

Original Research Article

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

**ABSTRACT**

In this study, the health risk caused by heavy metals exposure to communities along Mubi-Yola highways were evaluated. Samples from Mubi, Hong, Gombi, Song, and Gerei were collected and analyzed for Lead (Pb), Cadmium (Cd), Chromium (Cr), Zinc (Zn), Copper (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 pathways 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<sub>ing</sub>) and inhalation (CRI<sub>inh</sub>) exposure pathways were observed to pose no lifetime carcinogenic risk. The CRI for all the exposure pathways and for all age categories were <10<sup>-4</sup>. Similarly, the combine effect or total cancer risk (TCRI) for each exposure pathways show high probability for contracting 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.

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**Key words:** Soil. Metals. Risk assessment. Average daily intake. Target hazard quotient. Cancer risk index.

## 1. INTRODUCTION

The ongoing urban drift and the quest to acquire personal cars couple with the lack of viable public transportations has raised the demands for vehicles globally by a factor of 10 [1, 2]. In Nigeria, an estimated number of vehicles plying the roads stood 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 were 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 impact 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, road is a flashpoint, endangering the people attracted toward it to both accident and environmental associated risk. Therefore, measurement of the environmental cost contributed by vehicular activities is practically an understatement considering its multidimensional impacts to health and the entire ecosystems. 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 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.

For these reasons, the health risk assessments of vehicle-derived heavy metals (Cd, Pb, Zn, Cu, Cr and Ni) 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.

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## 2. MATERIAL AND METHODS

### 2.1. Study area:

The geographical coordinates of the study area lies between latitude  $7^{\circ}$  and  $11^{\circ}$  N of the equator and between longitude  $11^{\circ}$  and  $14^{\circ}$  E of the Greenwich meridian, located in Adamawa state, Nigeria. The entire state covers the land area of about  $38741\text{Km}^2$ [34].

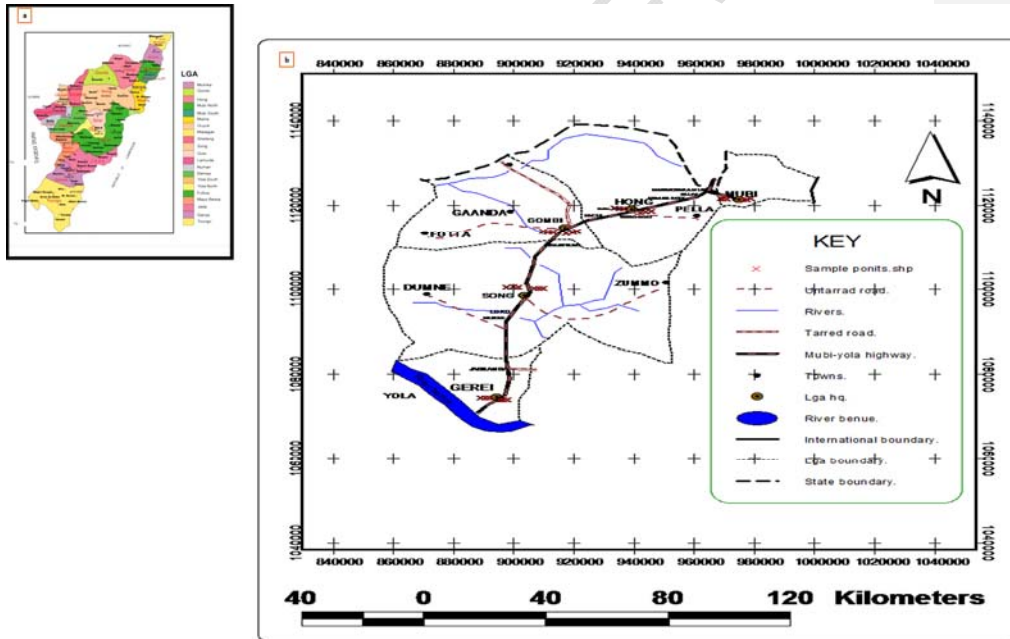


Fig 1. Map of the study area showing (a) Map of Adamawa state, Nigeria (b) The sampling points along Mubi-Yola highways

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## 2.2. Sample Collection:

For the study, thirty (30) soil samples were randomly collected from Five (5) major towns along Mubi –Yola highway. 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 was 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 involves 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 equations 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. Other parameters and their corresponding functions are described in table 1 [35-37].

