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Risk Study of Hydrocarbon Impacted Surficial Soil at the Heavy Duty Diesel Generator Plant in Delta Park University of Port Harcourt, Nigeria

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Authors' contributions

This work was carried out in collaboration between both authors. Author OAU designed the study, Carried out the site investigation, performed the laboratory statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author GOA managed the analyses of the study and supervised the work. Both authors read and approved the final manuscript.

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ABSTRACT

Aim: To analyse the potential risk of hydrocarbon polluted surficial soil, from a heavy-duty generator plant at Delta Campus, University of Port Harcourt, Nigeria.
Study Design: Conceptual site model (CSM).
Methodology: A CSM was designed and applied prior to sample collection in order to screen for heavy metals and other chemicals of concern (COCs) from three different high-risk points. The CSM showed a credible source-pathway-receptor chain at three high-risk points. Risk assessment associated with the heavy metals was significantly reduced based on the Department of Petroleum Resources (DPR) – Environmental Guidelines and Standards for the Petroleum Industry In Nigeria (EGASPIN) values after 28 days of bioremediation study.
Results: The hazard quotient of the target (COCs) namely Arsenic, Cadmium, Chromium and Lead was less than one (< 1). This suggests that the study area does not pose significant risk on both Adults and children.
Conclusion: The evaluation is essential for the formulation of remedial actions and risk-based management plans geared toward risk reduction. In other words, it is an approach to the

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determination of imminent risk posed by a pollutant to the environmental proxies. Poor education and sensitization of the public on the causal effect of pollution have been identified as a leading cause of indiscriminate pollution of the environment.

Keywords: Conceptual Site Model (CSM); heavy metals; hazard quotient; risk analysis.

1. INTRODUCTION

Risk is a term used to suggest a tendency for danger especially under legislation [1]. It can be narrowly classified based on health e.g. health risk or risk to the recipient or receptor of the action or the severity of detrimental effect it has on the biota. The parlance of environmental regulatory bodies has adopted the use of high and low to define the potency of risk to man or other living things. Variables such as time, exposure route and receptor are currently represented in the model equation as a predictive approach to risk evaluation [2]. Risk assessment is an evolving multi-disciplinary scientific discipline used to evaluate health and ecological risks associated with our being exposed to various chemicals of concern (COC). This evaluation is essential for the formulation of remedial actions and risk-based management plans geared toward risk reduction. In other words, it is an approach to the determination of imminent risk caused by a pollutant to the environmental proxies. Innovations in risk-based studies can serve a crucial role in the recovery, identification and application of risk studies. The environmental risk assessment involves calculating the probability for an ecosystem to receive a dose of pollutant or being in contact with it. Quantitative risk assessment examines the dangers and consequences based on variables, which involves estimating the size of such consequences and probability of events [3]. Risk assessment is technically a cheap and effective approach in the determination of long-term effects of pollution [4]. Hence, eco-recovery of impacted media is believed to serve geo-reference benefits. The benefit of this approach is that it offers an all-encompassing strategy ranging from the site visit to the pollutant.

The procedures employed are generally based on the contaminant-trajectory-receptor model [5]. It involves the examination of the site characteristics, the environmental behaviour and toxicity of the contaminants, the potential route of entry of the contaminants into the receptors (humans), the exposure of the receptors to the contaminants and their response to the dose. Thus, a baseline study of environmental media is critical for risk definition [6].

Impact of crude oil pollution is the most disturbing environmental challenge facing the world today [7]. Introduction of toxic contaminants associated with crude oil leaves a trail of challenges to the ecosystem both known and unknown. Recovery of crude oil pollutants from the soil by extraction has been described to be sluggish, time-consuming and less efficient. The mere presence of the pollutant on the polluted soil causes fluxes on the biodiversity of the soil. Diesel engine oil is a fraction of crude oil distillation. It solves a great portion of chemical energy need since it is used in the running of heavy-duty engines and vehicles. Transportation of these materials can pose challenges in the occurrence of spills. Diesel is dominated with non-volatile hydrocarbons than the volatile ones. It also has similar components with crude oil ranging from heavy metals to other derivatives [8]. It can cause a lot of detrimental effects on both flora and fauna. In addition to direct and indirect toxicity, the oil causes interference in the hydric relations of the plants either by asphyxiation or cell damage; this has been described to have an effect on the arability of soil for agricultural purposes. However, exposure of land to contaminants can affect plant growth and yield, although some other researchers have reported that the contaminants could biomagnify and pose a more endangering threat [9]. Spillage of used motor oils such as diesel or jet fuel contaminates our natural environment with hydrocarbon [10]. Hydrocarbon contamination in any environmental matrix could be associated with loss of genomic integrity and cancerous effects leading to a loss in biodiversity and disruption of ecosystem especially by the major contaminants of concern [11]. Liver and kidney dysfunction and damage are associated with the prolonged exposure of animals and plants to contaminants [12]. Because these compounds could be recalcitrant, chronic and life-endangering consequences have been reported with prolonged exposure [13]. The lack of standard practices in the disposal of tank sludge and transfer of the diesel oil into engines and generators could pose a serious threat in long term exposure [14].

