

Heavy metal contamination, pollution indices and health risk assessment of soil around an asphalt production company

By Joshua Olu

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Abstract

Heavy metals in the environment are of great ecological significance, their toxicity and contamination of soil risks and hazards to humans and the ecosystem. This study assessed the heavy metal contamination and pollution indices of soil around an asphalt production company. 13 soil samples were collected cross-sections around the asphalt plant. Cobalt (Co), cadmium (Cd), iron (Fe), lead (Pb), and zinc (Zn) were analyzed. Geo-accumulation index (Igeo), contamination factor (CF), ecological risk index (ERI), pollution load index (PLI), degree of contamination (DC), pollution index (PI), Nemerow integrated pollution index (NIPI), target hazard quotient (THQ), hazard index (HI), cancer risk (CR), and lifetime cancer risk (LCR) were used to estimate pollution and health risk. Cd, Pb, Co, Fe and Zn in the samples were: 0.006, 0.09-0.34, 0.06-0.22, 0.09-184.41 and 0.39-3.15 mg/kg respectively. The Igeo, CF, ERI, PLI, NIPI and PI values of the metals were within uncontaminated level. THQ and HI values for the metals were far lower than the recommended limit for children and adults. Co, Pb, and Cd in the soils did not exceed tolerable CR and LCR value of $1.0E-04$. It could be suggested that the Asphalt production company activities is not contaminating the soil around them.

Keywords: Environment; Health assessment; Heavy Metals; Pollution indices; Soil; Toxicity

Introduction

Naturally, heavy metals occur in the ecosystem with large variations in concentrations. Pollutions from the activities of humans, have introduced some of these heavy metals into the ecosystem¹. The presence of heavy metals in the environment is also of great ecological significance due to their toxicity at certain concentrations, translocation through food chains and non-biodegradability which is responsible for their accumulation in the biosphere¹. Environmental pollution by heavy metals, even at low concentrations have long-term cumulative health effects and human activities is of major concerns all over the world².

It has been reported that metals such as cobalt (Co), copper (Cu), chromium (Cr), iron (Fe), magnesium (Mg), manganese (Mn), molybdenum (Mo), nickel (Ni), selenium (Se) and zinc (Zn) are essential nutrients that are required for various biochemical and physiological function and inadequate supply of these micro-nutrients results in a variety of deficiency diseases or syndromes³.

Heavy metals are also considered as trace elements because of their presence in trace concentrations (ppb range to less than 10ppm) in various environmental matrices⁴. Their bioavailability is influenced by physical factors such as temperature, phase association, adsorption and sequestration. It is also affected by chemical factors that influence speciation at thermodynamic equilibrium, complexation kinetics, lipid solubility and octanol/water partition coefficients⁵. Biological factors such as species characteristics, trophic interactions, and biochemical/physiological adaptation, also play an important role⁶.

Soils are the major sink for heavy metals released into the environment by anthropogenic activities and unlike organic contaminants which are oxidized to carbon (IV) oxide by microbial action, most metals do not undergo microbial or chemical degradation⁷. Soils may become contaminated by the accumulation of heavy metals and metalloids through emissions from the rapidly expanding industrial areas, disposal of high metal wastes, leaded gasoline and paints, land application of fertilizers, animal manures, sewage sludge, pesticides, water irrigation, coal combustion residues, spillage of petrochemicals, and atmospheric deposition⁸⁻⁹.

The presence of toxic metals in soil can severely inhibit the biodegradation of organic contaminants¹⁰. Heavy metal contamination of soil may pose risks and hazards to humans and the ecosystem through: direct ingestion or contact with contaminated soil, the food chain (soil plant-human or soil-plant-animal human), drinking of contaminated ground water, reduction in food quality (safety and marketability) via phytotoxicity, reduction in land usability for agricultural production causing food insecurity, and land tenure problems¹¹⁻¹².

The adequate protection and restoration of soil ecosystems contaminated by heavy metals require their characterization and remediation¹³.

Numerous studies have been carried out on heavy metal contamination, identification of source distribution pattern, degree of pollution, and associated human health risks in many parts of the world¹⁴⁻¹⁶. Zhao et al.,¹⁶ reported that potentially hazardous metals in agricultural soils were contaminated by Cd, Cu, Zn, and Ni in southeastern China. They also stated that a higher concentration of heavy metals in soils can adversely influence soil quality, reduce crop yield, and also contaminate the agricultural products, resulting in potential health risks to humans. Ruiz-Fernandez et al.,¹⁷ emphasized on spatial and temporal distribution of heavy metal concentrations and its enrichment in Mexico. Khademi et al.,¹⁸ reported that the distribution of heavy metals was larger than the background values of Murcia City of Spain. They pointed out the heavy metals contamination in soils majorly caused by industrial activities in Murcia City. Jiang et al.,¹⁹ comprehensively studied on health risk assessment of heavy metals in soils for a township in Jiangsu province, China, finding human activities contributing greatly to heavy metal contamination in soils. In another study, Shehzad et al.,²⁰ have determined the concentrations of Cd, Co, Cr, Cu, Mn, Ni, Pb, and Zn in the urban soils of Rawalpindi, the fourth largest city of Pakistan. They found the contamination of soils by the heavy metals due to heavy traffic loads and industrial effluents in the urban soils of Rawalpindi, Pakistan²⁰. Adimalla and Wang²¹ emphasized on distribution, contamination, and health risk assessment of heavy metals in surface soils from the northern Telangana, India.

Principal sources to contaminate the soils in agricultural and urban regions in the world could be attribute to development of industries, indiscriminate usage of chemicals in agricultural fields, and municipal waste disposals²²⁻²⁴. The extreme increase of heavy metals in agricultural and urban soils could be the reason of the soil contamination and also impend to human health. In developing countries, the problem of heavy metal contamination has become much concerned, due to its linkage with human health²⁵⁻²⁶. Some studies pertaining to contamination of heavy metal in soils have been carried out in all over the world^{22, 27-28}. Krishna and Mohan²⁹ studied heavy metal contamination in surface soils around an industrial area, India. They found that the arsenic, chromium, copper, nickel, lead, and zinc concentrations were higher than the background values, due to industrial effects in the study region. Ciarkowska²³ demonstrated that the heavy metal pollution risk of meadow soils in urban area from Poland and found that industrial and anthropogenic sources are the primary of contaminants of the soils. Diami et al.,³⁰ well studied on ecological risk assessment and human health risks of heavy metals in surface soils in Malaysia and stated that contamination of heavy metals could be the reason for health risk in Malaysia. Therefore, significant concern has been attracting much attention in all over the world to soil contamination by toxic elements and impact on human health and environmental quality^{29, 31}.

Industrial wastes^{29, 32} and anthropogenic contamination³³⁻³⁶ is the major sources of heavy metal in soils. Galuskova et al.,³⁷ found that in the urban areas, the source for heavy metals was mainly from traffic movements. In rural regions, the heavy metal in soils was derived from the agricultural activity³³. Luo et al.,²⁴ reported that irrigation fields were mainly contaminated by copper and cadmium. Gu et al.,³⁴ conducted extensive study on heavy metals to exposed lawn soils from 28 urban parks in China and found that vehicle emission is the principal reason for contamination of the surface soil by heavy metals. Quan et al.,³¹ stated that heavy metal contamination in agricultural surface soils surrounded by e-waste recycling site is very dangerous and polluted soil with nickel, copper, zinc, cadmium, and lead were confirmed by Wong et al.,³⁸.

