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# Pollution Indices and Health Risk Assessment of Heavy Metals in Soil of Major Motor Parks in Yola, Nigeria

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**KEYWORDS**

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Soil; Motor parks

**ABSTRACT:** This study assessed the ecological risk and pollution level of motor parks' soil in Yola metro, Nigeria. Twenty (20) soil samples were collected from topsoil of the selected motor parks and heavy metals (Cu, As, Ni, Mn, Cd, Pb, Cr, and Zn) were analyzed by atomic absorption spectrophotometer. Contamination degree (DC), pollution load index (PLI), ecological risk index (RI), geo-accumulation index (I-geo), health risk index of the metals concentration were evaluated. The results showed that mean concentration of the metals in the soil were in the increasing order As<Ni<Mn<Cd<Pb<Cr<Cu<Zn, with average values ranged 0.09-061mg $kg^{-1}$, 0.21-0.44mg $kg^{-1}$, 0.35-0.58mg $kg^{-1}$, 2.14-3.08mg $kg^{-1}$, 1.86-3.70mg $kg^{-1}$, 0.56-5.49mg $kg^{-1}$, 10.20-20.12mg $kg^{-1}$, and 14.45–16.55 mg $kg^{-1}$, respectively. The concentration of Cd, Mn, Ni, Cr, Pb, and Zn exceeded the standard USEPA threshold limits and cadmium concentration is higher than its natural background value. The results of pollution indices indicated that the soil sample were less polluted, while the geo-accumulation index showed that the soil samples were highly contaminated. The ecological risk index indicated that the soil samples were in the range of moderate to considerable risk. The study revealed that cadmium is the main contaminant in the soil samples which posed a very high ecological risk. It is recommended that regular assessment of sources of pollution and health risk be regularly carried out in order to preserve the health of motorists, passengers and workers in the parks.

## INTRODUCTION

Environmental pollution by heavy metals has increasingly become a problem of great concern due to the adverse effects it is causing around the world [1]. Pollutants, such as industrial, agriculture, municipal, and transportation pose great threat to the environment and since the introduction of modern technology soil, has been the repository of societal waste generated via anthropogenic activities [2]. Human activities lead to the accumulation of heavy metals in air, soil and water which make environment to be polluted. The presence of heavy metals in soil may either come from natural occurrence or human activities [3]. Natural sources are chiefly influenced by geologic processes of primary materials such as rock weathering, atmospheric deposition, mineralogical composition, and soil geo-chemical interactions [4-5]. Whilst, the anthropogenic sources of heavy metals in soil may result from industrial waste discharge, solid waste incineration, domestic sewage disposal, transportation emissions, agricultural waste, mining activities and processing of crude oil [6].

Soil is crucial for human survival and societal development, its quality directly impacts food security, agricultural product quality, human health, and social progress. Due to the continued economic and societal growth, anthropogenic activities have caused a surge in soil pollution, particularly from heavy metals. Therefore,

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pollution disrupts the complex ecosystem balance and leading to decreased soil quality and viable agricultural output [7]. Heavy metals are released into the environment via various anthropogenic sources such as fossil fuel combustion, automobile emission, agriculture processes, waste incineration, sewage treatment, electrical power plants, industrial and mining activities [8-9]. Among the anthropogenic activities, one of the main sources of heavy metals pollution of the environment is its emission from transportation industry. Pollution impact resulting from toxic metals exposure in human and ecosystems has become burden of serious concern due to multiple point source, higher accumulation, magnification, and toxicity in biological organisms and food webs [9].

Soil contamination with heavy metals has attracted great attention due to their toxicity. It has tendency for long-range transportation in the soil and get to the ground water source and eventually pollute the water supplies [10]. In addition, heavy metals are absorbed by human from contamination of soil via direct ingestion, inhalation of the particulate dust, and dermal contact which consequently lead to their enrichment in food chain and webs [11]. The noxiousness, magnification and non-biodegradability of heavy metals found in the ecosystem is one of the major concerns that poses health-risk related issues and ecological hazards when present in higher proportion in the environment [12]. Various health-related issues such as cancer, liver problem, immune disorder, cardiovascular, renal, and neurological impairment are associated with excessive exposure to heavy metal contents in human beings [13-14]. In essence, soil pollution is reported when contaminants exceeded the background or natural value and this can be said to pose serious environmental, ecological and human health risk [15].

Motor parks are designated point in an urban area characterized by high vehicular activities that coordinate the intra- and inter-transport system [16-17]. However, motor parks are integral parts of environment and are frequently full of activities, but they contribute as a source of heavy metal pollution to the soil and environment, originating from traffic emissions, tire and brake wear, electronic waste incineration, domestic emissions, fuel leakage, and corrosion of metals, which can lead to soil contamination and pose potential health risks to individuals frequenting these locations [1, 10, 18]. Unfortunately, children are vulnerable to the adverse impacts of soil contamination as a result of higher absorption rate due to hand-to-mouth activities than adults [10, 19]. The assessment of pollution indices and health risks associated with heavy metals in soil, particularly in motor parks, is crucial due to the potential harm to human health and the environment. Studies have shown that heavy metals like lead, cadmium, chromium, arsenic, cobalt, nickel, copper, zinc, and others can contaminate soil through various anthropogenic activities, posing risks to individuals, especially children, due to toxicity and bioaccumulation [1, 5, and 7]. Pollution indices such as the geo-accumulation index, contamination factor, and potential ecological risk index are utilized to assess the contamination levels and ecological risks posed by heavy metals in soil samples from motor parks. Additionally, health risk assessment models have indicated varying levels of carcinogenic and non-carcinogenic risks to human populations, emphasizing the importance of understanding heavy metal contamination in soil and its impact on human health, highlighting the importance of monitoring and managing heavy metal pollution in such environments [1, 20]. Studies in various regions like China, Namibia, and other parts of the world have highlighted the significant heavy metal pollution in soil, with elements like As, Cd, Pb, and Zn being major concerns [1, 21-23].

Presently, several researchers have conducted investigations on the contents of heavy metals and studies on pollution load assessment, potential ecological and human health risk in soil of motor parks such as Benue [24], Ogbomosho [25], Gombe [3, 9, 26], Delta [27], Maiduguri [6], Benin-city [16-17], and various cities of the country. Meanwhile, there is no comprehensive data on the pollution level and ecological risk in the soil of motor parks of heavy metals in Yola metropolis and their concomitant effects on human health. Therefore, the purpose of this study is to assess the pollution load status, ecological risk, geo-accumulation form and health risk assessment of heavy metals in soil samples from motor parks in this urban environment due to automobile emission, discharge of spent fuel oils, vehicle servicing and repair, and other various anthropogenic activities. The main objectives are: 1.) to determine the concentration of Ni, Cu, Cr, Mn, As, Cd, Zn, and Pb in soil of the study area, 2.) to assess the pollution indices and ecological risk assessment of the soil samples, and 3.) to evaluate the human health risk assessment via ingestion, inhalation and dermal contact for the non-carcinogenic and carcinogenic risks of the soil in the motor parks.

