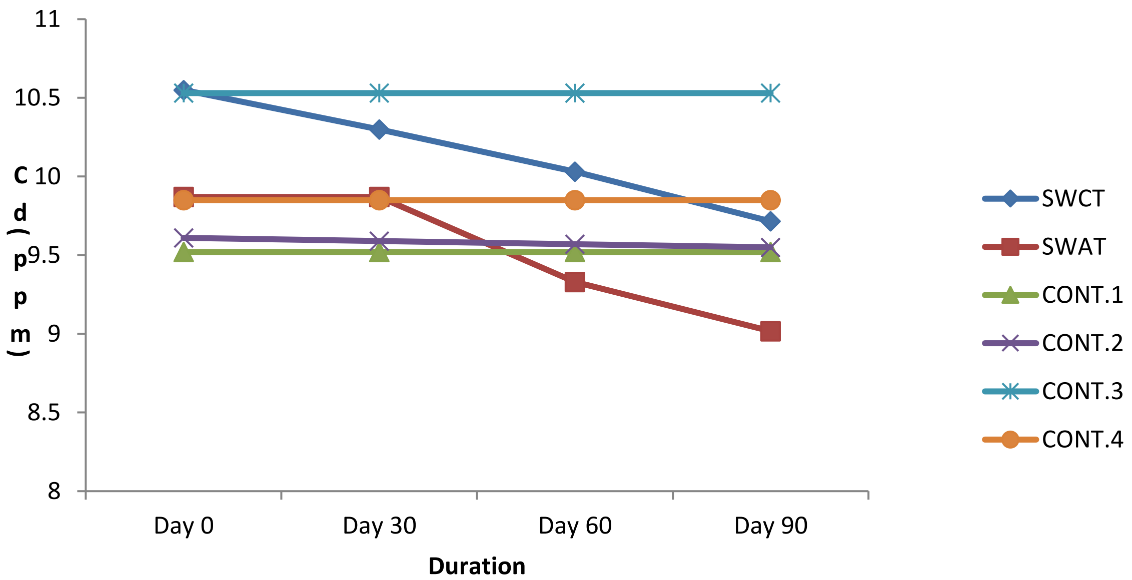

Figure 4: Cadmium (Cd) content of soils over 90 days period of incubation

SWCT: Soil with chronic treatment, SWAT: Soil with acute treatment, CONT. 1: Soil-Seedling-Treatment, CONT2: Soil+Seedling-Treatment, CONT. 3: Soil–Seedling+Chronic treatment, CONT. 4: Soil-Seedling+Acute Treatment.

