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Estimation of Human Health Risk Due to Heavy Metals around Schools and Auto-Mobile Workshops near Frequented Roads in Kaduna State, Nigeria

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ABSTRACT: Heavy metals are widely known for their potential to cause carcinogenic and non-carcinogenic health risks. In this work, the carcinogenic and non-carcinogenic health risks associated with heavy metals in the vicinity of schools and auto mechanic workshops close to busy roads in Kaduna state was assessed using NEX CG EDXRF MODEL with brand name RIGAKU situated at a UTM Laboratory, Malaysia. The obtained heavy metals concentrations were used to estimate the health effects that might result from exposure to carcinogenic and non-carcinogenic chemicals for both the population ages using US EPA methodology. Findings indicated that in some locations the carcinogenic and non-carcinogenic hazards associated with exposure for residents was greater than the US EPA acceptable thresholds of 10^{-4} and 1 respectively. This indicated that the heavy metals may result to unacceptable carcinogenic and non-carcinogenic risks, which is an issue of concern in public health especially looking at the way school children play around these areas. The present study therefore provides scientific basis for strategies required to protect human and environmental health in schools and automobile workshops.

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Kaduna state, as with other states of Nigeria has laid down laws and regulations controlling the erection of residential buildings/car garage with regards to distances from roads frequented by vehicular movements. However, due to the rapid urbanization and migration from rural areas to cities, more buildings were needed to accommodate people in the city and more cars were needed for daily needs. Consequently, buildings/garages were erected without adequate infrastructural planning and regards to government planned specifications to distances from roads. Most often, for economy to lands, whole new residential areas were built without allocations of proper and adequate space for roads thus some buildings/garage were erected very close to main roads highly frequented by vehicles. Literature reveals that several studies have been carried out on road side soil around the world and many studies have proved beyond doubt that the urban roadside environments are polluted by heavy metals (Laxmi, 2016; Yusuf, *et al*., 2015). Few studies have also investigated heavy metals in schools children's playgrounds and mechanic garage close to residential area in Nigeria (David *et al*., 2012; Demie, 2015 and Adesuyi, 2019). When the concentrations of heavy metals exceed a certain threshold, they produce adverse effects in humans. In general, high concentrations of all heavy metals present toxic effects (Ali *et al*., 2013). Some heavy metals such as,

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arsenic(As), lead (Pb), cadmium(Cd),, nickel (Ni), mercury (Hg), chromium (Cr)(VI), cobalt (Co) and selenium (Se) even in minor quantity are described as highly toxic and most problematic heavy metals because of their carcinogenicity among other properties (Bello *et al*., 2019). Considering the high toxicity of these elements, they rank among the high priority heavy metals (Tchounwou, *et al*., 2012; AMAP/UNEP, 2013; Rahman and Singh, 2020; Oludare *et al*., 2019 and Clemens, *et al*., 2013). While others such as Zn, Cu, Fe and Mn were regarded as potential non carcinogenic metals when their concentrations exceeded an acceptable threshold. Humans are exposed to these heavy metals via oral ingestion, inhalation or dermal absorption. For these reasons, the contamination of heavy metals in our surrounding has become one of the biggest environmental issues of the present time and its effects in the future. These toxic metals can be ingested or inhaled from soil and could present irreversible adverse effects on humans particularly children due to their pica behavior, physiology unique exposures and special vulnerabilities (Landrigan, *et al*., 2000 and 2004 and Aurelie *et al* 2020), especially in infants (1–7 years) due to their immature organs (Egeghy, *et al*., 2011 and Ferguson *et al*., 2017). Therefore, this work assessed the carcinogenic and non- carcinogenic human health risk for heavy metals around buildings/garages close to main/busy roads in Kaduna state, Nigeria.