## MATERIALS AND METHODS

### *Study area*

Yola metro is a capital of Adamawa state in north-eastern Nigeria as shown in Figure 1 was selected for this study because of its vast population of over 336, 648. The metropolitan city is divided into new Jimeta city and old traditional city, and they are both regarded as Yola city. It has a tropical savanna climate that borders on a hot semi-arid climate with dry and raining seasons. The temperature is high in the average range 27℃ - 44℃ year-round except during harmattan period and wet season. Yola is one of the commercial and economic hub of northeastern Nigeria where there will be influx and out flux of people into the ancient town. Due to this growing population, it has several motor parks that enhance transportation people and goods from neighbouring states. In this study, a total of four motor parks was purposively selected based on their high level of activity and proximity to major roads within the city. The selected motor parks included Adamawa Sunshine (Lat. 9º 16' 20.0" N; Long. 12º 27' 03.2" E), Fair-Plus (Lat. 9º 26' 71" N; Long. 12º 41' 84" E), Jimeta (Lat. 9º 27' 95" N; Long. 12º 28' 75" E) and Sauki (Lat. 9º 27' 88" N; Long. 12º 42' 43" E) Motor Parks; all in the heart of Yola city.

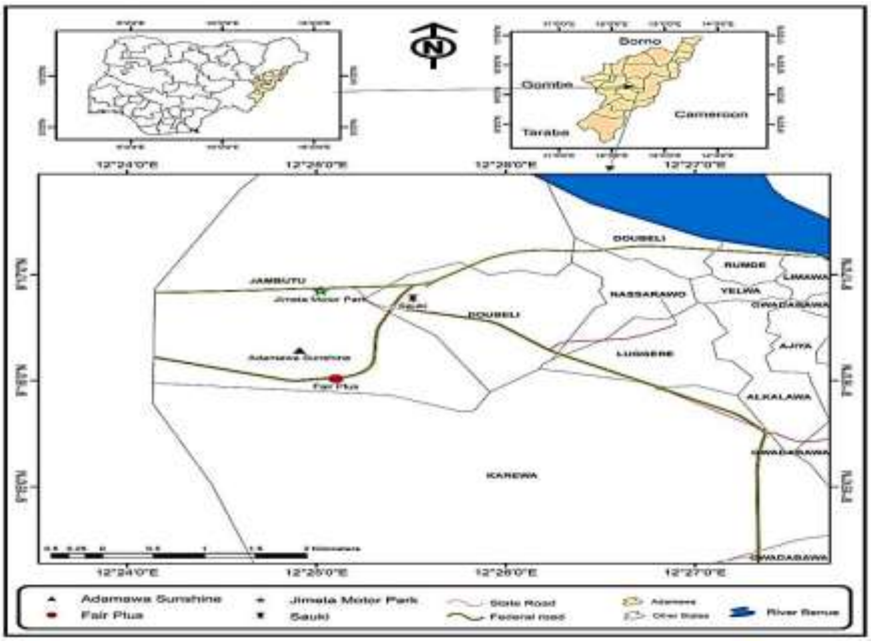


**Figure 1.** The map showing the study area

### *Chemical reagents*

Hydrochloric acid (HCl, 37%), nitric acid ($HNO_3$, 70%), hydrofluoric acid (HF, 68%), de-ionized water, distilled water. All chemicals used were of analytical grade (Analar grade) reagents.

### *Sample collection and pre-treatment*

The soil samples collection was carried out in the month of April, 2023 within the identified sampling points Adamawa sunshine (ASMP), Fair plus (FPMP), Jimeta (JMP), Sauki (SMP) motor parks in Yola. In this study, purposive sampling technique is adopted to select the motor parks for the study. The chosen motor parks are those with high human activities and vehicular traffic, which increases the potential for heavy metal contamination in the soil. The study also used systematic random sampling to select the sampling points between the range of 0 -5 cm within the selected motor parks. The soil samples were collected between 0-10cm from depth of the top soil in the location using a clean soil auger into a clean and Pre-treated polyethylene bag, labelled and transferred into laboratory. Five (5) samples were obtained from each locations and a total of twenty (20) samples were obtained in the motor parks. The soil samples were spread in an air-dried in a clean nylon and further grounded into fine particles. The samples collected from each motor parks were homogenized to make composite sample of each park. The ground soil was packed and stored in a clean and pre-treated polythene bag for the preparation and further analysis.

***Preparation and analysis of sample***

The soil samples were digested using tri-acid digestion method as described by Sanusi *et al.* [28]. About 1.0-g of soil sample was digested in the conical (digestion) flask with 30ml of aqua regia (HCl : $HNO_3$) 3:1 on a thermostat hot plate at 150°C. After about 2 hours of digestion, the flask and the content were removed from the heating mantle. Then 5.0ml of concentrated hydrofluoric acid (HF) was added and heated further for 30 minutes. The flask with the content was allowed to cool down to room temperature and filtered. After which the filtrate was quantitatively transferred into 50ml volumetric flask and made up to mark with distilled water. The solutions were prepared for further instrumental analysis of the heavy metal contents in the sample. Atomic absorption spectrophotometer (AAS) was used for the determination of heavy metals in the digested soil samples. The heavy metals analyzed in this study include arsenic (As), chromium (Cr), manganese (Mn), lead (Pb), cadmium (Cd), copper (Cu), and zinc (Zn).

***Quality control***

The quality control procedure was carried out throughout the analysis of the samples in the laboratory. Proper care was taken to ensure valid and reliable results. All plastics, glassware, and materials used were thoroughly washed, rinsed and soaked in nitric acid (70.5%) overnight, rinsed with distilled water and dried before use. Replicate measurements were being carried in the batches. Each of the prepared sample was analyzed in triplicate to monitor analytical precision and this ranges between 5-10%. Blank determinations without soil samples were also prepared and carried out to correct for the bias in the concentration of the analytes resulting from reagent impurities and faulty instrument.

***Data analysis***

The analysis of heavy metal concentration was carried out to evaluate the pollution load index and health risk assessment of the soil samples in the studied motor parks by estimating the contamination factor, degree of contamination, pollution load index, ecological risk and potential ecological risk indices, hazard quotient, hazard index, and cancer risk.

***Contamination factor (CF)***

The contamination factor is used to ascertain the existence possible level of contamination of a heavy metal. It is used to determine a single element pollution index and individual contribution of heavy metals to the sampling location's pollution index. It is expressed as a ratio of the metal concentration to the background value as shown by the formula in equation (1)

$$Cf = \frac{Cn}{Cb} \qquad (1)$$

Where Cn is the metal concentration in the sample, and Cb is the background value obtained from Department of Petroleum Resources [29]. Table 1 depicted the level of contamination or degree of contamination as adopted from Liu *et al*. [8].

***Degree of Contamination (DC)***

The degree of contamination is the sum total of the contamination factors (CF) of the metals for each sampling locations. It is mathematically expressed by the formula in equation (2).

$$\mathrm{DC} = \sum_i^n (CF)i \qquad (2)$$

Where (CF)i represent the contamination factor of the metal being considered.

**Table 1.** Level of contamination based on DC.

| CF values | DC values | Level of Contamination |
|---|---|---|
| **CF ≤ 1** | DC ≤ 8 | Low |
| **1 ≤ CF ≤ 3** | 8 ≤ DC ≤ 16 | Moderate |
| **3 ≤ CF ≤ 6** | 16 ≤ DC ≤ 32 | Considerate |
| **CF ≥ 6** | DC ≥ 32 | Very high |

Adapted from Liu *et al*. [8]

***Pollution load index***

The pollution load index (PLI) is a powerful statistical index that is used to evaluate the overall level of heavy metals pollution in a sampling location. PLI is determined by the expression (3).

$$PLI = \sqrt[n]{CF_1 \times CF_2 \times CF_3 ... CF_n} \quad (3)$$

Where CFi designates the contamination factor of the metal i and n=8. Mohammed *et al*. [6], and Lala *et al*. [30] assigned the interpretations of PLI based on the following classifications. PLI < 1 (Less polluted), PLI = 1 (Moderate level of pollution), and PLI > 1 (Highly polluted).