Routine evaluation of the impacted areas could give in-depth knowledge on the trajectory of the progress of the removal of the pollutants.

1.1 Adverse Effects of Heavy Metals and Hydrocarbons Intake

Poor education and sensitization of the public on the causal effect of pollution have been identified as a leading cause of indiscriminate pollution of the environment. Daily discharge of toxicant by accidental or autochthonous approaches is alarming, another is the accidents or anthropogenic activities that have left a trail of chronic damages to organs and tissues. Indexed pollutants are heavy metals and (PAHS) [15]. They cause a wide range of health challenges from both acute and chronic exposure [16]. The PAHs are regarded as poisons and are toxic to both fauna and flora, thereby changing the population dynamics of the polluted environment (Mangwani, et al. 2014). Technological advancement has increased the concentration of heavy metals and toxicants as they impair body function in higher animals [17]. Microorganisms in the sediment, soil and water can absorb these toxicants via ingestion and inhalation of particles and metals. Heavy metals can cause damage leading to neurological depositions, chronic inflammatory disease and also cancer. Metal ions can be a factor in premature ageing and other diseases [18].

1.2 Risk Assessment

Carlon, et al. [6] suggested that risk assessment is a mechanism for resolution of challenges associated with any kind of pollution. One of the critical elements used in the assessment is the source of the pollutant. This would be incomplete, without detailed site characterization, corrective actions [19]. Risk can be categorized as unacceptable or acceptable. CONCAWE, [5] suggested that risk studies involve an array quite an array of procedures.

Qualitative risk assessments are designed to give an in-depth definition of the level of harm that could be exposed to, using the variables that define the point and nature of pollutant [20].

Quantitative risk assessment quantifies consequences using variables specific to the pollutant [3]. To do risk analysis due to environmental pollution generated by specific equipment on extraction, gas-oil separation activity the proposed methodology is divided into five modules, interrelated, each with a series of steps and stages of work.

1.3 Risk Assessment Methods

This approach to risk estimation and categorization is divided into two, based on the United States Environmental Protection Agency (USEPA) and the American Society for Testing and Materials (ASTM), both are USA based standards.

1.4 USEPA Method

The method of the United States Environmental Protection Agency (USEPA) is human-health defined and it takes into account human exposure. This method consists of four steps:

(1) Data collection and evaluation, (2) Exposure assessment, (3) Toxicity assessment
(4) Risk characterization.

1.5 RBCA Method

The risk-based corrective action (RBCA) method provides a procedure for risk assessment of petroleum contaminated sites [21]. This method integrates exposure and risk assessment practices with site assessment activities and remedial measurement selection, ensuring that the chosen action is protective of human and the environment. The RBCA process utilizes a tiered approach in which corrective action activities are tailored to site-specific conditions and risks [19]. The risk assessment method consists of three tiers with increasing the gradation of difficulty and accuracy. This tiered approach will ensure that simple cases can be completed relatively quickly with minimum efforts and cost. More data collection and tests are required to assess the risk of complex cases and potentially serious situations. Information can be gradually expanded to reduce the uncertainty and subsequently improve the rationale for making a decision.

2. MATERIALS AND METHODS

2.1 Study Location

The samples were obtained from the diesel generator house facility at Delta Park, University of Port Harcourt, points of the sample collection from Delta, were mapped using a pocket-size Global Positioning System (GPS) device (Fig.1) .

