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Phytoremediation a Panacea for Sustaining Soil and Human Health in Crude Oil Producing Area of Nigeria

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Abstract
The application of *Jatropha gossypiifolia* for the remediation of impacted soils within the Niger Delta Zone of Nigeria was examined in this work. During the study, seeds of *J. gossypiifolia* were cultivated on different soils impacted with wastes from municipal dumpsite, automobile and, electronic workshops, and paint industry in Akwa Ibom State. Two kilograms each of the impacted soils in polyethene bags were amended with 20.0 mLday^{-1} of mixed citric and ethylene diamine tetraacetatic acids. Plants and soil samples before and after remediation were assessed for the concentrations of Cd, Cu, Ni, and Pb. The concentrations (mg kg^{-1}) of metals in the impacted soils before remediation process were Cd (3.00±0.82), Cu (23.85±3.31), Ni (11.39±2.08), and Pb (36.10±2.27), respectively. Levels of the metals phytoextracted were 2.27±0.67 mg kg^{-1}, 2.51±3.27 mg kg^{-1}, 10.17±2.29 mg kg^{-1}, and 34.81±2.37 mg kg^{-1} for Cd, Cu, Ni, and Pb, respectively. However, the concentrations of Cd, Cu, Ni, and Pb (mg kg^{-1}) were reduced to 0.68±0.18, 1.28±0.27, 1.19±0.25, and 1.14±0.13, correspondingly in soil after remediation. Higher values of all the environmental models were recorded for the metals during the pre than the post-remediation periods. The estimated daily exposure rates, non-carcinogenic and cancer risks for the adults and children were higher during the pre than the post remediation regimes however; the children class was more disposed to these hazards. The results revealed that the remediation of impacted soils by plants could sustain the soil environment and human life within the studied Region.

Keywords: Phytoremediation, Oil pollution, Soil contamination, Phytoextraction, Remediation, Nigeria.

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Introduction
The Niger Delta zone of Nigeria is the zone that produces crude oil, the main source of the country's economy. However, the oil and oil-related activities within the zone have degraded the air, soil and water ecosystems [1-4]. The flaring of flue gases by these Oil Companies into the atmosphere is a major source of air contaminants affecting the area [5-7]. The terrestrial and aquatic ecosystems are mainly impacted by wastes generated by these Companies, oil spillage and their metals installation [8-11]. According to Ola *et al*. [11], contaminants within the South-South Area of Nigeria emanate principally from the activities of crude oil activities. The impacts of crude oil activities in the South-South Area of Nigeria have threaten the existence of some species of plants and animals within the region [12, 13]. The contaminants generated by these Companies have impacted negatively and significantly on the soil and human health [14-16]. Consequently, a technique that is cheap, economical, eco-friendly and safe should be adopted to ameliorate the already bad status of the area. Some environmental management techniques can create serious threat to the environment and human life [17]. Environment highly contaminated with toxic substances due to oil activities might cause both the carcinogenic and non-carcinogenic problems in human health [18, 19]. It is opined that high buildup of metal toxicants in the environment might results in cancer and non-cancer human risks [20, 21]. Consequently, metals within the studied zone of Nigeria should be properly managed to forestall associated consequences on the health of soil and human life. Hence, the use of plant-based remediation method was employed to assess the effectiveness in ameliorating the negative effects of metal toxicants on soil and human health within the region. The plant *J. gossypiifolia* was employed in this study due to its availability and high potential for removing toxic metals from impacted soils [22, 23]. Studies have shown that phytoremediation technique is economical, eco-friendly and is the safest [24, 25]. Some environmental management techniques can exacerbate the contamination level of the already degraded environment in the Oil producing area of Nigeria [26, 27].

Preceding researches on the use of plants to clean the impacted Niger Delta Sector of Nigeria focused mainly on the remediation of crude oil impacted soils in the zone [28-34]. These studies never considered harnessing the potentials of plants for the cleaning up of other impacted soils thereby improving on the health of these soils and human beings. Conversely, the current research aimed at

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exploiting the potentials of *J. gossypiifolia* for the remediation of soils impacted with contaminants other than crude oil thus; improving on the health of these soils and human life. Aside from phytoremediation technique being relatively less expensive and a simple tool for elemental recovery, it is also used for the restoration of habitats, increase the population of flora and fauna, creation of greener environments preserve soil fertility, and generate low waste products [35, 36]. Nevertheless, the long-term applicability of phytoremediation depends upon some factors such as the type of contaminant, the condition of the soil, and the method used. Though phytoremediation can decrease contaminants in soils and improves the soil health the long-term challenges might include effective management of plant biomass, long-term monitoring, fate of the contaminant, toxicity to plants, and limited applicability to site with high level of contamination etc [37].

The work was undertaken to identify an easy and eco-friendly method that could be utilize for cleaning the highly impacted South-South zone of Nigeria. This research also focused on assessing the impacts of the technique on the revitalizing the soil and human health in the studied area that has been negatively impacted by the crude oil-related activities. The outcome of this work will be useful to the stakeholders in their planning and execution of regulations related to crude oil activities within the South-South zone of Nigeria.

Methodology

Study area

The oil producing zone of Nigeria locates within the Gulf of Guinea between latitude 4.15° N – 7.17° N and longitude 5.05° E – 8.68° E. The region is made up of Abia, Bayelsa, Akwa Ibom, Imo, Cross River, Rivers, Delta, Ondo, and Edo States. The area has two prominent seasons, (the dry and wet), the dry season commences on November and terminates in early March, whereas the dry season commences in December and terminates in April. The region has average annual temperature varies between 25 °C and 29 °C, while the yearly average rain range from 2400 to 4000 mm [38]. This study was carried in Akwa State as a foremost crude oil zone in Nigeria to propose a technique that can ameliorate the impacts of contaminants on plants, soil, and human [39, 40]. The State is located within latitudes 4° 32! and 5° 33! Northing and longitudes 7° 25! and 8° 25! Easting in Nigeria. The current activities related with crude oil exploration and exploitation in the region has generated high levels of gaseous, liquid, and solid wastes. Consequently, the air, water, and land environments have been highly contaminated with toxic substances.