MATERIALS AND METHODS

Sample collection, preparation and analysis: The entire Kaduna State was considered for the study, there are twenty-three local government areas (LGAs) in the state and fourteen local government areas from three geopolitical zones were selected randomly for the study. The sampled areas were selected randomly bearing in mind the closeness of mechanic garage/schools to busy roads. Soil samples were collected at specified locations from road end. The top 0 -1.0cm surface soil samples were collected at varying distances ranging between (0 – 10m) and depths (0 – 60cm) with the help of auger machine from road end to residence schools/mechanic garages. The focus on the top 1.0 cm surface soil is because it is the portion most accessible to children and likely to cause an immediate hazard to the occupants or the target group and distance 0 – 10m form the children's playground. The collected soil samples were sieved to grain size of 50 nm and stored in labeled double polythene bags. The laboratory determination of the heavy metals was carried out in UTM Laboratory, Malaysia. The elemental composition of the samples were obtained using NEX CG EDXRF MODEL with brand name RIGAKU. During the analysis, 3-5 grams of the sieved and grain sized sample was poured into white circular cups of height 7- 8 cm and a Prolene thin film pressed with a rod to make it compact (air tight) and then taken to EDXRF chamber for analysis. To ascertain the reliability of the quantitative results from the EDXRF, a library calibration using pure elements was run to check for instrumental drift. The drift monitor samples used for this study were Cu, Sn, SiO_2, and a Multi-channel analyser (MCA), all supplied by the manufacturer. Additionally, the MCA was run daily before the start of any analysis. In addition, CRMs are added to every set of soil samples analysed on the EDXRF to check the accuracy of the analytical results. Furthermore, the EDXRF limit of detection (LOD) was calculated using the equation provided by Kadachi and Al-Eshaika, 2012, and Fees, 2019.

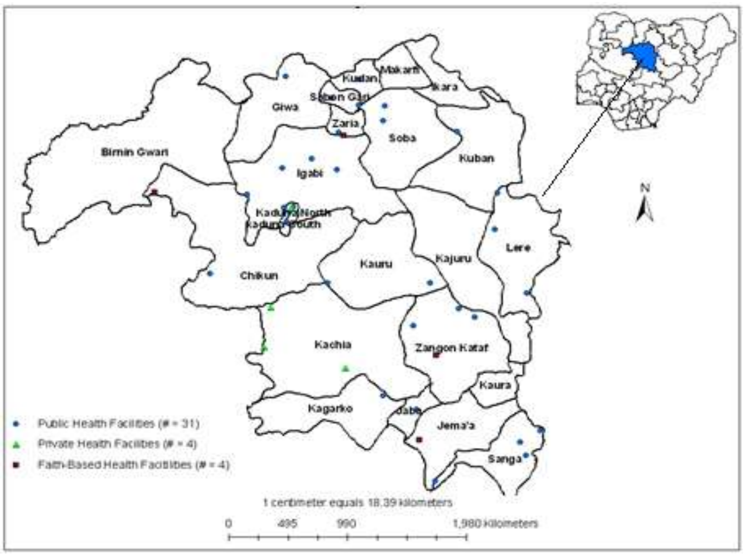

Fig 1: Sampling locations from Kaduna State

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Carcinogenic and Non-Carcinogenic risk assessment: Human health risk assessment was used to estimate the health effects that might result from exposure to carcinogenic and non-carcinogenic chemicals for both children and adults living in the vicinity of the auto mechanic workshops and children playing around the school vicinities in Kaduna state, Nigeria. The risk assessment methodology and the assumptions used were described elsewhere (Bello *et al*., 2019, USEPA, 1989, USEPA, 2002, 2004 Kamunda *et al*., 2017). Though, risk assessments based on the total concentrations of metals in soil might overestimate the actual hazards pose to humans (Desauces., 2012., Joyce *et al*., 2022 and Luo *et al*., 2012). Standard risk assessment models assume that non-carcinogenic effects exhibit a threshold, that is, for any contaminant, there is a level of exposure below which an adverse effect will not be observed, even to sensitive populations, over a specific exposure duration (USEPA, 2004). The exposure assessment for both non-carcinogenic and carcinogenic risks were carried out by considering ingestion, inhalation and dermal contact with the contaminated soil. Table 1.0 provides the exposure parameters used for the health risk assessment for standard residential exposure scenario through different exposure pathways.(U.S. Environmental Protection Agency, 1989; Kamunda, 2016).