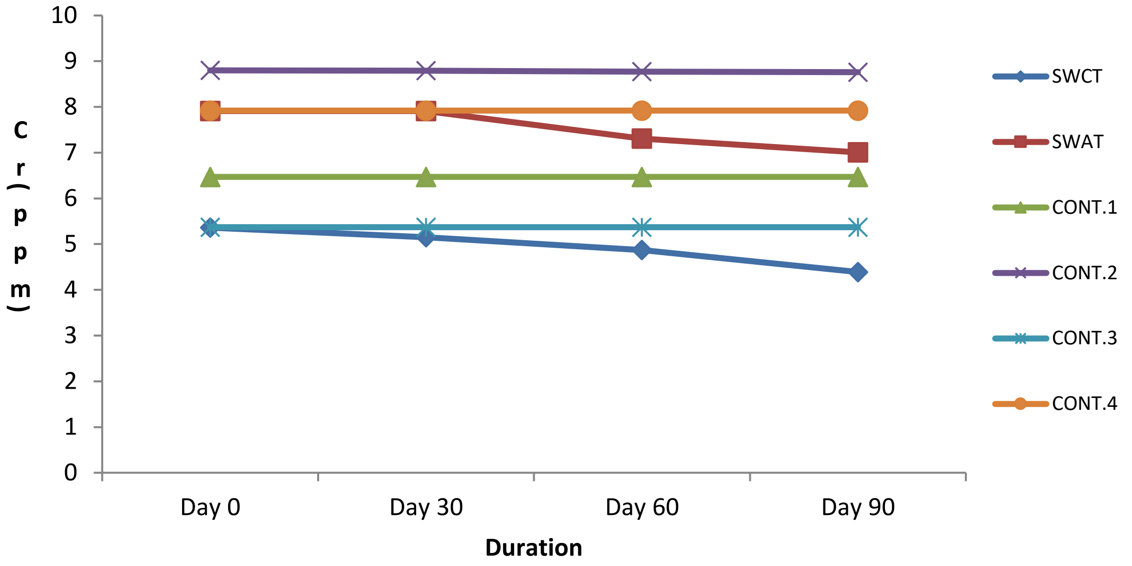

Figure 5: Chronium(Cr) content of soils over 90 days period of incubation
SWCT: Soil with chronic treatment, SWAT: Soil with acute treatment, CONT. 1: Soil-Seedling-Treatment, CONT2: Soil+Seedling-Treatment, CONT. 3: Soil – Seedling+Chronic treatment, CONT. 4: Soil-Seedling+Acute Treatment.

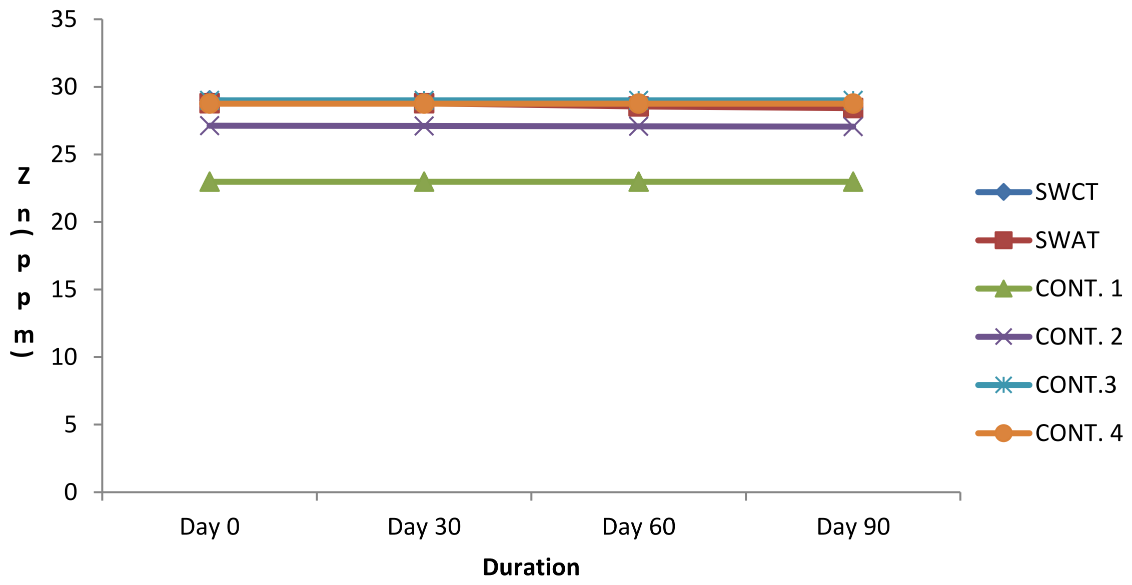

Figure 6: Zinc (Zn) content of soils over 90 days period of incubation
SWCT: Soil with chronic treatment, SWAT: Soil with acute treatment, CONT. 1: Soil-Seedling-Treatment, CONT2: Soil+Seedling-Treatment, CONT. 3:Soil–Seedling+Chronic treatment, CONT. 4: Soil-Seedling+Acute Treatment.