***Ecological Risk factor (Er) and Potential Ecological Risk Index (PERI)***

The ecological risk factor is the quantitative measure of ecological risk index associated with each metal. Meanwhile, the potential ecological risk index (PERI) is evaluating the toxicity of heavy metals in the soil samples and their consequential ecological and environmental effects. The potential ecological risk index is the sum of all the ecological risk factors associated with each metal. The Er and RI can be quantitatively expressed mathematically as shown equation (4) and (5).

$$Er = Tr \times CF \quad (4)$$

$$RI = \sum_{i=1}^{n} Er \quad (5)$$

Where, the Tr is the toxicity response factor of individual heavy metals determined. The toxicity response factor of the studied metals has the values of 10, 30, 2, 1, 5, 5, 5, and 1 for As, Cd, Cr, Mn, Pb, Cu, Ni and Zn respectively [8, 11]. Table 2 present the classification of ecological risk factor and potential ecological risk index of individual metals as categorized by [6, 8]

**Table 2.** Interpretation of Level of Risk from Ecological Risk and Potential Ecological risk Indices.

| Ecological Risk Index (Er) | Potential Ecological Risk Index (RI) | Risk Level |
|---|---|---|
| **Er < 40** | RI < 150 | Low Risk |
| **40 ≤ Er < 80** | 150 ≤ RI < 300 | Moderate Risk |
| **80 ≤ Er < 160** | 300 ≤ RI < 600 | Considerate Risk |
| **160 ≤ Er < 320** | RI ≥ 600 | High Risk |
| **Er ≥ 320** | | Extremely High/Disastrous Risk |

Adapted from Mohammed et al., [6] and Liu et al. [8]

***Geo-accumulation Index ($I_{geo}$)***

This parameter is established to evaluate the impact of anthropogenic activities on the level of heavy metals in the soil sample, and this can be calculated using the expression in equation (6).

$$I_{geo} = log_2 \frac{Cn}{Cb} \quad (6)$$

Where Cn is the concentration of metal and Cb is the value of geochemical background concentration in the soil. Lala *et al*. [30] and Okoro *et al*. [31] classified the scale of pollution based on the numerical values of $I_{geo}$ associated with soil sample as follows $I_{geo} < 0$ (background concentration), $0 < I_{geo} < 1$ (unpolluted), $1 < I_{geo} < 2$ (unpolluted to moderately polluted), $2 < I_{geo} < 3$ (moderately polluted), $3 < I_{geo} < 4$ (moderately to highly polluted), $4 < I_{geo} < 5$ (highly polluted), $I_{geo} \geq 5$ (very highly polluted).

***Health risk assessment***

Human health risk assessment of heavy metals in soil involves evaluating the potential risk of adverse health effects from exposure to contaminated soil. The risk assessment for non-carcinogenic and carcinogenic risk assessments are estimated via three exposure pathways of oral ingestion (through water and food), dermal contact (soil), and inhalation (dust) for both children and adults [32, 33]. The method developed by United States Environmental Protection Agency (USEPA, 1989) is used in this study to evaluate the health risk assessment. This study evaluated the non-carcinogenic risk of Cu, Cd, As, Pb, Mn, Cr, Zn, and Ni; and the carcinogenic risk of Cr, As, Cd and Ni.

***Exposure assessment***

The amount of heavy metals ingested through the three paths of oral intake, inhalation and skin contact were estimated using the average daily intake dose [34]. The exposure intake parameters of heavy metals in soil for only adults are presented in Table 3.

$$\text{ADDing} = \frac{Cs \times IRing \times EF \times FI \times ED}{BW \times AT} \times 10^{-6} \quad (7)$$

$$\text{ADDinh} = \frac{Cs \times IRinh \times EF \times FI \times ED}{PEF \times BW \times AT} \times 10^{-6} \quad (8)$$

$$\text{ADDder} = \frac{Cs \times SA \times \text{AF} \times EF \times ABS \times ED}{BW \times AT} \times 10^{-6} \quad (9)$$

Where ADD ($mg.Kg^{-1}day^{-1}$) is the average daily dose of exposure to metals through inhalation, dermal absorption and oral ingestion. Cs is the concentration of metals in the soil (mg $Kg^{-1}$); IRing is the ingestion rate (mg soil/day); IRinh is the inhalation rate ($m^3$ $hour^{-1}$); EF is the exposure frequency, ED is the exposure duration, FI is the fraction ingested from contaminated source usually assumed as unity (1); SA is the exposure skin area ($cm^2$); AF is the soil to skin adsorption coefficient ($mg/cm^2$); ABS is the absorption factor (%); BW is the body weight (Kg); PEF is the particle emission factor ($m^3$ $kg^{-1}$); and AT is the average action time, d [22, 23].

***Non-carcinogenic risk***

The non-carcinogenic hazard of individual metal is determined using hazard quotient (HQ), while the cumulative non-carcinogenic hazard of the multiple metals in each motor parks is estimated using hazard index (HI). Hazard quotient is the ratio of total average daily intake to the reference dose (RfD) of the individual heavy metals is determined. The non-carcinogenic risk was estimated using hazard index which is the sum total hazard quotient of heavy metals in a location.

$$\text{HQ} = \frac{ADI}{RfD} \quad (10)$$

$$\text{HI} = \Sigma\text{HQ} \quad (11)$$

When the value HQ/HI < 1, this shows there is no significant health risk. If HQ/HI > 1, there exist adverse health risk to the exposed population, and the higher the value, the more severe the risk. The values of reference dose and slope factors for the heavy metals are presented in Table 4.

***Carcinogenic risk***

The carcinogenic risk of potential toxic metals is the probability of individual exposed to carcinogens acquiring cancer over a long period of time. Incremental lifetime cancer risk was used to evaluate the human carcinogenic risk using equation (12).

$$\text{ILCR} = \text{ADI} \times \text{SF} \quad (12)$$

$$\text{TCR} = \Sigma\text{CR} \quad (13)$$

Where the ILCR is the incremental lifetime cancer risk of heavy metals in soil under different pathways, ADI is the long-time average exposure dose of carcinogenic heavy metals (mg/kg.d), and SF is the slope factor of carcinogenic metals (kg.d $mg^{-1}$). The acceptable range of carcinogenic risk is $10^{-6}$ - $10^{-4}$ according to United States Environmental Protection Agency, although there might possibility of carcinogenic risk. If the CR < $10^{-6}$, there is no cancer risk exists, but if the CR > $10^{-4}$, there is high cancer risk in the exposed population.

