



Vehicle-Derived Heavy Metals and Human Health Risk Assessment of Exposure to Communities along Mubi-Yola Highway in Adamawa State (Nigeria)

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Authors' contributions

This work was carried out in collaboration among all authors. Author IBB designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors PA and NAT managed the analyses of the study. Authors IBB, PA and NAT managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

In this study, the health risk caused by heavy metals exposure to communities along Mubi-Yola highways was evaluated. Samples from Mubi, Hong, Gombi, Song, and Gerei were collected and analyzed for Lead (Pb), Cadmium (Cd), Chromium (Cr), Zinc (Zn), Cupper (Cu), and Nickel (Ni) using Atomic Absorption Spectrophotometer (AAS). The mean concentrations of the metals used for the risk assessment were observed to fall in this order Zn>Pb>Ni>Cu>Cd>Cr. The non-carcinogenic risk based on the target hazard quotient (THQ) and human health index (HI) values for each exposure pathway and for each metal were observed to be less than (<) 1 which means, exposure to the heavy metals has no immediate risks for both the adults and children in the settlements. The lifetime cancer risk (CRI) for the metals for both the ingestion (CRI_{ing}) and inhalation (CRI_{inh}) exposure pathways were observed to pose no lifetime carcinogenic risk. The CRI for all the exposure pathways and for all age categories were <10⁻⁴. Similarly, the combine

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effect or total cancer risk (TCRI) for each exposure pathway show high probability for carcinogenic risk by ingestion route compared to exposure by inhalation. The order of exposure were observed to be adults<children. Though the CRI and TCRI results were observed to be within the acceptable range for developing cancer, the result however suggest that children could be more susceptible to potential carcinogenic risk following continual exposure to heavy metals from vehicular activity. Indicating some concern about the expansion of unregulated settlements along heavy traffic highways.

Keywords: Soil; metals; risk assessment; average daily intake; target hazard quotient; cancer risk index.

1. INTRODUCTION

Heavy traffic from vehicular activities are often used as indicator to define socio-environmental related crisis. Such activities in addition to population growth and poor public transportation systems has pushed the demands for vehicles globally by a factor of 10 [1,2]. In Nigeria, the number of vehicles plying the roads were estimated at 11.7 million, out of which commercial vehicles accounts for 58.08%, private vehicles constitute about 40.67% and others which include government and diplomatic vehicles accounts for the remaining 1.24% [3]. The number of vehicles was reported to have increased by 72.4% in 2017, showing the country spending about N600 billion annually on vehicle importations [3,4]. Based on this percentage, about 700,000 used vehicles were imported into the country annually [5,6], adding pressure to the poorly maintained roads, increasing the traffic volume and exposing communities residing on the roadside to greenhouse gases (GHG) and particulates emissions.

These expanded traffic activities compounded by the influx of used and substandard vehicles were reported to constitute a major environmental menace. Contaminating the ecosystem and posing health risk to the entire biota [7]. Poor engine performance typical of an aged and worn-out vehicles are major sources of environmental menace on the highways [8]. Vehicle-derived by-products are generally comprise of particles with different characteristics and mobility, depending off course on the size and process formation. Particle emission in the engine and tailpipes are ultrafine, while fine particles are produced mainly by chemical processes in the engine. The mechanical abrasion of the roads material, tires and brakes produce coarse particles [9,10]. These particles derived from vehicular activities, in addition to their impact on air and water has a direct effect on the vitality and health status of the soil.

Soils is a repository of nutrients, a vital community to all living things and same time a reservoir of inbounds and offload environmental wastes. Traffic activities in addition to other anthropogenic activities are major pollution sources to roadside ecosystems [11]. In addition to the GHG, vehicular emissions were reported to contain cadmium, zinc, nickel, soot's and other particulate matters [12,13] contributing to heavy metal overload in the nearby roadside soils [11]. Cadmium for example is mainly generated from burning of lubricating oil and from wearing of tires. Similarly, wearing of tires in addition to the galvanized components of vehicles are additional sources contributing to Zn buildup in the environment. Copper and leads are by-product of brake wearing, exhaust gas and worn-out metal alloys in the engine [14].