Firstly, the average daily intakes associated with ingestion of heavy metals through soil was estimated using equation 1.

$$ADI_{ing} = \frac{C \times IRing \times EF \times ED}{BW \times AT \times 10^6} \ldots\ldots\ldots 1$$

Where ADI_{ing} is the average daily intake of heavy metals ingested from soil in mg/kg-day; C is the concentration of heavy metal in mg/kg for soil and plants and in mg/L for water. IR_{ing} in mg/day is the ingestion rate, EF in days/year is the exposure frequency, ED is the exposure duration in years, BW is the body weight of the exposed individual in kg, AT is the time period over which the dose is averaged in days. CF is the conversion factor in kg/mg.

Secondly, the average daily intakes for inhalation of heavy metals via soil particulates was calculated using equation 2.

$$ADI_{inh} = \frac{Cs \times IRinh \times EF \times ED}{BW \times AT \times PEF} \ldots\ldots\ldots 2$$

Where ADI_{inh} is the average daily intake of heavy metals inhaled from soil in mg/kg-day, C_S is the concentration of heavy metal in soil in mg/kg, IR_{air} is the inhalation rate in m^3/day, PEF is the particulate emission factor in m^3/kg

Finally, the average daily intakes associated with dermal contact with soil was estimated using equation 3.

$$ADI_{derm} = \frac{Cs \times SA \times FE \times AF \times ABS \times EF \times ED}{BW \times AT \times 10^6} \ldots\ldots\ldots 3$$

Where, ADI_{derm} is the exposure dose via dermal contact in mg/kg/day. C_S is the concentration of heavy metal in soil in mg/kg, SA is exposed skin area in cm^2, FE is the fraction of the dermal exposure ratio to soil, AF is the soil adherence factor in mg/cm^2, and ABS is the fraction of the applied dose absorbed across the skin

Table 1: Exposure parameters used for the assessment of health risk (Adapted from Kamunda *et al*., 2017).

Parameter	Media	Unit	Child	Adult	References
Body weight(BW)	All	Kg	15	70	(DEA, 2010)
Exposure frequency(EF)	All	days/year	350	350	(DEA, 2010)
Exposure duration(ED)	All	Years	6	30	(DEA, 2010)
Ingestion rate(IRing)	Soil	mg/day	200	100	(DEA, 2010)
Inhalation rate(IRinh)	Soil	m^3/day	10	20	(DEA, 2010)
Skin surface area(SA)	Soil	cm^2	2100	5800	(DEA, 2010)
Soil adherence factor(AF)	Soil	mg/cm^2	0.2	0.07	(DEA, 2010)
Dermal absorption factor(ABS)	Soil	None	0.1	0.1	(DEA, 2010)
Dermal exposure ratio(FE)	Soil	None	0.61	0.61	(USEPA, 2004)
Particulate emission factor (PEF)	Soil	m^3/kg	1.3E+09	1.3E+09	(DEA, 2010)
Conversion factor (*CF*)	Soil	kg/mg	10^{-6}	10^{-6}	(USEPA, 2004)
Averaging time AT	Soil	Days			
Non-carcinogenic			365*ED	365*ED	(DEA, 2010)
Carcinogenic			365*70	365*70	

Non-carcinogenic hazards were characterized by a term called hazard quotient (HQ), which is a unit less number that is expressed as the probability of an individual suffering an adverse effect. It is defined as the quotient of ADI or dose divided by the toxicity threshold value, which is referred to as the chronic reference dose (RfD) in mg/kg-day of a specific heavy metal as shown in Equation 4:

$$HQ = ADI/RfD \ldots\ldots\ldots 4$$

For n number of heavy metals, the non-carcinogenic effect to the population is as a result of the summation of all the HQs due to individual heavy metals. This is considered to be another term called the Hazard Index (HI) as described by USEPA document. Equation 5 shows the mathematical representation of this parameter:

$$\mathrm{HI} = \sum_{k=1}^{n} \mathrm{HQ_k} = \sum_{k=1}^{n} \frac{\mathrm{ADI_k}}{\mathrm{RfD_K}} \ldots\ldots\ldots\ldots 5$$

Where, HQk, ADIk and RfDk are values of heavy metal k. If the HI value is less than one, the exposed population is unlikely to experience adverse health effects. If the HI value exceeds one, then there may be concern for potential non-carcinogenic effects. The reference doses are provided in table 2.0.