**Table 3.** Parameters for calculating exposure assessment of heavy metals in soil.

| Parameters | Unit | Value | |
|---|---|---|---|
| | | Children | Adult |
| **Ingestion Rate (ADing)** | mg $day^{-1}$ | 200 | 100 |
| **Inhalation rate** | $m^3$ $hour^{-1}$ | 7.5 | 20 |
| **Body Weight** | Kg | 15 | 70 |
| **Exposure Duration (ED)** | years | 6 | 30 |
| **Exposure Skin Area (SA)** | $cm^2$ | 2800 | 5700 |
| **Adherence factor (AF)** | $mg.cm^{-2}.day^{-1}$ | 0.2 | 0.07 |
| **Average Action time (AT)** | days | Non-carcinogenic ED×365 | Carcinogenic 70 ×365 |
| **Exposure frequency (EF)** | days $yr^{-1}$ | 350 | |
| **Particle Emission factor (PEF)** | $m^3$ $kg^{-1}$ | $1.36\times10^{9}$ | |
| **Dermal Absorption factor (ABS)** | - | 0.001 | |
| **Conversion Factor** | | $1.0\times10^{-6}$ | |

Data obtained: Liu *et al*. [5]; Cui *et al*. [22]; Abdullahi and Musa, [33]; Miletic *et al*. [35].

**Table 4.** Reference Dose (mg $kg^{-1}$ $day^{-1}$) and Cancer Slope Factor ($kg.day.mg^{-1}$) for Heavy metals in Soil

| Heavy metals | Rf ingestion | Rf inhalation | Rf Dermal | SF ingestion | SF inhalation | SF Dermal |
|---|---|---|---|---|---|---|
| **As** | $3.0\times10^{-4}$ | $3.0\times10^{-4}$ | $1.2\times10^{-3}$ | 1.5 | 15.1 | 3.66 |
| **Cu** | $4.0\times10^{-2}$ | $2.86\times10^{-5}$ | $1.2\times10^{-2}$ | | | |
| **Cd** | $1.0\times10^{-3}$ | $1.0\times10^{-3}$ | $1.0\times10^{-5}$ | 6.1 | 6.3 | 6.1 |
| **Cr** | $3.0\times10^{-3}$ | $2.9\times10^{-5}$ | $6.0\times10^{-5}$ | 0.5 | 41 | 20 |
| **Mn** | $1.4\times10^{-1}$ | $1.43\times10^{-5}$ | $1.84\times10^{-3}$ | | | |
| **Ni** | $2.0\times10^{-2}$ | $2.06\times10^{-2}$ | $5.4\times10^{-3}$ | 1.7 | 0.84 | 42.5 |
| **Pb** | $3.5\times10^{-3}$ | $3.5\times10^{-3}$ | $5.2\times10^{-4}$ | $8.5\times10^{-3}$ | $4.2\times10^{-2}$ | - |
| **Zn** | $3.0\times10^{-1}$ | $3.0\times10^{-1}$ | $6.0\times10^{-2}$ | | | |

Data obtained: Liu *et al*. [5]; Cui *et al*. [22]; Miletic *et al*. [35]; Adewumi *et al*. [36].

### *Statistical analysis*

Results obtained are presented in mean ± standard deviation from triplicate analysis of the sample solution. Statistical analyses were done using SPSS version 16. The mean values of the data were subjected to one-way analysis of variance (ANOVA) with 5% ($p < 0.05$) level of significance.

## RESULTS AND DISCUSSION

### *Spatial distribution concentration of heavy metals in soil*

The results of the analysis of heavy metals from the soil samples of the Sauki, Adamawa sunshine, Fair-plus, and Jimeta motor parks in Yola, Adamawa state is presented below. Atomic absorption spectrophotometer was used for the analysis of eight heavy metals (Cr, Cu, As, Pb, Cd, Ni, Zn and Mn). The results of the heavy metals concentration of the soil were presented in Table 5.

**Table 5.** Distribution of Heavy Metals concentrations in Soil Samples of selected Motor Parks

| Motor Parks | Heavy metals (mg kg$^{-1}$) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | As | Cu | Cd | Cr | Mn | Ni | Pb | Zn |
| **ASMP** | 0.61±0.53 | 10.20±4.23 | 3.08±1.42 | 5.49±3.51 | 0.53±0.21 | 0.40±0.17 | 1.86±0.95 | 16.55±2.96 |
| **FPMP** | 0.29±0.01 | 12.10±5.23 | 2.14±0.02 | 2.89±1.26 | 0.40±0.16 | 0.60±0.24 | 3.39±1.54 | 17.43±3.31 |
| **JMP** | 0.09±0.06 | 17.51±7.33 | 2.32±0.47 | 4.39±1.93 | 0.35±0.17 | 0.44±0.06 | 3.06±1.42 | 16.18±1.14 |
| **SMP** | 0.14±0.02 | 20.12±6.80 | 3.05±0.95 | 0.56±0.22 | 0.58±0.22 | 0.21±0.03 | 3.70±1.50 | 14.45±5.15 |
| **Control** | 0.33±0.25 | 26.30±13.36 | 1.25±0.81 | 4.85±3.39 | 0.28±0.16 | 0.16±0.08 | 0.64±0.45 | 10.06±6.01 |
| **USEPA MPL*** | 0.39 | 40 | 0.36 | 0.03 | 0.30 | 0.10 | 0.05 | 10 |
| ***P-values*** | P>0.5 | P>0.5 | P>0.5 | P>0.5 | P>0.5 | P>0.5 | P>0.5 | P>0.5 |

*MPL: Maximum Permissible Limit from USEPA, Statistically significant (P>0.05)

It can be revealed from Table 5 that the level of arsenic in the soil samples of the selected motor parks ranges from 0.61 mg kg$^{-1}$ (ASMP), 0.29 mg kg$^{-1}$ (FPMP), 0.09 mg kg$^{-1}$ (JMP), and 0.14 mg kg$^{-1}$ (SMP). The least concentration of arsenic is 0.09 mg kg$^{-1}$ observed at Jimeta motor park (JMP), while the highest concentration was 0.61 mg kg$^{-1}$ Adamawa Sunshine motor park (ASMP), and 0.33 mg kg$^{-1}$ for the control site. It can be shown that arsenic concentration is generally within the maximum acceptable limit by USEPA (0.39 mg kg$^{-1}$), except ASMP with higher concentration of 0.61mg kg$^{-1}$. Higher concentration of arsenic in Adamawa sunshine may be as a result of regular and frequent vehicular movement on the concentration of arsenic in this study were comparably lower than 36.07 – 176.62 ppm reported by [9]. Copper concentration in the studied motor parks ranges from 10.20 mg kg$^{-1}$ (ASMP), 12.10 mg $^{-1}$ (FPMP), 17.51 mg kg$^{-1}$ (JMP), 20.12 mg kg$^{-1}$ (SMP) and 26.30 mg kg$^{-1}$ for the control site. The results signified that the concentration of copper in the soil of the motor parks examined are lower than the control site, even though the level of copper in the soil of the tested sites are within the standard limit of 40 mg kg$^{-1}$ set by USEPA. The mean concentrations of copper in this study are far above the range of copper 0.18 – 0.29 mg kg$^{-1}$ reported by [6] of some motor parks in Maiduguri, Borno state Nigeria. The higher concentration of copper observed in this study may resultantly because of the wearing of metal bearings and metal bushings of vehicles which can make copper to accumulate in the soil surface [6].