The environmental menace associated with such heavy traffic activities attracted series of research on roadside soils, waterways and vegetation's along Nigeria highways [2,10,15-31]. These studies used heavy metal enrichment in roadside plants, dust or soils as an indicator to estimates the pollution levels generated by vehicular activities with some attempt toward establishing the ecological associated risk. Road is an intersection of complex activities, attracting migration and business activities. At the same time, a flashpoint, endangering the people attracted toward it to both accident and environmental associated risk. Since the distribution patterns of heavy metals on roadside soils are not often significantly correlated with the roadside distance [15,32], the distribution pattern of roadside distance of each heavy metal may vary substantially, varying from 50-100 m and in some rare cases up to 320 m depending off course on the traffic density, runoff and wind velocity [16,32,33]. This partial distribution of the heavy metals from traffic activity is major health risk factor to communities living near the main roads, a situation common to most communities

in Nigeria. Markets, businesses, water-ways and farmlands are located less than 50 m away from the roads. Therefore, exposing the populations along the highways to lifetime non-carcinogenic and carcinogenic health risk.

The measurement of the environmental cost contributed by vehicular activities is one thing and understanding its multidimensional impacts to health and the entire ecosystems is another. For these reasons, the health risk assessments of vehicle-derived heavy metals (Cd, Pb, Zn, Cu, Cr and Ni) [11-14] and their potential health impact to the roadside communities is

investigated and presented in this study. For the study, the roadside soil samples will be used as indicator to estimate the potential health risk following the ingestion, inhalation and dermal contact of the soil-laden with the heavy metals derived from vehicular activities. The roads in question links communities between Mubi to Yola, one of the biggest cattle market in West Africa, the second largest city in Adamawa state, Nigeria, and a city striving in businesses and commercial activities. The outcome from the study is intended to savor policy making toward regulating the expansion of settlements along the heavy traffic highways.