Cultivation of *Jatropha gossypiifolia* and Soil Amendment

This study used plastic bags of size 20 cm width by 10 cm height filled with 2.0 kg dry contaminated soils. The seeds of *J. gossypiifolia* (Bellyache *bush)* were cultivated on these bags and kept to grow. In all, sixteen (16) bags were utilized for this research, and they were divided into four (4) sets of four each [41-43]. Each set of four bags contained impacted soils with wastes from municipal dumpsite (WDS), automobile shops (AIS), electronic shops (EWS), and paint industry (PIS) in the State within the oil producing region in Nigeria. These different impacted soils were amended with 20.0 mLday^{-1} of mixed citric and ethylenediaminetetraacetatic acids (CA and EDTA). The unamended, uncultivated baseline soils obtained from the WDS, AIS, EWS, and PIS were used as the Controls in this study as reported by Oyedeji *et al*. [30] and Oh *et al*. [41]. All the bags were irrigated with 500 mL of distilled water daily apart from the day preceding the harvest. At the end of twelve weeks, the plants were harvested using hand trowel. For the use of plants for remediation study, the plants are usually harvested after twelve weeks in order to evaluate the efficiency of the method. This period gives enough time for the uptake and buildup of contaminants for the soil [44, 45]. The harvested plants were treated for further analytical procedures following the procedures of Njoku *et al*. [44] and Azorji *et al*. [45].

Samples collection and Treatment

The plants harvested were cleaned using distilled water, the plant biomass dried in air for twenty one (21) days, ground and sieved with 2 mm mesh. Ten grams (10 g) each of the impacted soils was obtained before the cultivation of *J. gossypiifolia* and after the harvest using hand trowel. The impacted soils collected were dried in air for three days, homogenized and sieved. Then one gram (1 g) of each plant biomass and soil were digested with 10 mL of 1:1 (w/v) HNO_3: H_2O in a beaker. The combination was mixed properly and put in a beaker with a watch glass cover thereafter, heated up to 95 °C followed by refluxing for a quarter of an hour. The mix was cooled, and 5 mL Conc. HNO_3 introduced and refluxed once more for half an hour. The container was covered with a ribbed apparatus and kept to dry up to 5 mL. Thereafter, the mixture was cooled and 2 mL of distilled water and 3 mL of 30 % hydrogen peroxide (H_2O_2) introduced. The mix was then heated till effervescence from the mix ceased. The mix was cooled

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again and 1 mL H_2O_2 introduced till effervescence was reduced. The mixture was cooled again the third time, 2 mL Conc. HNO_3 and 10 mL distilled water introduced then refluxed once more for half an hour. The mix was then centrifuged at 4000 rpm for half an hour to divide the filtrate from the residue. The concentrations of Cd, Cu, Ni, and Pb in the digests were determined using Inductively Coupled Plasma Optical Emission spectroscopic (ICP-OES) methods [44, 46].

Evaluation of soil quality

Contamination Factor

Contamination factor (CF) was employed to assess the intensity of soil contamination by trace metals in the studied samples with relative to the background values of the metals as documented by Shen *et al*. [47]. The CF of metals in the studied soils was estimated with Equation 1.

$$CF = \frac{\textit{Concentration of Trace metal in the studied Soil}}{\textit{Concentration of the Trace metal in the Background Soil}} \quad (1)$$

The background values ($mgkg^{-1}$) of the metals used were Cd = 0.3, Cu = 45, Ni = 68, and Pb = 20 according to Shen *et al*. [47]. According to Lacatusu [48], the different categories of CF are as follows: < 0.1 is the very slight contamination; 0.10–0.25 denotes the slight contamination; 0.26–0.5 is moderate contamination; 0.51–0.75 signifies the severe contamination; 0.76–1.00 is the very severe contamination; 1.1–2 stands for the slight pollution; 2.1–4.0 indicates moderate pollution; 4.1–8.0 is severe pollution; 8.1–16.0 shows the very severe pollution; and CF > 16 indicates excessive pollution.

Ecological risk factor

The ecological risk factor (ERF) was used to assess the hazards related with the metal loads within the studied impacted soils; the ERF was determined using Equation 2 according to Hakanson [49].

$$ERF = Tr \ x \ CF \quad (2)$$

Where Tr is the toxic-response factor of the metals and CF is the contamination factor of trace metals. As recommended by Hakanson [49], the Tr values of Cd, Cu, Ni, and Pb are 30, 5, 5, and 5, respectively. The classes of ERF in accordance with Cheng *et al*. [50] are: ERF < 40 is low ecological risk; 40 < ERF≤ 80 indicates moderate ecological risk; 80 < ERF ≤ 160 signifies appreciable ecological risk; 160 < ERF ≤ 320 denotes high ecological risk, and ERF > 320 is the severe ecological risk.

Potential ecological risk index

The potential ecological risk index (PERI) was utilized to examine the negative effects of trace metals on the various sites examined within the study area. PERI of the metals in the study area was calculated with Equation 3 as reported by Cao *et al*. [51].

$$PERI = \Sigma(ERF) \quad (3)$$

$\Sigma(ERF)$ in the above equation denotes the sum of the trace metals for each site.

PERI is categorized into the following classes by Chen *et al*. [50]: PERI < 40 represents low ecological risk, 40-80 is moderate ecological risk, 80-160 indicates the considerable ecological risk, 160-320 signifies the high ecological risk, and ≥320 is the very high ecological risk.