Table 2: Reference doses (RFD) in (mg/kg/day) (Adapted from Kamunda *et al*., 2017).

Heavy Metal	Ingestion RfD	Dermal RfD	Inhalation RfD	References
As	3.00E-04	3.00E-04	3.00E-04	USEPA,2002
Pb	3.60E-03	-	-	DEA,2010
Cd	5.00E-04	5.00E-04	5.70E-05	DEA,2010
Cr(VI)	3.00E-03	-	3.00E-05	USEPA,1991
Co	2.00E-02	5.70E-06	5.70E-06	USEPA,2011a
Ni	2.00E-02	5.60E-03	-	DEA,2010
Cu	3.700E-02	2.40E-02	-	USEPA,2011a
Zn	3.00E-01	7.50E-02	-	USEPA,2011a

Carcinogenic risks were estimated as the incremental probability of an individual developing cancer over a lifetime as a result of exposure to the potential carcinogen. Equation 6 was used for calculating the excess life time cancer risk:

$$\mathrm{Risk_{pathway}} = \sum_{k=1}^{n} \mathrm{ADI_k CSF_k} \ldots .6$$

Where, Risk is a unit less probability of an individual developing cancer over a lifetime. ADIk (mg/kg/day) and CSFk are the average daily intake and the cancer slope factor respectively for the Kth heavy metal, for n number of heavy metals.

The slope factor converts the estimated daily intake of the heavy metal averaged over a lifetime of exposure directly to incremental risk of an individual developing cancer (USEPA, 1989).

Table 3: Cancer slope factors (CSF) in $(mg/kg/day)^{-1}$.

Heavy Metal	Oral CSF	Dermal CSF	Inhalation CSF
As	1.50E+00	1.50E+00	1.50E+01
Pb	8.50E-03	-	4.20E-02
Cd	-	-	6.30E+00
Cr(VI)	5.00E-01	-	4.10E+01
Co	-	-	9.80E+00

The total excess lifetime cancer risk for an individual is finally calculated from the average contribution of the individual heavy metals for all the pathways using equation 7:

$$\mathrm{Risk_{total}} = \mathrm{Risk_{ing}} + \mathrm{Risk_{inh}} + \mathrm{Risk_{dermal}} \;\ldots 7$$

Where Risk(ing), Risk (inh) and Risk (derm) are risks contributions through ingestion, inhalation and dermal pathways.

The carcinogenic risk assessment is calculated using cancer slope factors provided by Table 3**.**

RESULTS AND DISCUSSION

Non carcinogenic risk assessment: The results of the heavy metals analysis was used to estimate the cancer and non-cancer risk which was the main context of this paper. The United States environmental protection agency considered hazard quotients and hazard index value of less than unity as an acceptable threshold, below which no non-cancer related effect will be observed as a result of exposure to heavy metals. The hazard quotient values for children residing in the studied area as a worst case scenario was presented in figure 1 for the schools and auto mechanics workshops considered, and the contributions of the exposure pathways (ingestion, inhalation and dermal contact) to the hazard quotients were presented in figure 2. The average hazard quotient due to the ingestion of soil by children in the study area was found to be greater than unity for all the schools and auto mechanic workshops considered, which indicates that the vicinities of the schools and auto mechanic workshops are not safe in terms of non-carcinogenic hazards. More than 80% contribution to the total hazard in children was contributed by the dermal pathway, while the remaining 20% contribution was majorly attributable to the ingestion pathway. Generally, inhalation pathway appears to be have a negligible contribution to the total hazard in children.

For adults, the hazard quotient was less than unity for Soba and Kachia schools as well as Giwa and Lere mechanic workshops as shown in fig 3. This clearly indicates that adults in the vicinities of these schools and auto mechanic workshops are not likely to be associated with non-carcinogenic hazards. Fig 4 presents the contribution of the exposure pathways to the total hazard quotient for adults. In this case, Ingestion pathways contributed most to the total hazard quotients observed in some locations (Soba and Kachia schools, Makarfi, Lere, Giwa and Igabi auto-mechanics workshops). This indicated that the heavy metals in the studied area may pose a serious burden of non-cancer related hazards in children.