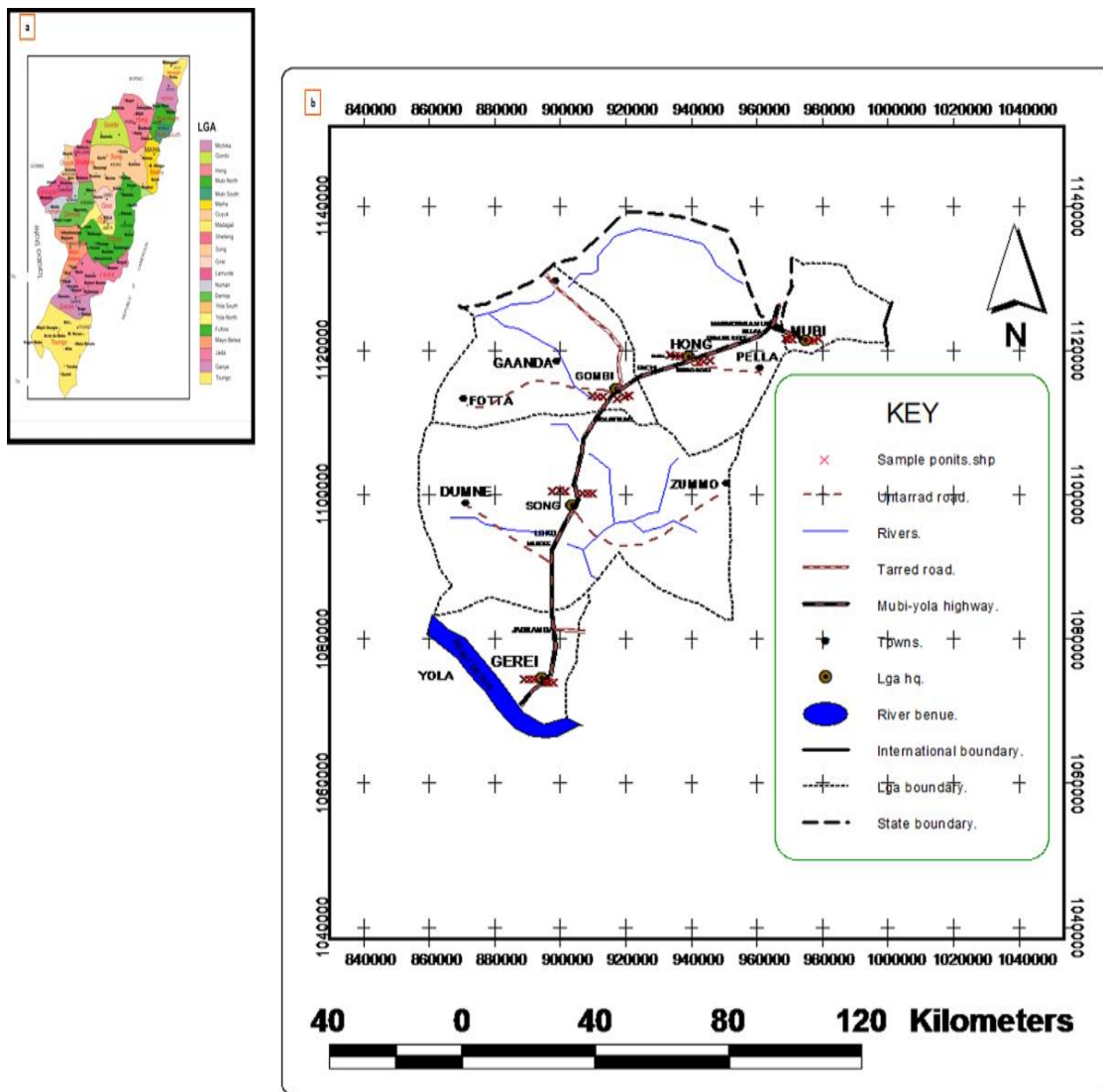


Fig. 1. Map of the study area showing (a) Map of Adamawa state, Nigeria (b) The sampling points along Mubi-Yola highways [34]

2. MATERIALS AND METHODS

2.1 Study Area

The geographical coordinates of the study area lies between latitude 7° and 11° N of the equator and between longitude 11° and 14° E of the Greenwich meridian, located in Adamawa state, Nigeria. The entire state covers the land area of about 38741Km² [34].

2.2 Sample Collection

For the study, thirty (30) soil samples were randomly collected from Five (5) major towns along Mubi–Yola highway. From the study areas, six surface soil samples were randomly collected from each town, three each from each side of the road at variable distances of 10 m, 20 m and 30 m away from the edge of the road. The respective sample points are Mubi, Hong, Gombi, Song and Gerei towns. Soil samples were pretreated and processed according to the method described by Alexander et al. [28]. The elemental concentrations of the digested soil samples were carried out using Atomic Absorption Spectrophotometer (AAS) 210 VPG Buck Scientific Model.

2.3 Health Risk Characterization

The risk assessment processes were carried out to predict the possible carcinogenic and non-carcinogenic risks that may prompt up following the exposure of the heavy metals in the soil to

both the adults and children residing along the study area. This was achieved by integrating possible exposure pathways to quantitatively estimate the likelihood of health hazard. The risk exposure pathways involve taken the average daily intake (ADI) of the toxic metals (mg/kg day) following either oral ingestion, dermal contact, or inhalation route respectively using the methods described in equation 1-3 [35].

$$ADI_{Ing} = 10^{-6} \times C_{soil} \times (IngR \times EF \times ED) / (BW \times AT) \quad (1)$$

$$ADI_{Inh} = C_{soil} \times (InhR \times EF \times ED) / (PEF \times BW \times AT) \quad (2)$$

$$ADI_{Dermal} = 10^{-6} \times C_{soil} \times (SA \times AF \times ABS \times EF \times ED) / (BW \times AT) \quad (3)$$

The ADI_{ing}, ADI_{inh}, and ADI_{Dermal} stands for average daily intake (ADI) for ingestion, inhalation and dermal exposure pathways respectively. Other parameters and their corresponding functions are described in Table 1 [35-37].

Target Hazard Quotient (THQ) was used to analyze the potential non-carcinogenic effect of the metals in the soil samples by relating the estimated ADI of each elements with their reference dose (RfD) for each exposure pathway as described in equation 4 [35]. The health index (HI), expressed as the sum of the THQ as described in equation 5 is used in the study to describe the cumulative non-carcinogenic effect [38,39]. The RfD for each metal and for each exposure pathway are presented in Table 2 [33,37,40-43].

Table 1. Exposure factors used for the health risk assessment through different exposure pathways for soil

Factor	Unit	Children	Adult
Body weight (BW)	kg	15	60
Exposure frequency (EF)	days/year	350	350
Exposure duration (ED)	years	6	30
Ingestion rate (_{ing} R)	mg/day	200	100
Inhalation rate (_{inh} Rair)	m ³ /day	10	20
Skin surface area (SA)	m ²	2100	5800
Soil adherence factor (AF)	mg/cm ²	0.2	0.7
Dermal Absorption factor (ABS)	-	0.1	0.1
Particulate emission factor (PEF)	m ³ /k	1.3 x 10 ⁹	1.3 x 10 ⁹
Conversion factor (CF)	kg/mg	10 ⁻⁶	10 ⁻⁶
Average time (AT)	days		
For carcinogen		365 x 70	365 x 70
For non-carcinogens		365 x ED	365 x ED