Pollution load index

The pollution load index (PLI) is another important model used for the evaluation of the severity of soil contamination by metals in the study area [52]. The PLI of the metals in the studied impacted soils was computed with Equation 4 below.

$$PLI = (CFCd \ x \ CFCu \ x \ CFNi \ x \ CFPb)^{1/4} \quad (4)$$

Where CF indicates the contamination factor of the metal, and the different classes of PLI according to Rai *et al*. [53] are as follows: 0 denotes no pollution; 1 indicates none to medium pollution; 2 signifies moderate pollution; 3 indicates moderate to strong pollution; 4 is strongly polluted; 5 stands for strong to very strong; while 6 denotes the very strong class [53].

Health risk appraisal

The estimated dietary intake (EDI) rate of trace metals in the impacted soils

The EDIs of Cd, Cu, Ni, and Pb for the adults and children through contact with the impacted soils during pre and post remediation periods were computed using Equation 5.

$$EDI = \frac{C \ x \ IR \ x \ EF \ x \ ED}{BW \ x \ AT} \quad (5)$$

The meaning and value for each of the health risk index in equation 5 above are shown in **Table 1** below.

Table 1. Meaning and value of Health Risk Index

Indices	Values Used
Ingestion rate (IR) (mg/day)	0.0002 $kgday^{-1}$ for child [54]. 0.0001 $kgday^{-1}$for adults [54].
Exposure frequency (EF) (day/yr)	350 days/year [55].
Exposure period (ED)(yr)	6 years – child [56]. 30 years – adult [56].
Mean time (AT) (day/yr)	365 days/year [57].
Weight of the body (kg)	15 kg – child [57]. 70 kg – adult [57].
Levels of metal in the studied soils (C) ($mg\ kg^{-1}$)	In Figure 1 below

Target hazard quotient (THQ) of trace metals in the studied soils

The target hazard quotient of metals for the adults and children via exposure to the studied impacted soils

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during the pre and post remediation regimes was computed using Equation 6.

$$THQ = \frac{EDI}{Rfd} \quad (6)$$

EDI in the equation is estimated dietary intake rate of trace metals calculated, while Rfd signifies the recommended oral reference dose of trace metals. The Rfd values of Cd, Cu, Ni, and Pb according to [58] are 0.001, 0.04, 0.02, and 0.0035 $mgkg^{-1}day^{-1}$, respectively.

Total Hazard index (THI) of metals in the impacted soils

The THI of trace metals for the adults and children due to contact with the impacted soils for pre and post remediation periods was estimated using Equation 7.

$$THI = \sum THQ = THQCd + THQCu + THQNi + THQPb \quad (7)$$

In the equation 7 above, ΣTHQ signifies the summation of target hazard index of Cd, Cu, Ni, and Pb

Incremental lifetime cancer risk (ILCR) of the carcinogens

The ILCR values of the cancer-causing metals (Cd, Ni, and Pb) for the adults and children due to contact with the studied impacted soils during the pre and post remediation regimes were determined by the means of Equation 8.

$$ILCR = CSF\ x\ EDI \quad (8)$$

CSF is the cancer slope factor for the carcinogens, whereas EDI stands for the estimated dietary intake rate of the metals. The CFS values of Cd, Ni, and Pb are 5.00E-1, 1.70E+0, and 8.50E-3, respectively [57].

Total cancer risks (TCR) of the toxic metals

The TCR values of Cd, Ni, and Pb for the adults and children via exposure to the impacted soils examined in the pre and post remediation periods were obtained with Equation 9.

$$TCR = \sum ILCR = ILCRCd + ILCRNi + ILCRPb \quad (9)$$

Where $\sum ILCR$ denotes the summation of incremental lifetime cancer risk values of Cd, Ni, and Pb.

Statistical treatment of data

The IBM SPSS Statistic version 29.0.2.0 (20) Software was employed for the statistical treatment of the results obtained. Microsoft excel sheet was used for the plotting of graphs and histograms. The Principal component analysis was performed by means of Varimax Factor analysis on the trace metals and values from 0.608 were deemed significant. Standard errors for the data obtained were calculated. T-test was used to analyze the variations between the concentrations of trace metals in the baseline soils (Controls) and the concentrations extracted by the studied plant at $p < 0.05$. The T-test was performed with IBM SPSS Statistic version 29.0.2.0 (20) Software.

Results

Concentrations of trace metals in the studied soils

The results of T-test of the metals in the baseline soils (before phytoextraction) and the metals extracted by *J. gossypiifolia* from the impacted soils are indicated in **Table 2** below.

Table 2. T-Test results of the difference between the concentrations of metals in soil before phytoextraction (Control) and the concentrations of metals extracted by *J. gossypiifolia*

	Test Value = 4					
	T	N	P=value (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Cd	-4.865	7	0.002	-1.36375	-2.0266	-0.7009
Cu	17.353	7	0.000	19.17875	16.5654	21.7921
Ni	9.009	7	0.000	6.77875	4.9996	8.5579
Pb	39.442	7	0.000	31.45000	29.5645	33.3355

* = Significant at $p \leq 0.05$

Table 3. Concentrations ($mgkg^{-1}$) of Trace Metals in the studied impacted soils before phytoextraction

	Cd	Cu	Ni	Pb
WDS	3.45	27.26	11.23	39.36
ARS	2.67	23.83	13.44	35.14
EWS	3.86	24.92	12.31	35.70
PIS	2.02	19.37	8.59	34.18
MIN	2.02	19.37	8.59	34.18
MAX	3.86	27.26	13.44	39.36
MEAN	3.00	23.85	11.39	36.10
SD	0.82	3.31	2.08	2.27
SE	0.21	0.83	0.52	0.57