It has been reported that accumulated heavy metals in soil enter into human body by soil ingestion, dermal contact, and inhalation of soil dust^{22-23, 26, 30-31, 39}.

Soils contaminated by heavy metals could pose very harmful impact on human health as well as environment. Diami et al.,³⁰ pointed out that the contamination of heavy metals not only portends the human health but also deteriorates the surface water, groundwater, and quality of atmosphere. Jarup⁴⁰ found that excessive intake of heavy metals lead to diseases related to kidney, blood, cardiovascular, and bone disease. For instance, chronic exposure to Pb and As can lead to adverse effects such as damage the nervous, enzymatic, immune system, kidney dysfunction, dermal lesion, skin cancer, and hypertension^{23, 26, 29-31, 41}.

Some other metals, such as cadmium (Cd), chromium (Cr), and copper (Cu), cause anuria, nephritis, and extensive lesions in the kidney³⁰. Consequently, due to their potential toxic, persistent, and irreversible characteristic, the heavy metals, such as Cd, Cr, As, Hg, Pb, Cu, Zn, and Ni, have been listed as priority control pollutants by the United States Environmental Protection Agency (US EPA) and caused more and more attention in many parts of the world^{39, 42-44}. Lot of interest has been paid to the quality of soil contamination and its effect on the human health all over the world. Detrimental health effects as a result of heavy metal contamination of the soil have been promiscuously reported^{29, 45}. Heavy metals in soils could pose long-term environmental and health implications because of their non-biodegradability and persistence^{29, 45-47}. Geo-accumulation index (Igeo) and ecological risk index (ERI) have been used to determine the heavy metals in contamination of soils in different regions in the world^{22-23, 26-27, 29-31, 33, 37, 40-41, 45}.

1 Average daily exposure dose, target hazard quotient (THQ), and hazard index (HI) have been used in worldwide to identify the carcinogenic and non-carcinogenic risk (NCR) of human health, when highly and continuously 7 exposed to heavy metals in soils, which is developed by US EPA 39, 48-49.

Bitumen plays a significant role in asphalt production as it acts as a binder to the aggregates. It is produced by the non-destructive distillation of crude oil during petroleum refining and consists of aliphatic and cyclic alkanes, aromatic hydrocarbons, heterocyclic compounds containing oxygen, nitrogen and sulphur as well as metals like nickel, vanadium and iron 50.

Pollutants released into the air by the hot mix asphalt plants can be categorized as chronic toxicants, carcinogens and acute system toxicants 51, which could result to irritation 25 of the upper respiratory tract, headache, fatigue, wheezing and shortness of breath dizziness, and nausea 52. Trace elements emission from Hot Mix Asphalt Plants may influence ecosystem behavior. These are the dryer, burner-blower, exhaust fan, dust collection 2 system asphalt cement heating and storage and reclaimed asphalt paving components 53.

2 The relative gradation of contamination levels by trace metals based on observed data from previous studies can be achieved using pollution indices (PIs) and efficient risks assessment approaches. However, the evaluation of pollution loading status and the estimation of impacts associated with human induced events on soils could be attained 32 through geochemical approaches such as geo-accumulation index and enrichment factor 42.

The aim of this study was to assess the heavy metal contamination of soil around an asphalt production company and its pollution indices.

18

Materials and Methods

Study Area

The study area is an Asphalt production company in Badagry local government area in Lagos, Nigeria with geographical location of latitude 6°24'52.53036N and longitude 2°58'46.62602E. The samples collection locations are indicated in Table 3

105

Sample Collection

Samples were collected from 0 - 30 cm layer 1 of the soil using plastic spatula from thirteen different spots at about 500 m from the asphalt production 7 plant and the exact locations of soil sampling points were recorded using a global positioning system. The soil samples were transferred into aluminium foil formed bags, labelled accordingly and then transported to the laboratory.

23

Sample Preparation and Analysis

Samples were air dried for 2 days at 60°C. Clods were crushed using a clean porcelain mortar and pestle, each sample was ground to powder and sieved through a 2 mm mesh. Samples were then digested and heavy metal (Co, Fe, Pb, Cd and Zn) concentrations for all samples were determined by Varian SpectraAA 400plus Atomic Absorption Spectrometer, using the respective lamps and wavelengths.

Pollution Indices

Geoaccumulation Index

Geoaccumulation Index (I_{geo}) Assessment. The index of geoaccumulation (I_{geo}) is used to evaluate the contamination by comparing the levels of metal obtain to the background levels originally used with bottom 13 ment 54-55. The index is then calculated using the Eq. (1)

$$I_{geo} = \log_2(C_n / 1.5B_n) \quad (1)$$

Where C_n represents the measured concentration of heavy metal in the soil sample. B_n is the geochemical background concentration of the heavy metal 54 (Table 1). It's very difficult to establish B_n values for the sediments of some studied areas, as a reference. 20, in some works B_n value (references point) has been taken as equal to the metals concentration in shale rocks. In this study, the geochemical 1 background soil concentrations of Cd, Co, Fe, Pb, and Zn were 0.3, 19, 47600, 20, and 95 mg/kg, respectively. The constant 1.5 allows to analyze natural fluctuations in the content of a given substance in the environment 55.

Pollution Load Index

Pollution Load Index (PLI). Estimation of pollution load index was done using Tomlinson's pollution load index (PLI) 56. This was calculated using the heavy metal data and metal concentration for the world shale (abundance of element in earth's upper continental crust) average as the background value 57. The PLI of soils was calculated by obtaining the n th root from the n number of obtained contamination factor (CF) for all the 63 al 58.

$$PLI = (CF_1 \times CF_2 \times CF_3 \times \dots \times CF_n)^{1/n} \quad (2)$$

Where n is the number of heavy metals and $CF = C_{metal} / C_{background}$.

98

Categorization of PLI used is presented in Table 1.

In Nigeria, the pollution index represents the metal content effectively measured in soil by chemical analysis and the reference value of contamination obtained using a standard table formulated by the Department of Petroleum Resources (DPR) of Nigeria, for maximum allowable concentration of heavy metals in soil; Cd=0.8, Pb=8, Zn= 140, Fe= 5000 and Co= 20 mg.kg⁻¹.

The standard employed for interpreting soil heavy contamination/pollution (C/P) varies from country to country based on chosen factors⁶⁰.

In addition, the pollution index (PI) according to Lee et al.,⁶¹ was used to evaluate soil pollution by comparing the metal concentrations obtained in this study with Dutch soil guidelines⁶².

PI is expressed as Eq. (3)

$$PI = Cn/Tn \quad (3)$$

Where Cn is the concentration of an individual trace metal and Tn is the corresponding target concentration of Dutch soil guidelines, which consider different land-use types and are based on extensive studies of both the human and ecotoxicological effects of soil contaminants⁶³.