Table 2. Reference doses (RfD) in (mg/kg-day) and Cancer Slope Factors (CSF) for the individual heavy metals per exposure pathways

Elements	RfD _{Ing}	RfD _{Dermal}	RfD _{Inh}	CSF _{Ing}	CSF _{Dermal}	CSF _{Inh}
Cd	5.60E-04	5.00E-04	5.7E-05	3.80E-01	-	6.30E+00
Pb	3.60E-03	5.25E-04	3.52E-03	8.50E-03	-	4.20E-02
Cr	3.00E-03	6.00E-05	3.00E-05	5.00E-01	-	4.10E+01
Cu	3.70E-02	2.40E-02	4.02E-02	-	-	-
Zn	3.00E-01	7.50E-02	3.00E-01	-	-	-
Ni	2.00E-02	5.60E-03	-	-	-	8.40E-01

The cancer risk index (CRI) which represents the probability of developing any type of cancer over a lifetime is calculated by integrating the ADI with the respective cancer slope factors (CSF) for each metal. The description is presented in equation 6 [35].

$$THQ = ADI_i / RfD_i \quad (4)$$

$$HI = \sum THQ_i \quad (5)$$

$$CRI = ADI_i \times CSF_i \quad (6)$$

A THQ or HI < 1 signify no associated risk, meaning the exposed population is unlikely to experience any adverse health hazard. A level of concerns however exist, if the THQ or HI > 1 [35]. Furthermore, the CRI is considered negligible if the CRI < 10⁻⁶, acceptable or tolerable if CRI is 10⁻⁶ < CRI < 10⁻⁴, and similarly considered high if the CRI > 10⁻⁴. Equation 7, provides a complete picture of the cancer risk for an individual following the combination of all the metals over a lifetime for all the exposure pathways.

$$TCRI = CRI (ing) + CRI (inh) + CRI (dermal) \quad (7)$$

Where, CRI (*ing*), CRI (*inh*), and CRI (*dermal*) are risks contributions through ingestion, inhalation and dermal pathways respectively [38].

3. RESULTS AND DISCUSSION

3.1 Concentrations of Heavy Metals in Roadside Soil along Mubi-Yola Highway

The mean concentrations of Cd, Pb, Cr, Cu, Zn, and Ni in the roadside surface soil along the Mubi – Yola highway are presented in Figs. 2-3. To get the human health risk indices following the direct exposure to the farmland soils through

either of the exposure pathways, the concentration of the metals in the soil were assessed based on permissible limits (PL) allowable for human consumption instead on the PL values set for agricultural purposes [44,45]. The was based on the assumption that, the heavy metals concentrations that are considered safe and within the PL set for agricultural soils will be of great health concerns if the same level of heavy metals are ingested, inhaled or come in contact with the skin [46].

The mean concentration of Cd in the soil samples as presented in Fig. 2 ranges from 0.03±0.01 – 0.06±0.03 mg/kg with an average mean value of 0.04±0.01 mg/kg. The concentration in the study areas were observed to be lower than the values reported by Shingu et al. [19,21,26,47] in dust samples collected in Yola, Mubi and Abuja. Similar high values were also reported by Ogundele et al. [29] in soil samples collected in heavy traffic roads in the North Central Nigeria. Even though these other studies reported a higher concentrations compared to the present study, the results from all the sample locations are observed to fall within the permissible limits (PL) of 0.05 mg/kg sets by FAO/WHO [48]. The presence of Cd in the soil samples could be attributed to activities which includes among others, combustion of lubricating oil and wearing of tires from road abrasion [49]. Cadmium is a classic carcinogens, at concentrations as low as ~1 mg/kg can be carcinogenic, could lead to hepatic, renal, and pulmonary injury [50,51].