The mean concentrations of Cd, Cu, Ni, and Pb in the impacted soils before the remediation process are shown in **Table 3.** The mean concentrations of Cd, Cu, Ni, and Pb in the baseline impacted soils (Controls) were 3.00±0.82 $mgkg^{-1}$, 23.85±3.32 $mgkg^{-1}$, 11.39±2.08 $mgkg^{-1}$, and 36.10±2.27 $mgkg^{-1}$, correspondingly

Mean concentrations of trace metals extracted by *J. gossypiifolia* from the impacted soils

The mean levels of metals extracted by the total biomass of *J. gossypiifolia* from the studied impacted soils are indicated in **Table 4**. **Table 4** indicates the mean concentrations (mg kg^{-1}) of Cd, Cu, Ni, and Pb extracted from the impacted soils by *J. gossypiifolia* as 2.27±0.67, 2.51±3.27, 10.17±2.29, and 34.81±2.37, respectively.

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Percentages of trace metals extracted by J. gossypiifolia and the left over after the process

Table 4. Concentration (mg kg^{-1}) of Trace Metals extracted from the impacted soils by *J. gossypiifolia*

	Cd	Cu	Ni	Pb
WDS	2.58	26.02	10.20	38.20
ARS	1.92	22.71	12.28	33.66
EWS	3.04	23.19	11.21	34.55
PIS	1.55	18.13	6.97	32.81
MIN	1.55	18.13	6.97	32.81
MAX	3.04	26.02	12.28	38.20
MEAN	2.27	22.51	10.17	34.81
SD	0.67	3.27	2.29	2.37
SE	0.17	0.82	0.57	0.59

*WDS = Waste Dumpsite; AIS = Automobile Waste–Impacted Soil; EWS = Electronic Waste-Impacted Soil; PIS = Paint Waste-Impacted Soil; MIN = Minimum; MAX = Maximun; SD = Standard Deviation

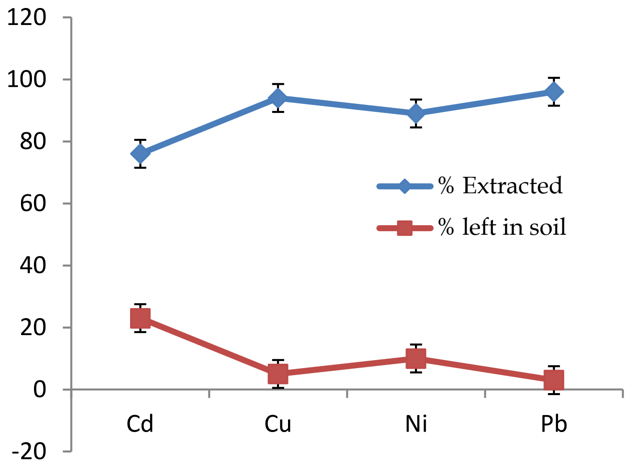

Figure 1. Proportions of trace metals extracted and those left in Soil after Remediation Process, **Legend:** ♦ indicates the proportion of trace metals extracted from the impacted soils by *J. gossypiifolia*; ■ signifies the concentrations of the metals in soil after phytoextraction

The results of the quantity of trace metals extracted and not extracted from the contaminated soils during the remediation process are illustrated in **Figure 1**. The mean proportions of Cd, Cu, Ni, and Pb phytoextracted from the impacted soils were 76%, 94%, 89%, and 96%, respectively (**Figure 1**). The mean values amounts of Cd, Cu, Ni, and Pb left in the studied soils after the remediation process were 23.0%, 5.4%, 10.5%, and 3.2%, respectively (**Figure 1**). The mean concentrations of Cd, Cu, Ni, and Pb loss after phytoremediation process of the impacted soils were 0.05, 0.06, 0.03, and 0.15 mg kg^{-1}, correspondingly.

Results of soil quality assessment during the pre and post-remediation periods

Contamination factor of metals in the studied soils

The contamination factors (CF) of the metals for the studied soils before and after phytoremediation by *J. gossypiifolia* are indicated in **Table 4.**

The ecological risk factor of metals in the studied soils

The results of ecological risk factor (ERF) of the metals in the impacted soils before and after the phytoremediation process are in **Table 5**. **Table 5** indicates the average values of contamination factor (CF) of Cd, Cu, Ni, and Pb in the baseline impacted soils as 10.00 ± 0.05, 0.53± 0.03, 0.17±0.06, and 1.81±0.07, respectively. However, after the remediation process by *J. gossypiifolia,* the mean CF values for Cd, Cu, Ni, and Pb were drastically reduced to 2.43±0.07, 0.03±0.01, 0.02±0.01, and 0.07±0.01, respectively.

The results of ecological risk factor (ERF) of the metals in the baseline impacted soils as shown in **Table 5** are 300.0±11.4, 2.65± 0.06, 0.85±0.03, and 9.05±1.15 for Cd, Cu, Ni, and Pb, respectively. Yet, after phytoremediation of the soils by *J. gossypiifolia* the ERF values of Cd, Cu, Ni, and Pb were reduced to 72.9± 8.27, 0.15±0.06, 0.10±0.02, and 0.35±0.08, respectively.