Nemerow integrated pollution index (NIPI) was also employed for the assessment of the overall pollution integrity of the investigated ecosystem⁶⁴. The NIPI was calculated using Eq. (4)

$$NIPI = [0.5 \times (I^2_{\text{mean}} + I^2_{\text{max}})]^{1/2} \quad (4)$$

Where I_{mean} is the mean value of all pollution index of the metals considered and I_{max} is the maximum value.

Table 1: Categorization of soil quality values

Values	Soil quality
43	<i>Igeo</i>⁵⁴
>5	Extremely contaminated
4-5	Strongly to extremely contaminated
3-4	Strongly contaminated
2-3	Moderately to strongly contaminated
1-2	Moderately contaminated
0-1	Uncontaminated to moderately contaminated
0	Uncontaminated
6	<i>Contaminated factor (CF)</i>⁶⁵
<1	Low
1≤CF<3	Moderate
3≤CF<6	Considerable
≥6	Very high
6	<i>Degree of contamination (DC)</i>⁶⁵
<1	Low
1≤DC<3	Moderate
3≤DC<6	Considerable
≥6	Very high
56	<i>Pollution load index</i>⁵⁸
8-10	Extremely polluted
6-8	Strongly polluted
4-6	Significantly polluted
2-4	Moderately polluted
0-2	Unpolluted to slightly polluted
85	<i>Potential ecological Risk factor</i>⁶⁵
<40	Low
40≤PERI<80	Moderate
80≤PERI≤160	Considerable
1600≤PERI≤320	High
>320	Very high
68	<i>Nemerow integrated pollution index (NIPI)</i>⁶⁶
≤ 0.7	Safe
0.7 < NIPI ≤ 1	Precaution
1 < NIPI ≤ 2	Slightly polluted
2 < NIPI ≤ 3	Moderately polluted
> 3	Heavily polluted

1

Ecological risk factor

Ecological risk index (ERI) is critical to measure both risk factor and metals concentrations in soil. The potential ecological risk index (PERI) can be determined through the following Eq. (5)

$$PERI = TRF \times CF \quad (5)$$

This is calculated separately for each metal.

Where PERI is the potential ecological risk factor/index, TRF represents the toxic-response factor, and CF represents contamination factor. The toxic response values for some of the toxic and trace elements are Co=5, Cd=30, Pb=5 and Zn=1 as suggested by Hakanson⁶⁵. The Potential ecological risk assessment PERI as established by Hakanson⁶⁵ is made using the following components.

(a) Contamination Factor (CF) is also called single pollution index (PI). Contamination factor is the quotient obtained by dividing the concentration of metals related to the target area by reference area. Their results are mostly associated with single pollution load, while their n-root was used for integrated pollution load index.

The contamination factor can be calculated through the following formula in Eq. 6 as suggested by Harikumar et

49⁷

$$CF = C_n / B_n \quad (6)$$

In the above equation, C_n is the concentration of metals in the target area, and B_n is the metals concentration of the reference area.

(b) The degree of contamination (DC) of one determined area is the sum of all Contamination factors:

$$DC = \sum CF \quad (7)$$

1

Assessment of Health risk for heavy metals in soils

Assessment of health risk is used to delineate the noncarcinogenic and carcinogenic risks to the human due to chemical exposure⁶⁸⁻⁷³. It has been reported that humans are exposed to soil metals through three main pathways, namely ingestion, inhalation, and dermal contact. US EPA proposed a fundamental method to estimate the dose received through ingestion, dermal, and inhalation^{39, 48-49}.

The health effects that might be attributed to noncarcinogenic trace metals in soil/sand/dust could be assessed by comparing an exposure via oral ingestion over a specified time period with a reference dose (RfD) for each metal over a similar exposure period. This non-cancer risk assessment ratio is termed target hazard quotient (THQ)⁴⁸. The RfD is the toxicity threshold value, which is specific for each chemical contaminant. To evaluate the overall exposure potential for combined chronic effects caused by all the metal contaminants, a hazard index (HI) approach was adopted. The HI is equal to the arithmetic sum of individual metal THQs. The estimated daily dose exposure through oral ingestion (EDD_{ing}), dermal (EDD_{dermal}) and inhalation absorption (EDD_{inh}), THQ, and HI is determined by the following equations, respectively^{48, 74-75}.

$$EDD_{inh} = \frac{C_{metal} \times EF \times ED \times IR_{inh}}{Bw \times AT \times PEF} \quad (8)$$

$$EDD_{ing} = \frac{C_{metal} \times EF \times ED \times IR_{ing}}{Bw \times AT} \times 10^{-6} \quad (9)$$

$$EDD_{dermal} = \frac{C_{metal} \times AF \times EF \times ED \times SA \times ABS}{Bw \times AT} \times 10^{-6} \quad (10)$$

$$THQ = EDD / RfD \quad (11)$$

$$HI = \sum_{i=1}^n THQ_i \quad (12)$$

2

Where C_{metal} is the concentration (mg/kg) of trace metal in soil sample; EF is the exposure frequency (365 d/year); ED is the exposure duration equal to 6 y and 18 y for children aged between 1 and 6 years and 6 and 18 years, respectively, and 52.4 years for adults World Bank 2013 estimate for average life expectancy in Nigeria)⁷⁶; IR_{ing} is the ingestion rate (100 and 50 mg/day for children and adults, resp.); IR_{inh} is inhalation rate⁷⁷; Bw is the average body weight (70, 48 and 19 kg for adults and children, resp.) and AT is the average exposure time for non-carcinogens (2190 d, age 1–6 y; 6570 d, age 6–18 y; 19162.5 d, adults); PEF is the particulate emission factor (m³/kg) = 1.36 × 10⁹; SA is the exposed skin surface area (cm²); AF is the adherence factor (kg/cm²-day); ABS is the dermal absorption factor; and RfD is the oral reference dose (mg/kg/day). The variable *i* denotes the *i*th heavy metal. The RfDs for Cd, Pb, and Zn are 0.001, 0.0035, and 0.3 mg/kg/, respectively⁷⁸. Target hazard quotient or hazard index ≤ 1 indicates that potential adverse health impacts from ingestion are unlikely, while

THQ or HI > 1 suggests that adverse chronic effects are likely from direct oral ingestion of contaminated soil samples ⁴⁸.

The carcinogenic risk or the lifetime cancer risk (LCR) is calculated by summation of the cancer risk (CR) from each exposure pathway.

$$\text{Cancer risk (CR)} = \text{EDD} \times \text{CSF} \quad (13)$$

$$\text{Lifetime cancer risk (LCR)} = \Sigma \text{CR (ingestion + inhalation + dermal)} \quad (14)$$

The cancer slope factor (CSF) value for Pb is 0.0085, Cd is 6.30E+00 mg/kg/day ³⁹ and Co is 9.80E+00 mg/kg/day ⁷⁹. The acceptable threshold value of CR is 1.0E-04, while the bearable LCR for regulatory purposes was ranged from 1.0E-06 to 1.0E-04 ³⁹, which was computed as a sum of CR (inhalation, ingestion, and dermal).