Lead is another classic example of carcinogens, a highly toxic metal even at a very low dose [52], known to impaired cognitive developments in children, facilitate the development of high blood pressure and cardiovascular diseases [53]. From the results in Fig. 2, an average mean concentration of 0.86±0.06 mg/kg was observed for Pb in all the sample locations. The

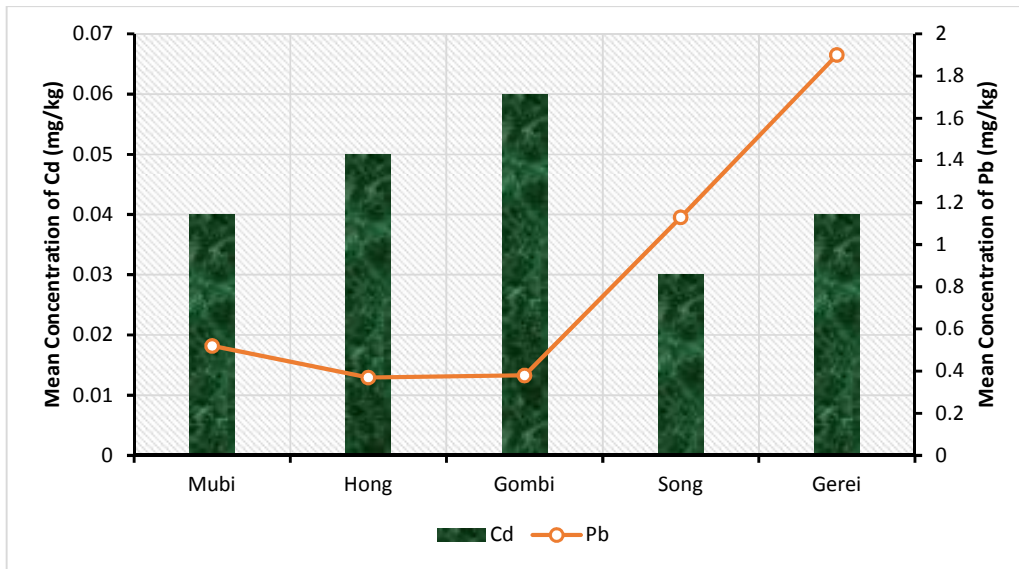


Fig. 2. Concentrations (mg/kg) of Cd and Pb in soils from the different locations along Mubi-Yola Highway. The results are presented as Mean± SD of three replicate analysis

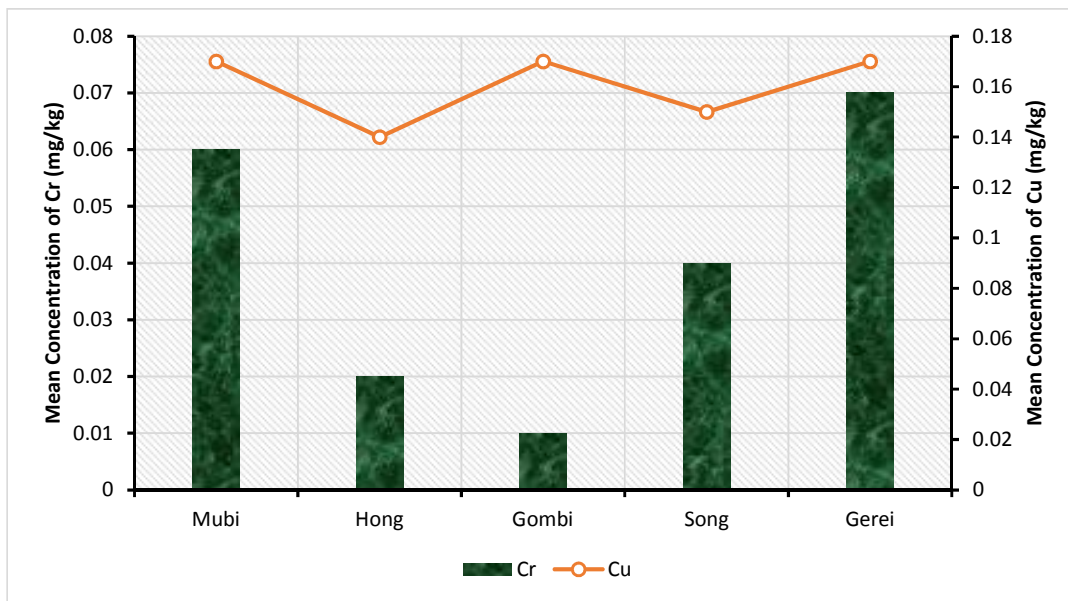


Fig. 3. Concentrations (mg/kg) of Cr and Cu in soils from the different locations along Mubi-Yola Highway. The results are presented as Mean± SD of three replicate analysis

concentration ranges from 0.37 ± 0.01 – 1.90 ± 0.15 mg/kg. These concentrations were found to be lower than the 24-157.667 mg/kg concentrations reported by Ogundele et al. [29], and 29.66 mg/kg by Tsafe et al. [24]. The values in this study were slightly above the PL of 0.35 mg/kg set by the FAO/WHO [48]. The most probable source of Pb in the soils could be attributed to the particulates and gasoline

emission from the heavy trucks conveying cattle's and other goods on the road [54].