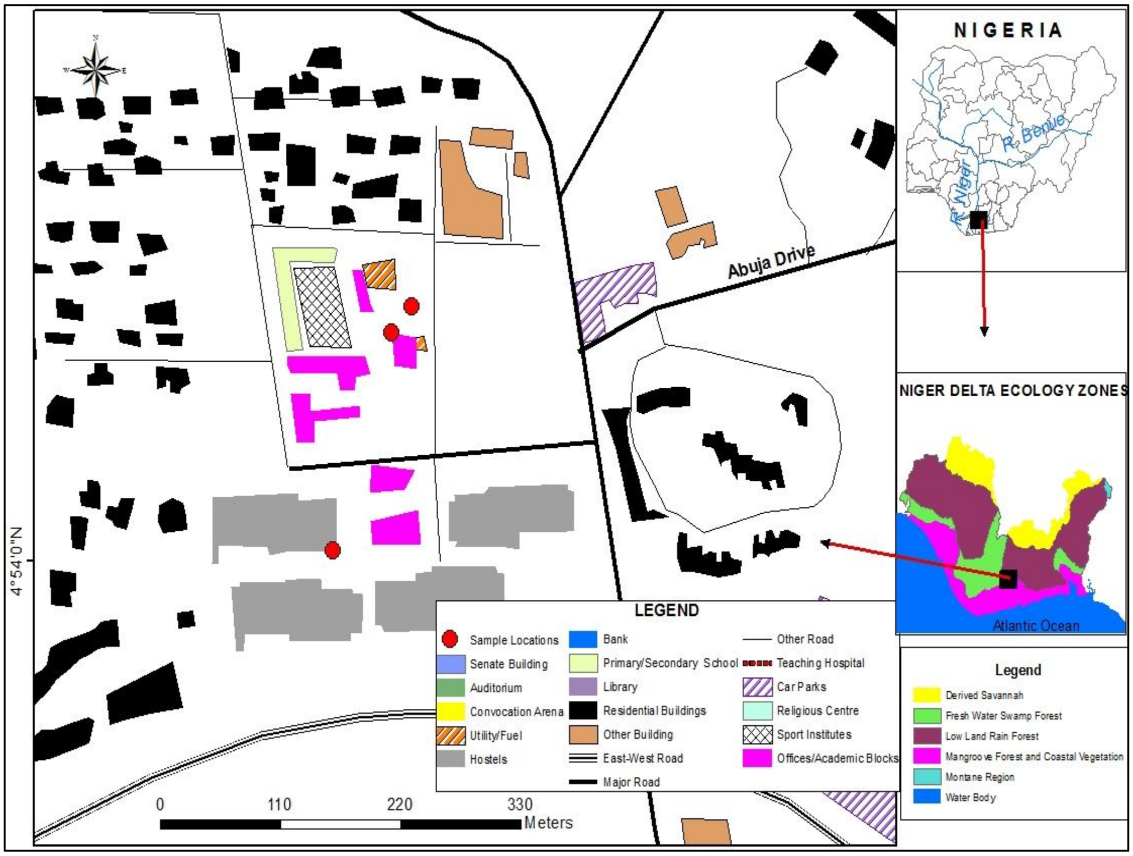

Fig. 1. Map of the delta campus, University of Port Harcourt, Rivers State. Constructed using the coordinates obtained from the site pre-visit and inventorization process

Designed at the Department of Geography and Environmental Management, University of Port Harcourt

2.2 Development of the Conceptual Site Model

Montana Department of Environmental Quality, [22] approach was adopted for risk and conceptual site model development. Information collected concerned receptors (Adults and Children, Adult workers, and Adults in industrial settings of the pollution, exposure pathways (proximity to potable water sources, farms and homes etc) and routes (ingestion, dermal contact or inhalation).

2.3 Sample Collection

The modified method of Karkush and Altaher, [4] was employed in the collection of the soil samples in and around the diesel polluted site using a soil auger. Surficial soil 0-15cm depth was collected over a distance of 0-500m from the polluted site. Soil samples were also obtained from pristine surficial soil. The samples were packed in sterile containers and transported in an ice chest to the laboratory of the Department of Microbiology, University of Port Harcourt.

2.4 Qualitative Risk Analysis and Quantitative Risk Analysis of the Site

The method of Mannan [23] was employed for qualitative risk analysis of the site. Causes, major effects, and possible preventive or corrective measures are identified and listed by performing a preliminary hazard analysis. The quantitative analysis of the site was employed in the calculation of the hazard quotients (HQ) from the specified exposure [21].

2.5 Conceptual Site Model (CSM) of Diesel Generator site, Delta Park, University of Port Harcourt

Fig. 3 is the CSM of the study site. It shows the possible primary sources either from improper disposal or feed system. The conceptual model took into consideration a possible leak or spills.

The model also considered possible pathways either from volatilization, run-offs or seepages. Other variables considered were exposure as a function of inhalation, dermal contact and ingestion. The target risks exposure to contaminants of concern namely total petroleum hydrocarbon, PCBs, BTEX and metals.

2.6 Calculation of Risk

The health risk associated with exposure of children and adult via dermal contact, inhalation and ingestion are calculated using the formula below as stated by Kamunda, et al. [24]

$$ADI_{ing} = \frac{C*IR*EF*ED*CF}{BW*AT} \quad (1)$$

$$ADI_{inh} = \frac{Cs*IRair*EF*ED}{BW*AT*PEF} \quad (2)$$

$$ADI_{dems} = \frac{Cs*SA*FE*AF*ABS*EF*EF*ED*CF}{BW*AT*} \quad (3)$$

Where ADI_{dems} is the exposure dose via dermal contact in mg/kg/day, ADI_{ing} = exposure dose via ingestion in mg/kg/day and ADI_{inh} = exposure dose via inhalation in mg/kg/day. Cs is the concentration of heavy metal in the soil in mg/kg, SA is exposed skin area in cm2, FE is the fraction of the dermal exposure ratio to the soil, AF is the soil adherence factor in mg/cm2, ABS is the fraction of the applied dose absorbed across the skin. EF, ED, BW, CF and AT are as defined in Table 4.

$$HQ = \frac{ADI}{RfD} \quad (4)$$

HQ is a unitless number that is expressed as the probability of an individual suffering an adverse effect. It is defined as the quotient of ADI or dose divided by the toxicity threshold value, which is referred to as the chronic reference dose (RfD) in mg/kg-day of a specific heavy metal as shown in equation 4. Kamunda, et al. [24].