**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 ( $IngR$ )	mg/day	200	100
Inhalation rate ( $InhR$ )	$m^3/day$	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)	$m^3/k$	$1.3 \times 10^9$	$1.3 \times 10^9$
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

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Target Hazard Quotient (THQ) was used to analyze the non-carcinogenic effects 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 RfD for each metals for each exposure pathways are presented in table 2. The health index (HI), expressed as the sum of the hazard quotients THQ as described in equation 5 is used in the study to describe the cumulative non-carcinogenic effect pose by the combination of the individual metal presents in the soil samples [38, 39]. 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 metals. The description is presented in equations 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<sup>-6</sup>, acceptable or tolerable if CRI is 10<sup>-6</sup> < CRI < 10<sup>-4</sup>, and similarly considered high if the CRI > 10<sup>-4</sup>. 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]

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

Elements	RfD <sub>ing</sub>	RfD <sub>dermal</sub>	RfD <sub>inh</sub>	CSF <sub>ing</sub>	CSF <sub>dermal</sub>	CSF <sub>inh</sub>	Ref.
<b>Cd</b>	5.60E-04	5.00E-04	5.7E-05	3.80E-01	-	6.30E+00	37,40
<b>Pb</b>	3.60E-03	5.25E-04	3.52E-03	8.50E-03	-	4.20E-02	33, 40, 41
<b>Cr</b>	3.00E-03	6.00E-05	3.00E-05	5.00E-01	-	4.10E+01	37, 41, 42
<b>Cu</b>	3.70E-02	2.40E-02	4.02E-02	-	-	-	37, 40
<b>Zn</b>	3.00E-01	7.50E-02	3.00E-01	-	-	-	37, 40
<b>Ni</b>	2.00E-02	5.60E-03	-	-	-	8.40E-01	37, 43

### 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 Fig 2-3. To get the human health risk representation following 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 compared to the PL values set for agricultural purposes [44, 45]. The was based on the assumption that, the heavy metals concentrations that are

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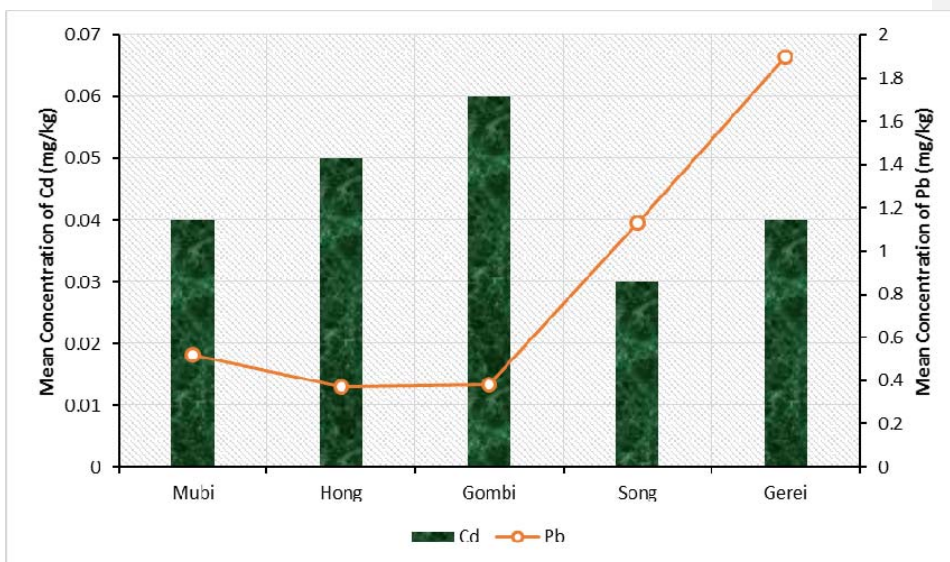
considered safe and within the PL set for agricultural soils will be of great health concerns if the same level of heavy metals are ingested, inhaled or come in contact with the skin [46].

The mean concentration of Cd in the soil samples as presented in Fig.2 ranges from  $0.03\pm 0.01$  –  $0.06\pm 0.03$  mg/kg with an average mean value of  $0.04\pm 0.01$  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 compared to the concentrations in this study 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  $\sim 1$  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 development of high blood pressure and cardiovascular diseases [53]. From the results in Fig.2, an average mean concentration of  $0.86\pm 0.06$  was observed for Pb in all the sample locations. The concentrations ranges from  $0.37\pm 0.01$  –  $1.90\pm 0.15$  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 was 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]

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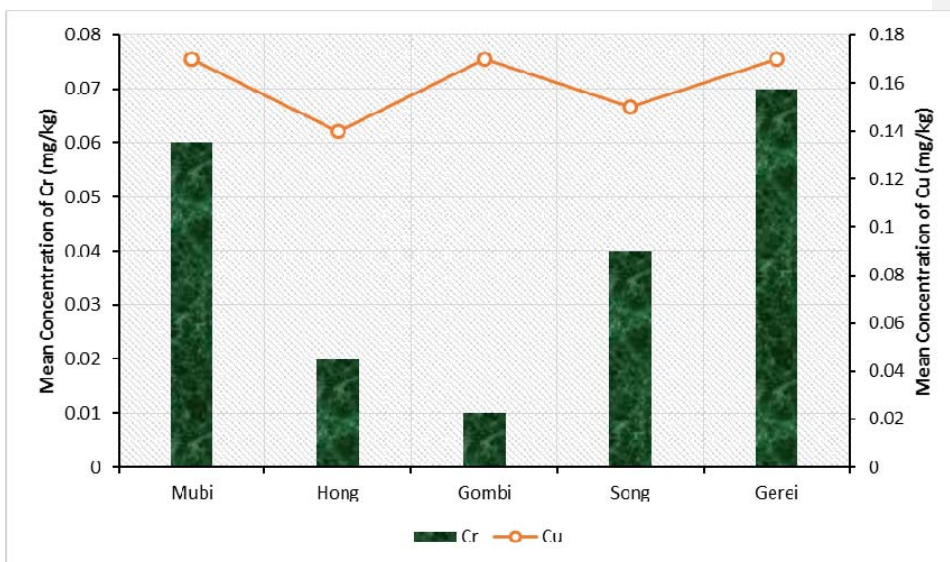
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**Fig.2: Concentrations (mg/kg) of Cd and Pb in soils from the different locations along Mubi-Yola Highway. The results are presented as Mean± SD of three replicate analysis**