Chromium toxicity is linked to severe respiratory, cardiovascular, gastrointestinal, hematological, hepatic, renal, and neurological disorders [55]. From the measured values as presented in figure 3, the concentration of Cr in all the sample locations ranges from 0.01 ± 0.00 - 0.07 ± 0.02

mg/kg, and equally observed to fall below the PL 0.50 mg/kg [48]. Furthermore, the average mean concentration as observed in the study are significantly lower to the 16.73 mg/kg recorded in soil samples collected in Plateau state, and the 10.57-77.10 mg/kg recorded in soil samples from the northern Nigeria [24,29]. Chromium, a metal linked to cancer pathogenesis found their way into the soil sample in the study locations most probably, from corrosion of vehicular parts [56].

In the study as presented in the figure, the concentrations of Cu were observed to be from 0.14 ± 0.01 – 0.17 ± 0.02 mg/kg. These values were found to be slightly below the PL of 0.20 mg/kg [48]. The presence of Cu in the soil samples could be a reflection of activities involving either engine wear, thrust bearings, bushing or bearing metals [57].

The concentration of Zn as shown in Fig. 4 ranges from 6.72 ± 0.31 - 13.57 ± 4.02 mg/kg. The values were observed to be above the 2.0 mg/kg set by FAO/WHO [48]. Other studies reported higher values of 68.9 mg/kg [24] in Yargalma, northern Nigeria and 30.8-219.23 mg/kg at north central Nigeria [29]. Zinc owing to its heat conducting properties are used in the production of brake linings, which means that the continual mechanical abrasion of the vehicles could release quantum of Zn particles. Similarly, engine oil combustion processes and attrition of motor vehicle tire could also release Zn into the environments [19,58]. Even though Zn is considered least toxic element and very essential component of healthy diet, beyond the PL limits could lead to health-related complications such as nausea, vomiting, diarrhea, fever and lethargy. Physiologically, have the propensity to interfere and in some cases alter the metabolic chemistry of other trace elements [59].

The result in Fig. 4 also show the concentration of Ni ranging from 0.16 ± 0.01 - 0.42 ± 0.89 mg/kg. All the values were observed to fall slightly above the 0.20 mg/kg set by the FAO/WHO [48] except in the sample collected at Hong. Furthermore, these values were observed to be lower than 1.65-11.85 mg/kg recorded in the north central Nigeria [29]. Nickel, a carcinogenic agent that can also induce systemic reactions [60] is used in fuel as antiknock agents and released into the environment on combustions [12].

3.2 Human Health Risk Characterization

The non-carcinogenic risks posed by the presence of Cd, Pb, Cr, Cu, Zn, and Ni in soils

along Mubi-Yola highways through different exposure pathways (ingestion, dermal contact and inhalation) are presented in Tables 3 and 4. Based on the exposure factors listed in Table 1, the calculated ADI_i values for each element and for each exposure pathway as presented in Table 3 for both the adults and children were observed to fall in this order $Zn > Pb > Ni > Cu > Cd > Cr$ respectively. However, these values were observed to be lower than their RfD values as listed in Table 2. From the result, the average exposure dose of the three exposure pathways are observed to decreased in the order of $ADI_{Inh} < ADI_{Ing} < ADI_{Dermal}$ for the adults and $ADI_{Inh} < ADI_{Dermal} < ADI_{Ing}$ for children respectively. Overall, the result show children are more susceptible to higher level of exposure dose compared to the adults.

The target hazard quotient (THQ) as described in Table 4 for all the elements following each exposure pathway were observed to be < 1 . The THQ_{Ing} and the THQ_{Inh} values for both the adults and children were observed to follow the ranking $Pb > Cd > Zn > Ni > Cr > Cu$. While the exposure through the dermal route were observed to follow the order $Pb > Cr > Zn > Cd > Ni > Cu$ for both adults and children. The $THQ < 1$ recorded for all the elements further suggest no associated risk following either the ingestion, inhalation or dermal exposure for both the adults and children respectively. The non-carcinogenic risks posed by combining the respective THQ values for each exposure pathway were observed to leads to human health index (HI) values < 1 , which means no associated risks for both the adults and children. However, the HI values for children were observed to be much higher than the adults suggesting that, at a relatively high levels of exposure, children will be more likely at risk than the adults. The HI were observed to fall in this order $HI_{dermal} > HI_{Ing} > HI_{Inh}$ respectively. The result was observed to fall in the same category with the findings conducted on the road dust in urban parks of Beijing [61] and the road dust sample in the city of Duzce, Turkey [62].