Therefore, children if not protected against ingestion of heavy metals in soil will develop one type of effect or another. Children are generally known to be more sensitive to the impact of environmental pollution due to their physiological, biological and social conditions compared to adults. For instance, in early childhood; the human organism and its immune system are still developing, the demand for oxygen and food in the human organism is higher, movement is restricted and so they spend more time in the contaminated area, secondary pollution impact from soil via near-surface air layer due to their short length and their hand-mouth behavior (Tepanosyan *et al*., 2018). It is worth noting that the heavy metals contributed unequally to the total hazard quotient for each of the major contributing pathways (ingestion and dermal contact). Consequently, to enable proper risk management, the contribution of each of each of the heavy metals to the hazard quotient for the ingestion and dermal contact pathways for the children and adults were presented in fig 1, 2, 3 and 4 in the appendix. The hazard quotients obtained in this work is greater than that which was reported for automobile repair workshop village and environs in Uyo metropolis, Nigeria as well as indoor dust from higher institutions in ondo state, Nigeria (Edu *et al*., 2015 and Oluwatosin *et al*., 2021).

The results of the present study indicate that the HQ for most of the metals was greater than 1. For metals which showed HQ and HI values less than 1, there was no risk posed to the health of children or adults by the metals. Exposure to metals with high HI values in contaminated soil is of great concern for both adults and children. According to the USEPA, adverse health effects are unlikely to occur if HQ < 1 (USEPA, 2001). However, if HQ > 1, adverse health effects are likely and HQ > 10 indicates high chronic risk, while THI values > 1 implies a significant probability of non-carcinogenic effects and THI < 1 indicates low probability of non-carcinogenic effects. Additionally, hazard index values ranging from 1 to 10 indicates moderate hazard, while THI > 10 indicates high hazard (Odukoya *et al*., 2016). According to Agomuo and Amadi, (2018) the higher the THI value, the higher the probability of experiencing long term health problems with associated toxicities.

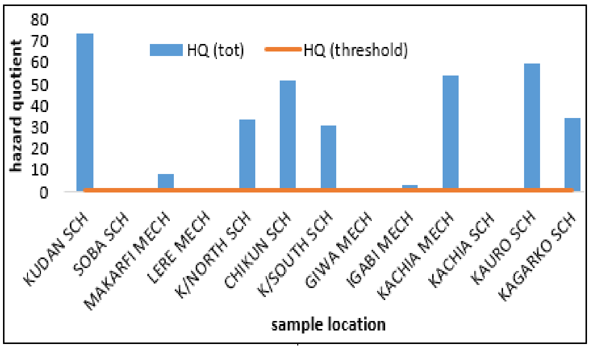

Fig 2: comparison between total hazard quotient in children and the acceptable threshold

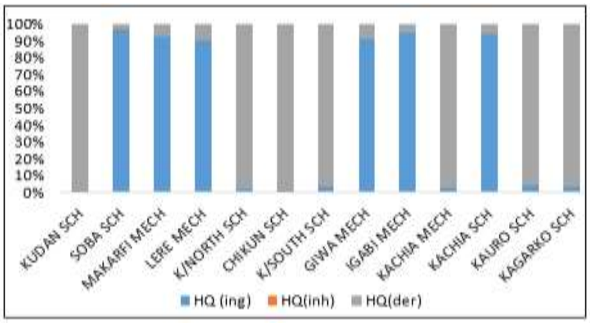

Fig 3: Contribution of the exposure pathways to the hazard quotient in children

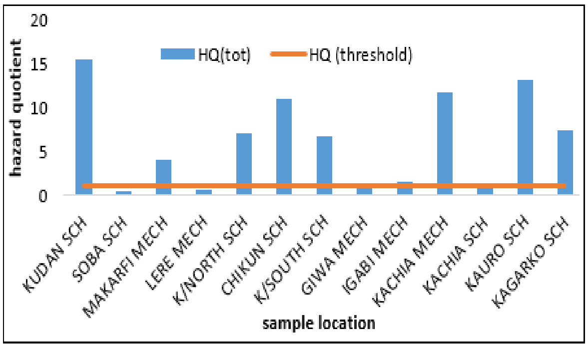

Fig 4: comparison between total hazard quotient in adults and the acceptable threshold