Table 5. Contamination and the Ecological risk factors of the trace metals

	Contamination Factor (CF)		Ecological Risk Factor (ERF)	
	BP	AP	BP	AP
Cd	10.0±0.05	2.43±0.07	300±11.4	72.9±8.27
Cu	0.53±0.03	0.03±0.01	2.65±0.06	0.15±0.06
Ni	0.17±0.06	0.02±0.01	0.85±0.03	0.10±0.02
Pb	1.81±0.07	0.07±0.01	9.05±1.15	0.35±0.08

*BF = Before phytoremediation; AP = After phytoremediation

Results of human health risk assessment in the pre and post-remediation periods

Results of estimated dietary intake rates of trace metals during the pre and post-remediation periods

The average estimated dietary intake (EDI) rate of the trace metals due to contact with the contaminated soils by the adults and children in the pre and post-remediation regimes are indicated in **Table 6**. The results **Table 6** shows that the mean estimated dietary index (EDI) values of Cd, Cu, Ni, and Pb for the adults during the pre-remediation regime are 1.23E-4, 9.80E-4, 4.68E-4, and 1.48E-3 mg $kg^{-1}day^{-1}$, correspondingly. During the same period, the average EDI values in favour of the children class were 2.30E-4, 1.83E-3, 8.74E-4, and 2.77E-3 mg $kg^{-1}day^{-1}$for Cd, Cu, Ni, and Pb, correspondingly.

During the post-remediation regime, the average EDI values of Cd, Cu, Ni, and Pb for the adults group were

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Table 6. Estimated dietary intake rates, Target hazard quotient, and total hazard index of metals during the pre and post phytoextraction periods

	EDI, THQ AND THI FOR PRE-PHYTOEXTRACTION PERIOD			
	EDI		THQ	
	ADULTS	CHILD	ADULTS	CHILD
Cd	1.23E-4	2.30E-4	1.23E-1	2.30E-1
Cu	9.80E-4	1.83E-3	2.45E-2	4.58E-2
Ni	4.68E-4	8.74E-4	2.34E-2	4.37E-2
Pb	1.48E-3	2.77E-3	4.23E-1	7.97E-1
THI			2.13E-1	1.12E+0
	EDI, THQ AND THI FOR POST-PHYTOEXTRACTION PERIOD			
	ADULTS	CHILD	ADULTS	CHILD
Cd	3.00E-5	5.60E-5	3.00E-2	5.60E-2
Cu	5.47E-5	1.03E-4	1.37E-3	2.58E-3
Ni	5.06E-5	9.44E-5	2.53E-3	4.99E-3
Pb	5.30E-5	9.90E-5	1.51E-2	2.83E-2
THI			4.90E-2	9.19E-2

3.00E-5, 5.47E-5, 5.06E-5, and 5.30E-5 mg $kg^{-1}day^{-1}$, correspondingly. In the same period too, the average EDI values of Cd, Cu, Ni, and Pb for the children class were 5.60E-5, 1.03E-4, 9.44E-5, and 9.90E-5 mg $kg^{-1}day^{-1}$, correspondingly.

Target hazard quotient of trace metals during the pre and post-remediation periods

The target hazard quotients (THQs) of trace metals due to the exposure to the impacted soils by adults and children during the pre and post-remediation regimes are shown in **Table 6**. The mean target hazard quotient (THQ) values of Cd, Cu, Ni, and Pb via the impacted soils obtained during the pre-remediation periods for the adults as shown in **Table** 6 are 1.23E-1, 2.45E-2, 2.34E-2, and 4.23E-1, respectively. In the similar period, the mean THQ values of Cd, Cu, Ni, and Pb for the children were 2.30E-1, 4.58E-2, 4.37E-2, and 7.97E-1, respectively. Nevertheless, during the post-remediation regime the mean THQ values of Cd, Cu, Ni, and Pb for the adults reduced to 3.00E-2, 1.37E-3, 2.53E-3, and 1.5E-2, respectively. In the same period, the mean THQ values of Cd, Cu, Ni, and Pb for the children class also reduced to 5.60E-2, 2.58E-3, 4.99E-3, and 2.83E-2, respectively.

The total hazard index of trace metals during the pre and post-remediation periods

The average total hazard index (THI) of trace metals due to contact with the impacted soils by adults and children during the pre and post-remediation regimes are indicated in **Table 6**. The average total hazard index (THI) values of the metals for the adults and children during the pre-remediation period as indicated in **Table 6** are 2.13E-1 and 1.12E+0, respectively. However, during the post-remediation regime the average THI values for the adults and children were reduced to 4.90E-2 and 9.19E-2, respectively.

Results of cancer risk of metals in the pre and post-remediation regimes

The results of cancer-causing metals (Cd, Ni, and Pb) for the adults and children via exposure to the impacted soils in the pre and post-remediation regimes are indicated in **Table 7**. **Table 7** indicates the mean incremental lifetime cancer risk (ILCR) values of Cd, Ni, and Pb for the adults during the pre-remediation period as 6.15E-5, 7.80E-4, and 1.26E-5, respectively. The average ILCR values of Cd, Ni, and Pb for the children during the same period were 1.14E-4, 1.49E-3, and 2.36E-5, respectively. But, during the post-remediation regime, the average ILCR values of Cd, Ni, and Pb for the adults were reduced to 1.50E-5, 8.60E-5, and 4.51E-7, respectively. Whereas, the mean ILCR values of Cd, Ni, and Pb for the children class during the post remediation period were also reduced to 2.80E-5, 1.61E-4, and 8.42E-7, correspondingly.