The levels of cadmium are in the range of 3.08 mg kg$^{-1}$ (ASMP), 2.14 mg kg$^{-1}$ (FPMP), 2.32 mg kg$^{-1}$ (JMP), 3.05 mg kg$^{-1}$ (SMP), and 1.01 mg kg$^{-1}$ in the control site of the soil samples. The concentrations of Cd in the soil of motor parks considered for analysis are significantly higher than the proportion obtained for the control soil sample. In a similar manner, the mean value of Pb in the soil samples of the motor parks ranges from 1.86 mg kg$^{-1}$ (ASMP), 3.39 mg kg$^{-1}$ (FPMP), 3.06 mg kg$^{-1}$ (JMP), 3.70 mg kg$^{-1}$ (SMP), and 0.64 mg kg$^{-1}$ in the control site. Meanwhile, the mean concentrations of Cd and Pb in the soil of the motor parks analyzed are far above the maximum threshold limits (0.36 mg kg$^{-1}$ and 0.05 mg kg$^{-1}$) set by USEPA for Cd and Pb respectively, including that of the control samples. Nevertheless, the concentrations of Pb in this study are lower while Cd values were higher respectively, than the values obtained by Solgi [37] conducted in urban motor parks in Asadabad Iran. Previous studies by Mohammed *et al*. [6] reported that Pb was not detected while lower Cd values were recorded in the motor parks' soil of Maiduguri in Borno state. However, Cd values in this current study are in agreement with the value (ND – 4.16 ppm) obtained from soil of motor parks carried in Gombe state by [9]. In general, the higher results pointed to the fact that the soil of the motor parks are being contaminated with Cd and Pb resulting from automobile exhaust being released from the burning of leaded gasoline, garbage disposal, discarded lead-acid batteries and improper disposal of spent oils within the motor parks.

The concentrations of chromium in the motor parks' soil range from 5.49 mg $kg^{-1}$ (ASMP), 2.89 mg $^{-1}$ (FPMP), 4.39 mg $kg^{-1}$ (JMP), 0.56 mg $kg^{-1}$ (SMP), and 4.85 mg $kg^{-1}$ at control site. It is evident from Table 3 that the concentration of chromium in the soil samples are very far above the standard acceptable limit (0.03 mg $kg^{-1}$) set by USEPA and this indicated that the motor parks' soil is considerably contaminated with chromium. The concentrations of Cr obtained are significantly higher than the level reported 0.06-0.11 mg $kg^{-1}$ and 0.04-0.15 mg $kg^{-1}$ in the soils of motor parks from Gombe and Maiduguri, Borno state respectively [3, 6]. The higher concentration might be as a result of dumping of electroplating wastes materials and sewage sludge disposal on the land. Manganese concentration in the soil ranges from 0.53 mg $kg^{-1}$ (ASMP), 0.40 mg $kg^{-1}$ (FPMP), 0.35 mg $kg^{-1}$ (JMP), 0.58 mg $kg^{-1}$ (SMP), and 0.28 mg $kg^{-1}$ at control site. Similarly, the level of nickel concentration in the soil ranges from 0.40 mg $kg^{-1}$ (ASMP), 0.60 mg $kg^{-1}$ (FPMP), 0.44 mg $kg^{-1}$ (JMP), 0.21 mg $kg^{-1}$ (SMP), and 0.16 mg kg $^{1}$ at the control site. The mean values of Mn and Ni obtained in this study are slightly above the range of regulatory standard limit, 0.30 mg $kg^{-1}$ and 0.10 mg $kg^{-1}$ set by USEPA, respectively. However, it is observed that the Mn and Ni concentrations are relatively lower than the range recorded in soil of some Gombe motor parks (2.60-3.45 mg $kg^{-1}$ and 5.08-7.18 mg $kg^{-1}$) as reported by [3]. The levels of Mn and Ni recorded may be attributed to human activities around the park and the emission of these heavy metals from combustion of fossil fuels. Although, zinc is a beneficial to human health, nevertheless higher concentration may pose deleterious effects on human body-burden. The mean concentration of zinc recorded in the soil of the motor parks ranges from 16.55 mg $^{-1}$ (ASMP), 17.43 mg $kg^{-1}$ (FPMP), 16.18 mg $^{-1}$ (JMP), 14.45 mg $kg^{-1}$ (SMP) and 10.06 mg $kg^{-1}$ at control site. It is obvious that the values of zinc in the soil have slightly exceed the USEPA recommended standard limit of 10 mg $kg^{-1}$. Although, the Zn concentrations obtained are higher than 0.0385 mg $kg^{-1}$ and 0.09-1.18 mg $kg^{-1}$ recorded in soil of Ogbomoso and Maiduguri of motor parks respectively as reported by [25] and [6]. However, the Zn concentrations in this study are relatively lower than 18.41-27.37 mg $kg^{-1}$obtained in Gombe motor parks as reported by [3]. Major sources of zinc in the soil can be attributed to attrition of tires resultantly from poor state of road network, and dumping of electroplating materials. It is ostensibly clear that motor parks' soil have received high amount of heavy metals found in fossil fuels resulting chiefly from emission of automobile exhaust which appears in particles transported in air and accumulated and contaminated the soil.

***Contamination and pollution load indices***

The values of contamination factors, degree of contamination, and pollution index of the heavy metals in the study area were estimated and presented in Table 6. The contamination factor in the soil samples analyzed for As ranged from 0.007 – 0.047, Cu ranged from 0.227 – 0.447, Cd ranged from 7.133 – 10.267, Cr ranged from 0.006 – 0.055, Mn ranged from 0.00041 – 0.00068, 0.0031 – 0.0088, Pb ranged from 0.093 – 0.185, and Zn ranged from 0.152 – 0.184. It is crystal clear from Table 6 that the average values of contamination factors for Ni, Cd, Mn, Cu, As, Cr, Zn and Pb are less than one (CF < 1) which signifies that the soil samples from the parks are low contaminated in accordance with interpretation in Table 2. The Cadmium contamination factor in all the samples is higher than six (CF>6), implying that the soil of the motor parks are very highly contaminated with cadmium based on classification in Table 1. Hence, serious intervention and remedial measure are urgently required to remove cadmium from those soils and mitigate its contamination level. Furthermore, the degree of contamination (DC) values of the motor parks are 10.87 (ASMP), 7.83 (FPMP), 8.50 (JMP), and 10.97 (SMP), respectively. The DC values indicated that ASMP, JMP, and SMP are classified in moderately contaminated and FPMP in low contaminated class. The pollution load index (PLI) of the examined soil samples ranged from 0.067, 0.060, 0.053, and 0.045 (Table 6) for ASMP, FPMP, JMP, and SMP, respectively. It can be clearly shown from Figure 2 that the PLI values are less than one (PLI<1), and this indicated that the soil samples of the motor parks are less polluted.