Table 2: Reference values of some parameters for exposure health risk assessment of heavy metals in the soil samples

Factor	Unit	Adult	Children 1-6year	Children 6-18year	Reference
EF	Days/year	365	365	365	39
ED	Year	52.4	6	18	76
IR _{ing}	mg/day	100	200	50	39, 48
104	m ³ /day	12.8	7.63		39
Bw	Kg	70	19	48	78
AT	Day	19162	6570	2190	76
PEF	m ³ /kg	1.36 x 10 ⁹	1.36 x 10 ⁹	1.36 x 10 ⁹	39
SA	cm ²	4350	1600		39
AF	kg/cm ² -day	0.7	0.2		39
ABS	/	0.001	0.001		39
RfD	mg/kg day	Ingestion: Pb (1.40E-03), Zn (0.3), Cd (1.00E-03) Dermal: Pb (5.25E-04), Zn (6.00E-02), Cd (2.50E-05) Inhalation: Pb (3.52E-03), Zn (3.00E-01), Cd (1.00E-03)			39, 44

EF-exposure frequency, ED-exposure duration, IR_{ing}-ingestion rate, IR_{inh}-inhalation rate, Bw-average body weight, AT-average exposure time for non-carcinogens, PEF-particulate emission factor, SA-exposed skin surface area, AF-adherence factor, ABS-dermal absorption factor, RfD- oral reference dose

2 Statistical Analysis

The data were transformed and analysed using the Graphpad Prism 8 and SPSS 22 software. Pearson's matrix correlation analysis was done to explore the interrelationship among heavy metals in soil samples and also attempt to identify their probable origin. The statistical analyses were performed with a 95% confidence interval (significance $p < 0.05$). The spatial distribution analysis was done using Krigging methods of interpolation with PAST 4 and ARCGIS 10.4, while the sample site location map was digitized using QGIS 3.12 software.

1 Results and Discussion

Heavy metal concentrations in soils sample

In this study the levels of the metals in the soil at various sampling point locations were indicated in Table 3 and Fig.1. The minimum, maximum, mean, median, standard deviation, coefficients of variations (CV), skewness and kurtosis in the study area were presented in Table 4. The cobalt ranged between 0.05660 and 0.2260, zinc ranged between 0.3925 and 3.149, iron ranged between 0.09390 and 184.4, lead ranged between 0.0815 and 0.3476, cadmium ranged between 0.0064 and 0.1050.

As a component of cyanocobalmin (vitamin B12), cobalt is essential in the body; the cobalt has been identified in most tissues of the body, with the highest concentrations found in the liver ⁸⁰. Cobalt enters the air through burning of oil and cobalt compounds that are used as colorants in glass, ceramics, and paints, as catalysts, and as paint driers. Cobalt compounds are also used as trace element additives in agriculture and medicine ⁸⁰. After it enters the air cobalt is associated with particles which will settle to the ground within few days. Some of the compounds may then settle in water, food and drinking water and these are the largest sources

of exposure to the general population⁸¹. The cobalt in all the soil samples in this study from Table 4 were within permissible limit of 74 mg/kg.

Zinc plays a key role in physical growth and development, the functioning of the immune system, reproductive health, sensory function and neurobehavioral development, and plant growth and animals⁸²⁻⁸³. Inadequate Zn level is harmful for humans (premature birth and low birth weight), animals, and crops yields. In the study, all collected soil sampling Zn were within the permissible limit of 50 mg/kg

Table 3: Soil samples locations and its analysis of Co, Zn, Fe, Pb and Cd in the study area.

Sample	Location	Co(mg/kg)	Zn(mg/kg)	Fe(mg/kg)	Pb(mg/kg)	Cd(mg/kg)
1	6.46591°N, 2.97945°E	0.1407	0.6422	140.1032	0.1057	0.0112
2	6.41687°N, 2.97934°E	0.1029	0.7263	109.7970	0.1570	0.0083
3	6.41665°N, 2.97954°E	0.2260	0.6090	142.1640	0.3476	0.0237
4	6.41691°N, 2.97965°E	0.1420	0.7006	111.1725	0.1298	0.0112
5	6.41706°N, 2.97976°E	0.1347	0.7999	184.4112	0.1566	0.0112
6	6.41692°N, 2.98016°E	0.1132	0.4401	60.8786	0.1761	0.0116
7	6.41669°N, 2.9782°E	0.2101	0.7374	152.9833	0.1699	0.0091
8	6.41644°N, 2.97986°E	0.1210	0.3925	68.8919	0.0800	0.0114
9	6.416°N, 2.97992°E	0.1485	0.7324	48.6736	0.1985	0.0087
10	6.41536°N, 2.97988°E	0.1961	0.5352	65.3164	0.3040	0.105
11	6.4168°N, 2.97994°E	0.1076	3.149	139.5473	0.0981	0.0076
12	6.41672°N, 2.97964°E	0.0692	ND	3.5008	0.1684	0.0198
13	6.41671°N, 2.97963°E	0.0566	ND	0.0939	0.1247	0.0064

ND- Not detected

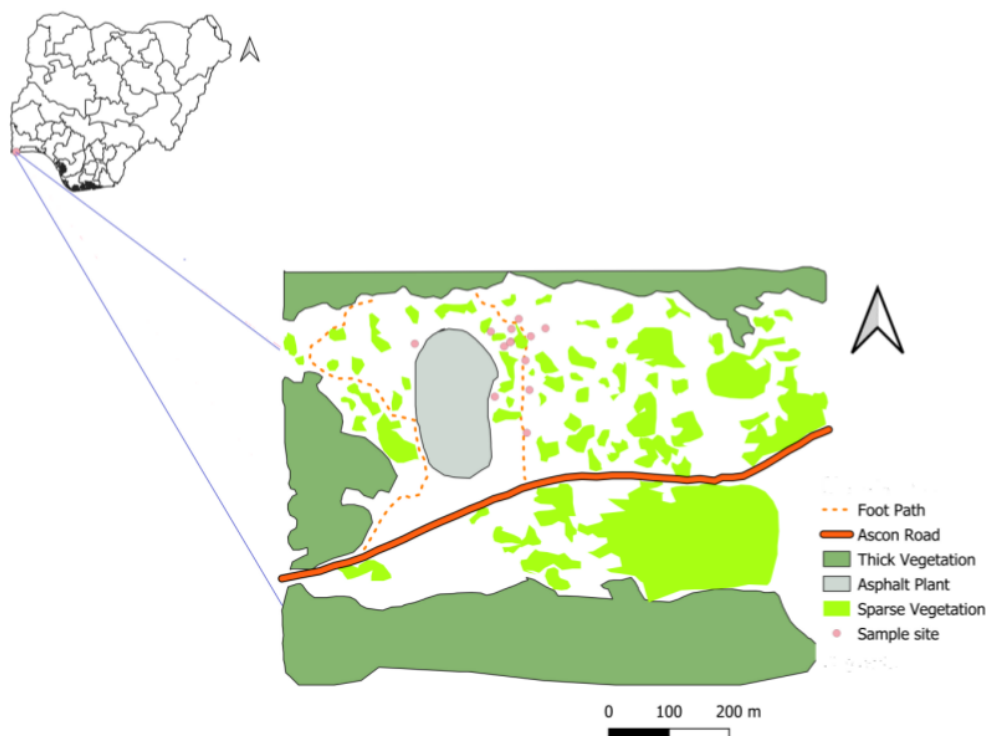


Fig.1: Digitized map show location of the sampling sites

Iron is the second most abundant metal on the earth's crust. Iron occupies the 26th elemental position in the periodic table and it is a crucial element for growth and survival of almost all living organisms⁸⁴. An extremely higher level of iron enters into the body crossing the rate-limiting absorption step and becomes saturated. These free irons penetrate into cells of the heart, liver and brain. Due to the disruption of oxidative phosphorylation by

free iron, the ferrous iron is converted to ferric iron that releases hydrogen ions, thus increasing metabolic acidity. The free iron can also lead to lipid peroxidation, which results in severe damage to mitochondria, microsomes and other cellular organelles.⁸⁹ In this study, 54% of the soil samples had iron concentration that exceeds the permissible limits. All other heavy metals analyzed in the soil samples were within the permissible limit (Table 4).