Total cancer hazards of metals during the pre and post-remediation periods

The average total cancer risk (TCR) values of the carcinogens due to the exposure of the adults and children to the studied impacted soils in the pre and post-remediation regimes are in **Table 7**. The results in **Table 7** indicate the average TCR values of Cd, Ni, and Pb for the adults and children classes during the pre-remediation period as 8.54E-4 and 1.63E-3, respectively. Whereas, the average TCR values of the metals for the adults and children during the post-remediation regime were 1.00E-4 and 1.90E-4, respectively

Table 7. ILCR of trace metals for the pre and post phytoextraction periods

	ILCR for pre-phytoextraction period	
	Adults	Child
Cd	6.15E-5	1.14E-4
Cu	-	-
Ni	7.80E-4	1.49E-3
Pb	1.26E-5	2.36E-5
TCR	8.54E-4	1.63E-3
	ILCR for post-phytoextraction period	
	Adults	Child
Cd	1.50E-5	2.80E-5
Cu	-	-
Ni	8.60E-5	1.61E-4
Pb	4.51E-7	8.42E-7
TCR	1.01E-4	1.90E-4

Principal Component Analysis (PCA) of metals in the studied contaminated soils

The results of PCA of the metals in the impacted soils during the pre and post-remediation periods are shown in **Table 8**. The PCA results of the metals in the pre-remediation period indicated one outstanding factor responsible for the buildup of the metals in the impacted soils (**Table 8**). The factor had Eigen value of 2.88 and a total variance of 72% (**Table 8**). However, during the post-remediation period the PCA indicated two principal factors for the occurrence of the metals in the soils assessed. The first factor (PC1) with Eigen value of 2.66, added 66.5% of the cumulative variance (93.4%), while the second factor (PC2) with Eigen value 1.08 donated 26.9% of the cumulative variance (93.4%) (**Table 8**).

Table 8. Result of principal component analysis of metal in the impacted soils examined

Variable	PRE	POST	
	PC1	PC1	PC2
Cd	0.895	-0.908	-0.417
Cu	0.993	-0.634	0.704
Ni	0.669	0.876	0.474
Pb	0.802	0.817	-0.425
% Total Variance	72.0	66.5	26.9
% Cumulative variance	72.0	93.4	93.4
Eigen value	2.88	2.66	1.08

Discussion

The T-test results for the concentrations of trace metals in the control soils and the concentrations of trace metals extracted by *J. gossypiifolia* in **Table 2** indicates that the p-values for all metal pairs were less than 0.05. Consequently, there were significant variations among the concentrations of trace metals in the control soils and the concentrations of the metals extracted from the impacted soils by *J. gossypiifolia* at $p < 0.05$. The p-value of 0.000 indicates strong statistical significance in variations between their values in the control plots and the concentrations extracted by the plant. This study used a one-sample t-test to compare the means of the results obtained because it is simple and suitable for comparing samples means. The error bar at each point signifies statistically significant difference at $p < 0.05$.

The concentrations of Cd, Cu, Ni, and Pb in the baseline impacted soils (Controls) as indicated in **Table 3** revealed that Cd and Cu exceeded their recommended standards of 0.80 mg kg^{-1} and 10.10 mg kg^{-1} by FAO/WHO [59] before the remediation process, however; the values obtained for Ni and Pb were within their safe limits of 35.0 mg kg^{-1} and 85.0 mg kg^{-1}, respectively. The high Cd and Cu reported can impact negatively on the soil organisms, soil health, and upset the ecosystems. Prolonged exposure via the food chain could cause osteoporosis, cancer risk, and kidney damage. However, as metals persist and bioaccumulate in soil for a long period, the values reported for Ni and Pb could still be harmful over time [60]. The results also indicated high level of Cd in the electronic waste-impacted soil as observed by Adu and Aneke [61]. The highest concentrations of Cu and Pb were obtained in dumpsite waste-impacted soil as reported by Agbeshie *et al.* [62]. Paint waste-impacted soil showed the highest potential of polluting the soil with Ni [63]. The results obtained also indicated low standard errors indicating a high degree of precision is the data obtained for the metals.

The results in **Table 4** indicated that studied plant *J. gossypiifolia* showed very high capacity for extracting these metals mostly Pb from the impacted soil as reported by Alaboudi *et al.* [64]. Thus, the plant could be effectively used for the remediation of metal-impacted soils. The sequence for the concentrations of the metals extracted by *J. gossypiifolia* from the impacted soils followed the order Pb > Ni > Cu > Cd. The low concentrations of Cd extracted by *J. gossypiifolia* from the soils are agreement with the findings by Li *et al.* [65]. Nevertheless, the reported order could have been influenced by their concentrations in the baseline soils before the remediation process [66, 67]. Relatively, the concentrations of the metals extracted by *J. gossypiifolia* from the impacted soils were higher than the left over after the remediation process as previously observed by Petelka *et al.* [68]. Accordingly, phytoremediation technique has the potential of reducing the concentrations of metals from impacted sites, thereby preventing their related negative impacts on the environment and human health. The low standard errors obtained indicate that the sample data are perfect representative of the general population, and the samples may not have been significantly different from the population.

The results in **Figure 1** confirm that *J. gossypiifolia* has very high capacity to extract metals from impacted soils as opined by Ejeh *et al.* [69]. The proportion of metals extracted from the studied impacted by *J. gossypiifolia* followed a descending order of Pb > Cu > Ni > Cd. The elevated proportion of Pb phytoextracted from the impacted soils reported is consistent with the results obtained by Ibrahim and El Afandi [70]. The high phytoremediation ability of *J. gossypiifolia* corroborates the fact that it could be effectively utilized for remediation process and alleviates the associated human health hazards as reported by Chi *et al.* [22] and Devanesan *et al.* [23].

The results in **Figure 1** indicate that *J. gossypiifolia* effectively remediated the impacted soils. The

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proportions of the metals left in the impacted soils after phytoextraction process followed the order Cd > Ni > Cu > Pb. Thus, the proportion of Cd not extracted from the soils was the highest and could be attributed to the soil properties and its relatively less mobility in soil. This is consistent with the findings by Heredia *et al*. [71] and Surukite *et al*. [72].