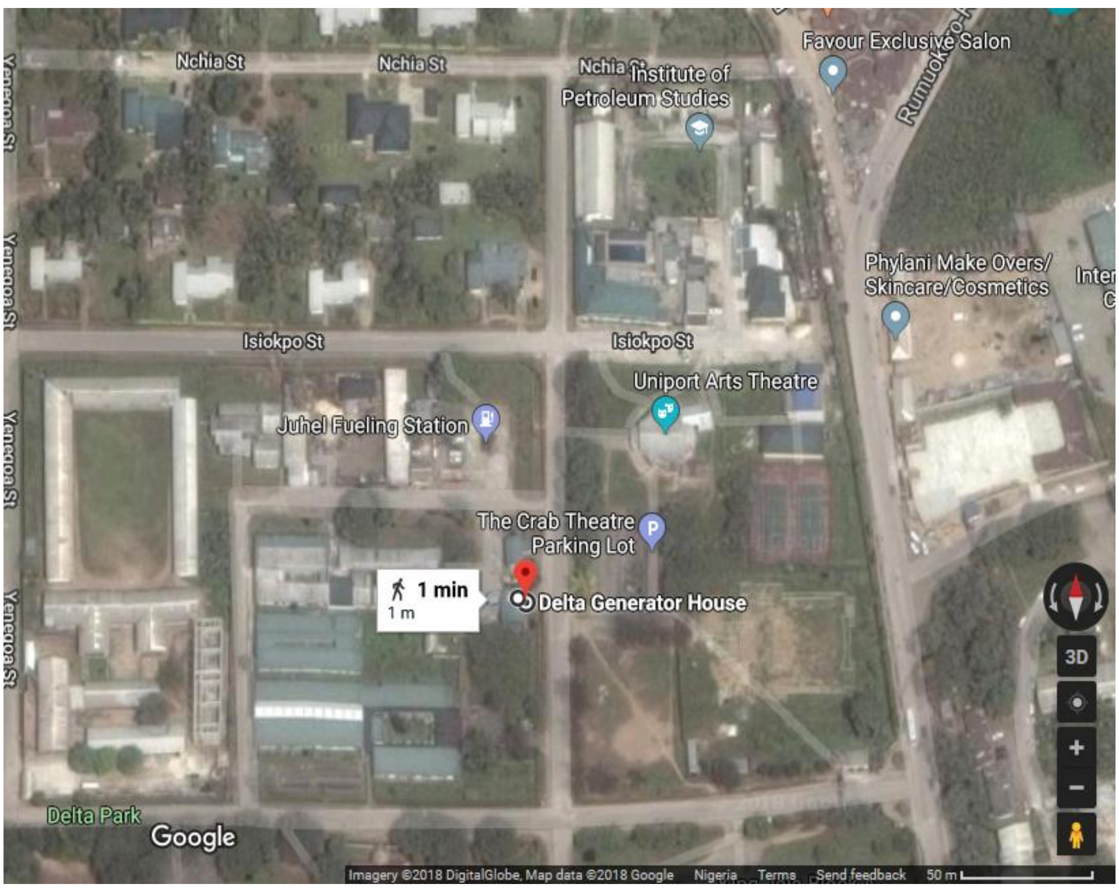

Fig. 2. Google map of delta campus, University of Port Harcourt, showing the location of the Heavy-duty engines

Table 1. Geotechnical evaluation of soil samples obtained from heavy-duty diesel generator engine sites in delta campus, UNIPORT

Geological attribute	Parameters	Site P1(PT)	Site P2 (200m)	Site P3 (400m)
Soil texture	Sandy (%)	8.04 ± 0.01^{a}	65.35 ± 0.007^{c}	31.9 ± 0.134^{b}
	Specific Gravity	2.61	2.53	2.72
	Clay (%)	23.87 ± 0.02^{b}	18.58 ± 0.19^{a}	53.67 ± 0.24^{c}
	Silt (%)	68.14 ± 0.04^{c}	15.61 ± 0.36^{b}	14.2 ± 0.16^{a}
	Soil type	Silty Loam	Sandy Loam	Silty Clay
	Particle size (μm)	2-50	50-2000	0-2
	Hydraulic Conductivity(m/s)	2.59 ± 0.023^{b}	12.41 ± 0.06^{c}	0.44 ± 0.012^{a}
	Permeability (mL/s)	0.22 ± 0.15^{b}	0.75 ± 0.02^{c}	0.01 ± 0.00
Atterberg's Limit	Liquid Limit (wt %)	7.92 ± 0.038^{b}	2.05 ± 0.02^{a}	17.5 ± 0.09^{b}
	Plastic Limit (wt %)	2.84 ± 0.02^{c}	1.94 ± 0.23^{a}	2.09 ± 0.012^{b}
	Plasticity Limit (wt %)	5.25 ± 0.13^{b}	0.043 ± 0.003^{a}	15.37 ± 0.03^{c}
	Description	Slightly plastic	Non-plastic	Medium Plastic