**Table 6.** Levels of contamination and pollution load index of the motor parks.

| Motor Parks | Contamination factors | | | | | | | | DC | PLI |
|---|---|---|---|---|---|---|---|---|---|---|
| | AS | Cu | Cd | Cr | Mn | Ni | Pb | Zn | | |
| **ASMP** | 0.047 | 0.227 | 10.267 | 0.055 | 0.00068 | 0.0059 | 0.093 | 0.174 | 10.87 | 0.067 |
| **FPMP** | 0.022 | 0.269 | 7.133 | 0.029 | 0.00047 | 0.0088 | 0.170 | 0.184 | 7.82 | 0.060 |
| **JMP** | 0.007 | 0.389 | 7.733 | 0.044 | 0.00041 | 0.0065 | 0.153 | 0.170 | 8.50 | 0.053 |
| **SMP** | 0.011 | 0.447 | 10.170 | 0.006 | 0.00068 | 0.0031 | 0.185 | 0.152 | 10.97 | 0.045 |

DC: Degree of Contamination, PLI: Pollution Load Index

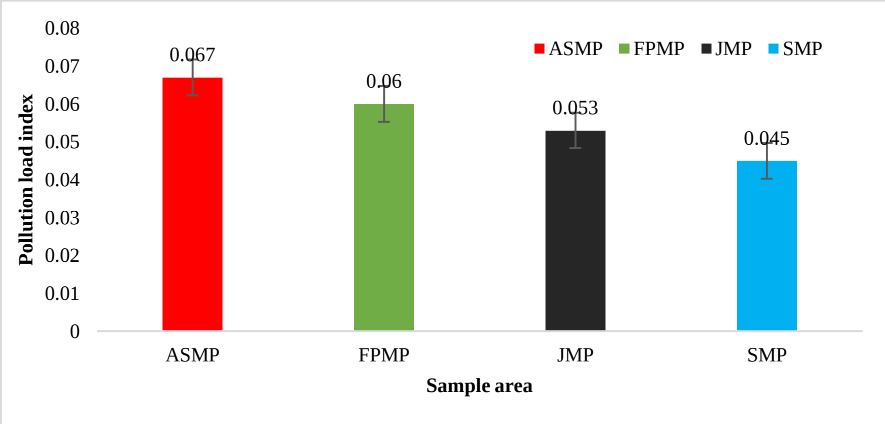


**Figure 2.** Pollution Load Index of the Soil of Motor Parks

### *Ecological risk assessment*

The ecological risk associated with the heavy metals in the soil samples was examined using the ecological risk factor (Er) and potential ecological risk index (RI) and the results presented in Table 7. It is obvious from ecological risk factors in Table 7 that the cadmium with Er values ranged from 213.99 – 308.01 is the main contaminant in all the study area because it presents an extremely very high risk. The Er values of the other metals Mn, Ni, Cr, Pb, Zn, As, and Cu are less than 40 (Er<40), and these show that the heavy metals pose low level of ecological risk. Similarly, the potential ecological risk index (RI) was also evaluated as presented in Table 7 and Figure 3. The risk index ranged from 310.40, 216.69, 235.06, and 308.55 for ASMP, FPMP, JMP, and SMP, respectively. Meanwhile, the estimated RI values of soil samples in the study area revealed that the level of ecological risk ranges from moderate to considerable risk in accordance with interpretation in Table 2. The soil samples of FPMP and JMP are in the moderate risk class, while ASMP and SMP are classified as considerate risk. It is pertinent that precautionary and preventive measures are being taken to avoid the exacerbation of future ecological risk.

**Table 7.** Ecological risk factor and potential ecological risk index of the soil.

| Motor Parks | Ecological risk factors | | | | | | | | RI |
|---|---|---|---|---|---|---|---|---|---|
| | AS | Cu | Cd | Cr | Mn | Ni | Pb | Zn | |
| **ASMP** | 0.47 | 1.135 | 308.01 | 0.110 | 0.00068 | 0.030 | 0.465 | 0.174 | 310.40 |
| **FPMP** | 0.22 | 1.345 | 213.99 | 0.058 | 0.00047 | 0.044 | 0.850 | 0.184 | 216.69 |
| **JMP** | 0.07 | 1.945 | 231.99 | 0.088 | 0.00041 | 0.033 | 0.765 | 0.170 | 235.06 |
| **SMP** | 0.11 | 2.235 | 305.10 | 0.012 | 0.00068 | 0.016 | 0.925 | 0.152 | 308.55 |

RI: Potential Ecological Risk Index

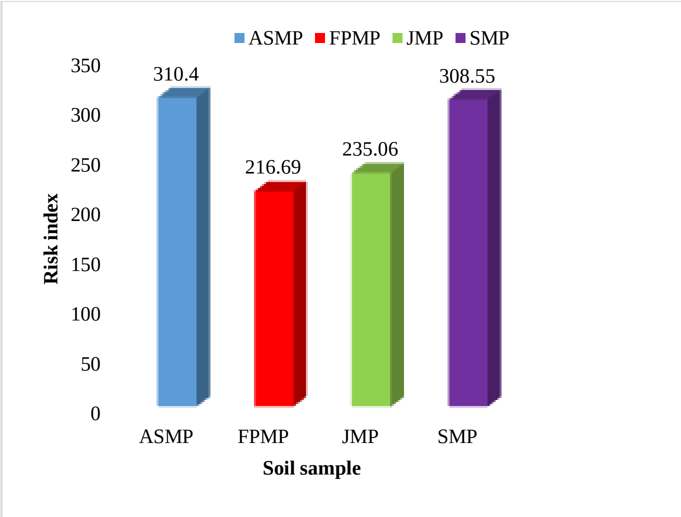


**Figure 3.** Potential ecological risk index of soil samples of motor parks.

### *Geo-accumulation Index (I-geo)*

The geo-accumulation index of the heavy metals in the top surface soil was evaluated to examine the anthropogenic activities on contamination effect of the soil samples. The results of the geo-accumulation index are presented in Table S1 which shows that the I-geo value of each single metal in all the soil samples of the motor park, and this ranges from -5.00 to -7.12 for As, -1.75 to -2.73 for Cu, 2.25 to 2.78 for Cd, -4.77 to -8.07 for Cr, -11.10 to -11.83 for Mn, -7.41 to -8.92 for Ni, -3.02 to -4.01 for Pb, and -3.03 to -3.30 for Zn. The I-geo values of manganese, arsenic, copper, chromium, lead, cadmium, and nickel are in the background value of less than zero (I-geo <0, grade 0) as shown in Figure 4. This indicated that the soil samples in the study areas of the motor parks are uncontaminated with respect to the heavy metals. Whilst, the I-geo value of cadmium which ranges between 2.25 – 2.78 (level of grade 2), is moderately contaminated in the sampling areas. The findings revealed that the pollution status of the motor parks' soil is uncontaminated apart from cadmium that is moderately contaminated and this could be attributed to various anthropogenic activities going on around the parks, and hence there is a need for remediation measure.