Based on the mean concentrations of the metals in the control soils and those extracted by the plant, the proportions of Cd, Cu, Ni, and Pb lost during the remediation process were 1.0%, 0.6%, 0.5%, and 0.8%, correspondingly. Thus, Cd had the highest proportion of metal lost during the phytoextraction process. This high proportion of Cd lost in the process is in agreement with the findings by Njoku and Nwani [44]. This could be attributed to microbial activities in the studied soils. Nevertheless, *J. gossypiifolia* showed a promising result as an effective phytoremediation agent. The low proportions of metals lost in the process confirm the findings by Kafle *et al*. [24].

The results in **Table 5** shows that contamination factor (CF) of Cd belonged to the severe pollution category; Cu and Ni in the severe contamination and slight contamination classes, respectively; whereas, Pb belonged to the slight pollution category in the control soils [48, 49]. The high CF values of Cd, Cu, and Ni in the impacted soils can pose serious negative effects on the soil, crop yields, and human health [73]. However, after the remediation process the CF of Cd was reduced to the moderate pollution category, while Cu, Ni and Pb were in the very slight contamination class. Consequently, phytoremediation process by *J. gossypiifolia* can effectively reduced the negative impacts of the metals in the impacted soils as opined by Yan *et al*. [74] and Priya *et al*. [75].

The results in **Table 5** indicate that before the remediation process, the ecological risk factor (ERF) of Cd was in the high potential ecological risk category, while the ERF values of Cu, Ni, and Pb were in the low potential ecological risk group [49]. However, after the phytoremediation process the ERF of Cd was reduced to the moderate potential ecological risk class. Though, the ERF values of Cu, Ni, and Pb were reduced, they were still in the low potential ecological hazard group, according to Hakanson [49]. Apparently, the use of *J. gossypiifolia* for the remediation of impacted soils could ameliorate the negative impacts associated with metals in the environment and human health as reported by Ashraf *et al*. [76].

The mean values of potential ecological risk index (PERI) of the metals recorded during the pre and post-remediation regimes were 313.0±148.0 and 74.0±36.4, respectively. Thus, in the pre-remediation period the ecological risk of the metals was in the high ecological risk category based on Cheng *et al*. [50] classifications. Consequently, the risk associated with the metals in the pre-remediation period was detrimental to the environment and living organisms [77]. But, after the remediation process the mean value of PERI of the metals was reduced to the moderate ecological risk class. This confirms that phytoextraction technique can effectively avert the negative environmental and human risks associated with metals in impacted soils [78]. Apparently, phytoremediation technique could be employed for the cleaning of impacted soils in the studied environment and forestall the ecological hazards associated with the metals.

The pollution load index (PLI) values of the metals in the studied impacted soils were 1.13±0.01 and 0.10±0.01 during the pre and post remediation periods, respectively. Thus, the PLI of the metals was in the medium pollution category during the pre-remediation regime, however; in the post remediation period it reduced to the no pollution class according to Rai *et al.* [53] classifications. This revealed that the pollution potentials and their related negative consequences were higher during the pre-remediation regime than in the post-remediation period [79]. Hence, phytoremediation has the potential of alleviating the toxicity of metals and their related risks in the environment and human health [80, 81].

Table 6 reveals that the EDI values obtained for the adults and children during the pre and post-remediation periods were within their recommended oral reference (Rfd) limits in Table 1 by USEPA [57]. Consequently, both categories of people may not be exposed to adverse health effects related to the exposure to these metals through the impacted soils [82, 83]. The average EDI values of the metals for the adults and children during the pre and post-remediation periods were in the orders Pb > Cu > Ni > Cd and Cu > Pb > Ni > Cd. Thus, the adults and children were more exposed to health problems associated with Pb in the pre-remediation period, but; during the post-remediation regime they were exposed to the essential Cu. The results of EDI of the metals obtained indicated higher values for the children category during the two regimes as documented by Atikpo et al. [84] and Ismail et al. [85]. Evidently, the children group might have been more disposed to the

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health risks related to the exposure to these metals [20]. The EDI values of the metals were higher during the pre than the post-remediation period for both populations. Consequently, phytoremediation technique may be an effective agent for the reduction of the dietary intake rates of the metals in impacted soils and forestall their associated health risks [86]. Accordingly, phytoremediation technique could be used as a panacea for sustaining the heath of soil and human health in the oil producing region of Nigeria.

The target hazard quotient (THQ) of the metals were higher the pre than the post-remediation regime for the adults and children. However, the mean THQ values of the metals for the adults and children classes in the pre and post-remediation periods were below one as obtained by Kia *et al*. [87]. Hence, the adults and children population may be exposed to a minimal level of non-carcinogenic health risks associated with the metals [88]. Higher THQ values of the metals were reported for the children class that the adults in both the pre and post-remediation periods as obtained by Ahmed *et al*. [89] and Anyanwu & Chris [90]. Thus, the children class might be more susceptible to the non-carcinogenic risks associated with the metals than the adults. The higher THQ values obtained during the pre-remediation period confirms that phytoremediation technique could be effectively harnessed to reduce the non-cancer risks of metals in impacted soils as opined by Bhat *et al*. [86].

The general mean total hazard index (THI) values of the metals for the children were higher than those of the adults in both regimes as reported by Emmanuel *et al*. [82] and Okoro *et al*. [91]. This confirms that the children class could be more prone to the non-carcinogenic risks associated with the exposure to the metals than the adults [91]. The results also revealed that the mean THI value of the metals for the children class during the pre-remediation period was higher than one as documented by Rinklebe *et al*. [92]. However, the mean THI values for the adults in the pre and post-remediation regimes, and the children during the post-remediation period were less than one. This corroborates the high vulnerability of the children class to the non-carcinogenic risks through exposure to the metals via the impacted soils. The average THI values for both the adults and children in the pre-remediation regime exceeded the values obtained during the post-remediation regime. Consequently, phytoremediation technique can reduce the non-cancer risks of metals in impacted soils [86].