Note I: Concentrations/ Numeric values are triplicate Mean+ Standard errors; superscripts (alphabets) along the horizontal columns suggest correlational variance at p-values < 0.05. Similar superscript suggests there is no significant difference, whereas, superscripts a, b and c also indicate proximity to α<0.05. Note II: Uniport: University of Port Harcourt, Rivers State

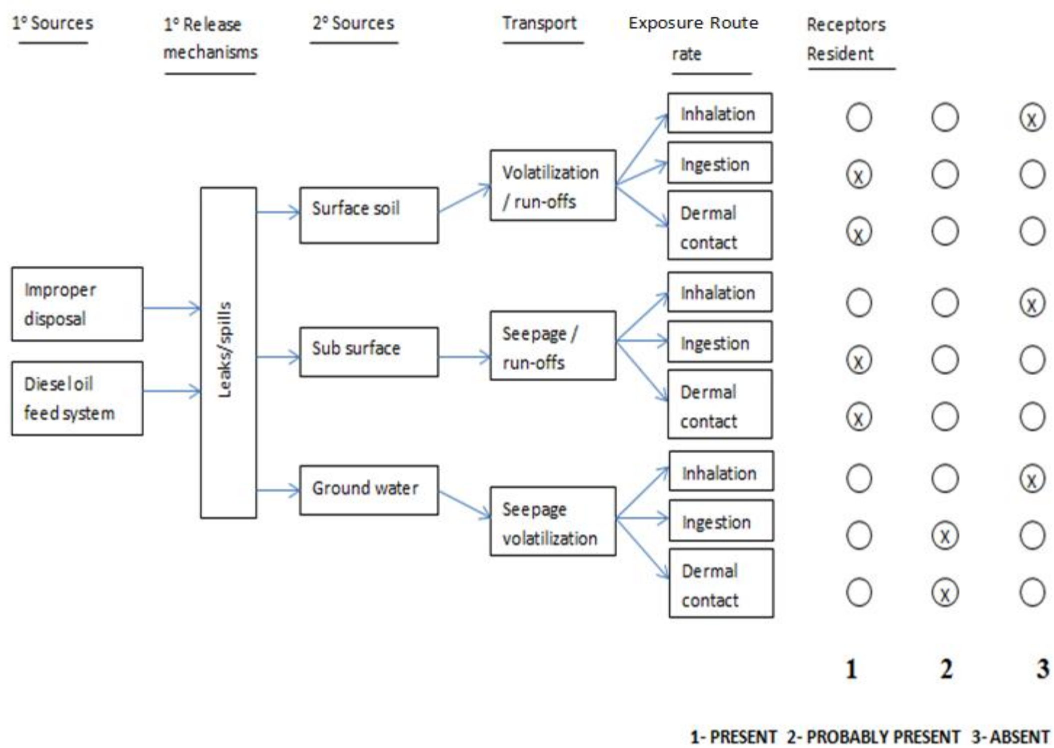

Fig. 3. Conceptual site model of delta park risk studies for TPH and Heavy metals

Table 2. Qualitative Analysis of PCOCs for the study area

	TPHs	PCBs	BTEX/VOC	Metals
Surface Soil	Δ	◯	◯	Δ
Sub-Soils	Δ	◯	◯	Δ

Δ = Is likely to be present and should be examined; ◯ = Not Likely to be present

Table 3. Baseline properties of Metals and TPH in soil samples obtained from heavy-duty diesel generator engine sites in Delta Park, UNIPORT

Parameters(units)	Site P1(0)	Site P2 (200 m)	Site P3(500 m)
TPH (mg/kg)	19692.1 ± 4.1^{c}	833.7 ± 6.76^{b}	31.0 ± 4.16^{a}
PAH (mg/kg)	3.94^{b}	1.14^{a}	<0.1
Lead (mg/kg)	15.3 ± 0.009^{c}	12.75 ± 0.13^{b}	11.28 ± 0.01^{a}
Cadmium (mg/kg)	6.14 ± 0.01^{b}	3.67 ± 0.07^{c}	5.11 ± 0.06^{a}
Arsenic (mg/kg)	4.53 ± 0.012^{b}	4.65 ± 0.015^{c}	1.44 ± 0.032^{a}
Chromium (mg/kg)	9.31 ± 0.008^{b}	9.61 ± 0.009^{c}	9.11 ± 0.07^{a}

Note: Concentrations/ Numeric values are triplicate Mean+ Standard error; superscripts (alphabets) along the horizontal columns suggest correlational variance at p-values < 0.05. Hence, similar superscript suggests there is no significant difference, whereas, the reverse suggests the significant difference. Also, superscripts a, b and c indicate the proximity to α<0.05

Table 4. Exposure parameters used for the health risk assessment through different exposure pathways for soil