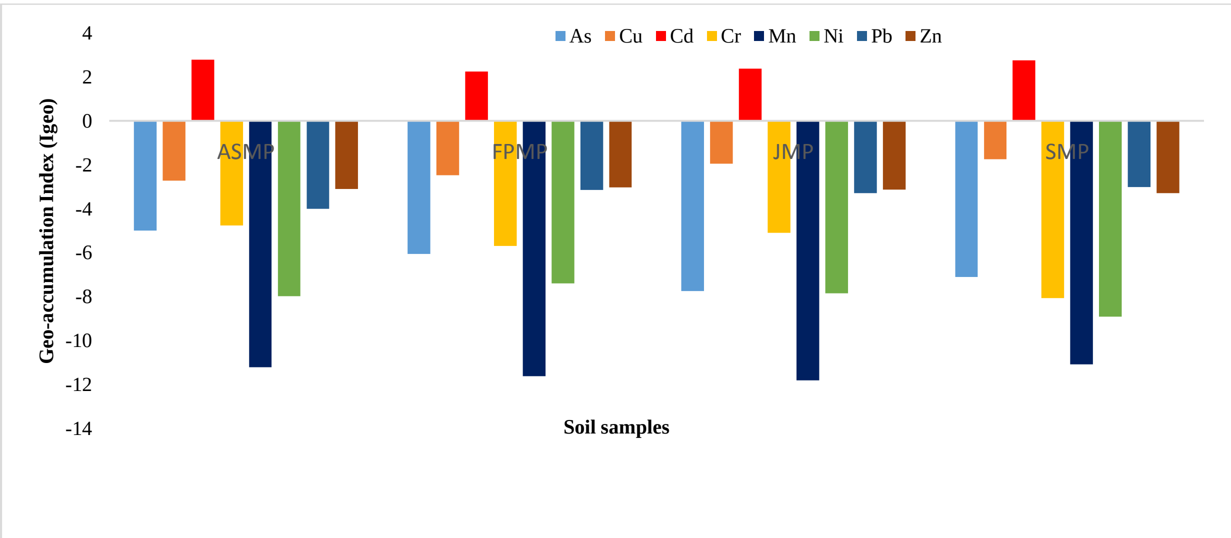


**Figure 4.** Geo-accumulation Index of Heavy metals in Soil samples.

***Health risk assessment***

***Exposure assessment***

The results of average daily intake of heavy metals from human exposure assessment on adults in soil of the motor parks are presented in Table S2 – S5. The daily exposure of As, Cu, Cd, Cr, Mn, Ni, Pb, and Zn were calculated through the pathways of ingestion, inhalation and dermal contact. Table S2 presents the exposure daily intake (ADI) for the heavy metals via the three pathways in ASMP soil. The results show that Zn has the highest exposure rate in three pathways of $2.27\times10^{-5}$, $3.26\times10^{-9}$, and $2.71\times10^{-6}$; while Ni has the lowest value of daily exposure dose of $5.48\times10^{-7}$, $7.88\times10^{-11}$, and $6.56\times10^{-8}$ for ingestion, inhalation and skin contact; respectively. Similarly, Table S3 presents the ADI for heavy metals in FPMP and like ASMP, Zn has the highest average daily exposure dose of $2.389\times10^{-5}$, $3.44\times10^{-9}$, and $2.86\times10^{-6}$ while As has the least ADI values of $3.97\times10^{-7}$, $5.72\times10^{-11}$, $4.76\times10^{-8}$; in three pathways respectively. Table S4 and S5 present the results of average daily intake for heavy metals in soil of JMP and SMP for ingestion, inhalation, and dermal exposure. Contrary to the results from ASMP and FPMP, the results showed that copper and Arsenic are the metals that contributed the highest and least ADI values in the JMP and SMP respectively. The daily dose contribution of Cu to the average daily intake of heavy metals in JMP and SMP are $2.69\times10^{-5}$, and $3.09\times10^{-5}$, respectively. Also, the average daily intake contribution of As to the average daily intake of heavy metals are $1.38\times10^{-7}$, and $2.15\times10^{-7}$. The exposure pathways trend decreases in the order Ingestion > Dermal > Inhalation. The results revealed that ingestion pathway is the dominant pathway in this study and this is consistent with the study conducted by [23, 33]. By implication, motorists, travelers, hawkers and workers of these motor parks may be greatly exposed to heavy metals through oral and dietary route.

***Non-carcinogenic risk***

Non-carcinogenic risk index of the motor parks' soil for the heavy metals is estimated using HQ and HI, and the results are presented in Table 8. The results showed Cd has the highest individual hazard quotient in the soil of the study areas, whereas Ni has the least hazard quotient in ASMP and FPMP; and As contributed least to the target hazard quotient in JMP and SMP. Additionally, the hazard index (HI) values of the motor parks are in the order FPMP ($4.15\times10^{-1}$) < JMP ($4.80\times10^{-1}$) < SMP ($4.97\times10^{-1}$) < ASMP ($6.21\times10^{-1}$). Thus, HQ and HI values were less than the EPA guideline value of 1. This shows that exposure to heavy metals in the motor parks pose insignificant non-carcinogenic health risks to human body.

**Table 8.** Non-carcinogenic Health Risk to Human in Motor Parks' Soil

| Metals | HQASMP | HQFPMP | HQJMP | HQSMP |
|---|---|---|---|---|
| **As** | 7.80E-04 | 3.70E-04 | 1.15E-04 | 1.80E-04 |
| **Cu** | 1.30E-03 | 1.55E-03 | 2.24E-03 | 2.57E-03 |
| **Cd** | 4.72E-01 | 3.28E-01 | 3.56E-01 | 4.86E-01 |
| **Cr** | 1.40E-01 | 7.40E-02 | 1.12E-01 | 1.43E-02 |
| **Mn** | 4.42E-04 | 3.33E-04 | 2.92E-04 | 4.84E-04 |
| **Ni** | 1.14E-04 | 1.70E-04 | 1.25E-04 | 5.97E-05 |
| **Pb** | 5.49E-03 | 1.00E-02 | 9.03E-03 | 1.09E-02 |
| **Zn** | 4.23E-04 | 4.46E-04 | 4.14E-04 | 3.69E-04 |
| **HI** | 6.21E-01 | 4.15E-01 | 4.80E-01 | 4.97E-01 |

HQ: Hazard Quotient, HI: Hazard Index

***Carcinogenic risk***

The results of carcinogenic risk analysis of human exposure to heavy metals in the motor parks' soil samples are presented in Table 9. Incremental lifetime cancer risk (ILCR) is calculated for Cd, As, Cr and Ni that may show likelihood of carcinogenic health risk. Apparently, the individual carcinogenic risk (CR) values of As in the soil of the motor parks are below the EPA safe limit value of $1.0\times10^{-6}$ with exception of ASMP, while the carcinogenic risk (CR) values of Cr, Cd, and Ni are within acceptable range of $1.0\times10^{-6}$ - $1.0\times10^{-4}$. The incremental lifetime cancer risk values of the motor parks are in the order ASMP ($5.60\times10^{-5}$) > JMP ($4.35\times10^{-5}$) > FPMP ($3.79\times10^{-5}$) > SMP ($3.31\times10^{-5}$). In this study, the ILCR values are within the acceptable range limit and hence, exposure to heavy metals in the motor parks presents a negligible carcinogenic health risk to human body. As a result, FPMP, JMP, and SMP are considered safe because of their low risk status, and the medium risk status of ASMP calls for concern. Therefore, frequent check of carcinogenic risk is desirable due to its probable cumulative effect on the human health.