Lead is the second most common contaminant, and also, it is a second on the list of the top 20 hazardous substances as proposed by the US Environmental Protection Agency (US EPA) and Agency for toxic substances and disease registry.⁸⁰ The normal concentration of Pb in soils is in the range of 10–20 mg/kg, and a concentration level of larger than 100 mg/kg indicates danger for humans.^{29, 86} Excessive intake of Pb leads to metabolic disorders and neuro-physical deficits in children and harm the hematologic and renal system.³⁴ Pb interferes with the absorption of iron into the protoporphyrin which causes anemia and renal deterioration.⁸⁷ In this study, all collected soil sampling were within the permissible limit of 85 mg/kg.

The highest level of cadmium compounds in the environment (accumulated in sedimentary rocks, and marine phosphates) contain about 15 mg cadmium/kg.⁸⁸ Cadmium has the capability to bind with cysteine, glutamate, histidine and aspartate ligands and can lead to the deficiency of iron.⁸⁸ In this study, all collected soil sampling were within the permissible limit of 0.8 mg/kg as shown in Table 4.

In Table 4, the coefficients of variation (CV) of Co and Pb had a value larger than 20%, but lower than 50%, illustrating a moderate degree of variation, while the CV of Zn and Fe were larger than 50%, but lower than 100%. Cd had a value higher than 100% indicating a high degree of variation taking into view the study by Qing et al.,²⁶ Yao et al.,⁸⁹ and Zhou et al.,⁹⁰.

The mean concentration of heavy metals in the soils in this study followed a generalized decreasing order of $Cd < Co < Pb < Zn < Fe$. The coefficient of variation (CV %) of heavy metals in the soils samples followed an increasing order of $Co (37.26\%) < Pb (45.36\%) < Fe (61.39\%) < Zn (89.49\%) < Cd (139.6\%)$. The very large CV for Cd, Zn and Fe indicated that the concentration of these heavy metals varied greatly with respect to different sampling sites around the asphalt company.

In comparison with PL1 (Dutch standard)⁹¹ and PL2 (US Environmental Protection Agency Sediment Quality Guidelines), the mean concentrations of Co, Zn, Pb and Cd were largely below the PL1 and the corresponding PL2 value, illustrating that soils around the Asphalt manufacturing company in Badagry, Lagos are not greatly polluted by these heavy metals. The mean concentration of Fe was close to PL1 and surpassed PL2 values.

The Pearson matrix correlation between the heavy metals shows significance at $p < 0.05$ for the relationship between cobalt and iron, lead and cobalt, cadmium and lead as shown in Table 5.

Spatial distribution

The spatial distributions of heavy metals in soils from around the asphalt producing company were depicted in Figs. 2. The Co and Fe in soils of this study area had similar spatial distributions, with no higher concentrations located in any part rather the lower concentration and intermittent concentration were broadly spread and cross each other, although for the Fe the moderate concentration were more pronounced and all around the polarity. The Pb and Zn were similar also, the higher concentration of the heavy metals were located at the northern part southern part and concentrations located in the north-eastern part and spread through the eastern part to the southern part. Cd spatial distribution in soil shows higher concentration in the south and south-eastern part and low concentration located in the north-western parts of the study region (Fig. 2). Compared with other heavy metals Cd in soils showed different spatial distributions, but they were not exceeding the standard values.

Heavy metal pollution indices

Around the globe, Igeo and ERI have been used to evaluate the degree of metal contamination/pollution in soils.^{22, 24, 28-30, 93-94} Looking at Table 6, the calculated Igeo values of the five heavy metals in the soils around the asphalt manufacturing company varied and all fall under the class 0 which are uncontaminated levels. The Igeo values of Co, Zn, Fe, Pb and Cd in the soils were ranged from -8.976 to -6.978, -8.504 to -5.500, -19.54 to -8.597, -8.551 to -6.431 and -6.136 to -2.100 with mean values of -7.811, -7.611, -10.60, -7.579 and -5.117, respectively (Table 6), which indicated non-contamination by these metals.⁹⁵⁻⁹⁶

The computed contamination factor (CF) values from Table 6 shows that all the five heavy metals in the soil samples were in the < 1 value which signified low contamination according to Hakanson⁶⁵ from Table 1. The CF values of Co, Zn, Fe, Pb and Cd in the soils were ranged from 0.0028 to 0.0113, 0.0028 to 0.0225, 1.88E-05 to 0.0369, 0.0009 to 0.00411 and 0.008 to 0.1313 with mean values of 0.0068, 0.0061, 0.0020, 0.0020 and 0.0236 respectively (Table 6).

1

Table 4: Descriptive statistics of soil heavy metal concentrations and comparison with some standard

Units/Element	Co (mg/kg)	Zn(mg/kg)	Fe(mg/kg)	Pb(mg/kg)	Cd(mg/kg)
Minimum	0.05660	0.3925	0.09390	0.08000	0.006400
Maximum	0.2260	3.149	184.4	0.3476	0.1050
Mean	0.1360	0.8604	94.43	0.1705	0.01886
Median	0.1347	0.7006	109.8	0.1570	0.01120
SD	0.05069	0.7700	57.97	0.07733	0.02633
CV	37.26%	89.49%	61.39%	45.36%	139.6%
Skew	0.3614	3.143	-0.2690	1.362	3.401
Kurt	-0.3648	10.19	-0.9305	1.553	11.89
PL1	74	50	95	85	0.8
PL2	-	110	30	40	-
PL3	19	95	47600	1	0.3
%SWL	100	100	46	100	100
%SEL	-	-	54	-	-

SD: standard deviation

CV: coefficients of variation

Skew: skewness

Kurt: kurtosis

PL1: permissible limit (13)ch standard [91])

PL2: permissible limit (US Environmental Protection Agency Sediment Quality Guidelines)

PL3: World geochemical background value in average shale [92].

%SWL: % of samples within the limits

%SEL: % of samples exceeding the limits

13

Table 5: Pearson Correlation Matrix for Stream Sediment Data from the Study Area

	Co	Zn	Fe	Pb	Cd
Co	1	-0.3014	0.5511	0.6643	0.4098
Zn	-0.3014	1	0.3054	-0.3021	-0.1873
Fe	0.5511	0.3054	1	0.0283	-0.1472
Pb	0.6642	-0.3021	0.0283	1	0.6201
Cd	0.4097	-0.1873	-0.1472	0.6201	1

Correlation are significant at $p < 0.05$.