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

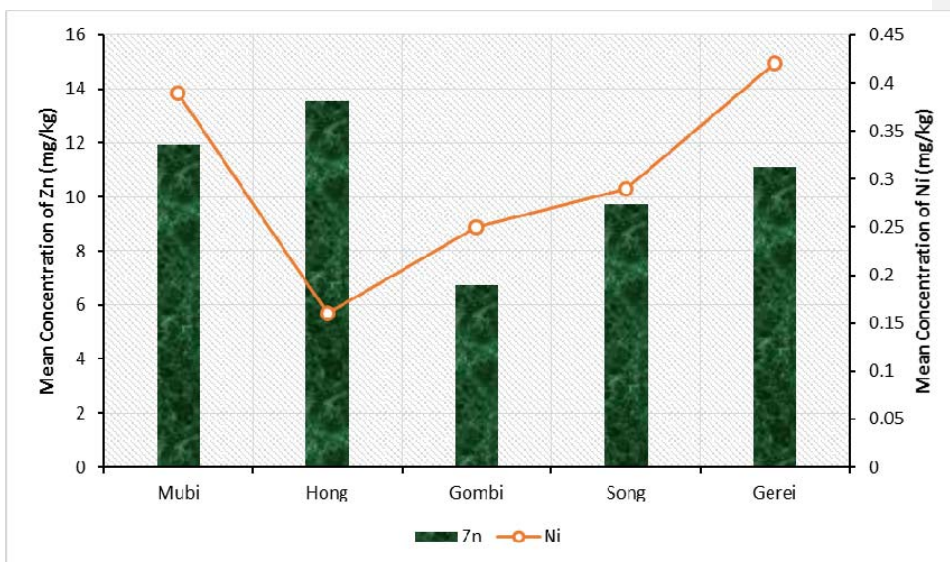
In the study as presented in the figure, the concentrations of Cu was observed to fall from  $0.14 \pm 0.01$  –  $0.17 \pm 0.02$  mg/kg. These values were found to be slightly below the PL of 0.20 mg/kg [48]. The presence of Cu in the soil samples could be a reflection of activities involving either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



**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**

The concentration of Zn as shown in Fig, 4 ranges from  $6.72 \pm 0.31$ -  $13.57 \pm 4.02$  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 releases 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  $0.16 \pm 0.01$ -  $0.42 \pm 0.89$  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].



**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 analys**

### 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 table 3 and 4. Based on the exposure factors listed in table 1, the calculated  $ADI_i$  values for each element and for each exposure pathways 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.

**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
<b>Average ADI</b>	<b>1.92E-05</b>	<b>1.54E-04</b>	<b>2.96E-09</b>	<b>5.91E-09</b>	<b>7.80E-05</b>	<b>3.23E-05</b>

The target hazard quotient (THQ) as described in table 4 for all the elements following each exposure pathways were observed to be <1. The THQ<sub>ing</sub> and the THQ<sub>inh</sub> 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 pathways 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<sub>dermal</sub>>HI<sub>ing</sub>>HI<sub>inh</sub> 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].

**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 <sub>ing</sub>		THQ <sub>inh</sub>		THQ <sub>dermal</sub>	
	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
<b>HI</b>	<b>6.16E-04</b>	<b>4.93E-03</b>	<b>5.87E-07</b>	<b>1.17E-06</b>	<b>1.68E-02</b>	<b>6.97E-03</b>

The lifetime cancer risk (CRI) for the adults and children are presented in table 5. The carcinogenic risk were 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<sub>ing</sub> for both age categories were observed to be in the order of Cr>Cd>Pb and the CRI<sub>inh</sub> 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 ( $5.77 \times 10^{-7}$ ). The order for exposure was observed to be in the decreasing order, adults<children. 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. Though, the results establishes no potential carcinogenic risk from Cd or Pb exposure, at a relatively high levels of exposure, children will be more likely at risk than the adults. Indicating some concern about building houses, markets and farms along heavy traffic highways.

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

Elements	CRI <sub>ing</sub>		CRI <sub>inh</sub>		CRI <sub>dermal</sub>	
	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	-	-

## 5. 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 in all the metals in all the exposure pathways. Overall, the ingestion exposure pathway were observed to be the major route compared to the lifetime CRI by inhalation exposure route. The order of exposure were observed to be adults<children. However, 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

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