**Table 9.** Carcinogenic health risk to human in motor parks' soil

| Metals | CRASMP | CRFPMP | CRJMP | CRSMP |
|---|---|---|---|---|
| **As** | 1.62E-06 | 7.71E-07 | 2.39E-07 | 3.72E-07 |
| **Cd** | 2.88E-05 | 2.00E-05 | 2.17E-05 | 2.85E-05 |
| **Cr** | 2.18E-05 | 1.15E-05 | 1.74E-05 | 2.23E-06 |
| **Ni** | 3.72E-06 | 5.58E-06 | 4.09E-06 | 1.95E-06 |
| **ILCR** | 5.60E-05 | 3.79E-05 | 4.35E-05 | 3.31E-05 |
| **Risk Status** | Medium risk | Low risk | Low risk | Low risk |

CR: Cancer Risk, ILCR: Incremental Lifetime Cancer Risk

## CONCLUSIONS

This study examined the contamination, pollution status, and health risk assessment of soil samples of Adamawa sunshine, Sauki, Fair-plus, and Jimeta motor parks in Yola metropolis, Nigeria. Twenty (20) soil samples taken at a depth of about 0-10 cm of the soil surface were collected using a soil auger from four (4) different motor parks, and were analyzed for Ni, Cd, Cu, As, Cr, Pb, Mn and Zn. The concentrations of the heavy metals determined in the soil samples are in the order Zn>Cu>Pb>Cr>Cd>Mn>Ni>As, where the concentrations of cadmium exceeded the background value by ten times. The average concentration of the metals in the motor parks' soil is far above the USEPA threshold limit, except Cu and few metals in some motor parks, which signaled the effect of anthropogenic interference which could result from automobile exhaust emission, repairing service, wear and tear of motor parts, waste incineration of vehicle electrical and electronic parts, and spent oil disposal. The pollution load index (PLI), potential ecological risk (PERI) and risk index (RI), and geo-accumulation index were assessed in the soil samples. The results obtained using the risk indices indicated that the soil of the motor parks are in the range between low to moderately contaminated level. The study clearly revealed that cadmium poses potential high risk to the environment and ecosystem in the motor parks' soil that could resultantly be from anthropogenic activities taken place within the parks. Furthermore, non-carcinogenic and carcinogenic risk indices of the soil samples were assessed. In this study, the adult values of HQ and HI of the soil samples are less than acceptable value of 1. It is therefore revealed that exposure to heavy metals in the motor parks have no potential of adverse non-carcinogenic effects to human. Thus, cancer risk (CR) and incremental lifetime cancer risk (ILCR) of ASMP, FPMP, JMP, and SMP are within the acceptable range which pose low carcinogenic risk to human health. It is noteworthy that the pollution status of the motor parks is in the range of low to moderately polluted however, the results of PERI, I-geo, as well as hazard quotient and cancer risk of cadmium indicated a potential risk of exposures to motorists, travelers, hawkers particularly susceptible children moving around the parks. Therefore, it is recommended that frequent monitoring of heavy metal contents of the motor parks should be sustain with a view to mitigate the adverse ecological and human health risks to the contaminated soil.

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***Conflicts of interest***

The authors declare that there are no potential conflicts of interest concerning the research, authorship and/or publication of this article.

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**Appendix A**

**Table S1.** Geo-accumulation Index of the Motor Park's Soil Samples.

| Motor Parks | Geo-accumulation Index (*Igeo*) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **AS** | **Cu** | **Cd** | **Cr** | **Mn** | **Ni** | **Pb** | **Zn** |
| ASMP | -5.00 | -2.73 | 2.78 | -4.77 | -11.23 | -7.99 | -4.01 | -3.11 |
| FPMP | -6.07 | -2.48 | 2.25 | -5.70 | -11.64 | -7.41 | -3.15 | -3.03 |
| JMP | -7.76 | -1.95 | 2.37 | -5.10 | -11.83 | -7.86 | -3.29 | -3.14 |
| SMP | -7.12 | -1.75 | 2.76 | -8.07 | -11.10 | -8.92 | -3.02 | -3.30 |

**Appendix B**

**Table S2**. Average Daily Intake of Heavy Metals in Soil of ASMP.

| Metals | ADing | ADinh | ADDer | ADtotal |
|---|---|---|---|---|
| **As** | 8.356E-07 | 1.202E-10 | 1.000E-07 | 9.358E-07 |
| **Cu** | 1.397E-05 | 2.011E-09 | 1.673E-06 | 1.565E-05 |
| **Cd** | 4.219E-06 | 6.071E-10 | 5.050E-07 | 4.725E-06 |
| **Cr** | 7.521E-06 | 1.082E-09 | 9.002E-07 | 8.422E-06 |
| **Mn** | 7.260E-07 | 1.045E-10 | 8.691E-08 | 8.130E-07 |
| **Ni** | 5.479E-07 | 7.884E-11 | 6.559E-08 | 6.136E-07 |
| **Pb** | 2.548E-06 | 3.666E-10 | 3.050E-07 | 2.853E-06 |
| **Zn** | 2.267E-05 | 3.262E-09 | 2.714E-06 | 2.539E-05 |

**Appendix C**

**Table S3**. Average Daily Intake of Heavy Metals in Soil of FPMP.

| Metals | ADing | ADinh | ADDer | ADtotal |
|---|---|---|---|---|
| **As** | 3.973E-07 | 5.716E-11 | 4.755E-08 | 4.449E-07 |
| **Cu** | 1.658E-05 | 2.385E-09 | 1.984E-06 | 1.856E-05 |
| **Cd** | 2.932E-06 | 4.218E-10 | 3.509E-07 | 3.283E-06 |
| **Cr** | 3.959E-06 | 5.696E-10 | 4.739E-07 | 4.434E-06 |
| **Mn** | 5.480E-07 | 7.884E-11 | 6.559E-08 | 6.136E-07 |
| **Ni** | 8.219E-07 | 1.183E-10 | 9.838E-08 | 9.204E-07 |
| **Pb** | 4.644E-06 | 6.682E-10 | 5.559E-07 | 5.200E-06 |
| **Zn** | 2.388E-05 | 3.436E-09 | 2.858E-06 | 2.674E-05 |

**Appendix D**

**Table S4**. Average Daily Intake of Heavy Metals in Soil of JMP.

| Metals | ADing | ADinh | ADDer | ADtotal |
|---|---|---|---|---|
| As | 1.233E-07 | 1.77E-11 | 1.476E-08 | 1.381E-07 |
| Cu | 2.398E-05 | 3.451E-09 | 2.871E-06 | 2.686E-05 |
| Cd | 3.178E-06 | 4.573E-10 | 3.804E-07 | 3.559E-06 |
| Cr | 6.014E-06 | 8.653E-10 | 7.198E-07 | 6.734E-06 |
| Mn | 4.795E-07 | 6.899E-11 | 5.739E-08 | 5.369E-07 |
| Ni | 6.027E-07 | 8.673E-11 | 7.215E-08 | 6.750E-07 |
| Pb | 4.192E-06 | 6.031E-10 | 5.018E-07 | 4.694E-06 |
| Zn | 2.216E-05 | 3.189E-09 | 2.653E-06 | 2.482E-05 |

**Appendix E**

**Table S5**. Average Daily Intake (mg $kg^{-1}$ $day^{-1}$) of Heavy Metals in Soil of SMP.

| Metals | ADing | ADinh | ADDer | ADtotal |
|---|---|---|---|---|
| **As** | 1.918E-07 | 2.759E-11 | 2.296E-08 | 2.148E-07 |
| **Cu** | 2.756E-05 | 3.966E-09 | 3.299E-06 | 3.087E-05 |
| **Cd** | 4.178E-06 | 6.012E-10 | 5.001E-07 | 4.679E-06 |
| **Cr** | 7.671E-07 | 1.104E-10 | 9.183E-08 | 8.591E-07 |
| **Mn** | 7.945E-07 | 1.143E-10 | 9.510E-08 | 8.897E-07 |
| **Ni** | 2.877E-07 | 4.139E-11 | 3.443E-08 | 3.221E-07 |
| **Pb** | 5.069E-06 | 7.293E-10 | 6.067E-07 | 5.676E-06 |
| **Zn** | 1.980E-05 | 2.848E-09 | 2.369E-06 | 2.217E-05 |