Parameter	Unit	Child	Adult
Bodyweight (BW)	kg	15	70
Exposure frequency (EF)	days/year	350	350
Exposure duration (ED)	years	6	30
Ingestion rate (IR)	mg/day	200	100
Inhalation rate (IRair)	M^3/day	10	20
Skin surface area (SA)	Cm^2	2100	5800
Soil adherence factor (AF)	mg/cm^2	0.2	0.07
Dermal Absorption factor (ABS)	none	0.1	0.1
Dermal exposure ratio (FE)	none	0.61	0.61
Particulate emission factor (PEF)	m^3/kg	$1.3\ \ 10^9$	$1.3\ \ 10^9$
Conversion factor (CF)	kg/mg	10^{6}	$_{10}$ 6
Average time (AT)	days	365 70	365 70
For carcinogens			
For non-carcinogens		365 ED	365 ED

Adopted from Kamunda, et al. [24]

3. RESULTS AND DISCUSSION

Bioremoval of Lead (Pb) is presented in Fig. 4 during the remediation of the diesel polluted soil. The samples obtained from the set amended with fungal consortium were observed to have reduced from 13.27 mg/kg to 11.85 mg/kg between the 0 to 28th day. Furthermore, the set amended with bacterial consortium had a lead (Pb) concentration decline from 13.27 to 11.02 mg/kg. The set up amended with consortia of the bacteria and fungi had reduced from 13.2 mg/kg to 9.18 mg/kg while the control set up was observed to have a fairly constant concentration of lead.

Furthermore, Bioremoval of Arsenic (As) was monitored during the remediation study as presented in Fig. 5. The soil samples amended with bacterial consortia was observed to be removed from 5.36 mg/kg to 4.91 mg/kg. The experimental control of arsenic remained constant.

Bioremoval of chromium (Cr) is presented in Fig. 6. The concentration of chromium was significantly reduced from 9.7 mg/kg to 3.62 mg/kg between 0-28th day for the sample amended with bacterial and fungal consortia. In addition, the sample amended with bacterial consortia alone reduced from 9.43 mg/kg to 5.7 mg/kg. The control experiment does not have any changes in the concentration of chromium. Similarly, the result for bioremoval of Cadmium (Cd) is presented in Fig. 7.

During the remediation of diesel polluted soil, the samples treated with bacterial consortia were observed to have a reduction in heavy metal concentration Lead (Pb) reduced from 13.27 mg/kg to 11.85 mg/kg for bacteria consortia while bacterial and fungi consortia reduced from 13.2 mg/kg to 9.18 mg/kg. Arsenic (As) reduced from 5.36 mg/kg to 4.91 mg/kg. Chromium (Cr) was reduced from 9.7 mg/kg to 3.62 mg/kg and bacteria consortia above reduced from 9.43 mg/kg to 5.7 mg/kg. Ezemonye, et al. [25]

reported that biostimulation can lead to the uptake of metals. In their study vermidegradation coupled with effective biostimulation led to a reduction in metals. Metal-binding protons could be attributed to the success of the degradation.

The result revealed 8.04$\pm$0.001% of sample P_1 was sandy while 65.35%$\pm$0.007% of P_2 was sandy while 31.9$\pm$0.13% of P_3 was sandy. The soil sandy quality increased with the increase of distance away of pollutant. P_1 was adjudged to have a clay content of 53.67% and P_2 was 23.87% and samples obtained from the 100 m mark P_1 was also adjudged to have a high silt content of 68.14$\pm$0.04%. However, Patil, et al. [26] reported a particulate quality of clay 0.24%, sand 12.83 and silt quality of 86.42% and water holding capacity of 10.5%.

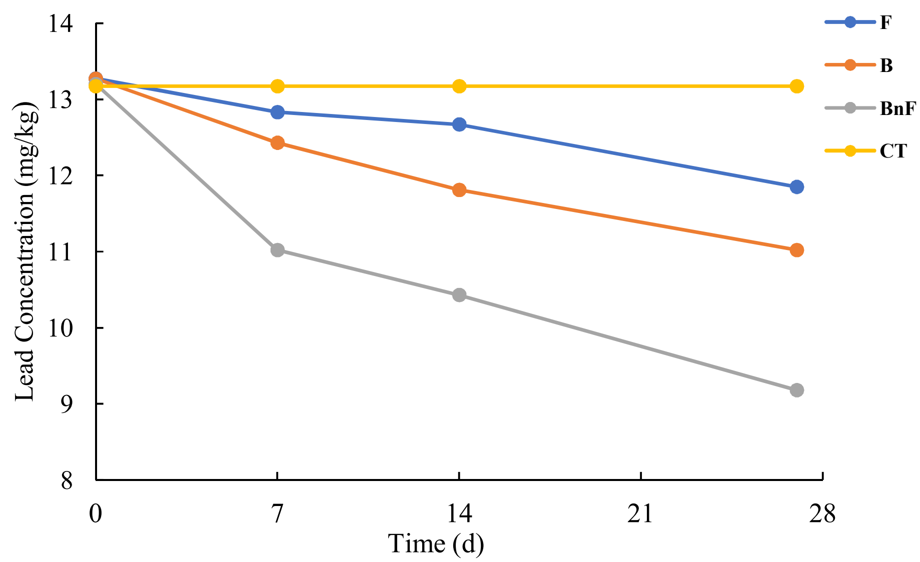

Fig. 4. Concentration of Lead, (Pb) during the bioremediation of diesel polluted soil
Key: CT: Control; BnF: consortia of bacteria and fungi; F: Fungal consortia; B: bacteria consortia