As presented in **Table 7**, the incremental lifetime cancer risk (ILCR) of Cd and Pb for the adults during the pre-remediation period belonged to the medium cancer risks class, whereas Ni belonged to the high cancer hazard class [93, 94]. Whereas, the ILCR of Cd, Ni, and Pb for the children in the same period belonged to the high, very high and medium cancer risks categories, correspondingly. In the post-remediation period, the cancer risks of Cd and Ni for the adults belonged to the medium cancer risk category, while that of Pb belonged to the negligible cancer class. For the children class, the ILCR values of Cd, Ni, and Pb in the post remediation period belonged to the medium, high, and negligible cancer risks categories, correspondingly. The average ILCR values of the carcinogens for the adults and children classes during the two regimes followed the order Ni > Cd > Pb. Accordingly, Ni had the highest cancer-causing potentials through exposure to the impacted soils during these periods as reported by Okon *et al*. [80] and Bala *et al*. [95]. Obviously, the cancer risks of the carcinogens for the children exceeded those of the adults' group as reported by Emmanuel *et al*. [82]. The results also revealed higher average ILCR values of the carcinogens during the pre-remediation than the post-remediation regime. Hence, phytoremediation could be employed for the reduction of cancer risks of metals in impacted soils within the Oil producing area of Nigeria [45]. The results also revealed that the average ILCR values of Ni for the adults during the pre-remediation period exceeded the recommended standard of 1.00E-6 – 1.00E-4 by USEPA [93]. During the post-remediation period, the mean ILCR values of Cd and Ni for children were also higher than the recommended limit. Consequently, during the pre and post-remediation periods, prolonged exposure to the impacted soils might cause cancer-related health problems associated with high Cd and Ni in the adults and children, respectively [96-99]. However, in the post-remediation period, the mean ILCR of the metals for the adults were within the acceptable limit (1.00E-6 – 1.00E-4) by USEAP [93]. This is consistent with the results obtained by Emmanuel *et al*. [82] from a similar work. The results showed higher mean ILCR values of the carcinogens for the children than the adults during both regimes as published by Emmanuel *et al*. [82] and Belew *et al*. [100]. Thus, the children group might be more exposed to the cancer risks in the pre and post-remediation regimes than the adults. The average ILCR values of the carcinogens for the adults and children were relatively higher during the pre than the post-remediation period. Hence, the phytoremediation technique could be effectively utilized for the cleaning of impacted soils thereby eradicating

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cancer risks associated with the carcinogens as opined by Kumar *et al*. [25].

The mean total cancer risk (TCR) of the carcinogens for the adults during the pre-remediation period belonged to the high cancer risk category, while that of the children class belonged to the very high cancer risk class. The mean TCR values obtained during the pre-remediation period exceeded the 1.00E-4 recommended limit by USEPA [93]. However, during the post-remediation period the TCR values were reduced, though; the value for children was still higher than the recommended limit. Thus, constant exposure to these carcinogens might result in cancer and cancer-related ailments in the adults and children. The TCR values of the carcinogens obtained for the children were generally higher than those of the adults' class during the pre and post-remediation periods. Consequently, the children class might be more exposed to the cancer risks than the adults as documented by Demissie *et al*. [101]. Higher TCR values of the metals were recorded in the pre-remediation regime than the post-remediation period. Consequently, phytoremediation technique can reduce or eradicate cancer incidences associated with metals in impacted soils [102].

The principal component analysis (PCA) was utilized to establish the sources of the metals in the impacted soils examined during the pre and post remediation periods [103, 104]. The single factor identified by PCA in the pre-remediation period had significant loadings on all the metals determined. This factor could represent the impact of wastes on the quality of the soils examined [105]. During the post-remediation period, the first factor identified by PCA showed significant loadings on all the metals and could be the anthropogenic effects of the wastes on the soil quality. The second factor had strong loading on only Cu, and this may be the influence of the natural geological processes on the waste-impacted soils [106, 107]. Consequently, the remediation of impacted soils by plants could alter the chemistry of the contaminants thereby reducing their negative impacts on soil and human health [24, 74].

Conclusion

This study on the application of phytoremediation as an effective technique for maintaining soil and human health identified very high levels of trace metals in the baseline impacted soils (Controls). The utilization of mixed citric and ethylenediaminetetraacetic acids chelants proved to be effective soil amendment property for phytoremediation. It could be concluded from the results that *J. gossypiifolia* could be successfully applied for the cleaning of soil impacted soils. The research has also revealed that phytoremediation technique could be employed to ameliorate the ecological risks associated with metals in metal-impacted soils. The phytoremediation technique could be effectively used for the reduction of human exposure to toxic metals in impacted soils and the related human health problems. The remediation technique also demonstrated good potentials for the control of carcinogenic and non-carcinogenic human health risks associated with toxic metals in impacted soils. However, the management of waste products generated during the remediation process became a serious shortfall. The expansion of the scope of phytoremediation technique to accommodate the areas not captured in this study has been recommended. However, the use of *J. gossypiifolia* as a remediation tool has proved to be a panacea for sustaining the health of soil and human, hence; could used for the cleaning of impacted soils within the area investigated.

Authors' contributions

All the authors contributed during the study and development of the manuscript evenly.

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There is no conflict of interest

Authors Contribution

Conceptualization, A.M.E.; G.A.E. Methodology. A.M.E.; G.A.E.; E.A.M. Formal analyses. A.M.E.; G.A.E Investigation. A.M.E.; E.A.M. Resources. A.M.E. Writing-original draft preparation. A.M.E.; G.A.E.; E.A.M. Writing-review, editing and Supervision. G.A.E.; E.A.M.

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