22

Degree of contamination from Fig. 3A show that soil sample 10 had the highest value of 0.132 while sample 13 had the lowest value of 0.014. The plot shows that the degree of contamination from the soil samples in this study were lesser than 1 which indicates from Table 1 that the soil samples had a low contamination degree which could be said to be safe.

According to Adebawale et al.⁹⁷ the PLI as an index which serve as a quick tool for comparing the pollution status of the different sampling sites, from Fig.3B, soil sample 10 displayed the highest value of pollution load index of 0.012, while sample 3 was next to it with a value of 0.011, sample 13 shows the lowest value of 0.0038. $PLI > 1$ is an indication of pollution whereas $PLI < 1$ is unpolluted from Table 1⁹⁸⁻⁹⁹, in this study all soil sample had PLI that is lesser than 1 which indicate unpolluted.

6

The Ecological risk factors of Fe were not computed due to unavailability of its toxic response factors (TRF) in literatures Fig. 3C shows the Potential ecological risk index (PERI) of zinc, cobalt and lead in soil samples. Co shows higher value of PERI than zinc and lead in all the soil samples. Fig.3D shows the PERI of cadmium in soil samples, with soil sample 10 displaying the highest value indicated by the peak in the plot. All the four heavy metals computed for ecological risk factors shows a value lesser than 40 which signify low potential ecological risk index from Table 1 according to Hakanson⁶⁵.

From Table 7, all the heavy metal analyzed in this study had mean values lesser than the target values. The pollution index (PI) of the heavy metals shows that Cd had the highest value of 0.0236 followed by Fe with a value of 0.0189, Zn, Pb and Co had a PI values of 0.0061, 0.002 and 0.0002 respectively. Nemerow integrated pollution index (NIPI) of the heavy metals in all the soil samples is 0.0182. According to Cheng et al.,⁶⁶, NIPI value < 0.7 is considered safe, therefore the soil samples are safe from pollution.

Table 6: Geo-accumulation index (Igeo) and Contamination factor (CF) values of the heavy metals in soils samples

				Igeo classification and % of samples						
Heavy metals	Minimum	Maximum	Mean	Class 0 (Igeo<0) (%)	Class 1 (0<Igeo<1) (%)	Class 2 (1<Igeo<2) (%)	Class 3 (2<Igeo<3) (%)	Class 4 (3<Igeo<4) (%)	Class 5 (4<Igeo<5) (%)	Class 6 (Igeo[5] (%)
Co	-8.976	-6.978	-7.811	100	-	-	-	-	-	-
Zn	-8.504	-5.500	-7.638	100	-	-	-	-	-	-
Fe	-19.54	-8.597	-10.60	100	-	-	-	-	-	-
Pb	-8.551	-6.431	-7.579	100	-	-	-	-	-	-
Cd	-6.136	-2.100	-5.117	100	-	-	-	-	-	-
CF classification and % of samples										
				(<1) (%)	(1≤CF<3) (%)	(3≤CF<6) (%)			(<1) (%)	
Co	0.0028	0.0113	0.0068	100	-	-			-	
Zn	0.0028	0.0225	0.0061	100	-	-			-	
Fe	1.88e-5	0.0369	0.0020	100	-	-			-	
Pb	0.0009	0.0041	0.0020	100	-	-			-	
Cd	0.008	0.1313	0.0236	100	-	-			-	

Class 0 uncontaminated, Class 1 uncontaminated to moderately contaminated, Class 2 moderately to heavily contaminated, Class 3 moderately contaminated, Class 4 heavily contaminated, Class 5 heavily to extremely contaminated, Class 6 extremely contaminated

Table 7: pollution index (PI) and NIPI of heavy metals of soil samples

	Co	Fe	Pb	Cd	Zn	I _{mean}	I _{max}	NIPI
Mean	0.1360	94.43	0.1705	0.0189	0.8604			
Target value	70	5000	85	0.8	140			
PI Value	0.0002	0.0189	0.002	0.0236	0.0061	0.0102	0.0236	0.0182

Assessment of health risk to human

1

Non-carcinogenic health risks

Non-carcinogenic health risk assessment of five heavy metals (Co, Pb, Fe, Cd and Zn) in the soils sample via likely exposure pathways: dermal contact (EDD_{dermal}), ingestion (EDD_{ingestion}) and inhalation (EDD_{inhalation}) were done for adults and children. The EDD_{ingestion} values of Co, Fe, Pb and Cd all showed the drift of Children>Adults, while EDD_{inhalation}, and EDD_{dermal} values of Co, Zn, Fe, Pb and Cd all showed the drift of Children<Adults from Table 8.

The target hazard quotient (THQ) and Hazard index (HI) could not be computed for Co and Fe because there was no RfD value from literatures. It was noticed from Table 9 that the target hazard quotient (THQ) of adults and children due to exposure pathways under consideration in this study occurred in the following decreasing order of ingestion>dermal>inhalation. Similar drift of results have been reported in various parts of the world (21, 30, 89, 100-101).

Non-carcinogenic health risks of soil to exposed heavy metals from table 9 shows for children via ingestion as being 1.87E-05 to 1.50E-05 for Zn, 8.15E-05 to 3.54E-04 for Pb, 9.13E-06 to 1.15E-04 for Cd. This shows that the target hazard quotient (THQ) of Pb was significantly larger than other heavy metals in the soils in the study area. More so, computed hazard index (HI) values were also lesser than 1 for Pb ranged from 8.88E-05 to 3.83E-04 for adult and 2.016E-04 to 8.756E-04 for children, this suggested none detrimental effects on children in the study area (Table 9). Dermal contact and inhalation pathways were much lower than the ingestion which was also very low. THQ levels, indicate that dermal contact and inhalation pathways could not pose a health risk for children health in the study area. Table 9 suggested that THQ values for adults via the three pathways were

1 less than one, which indicated that there were no non-carcinogenic risks for adults. The HI was found in the order of Zn<Cd<Pb for both adults and children in the studied area.