The lifetime cancer risk (CRI) for the adults and children are presented in Table 5. The carcinogenic risk was analyzed for Pb, Cd, Cr and Ni for the ingestion and inhalation exposure pathways only. For regulatory purposes, a cancer risk in the range of 10^{-6} to 10^{-4} are considered acceptable [35]. From the results presented in the table, the CRI for both the ingestion and inhalation exposure pathways were found to be within the range that pose no

carcinogenic risk ($<10^{-4}$). The CRI_{ing} for both age categories were observed to be in the order of $Cr>Cd>Pb$ and the CRI_{inh} in the order $Ni>Cr>Cd>Pb$. In all, the CRI for both exposure pathways were observed to be higher in children than the adults. The combine effect for each exposure pathways (TCRI) show high possibility of carcinogenic risk by ingestion route for children (5.77×10^{-7}). From the results it will suffice to say that children are more susceptible to potential carcinogenic risk than the adults. Furthermore, the ingestion exposure pathway were observed to be the major route compared to the lifetime CRI by inhalation exposure route.

According to the results, the potential carcinogenic risk following the ingestion route could come from Cr exposure. Similarly, exposure to Ni could be the likely source of carcinogenic risk by inhalation exposure pathway.

The vulnerability of children to non-carcinogenic and carcinogenic risks compared to the adults as observed for all the exposure pathways in a more practical sense could be linked to the higher intake rates per unit body weight observed in children [35,63]. The unintentional oral contact with the contaminated soil, and slow

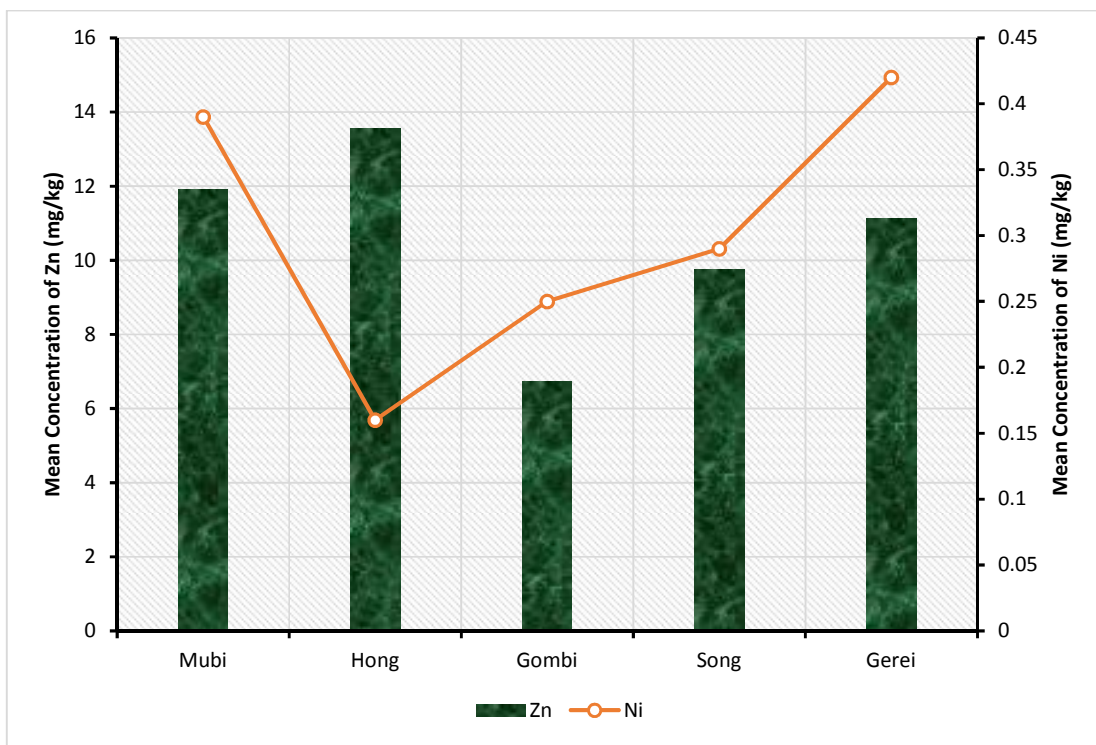


Fig. 4. Concentrations (mg/kg) of Zn and Ni in soils from the different locations along Mubi-Yola Highway. The results are presented as Mean± SD of three replicate analysis