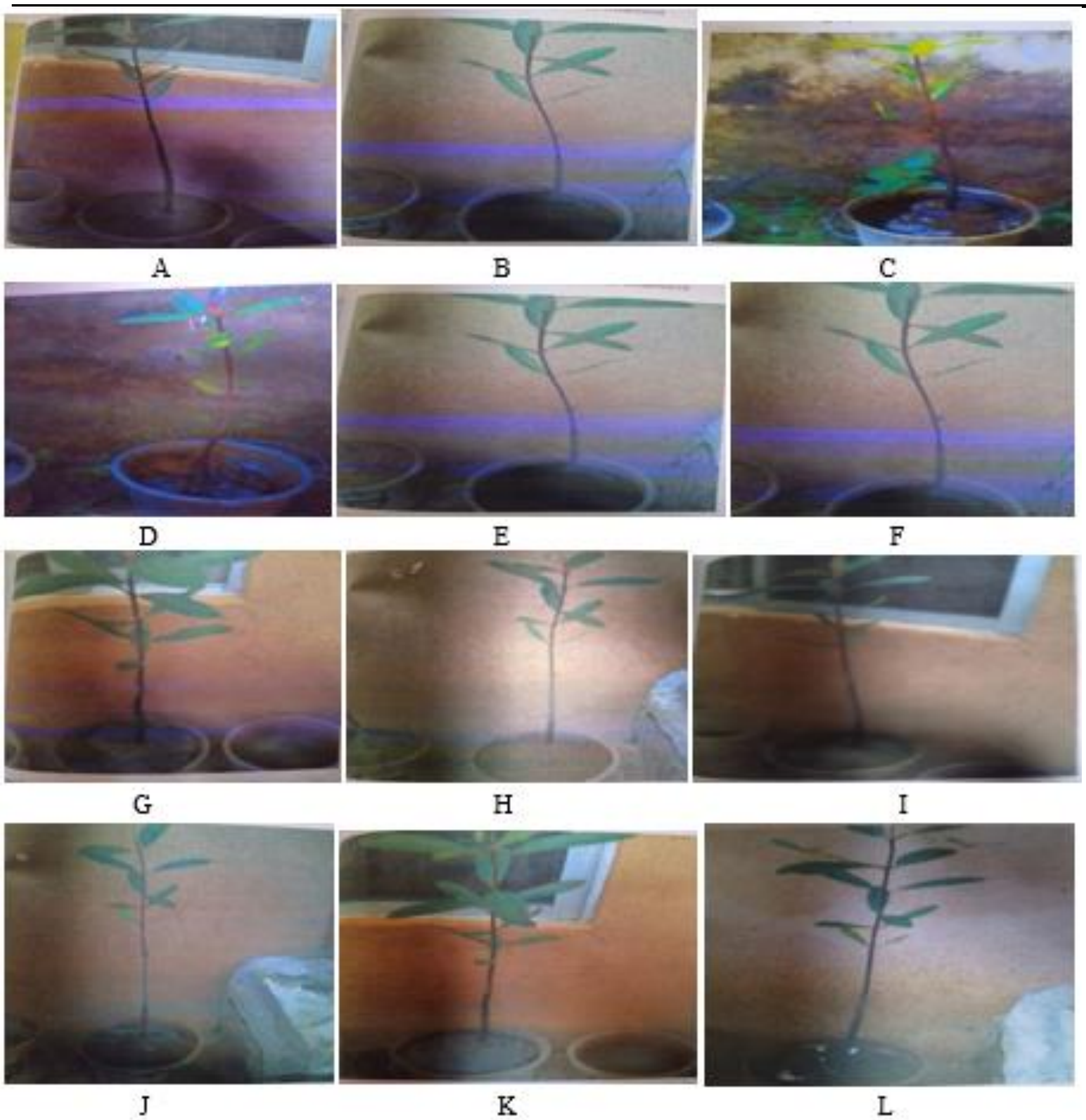

Plate 1: Pictorial presentations of the mangrove seedlings status for 90 days

Keys: A(Soil+Seedling+Acute treatment at day 0); B(Soil+Seedling+Chronic treatment at day 0); C(Soil+Seedling+Acute treatment at day 14); D(Soil+Seedling+Chronic treatment at day 14); E(Soil+Seedling+Acute treatment at day 28); F(Soil+Seedling+Chronic treatment at day 28); G(Soil+Seedling+Acute treatment at day 42); H(Soil+Seedling+Chronic treatment at day 42); I(Soil+Seedling+Acute treatment at day 56); J(Soil+Seedling+Chronic treatment at day 56; K(Soil+Seedling+Acute treatment at day 90) ; L(Soil+Seedling+Chronic treatment at day 90)

DISCUSSION

Findings from this work on the reactions of mangrove ecosystem to acute and chronic crude oil contamination revealed that the reactions of both mangrove plants and soil vary with the different types of crude oil contamination exposure and concentration. Mangrove seedlings on contaminated soils showed some amount of growth; this includes increase in stem height, stem girth, numbers of leaf and leaf area.

The soil analysis correlates with a former report of Fawole (2016) that sand content of loam sand ranges from 29-67 ± 12.83% and there may be a decrease as the soil depth increases; also, the silt content ranges from 11-25 ± 3.31%. It is very needful to have a required knowledge of the soil under investigation in order to avoid soil resource illiteracy and give proper nutrient management during the course of research (Obiora *et al.*, 2016).