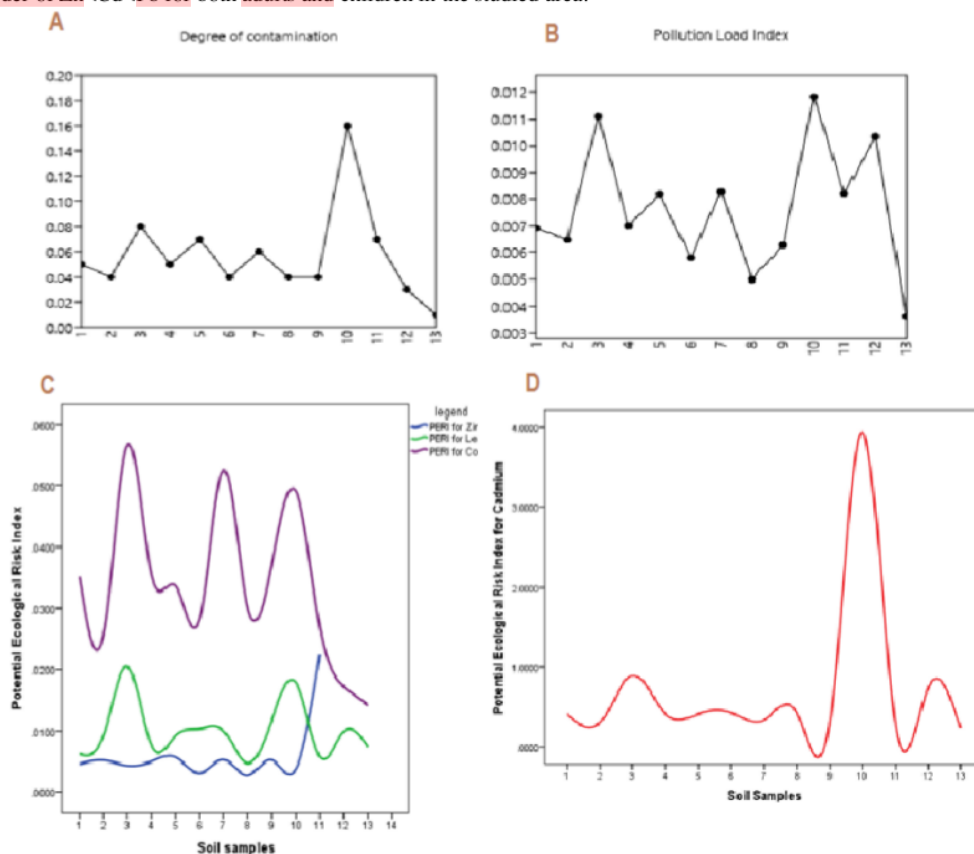


Fig.3: (A).Degree of contamination (DC) of the area where soils samples are collected, (B) Pollution load index of the area where soils samples are collected (C) Potential ecological risk index of zinc, cobalt and lead in soil samples (D)

Table 8: inhalation, Ingestion and dermal pathways of non-carcinogenic and carcinogenic risks for children and adults in the study area

Heavy metals		EDD _{Inhalation}		EDD _{Ingestion}			EDD _{Dermal}	
		Adult	Children 1-6 yrs	Adult	Children 1-6 yrs	Children 6-18 yrs	Adult	Children 1-6 yrs
Cobalt	Min.	7.60E-12	5.57E-12	8.07E-08	1.99E-07	1.77E-07	2.46E-09	3.18E-10
	Max	3.03E-11	2.22E-11	3.22E-07	7.93E-07	7.06E-07	9.81E-09	1.27E-09
	Mean	1.83E-11	1.34E-11	1.94E-07	4.77E-07	4.25E-07	5.91E-09	7.64E-10
Zinc	Min.	5.27E-11	3.86E-11	5.60E-07	1.38E-06	1.23E-06	1.70E-08	2.20E-09
	Max	4.23E-10	3.10E-10	4.49E-06	1.11E-05	9.84E-06	1.37E-07	1.77E-08
	Mean	1.16E-10	8.47E-11	1.23E-06	3.02E-06	2.69E-06	3.74E-08	4.83E-09
Iron	Min.	1.26E-11	9.24E-12	1.34E-07	3.30E-07	2.93E-07	4.08E-09	5.27E-10
	Max	2.48E-08	1.82E-08	0.000263	0.000647	0.000576	8.01E-06	1.04E-06
	Mean	1.27E-08	9.29E-09	0.000135	0.000331	0.000295	4.10E-06	5.30E-07
Lead	Min.	1.07E-11	7.87E-12	1.14E-07	2.81E-07	2.50E-07	3.47E-09	4.49E-10
	Max	4.67E-11	3.42E-11	4.96E-07	1.22E-06	1.09E-06	1.51E-08	1.95E-09
	Mean	2.29E-11	1.68E-11	2.43E-07	5.98E-07	5.33E-07	7.40E-09	9.57E-10
Cadmium	Min.	8.59E-13	6.30E-13	9.13E-09	2.25E-08	2.00E-08	2.78E-10	3.59E-11
	Max	1.41E-11	1.03E-11	1.50E-07	3.68E-07	3.28E-07	4.56E-09	5.90E-10
	Mean	2.53E-12	1.86E-12	2.69E-08	6.62E-08	5.89E-08	8.19E-10	1.06E-10

Seemingly, the HI values for Pb, Cd and Zn are all lower than the safe level ($HI = <1$) for all sampling sites, indicating that there is no significant health risk of non-carcinogenic effect of these metals in the study area for adults and children. Although for the non-carcinogenic health risks looking at it from the two population groups perspective, the value magnitude for children were higher than the risks for adults, suggesting that children faced more potential harmful health risks from the heavy metals in soils around the asphalt company, this magnitude similarity was also reported by Adimalla ¹⁰⁰.

Carcinogenic health risks

Some heavy metals such as Cd, Pb, As, Cr, Co can increase cancer risk in an exposed population. Cancer risks (CR) and life time cancer risk LCR (also known as total carcinogenic risks (TCR)) values lower than $1.0E-06$ be regarded as negligible, whereas a CR and LCR above $1.0E-04$ are likely to be detrimental to humans ^{79, 104}.

In this study, Co, Pb and Cd assessment for carcinogenic health risks through three exposure routes for adults and children were determined and stated in Table 9. It was found that the $CR_{inhalation}$, $CR_{ingestion}$ and CR_{dermal} for Co for Adult ranged from $7.44E-11$ to $2.97E-10$, $7.91E-07$ to $3.16E-06$ and $2.41E-08$ to $9.62E-08$ respectively while children, $CR_{inhalation}$ ranged from $5.46E-11$ to $2.18E-10$, $CR_{ingestion}$ ranged from $1.95E-06$ to $7.77E-06$ and CR_{dermal} ranged from $3.11E-09$ to $1.24E-08$. The mean value of $CR_{inhalation}$, $CR_{ingestion}$ and CR_{dermal} Pb and Cd for adult are $1.95E-13$, $2.07E-09$, and $6.29E-11$; $1.60E-11$, $1.69E-07$, and $5.16E-09$, respectively and for children $1.43E-13$, $5.09E-09$ and $8.14E-12$; $1.17E-11$, $4.17E-07$ and $6.67E-10$ respectively (Table 9). However, the LCR of Co, Pb and Cd values ranged from $8.15E-07$ to $3.26E-06$, $1.00E-08$ to $4.34E-09$, and $5.93E-08$ to $9.72E-07$ for adult, respectively, $1.95E-06$ to $7.78E-06$, $2.37E-09$ to $1.04E-08$, and $1.42E-07$ to $2.32E-06$ for children respectively (Table 9).