Table 3. Average daily intake (ADI) values in mg/kg/day for adults and children in soil from Mubi-Yola highways

Elements	ADI _{ing}		ADI _{inh}		ADI _{Dermal}	
	Adults	Children	Adults	Children	Adults	Children
Cd	7.03E-08	5.63E-07	1.08E-11	2.16E-11	2.85E-07	1.18E-07
Pb	1.37E-06	1.10E-05	2.11E-10	4.23E-10	5.58E-06	2.31E-06
Cr	6.39E-08	5.11E-07	9.83E-12	1.97E-11	2.60E-07	1.07E-07
Cu	2.56E-07	2.05E-06	3.93E-11	7.87E-11	1.04E-06	4.30E-07
Zn	1.70E-05	1.36E-04	2.61E-09	5.22E-09	6.89E-05	2.85E-05
Ni	4.83E-07	3.86E-06	7.43E-11	1.49E-10	1.96E-06	8.11E-07
Average ADI	1.92E-05	1.54E-04	2.96E-09	5.91E-09	7.80E-05	3.23E-05

Table 4. Hazard quotient (HQ) values for heavy metals in adults and children for soil from Mubi-Yola highways for non-carcinogenic risk

Elements	THQ _{Ing}		THQ _{Inh}		THQ _{Dermal}	
	Adults	Children	Adults	Children	Adults	Children
Cd	1.26E-04	1.00E-03	1.90E-07	3.80E-07	5.71E-04	2.36E-04
Pb	3.82E-04	3.05E-03	6.01E-08	1.20E-07	1.06E-02	4.40E-03
Cr	2.13E-05	1.70E-04	3.28E-07	6.56E-07	4.33E-03	1.79E-03
Cu	6.91E-06	5.53E-05	9.79E-10	1.96E-09	4.33E-05	1.79E-05
Zn	5.66E-05	4.53E-04	8.70E-09	1.74E-08	9.19E-04	3.80E-04
Ni	2.41E-05	1.93E-04	-	-	3.50E-04	1.45E-04
HI	6.16E-04	4.93E-03	5.87E-07	1.17E-06	1.68E-02	6.97E-03

Table 5. Cancer risk (CRI) values for heavy metals in adults and children for soil from Mubi-Yola highways

Elements	CRI _{Ing}		CRI _{Inh}		CRI _{Dermal}	
	Adults	Children	Adults	Children	Adults	Children
Cd	2.67E-08	2.14E-07	6.82E-11	1.36E-10	-	-
Pb	1.17E-08	9.35E-08	8.88E-12	1.78E-11	-	-
Cr	3.2E-08	2.56E-07	4.03E-10	8.06E-10	-	-
Cu	-	-	-	-	-	-
Zn	-	-	-	-	-	-
Ni	-	-	6.24E-09	1.25E-08	-	-
TCRI	7.04E-08	5.63E-07	6.72E-09	1.34E-08	-	-

detoxification processes common among children are additional factors contributing to the increase susceptibility by children [35,63]. The high CRI by ingestion route were observed to follow the same outcome by Sun et al. [35] reporting exposure by ingestion route to be the major contributor to the lifetime cancer risk. The ingestion of dust or soil laden with heavy metals were reported to adversely increase the level of metals in blood among children [64] and further reported to increase the blood-Pb level in two-thirds of children in Shenzhen city in China [65,66]. Though, the results establishes no potential carcinogenic risk from Cd or Pb exposure, at a relatively high levels of exposure, children as discussed above will be more likely at risk than the adults. Indicating some concern about building houses, markets and farms along heavy traffic highways.

4. CONCLUSION

The study shows the average mean concentrations of the metals decreasing in the order Cr<Cd<Cu<Ni<Pb<Zn. The THQ for the non-carcinogenic risk were all <1 for all the metals and for the exposure pathways. Similar trend were observed for the HI for both the adults and children. Which means the population are in

no immediate danger to potential non-carcinogenic risk. The results further show no immediate carcinogenic risk from all the metals in all the exposure pathways. Overall, the ingestion exposure pathways were observed to be the major route compared to the lifetime CRI by inhalation exposure route. The order of exposure was observed to be adults<children. The higher CRI values in children indicates some concern about the expansion of unregulated settlements along heavy traffic highways. Suggesting that, at a relatively high levels of exposure, children in the roadside communities will be more likely at risk than the adults.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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