This study confirms a report that says mangroves are highly sensitive to oil exposure, crude oil contamination may kill them out rightly within weeks or months or cause yellowing of leaves and defoliation (Peterson *et al*., 2004).

There was a consistent and gradual increase in the stem length, leaf area and stem diameter in all the mangrove plants experimented on, even though there were variations. There was addition of leaves to all the mangrove seedlings during the ninety–day period of growth. Seedlings with acute and chronic treatment have six additional leaves each while seedling without treatment has four additional leaves at the end of 90 days of experiment. This result strongly suggests that these mangrove plants have been able to firstly adapt to crude oil contamination and have also been able to utilize the crude oil for growth hence the increase in all the growth parameters employed with the highest increase occurring in seedling with chronic treatment. This is in support of a former report that mangrove plants have potential phytoremediation properties because they act as pollutant eradicators (Paz-Alberto *et al*., 2015). Also, some plants have been identified to tolerate or hyperaccumulate toxic substances in their shoots or leaves because they exhibit growth without signs of toxicity when grown in polluted soils (Kramer, 2010; Kumar *et al*., 2018).

There was a gradual reduction in pH, concentration of TPH and heavy metals in the contaminated soils except in soil with acute treatment (SWAT)which showed an increase in Pb concentration during the ninety days of growth. This confirms a report that some plants have the ability to extract some tangible quantity of TPH and heavy metals, tolerate them and use them for growth (Ghazaryan*et al*., 2021; Bhat*et al*., 2022). Also, Steliga and Dorota, (2021) reported that after biodegradation process of some soils were characterized by an elevated content of heavy metals including leads (Pb).

The result showed a slight decrease in the pH of the treated soils containing the mangrove seedlings with the highest decrease in soil with chronic treatment SWCT. This correlates with a former report that most heavy metals are more mobile under lower pH, oxidizing conditions and are more soluble at PH 4-5 than in a PH range of 5-7 (Plants and Raiswel, 1983; Brummer *et al*., 2008).

There was a gradual and consistent decrease in TPH concentration in all the soil samples, CONT.1 maintained the same TPH concentration throughout the period of incubation while CONT 3showed continuous increase in TPH concentration suggesting that the increase in TPH concentration is as a result of the weekly addition of crude oil and without seedling to phytoremediate the TPH. This confirms a former report that phytoremediation is one of the suitable techniques for removal of TPH from sandy soil, with the use of phytoremediation TPH concentration was decreased by about 80% within 90 days (Gouda *et al.,* 2016).

Controls 1, 3 and 4 maintained a constant Pb concentration throughout the 90 days of incubation while there was a slight reduction in Pb concentration in SWCTand in SWAT.This correlates with a report that plants take up limited quantity of Pb from their roots due to immobility of Pb in soil and a lot of physiological mechanisms in plants that prevent Pb from moving into above ground tissues (Egendorf *et al*., 2020).

The results revealed a decrease in cadmium (Cd) concentration in SWCT, SWAT, CONT. 4 and CONT.2 while CONT.1 and 3 maintained a constant cadmium concentration at the end of incubation period.This agrees with Subasic *et al*. (2022) which says that phytoremediation is one of the approaches for Cd remediation from polluted soils.

There was reduction in chromium (Cr) concentration in the soil samples and the highest decrease was observed in SWCT while CONT.1, CONT.3 and CONT. 4 maintained constant Cr concentration from day 0 to day 90. In another study conducted by Adiloğlu *et al*. (2015), 100 $mgkg^{-1}$ Cr $(NO_3)_3$ chromium was used as a contaminant in an agricultural field, and growing canola plant was used as the phytoremediation plant. According to the research results, phytoremediation method can be used for removing of the chromium heavy metal from contaminated soils.

All the samples demonstrated a decrease in Zn concentrations; in another study conducted by Olegario *et al.* (2010), the concentration of Zn in soil was decreased at day 45 (average103.09 µg/g) and then remained almost the same for other replications.

CONCLUSION

The comparison of the rate of reduction of heavy metals and TPH among the crude oil contaminated soil samples showed that the acute contamination of crude oil has impact that is more negative on mangrove soil ecosystem than the chronic contamination. In addition, mangrove seedling exposed to chronic treatment of crude oil has more phytoremediative ability than mangrove seedling exposed acute treatment.

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