Table 9: Non-carcinogenic and Carcinogenic risk via ingestion, dermal, and inhalation exposure pathways for adult and children

Non-Carcinogenic Risk									
Heavy metal		Adult				Children 1-6 yrs			
		THQ_{inh}	THQ_{ing}	THQ_{der}	HI	THQ_{inh}	THQ_{ing}	THQ_{der}	HI
Zinc	Min.	$1.76E-10$	$1.87E-06$	$2.84E-07$	$2.15E-06$	$1.29E-10$	$4.59E-06$	$3.67E-08$	$4.63E-06$
	Max	$1.41E-09$	$1.50E-05$	$2.28E-06$	$1.73E-05$	$1.03E-09$	$3.68E-05$	$2.95E-07$	$3.71E-05$
	Mean	$3.85E-10$	$4.09E-06$	$6.23E-07$	$4.71E-06$	$2.82E-10$	$1.01E-05$	$8.05E-08$	$1.01E-05$
Lead	Min.	$3.05E-09$	$8.15E-05$	$6.62E-06$	$8.81E-05$	$2.24E-09$	0.000201	$8.56E-07$	$2.01E-04$
	Max	$1.33E-08$	0.000354	$2.88E-05$	$3.83E-04$	$9.72E-09$	0.000871	$3.72E-06$	$8.75E-04$
	Mean	$6.50E-09$	0.000174	$1.41E-05$	$1.88E-04$	$4.77E-09$	0.000427	$1.82E-06$	$4.29E-04$
Cadmium	Min.	$8.59E-10$	$9.13E-06$	$1.11E-05$	$2.02E-05$	$6.30E-10$	$2.25E-05$	$1.44E-06$	$2.39E-05$
	Max	$1.41E-08$	0.00015	0.000182	$3.32E-04$	$1.03E-08$	0.000368	$2.36E-05$	$3.92E-04$
	Mean	$2.53E-09$	$2.69E-05$	$3.28E-05$	$5.97E-05$	$1.86E-09$	$6.62E-05$	$4.24E-06$	$7.04E-05$
Carcinogenic Risk									
		CR_{inh}	CR_{ing}	CR_{der}	LCR	CR_{inh}	CR_{ing}	CR_{der}	LCR
Cobalt	Min.	$7.44E-11$	$7.91E-07$	$2.41E-08$	$8.15E-07$	$5.46E-11$	$1.95E-06$	$3.11E-09$	$1.95E-06$
	Max	$2.97E-10$	$3.16E-06$	$9.62E-08$	$3.26E-06$	$2.18E-10$	$7.77E-06$	$1.24E-08$	$7.78E-06$
	Mean	$1.79E-10$	$1.90E-06$	$5.79E-08$	$1.96E-06$	$1.31E-10$	$4.68E-06$	$7.49E-09$	$4.69E-06$
Lead	Min.	$9.13E-14$	$9.70E-10$	$2.95E-11$	$1.00E-09$	$6.69E-14$	$2.37E-09$	$3.82E-12$	$2.37E-09$
	Max	$3.97E-13$	$4.21E-09$	$1.28E-10$	$4.34E-09$	$2.91E-13$	$1.04E-08$	$1.66E-11$	$1.04E-08$
	Mean	$1.95E-13$	$2.07E-09$	$6.29E-11$	$2.13E-09$	$1.43E-13$	$5.09E-09$	$8.14E-12$	$5.10E-09$
Cadmium	Min.	$5.41E-12$	$5.75E-08$	$1.75E-09$	$5.93E-08$	$3.97E-12$	$1.42E-07$	$2.26E-10$	$1.42E-07$
	Max	$8.88E-11$	$9.43E-07$	$2.87E-08$	$9.72E-07$	$6.51E-11$	$2.32E-06$	$3.71E-09$	$2.32E-06$
	Mean	$1.60E-11$	$1.69E-07$	$5.16E-09$	$1.74E-07$	$1.17E-11$	$4.17E-07$	$6.67E-10$	$4.18E-07$

THQ_{inh} - Target hazard quotient inhalation, THQ_{ing} - Target hazard quotient ingestion, THQ_{der} - Target hazard quotient dermal, HI - hazard index, CR - Cancer risk, LCR - Life-time cancer risk

As shown in Table 9, for each soil sampling site, the $CR_{inhalation}$ and CR_{dermal} values of Co, Pb and Cd through inhalation and dermal contact exposure pathway for adults and children are all lower than the recommended limit of $1.0E-06$ ⁷⁷, this was also reported in a study by Adimalla ¹⁰⁰ where the $CR_{inhalation}$ and CR_{dermal} values of Pb and Cd among 4 heavy metals been investigated for carcinogenic risk for adults and children are all lower than the recommended limit of $1.0E-06$ in surface soil samples in the Medak province, India. There were no significant carcinogenic health risks for both children and adults via inhalation and dermal contact exposure pathway with the soil samples around the Asphalt production company with the finding in this study.

Co has typically greater potential towards carcinogenic health risk when compared to other heavy metals for both adults and children, while the LCR ranged from $8.15E-07$ to $3.26E-06$, $1.95E-06$ to $7.78E-06$ for adults and children, respectively (Table 9). LCR of Co for adults and children with a mean of $1.96E-06$ and $4.69E-06$, respectively. The 3 heavy metals $CR_{ingestion}$ shows higher values for children when placed side by side with the adult and this signify that children are more prone to carcinogenic health risk with these soils via ingestion pathway

Conclusion

Heavy metals from soils samples around an asphalt production company concentration, spatial distribution, pollution indices and health risk assessment were investigated on this study. The non-carcinogenic and carcinogenic risks due to life time exposure via ingestion of soils, inhalation of soil particulate materials, and soil dermal contact were evaluated to assess the risk pose by these heavy metals.

The concentrations of Co, Zn, Fe, Pb and Cd were determined in 100 soil samples, 54% of the soil samples had concentration that exceeds the permissible limits. All other heavy metals analyzed in the soil samples were within the permissible limit.

The geochemical index (Igeo) values of the five heavy metals in the soils around the asphalt manufacturing company varied and all fall under the class 0 which are uncontaminated levels. Also the computed contamination factor (CF) values shows that all the five heavy metals in the soil samples were in the <1 value which signified low. All the four heavy metals (Co, Zn, Pb and Cd) evaluated for ecological risk factors shows a value lesser than 40 which signify low potential ecological risk index (PERI). The pollution index (PI) of the heavy metals shows that Cd had the highest value of 0.0236 followed by Fe with a value of 0.0189, Zn, Pb and Co had a PI values of 0.0061, 0.002 and 0.0002 respectively. Nemerow integrated pollution index (NIPI) of the heavy metals in all the soil samples is 0.0182 which is considered safe.

The results of non-carcinogenic health risk analysis project that the contribution of ingestion is much higher than the inhalation and dermal contacts in the study area for children and adults. Both hazard quotient (HQ) and hazard index (HI) values for Co, Zn, Cd, Fe and Pb are far lower than the recommended limit (HI=1) for children and adults, suggesting that these metals have a negligible non-carcinogenic risk for people in the study area.

The $CR_{inhalation}$ and CR_{dermal} values of Co, Pb and Cd of soils sample through inhalation and dermal contact exposure routes for adults and children are all lower than the recommended limit of $1.0E-06$. the $CR_{ingestion}$ for the 3 heavy metals shows that the values for children was higher when compared to the adult and this signify that children are more at carcinogenic health risk with these soils via ingestion pathway. The 3 heavy metals did not exceed bearable LCR value of $1.0E-04$ for the 3 pathways investigated in this study. From all these analysis and computation made it could be suggest that the Asphalt production company activities and effluent is not contaminating the soil around them.

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Author Contributions: Olu, J. conducted this research, wrote the manuscript, digitized the location map, did the spatial and statistical calculations and analysis with interpretations.

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