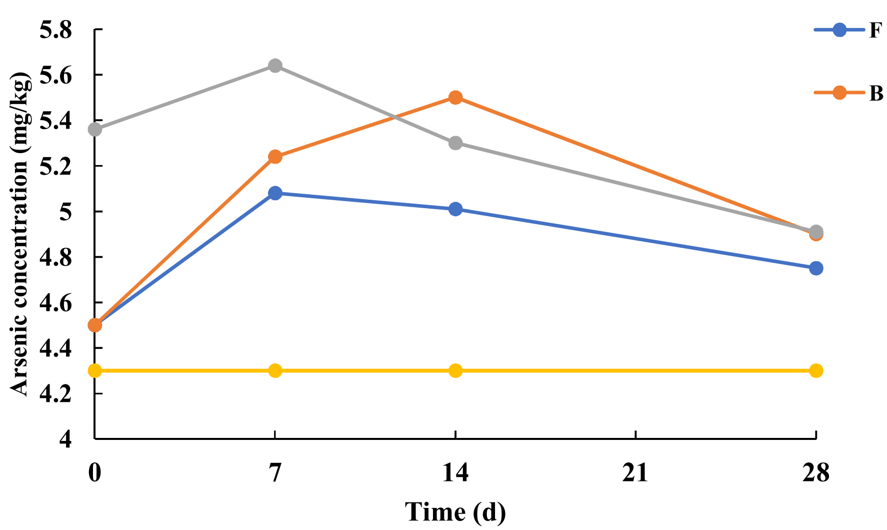

Fig. 5. Concentration of Arsenic, (As) during the bioremediation of diesel polluted soil
Key: CT: Control; BnF: consortia of bacteria and fungi; F: Fungal consortia; B: bacteria consortia

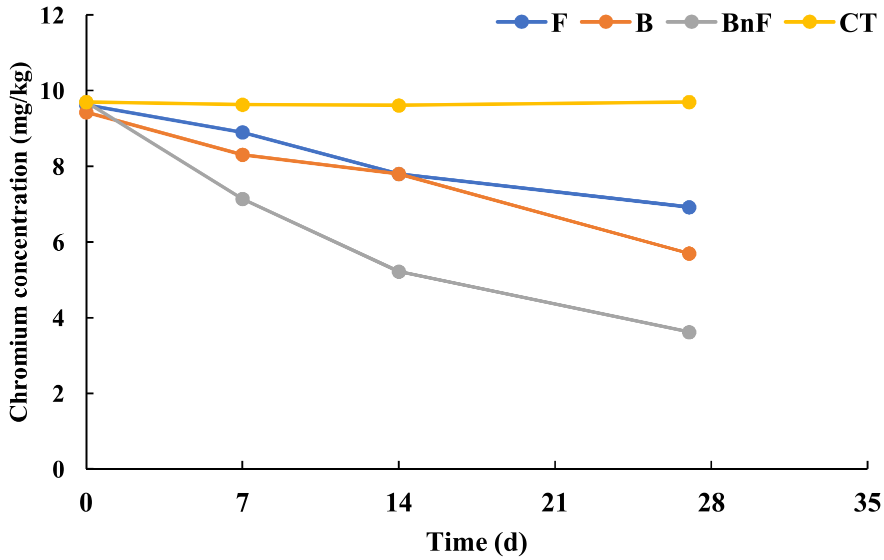

Fig. 6. Concentration of Chromium, (Cr) during the bioremediation of diesel polluted soil
Key: CT: Control; BnF: consortia of bacteria and fungi; F: Fungal consortia; B: bacteria consortia

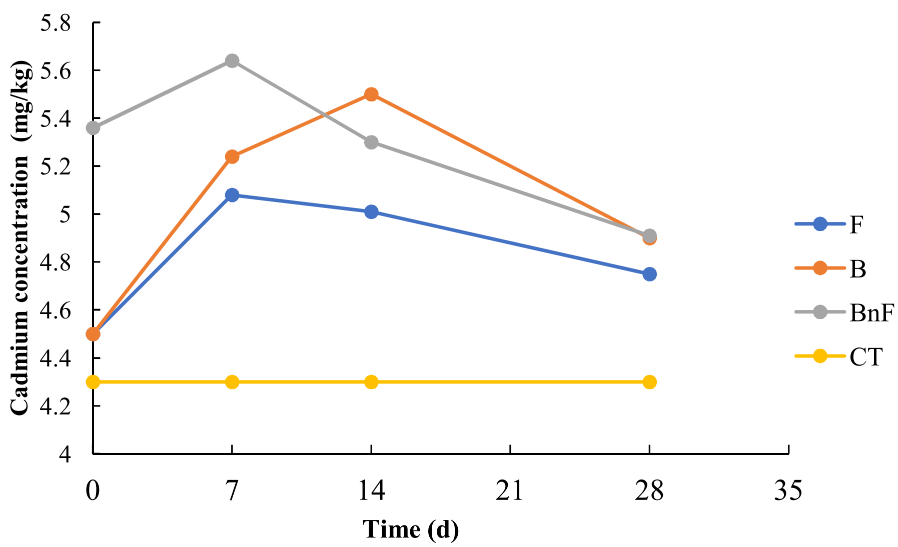

Fig. 7. Concentration of Cadmium, (Cd) during the bioremediation of diesel polluted soil
Key: CT: Control; BnF: consortia of bacteria and fungi; F: Fungal consortia; B: bacteria consortia

Risk is estimated based on receptor i.e. the adult and children and several variables as described in Table 5. The Hazard quotient 0.013 was reported for children while adults were 0.014. Furthermore, cadmium with Average Daily Intake (ADI) of 1.7x10^{-6} mg/kg/day on day zero reduced to 1.9x10^{-6} for children while adult recorded a reduction from 6.6x10-7 mg/kg/day to 6.05 x10^{-7} mg/kg/day. Risk Average Daily Intake (ADI dermal contact) revealed Lead (Pb) reduced from 5.2x10^{-6} mg/kg/day to 4.7x10^{-6} mg/kg/day with a Hazard Quotient (HQ) of 2.06 x 10^{5} and 1.7x10^{5}. However, the average daily intake of Chromium by children was observed to reduce from 7.5 x10^{-6} mg/kg/day to 1.06x10^{5} mg/kg/day and had a hazard quotient of 0.138 to 0.187. This was similar to the finding by Kamunda, et al. [24] who reported 1.96x10^{-4} mg/kg/day for chromium.

Table 5. Risk-based values at 28th day of remediation

	ADI (Dermal contact)					HQ (Dermal contact)			
	Receptor	**0**	**7**	**14**	**28**	**0**	**7**	**14**	**28**
Pb	Children	1.72E-06	1.6E-06	1.33E-06	1.92E-06	0.000210575	0.000210575	0.000251	0.000201216
	Adult	9.85E-07	9.16E-07	7.63E-07	1.09438E-06	0.003675643	0.003675089	0.003656	0.003647948
Cd	Children	6.32E-07	6.32E-07	7.52E-07	6.03649E-07	0.001263452	0.001263452	0.001505	0.001207299
	Adult	6.67E-07	6.88E-07	6.89E-07	6.03649E-07	0.001333644	0.001375759	0.001379	0.001207299
Cr	Children	1.01E-06	8.29E-07	5.26E-07	1.41035E-06	0.000894355	0.000736679	0.000468	0.001253647
	Adult	2.68E-06	2.21E-06	1.4E-06	3.76094E-06	0.000894355	0.000736679	0.000468	0.001253647
	ADI (ingestion)					**HQ(ingestion)**			
	Receptor	**0**	**7**	**14**	**28**	**0**	**7**	**14**	**28**
Pb	Children	5.2E-06	5.4E-06	5.38E-06	4.7-06	2.06621E-05	1.92596E-05	1.7E-05	2.14808E-05
	Adult	2.64E-08	2.64E-08	3.15E-08	2.526E-08	0.003856925	0.003595129	0.003175	0.004009741
Cd	Children	5.21E-06	5.37E-06	5.38E-06	4.71E-06	0.010410959	0.010739726	0.010762	0.009424658
	Adult	2.79E-08	2.88E-08	2.88E-08	2.526E-08	5.5773E-05	5.75342E-05	5.77E-05	5.04892E-05
Cr	Children	7.58E-06	6.25E-06	3.97E-06	1.061E-05	0.133044941	0.109589041	0.069599	0.186493631
	Adult	4.06E-08	3.35E-08	2.13E-08	5.69E-08	0.000712741	0.000587084	0.000373	0.000999073

According to USEPA [27] $1.0x10^{-6}$ mg/kg/day to $1.0x10^{-4}$ mg/kg/day was acceptable for cancer risk. The cancer risk for this study was higher than the regulatory limit for countries like South Africa. The opinion of Kamunda, et al. [24] suggests that hazard quotient (HQ) and hazard index (HI) greater than 1.0 suggests a cause for risk and carcinogenic effect.

4. CONCLUSION

The present study concludes that in the remediation of diesel polluted soil, the samples treated with bacterial and fungal consortia were observed to have a reduction in heavy metal concentration. Risk study should depend on the critical hazard detection and the removal strategy should also be systematic and scientifically sound. The methodology should not only help in assessing the extent of contamination and associated risks at a site, but it should also be able to identify appropriate remediation technologies.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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