Comparing the HI values for children and adults revealed that children have higher chances of non-carcinogenic and/or harmful health risks arising from exposure to heavy metals in the oil impacted soils than adults, although the calculated heavy metals exposure risks associated with contaminated soils showed a high degree of uncertainty (Gbadamosi *et al*., 2019). As such, the risk evaluation based on the total concentrations of heavy metals in the contaminated soils may overestimate the actual hazards they pose to humans. Considering the hazard index of a contaminated environment, Grzetic and Ghariani noted that health hazards arising from exposure to heavy metals are common as a result of the cumulative effects of different heavy metals (Grzetic and Ghariani, 2008).

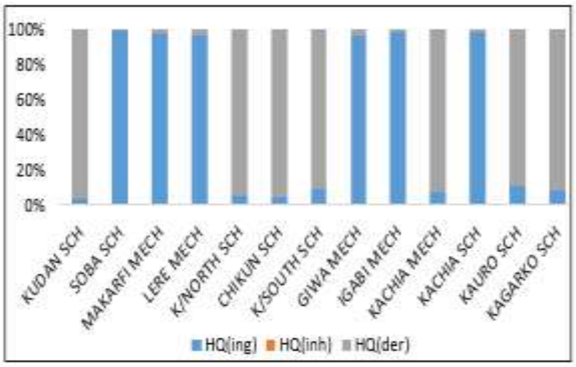

Fig 5. Contribution of the exposure pathways to the hazard quotient in adults

Non carcinogenic risk assessment: US EPA considers excess cancer risks that are below 1 chance in 1,000,000 (1×10^{-6} or 1E−06) to be so small as to be negligible, and risks above 1 in 10,000 (1×10^{-4}) to be sufficiently large that some sort of remediation is desirable. An Incremental Lifetime Cancer Risk (ILCR) greater than one in 10, 000 (ILCR $>10^{-4}$) is benchmark for gathering additional information, whereas 1/1000 or greater (ILCR $>10^{-3}$) is a moderate increased risk and should be given high priority as a public health concern (US EPA, 2001). The world health organization on the other hand consider a cancer risk threshold of 1E-06 to be acceptable, which translates to 1 person out of 1,000,000. All the cancer risks for ingestion, inhalation and dermal contact in adult and children were less than the USEPA threshold, implying that the exposed population would not be subjected to cancer risk probability of more than 1 chance in 10,000 population. The carcinogenic risks for children living in the vicinity of the contaminated soil and auto mechanic workshops in Kaduna state were presented in fig 5 and the percentage contribution of the pathways to the total observed risk was presented in figure 6. It could be observed that ingestion was the major pathways in Soba School, Lere mechanics, Kaduna north school, Chikun School, Kaduna south school, Giwa mechanic, Igabi mechanic, Kachia mechanic and Kagarko School. From all the schools and auto mechanic workshops considered, only Makarfi mechanic and Kauro School had cancer risks greater than the US EPA acceptable thresholds. Dermal contact with soil was observed to be the major contributing pathway to this elevated cancer risk, therefore, to minimize risk, there is need for soil remediation. Fig 7 presented the cancer risks for adults living in the vicinity of the schools and auto mechanic workshops, while fig 8 presented the percentage contribution of the exposure pathways to the total cancer risk. From these figures, it could be observed that ingestion pathway contributed about 80% to the cancer risk in almost all the considered sample locations. Similarly, only Makarfi mechanic and Kawo School had cancer risk values greater than the US EPA acceptable thresholds. This clearly indicated both children and adults living along Makarfi mechanic and Kawo School are subjected to cancer risk of significant concern. It is worth noting that the heavy metals contributed unequally to the total cancer risk for each of the major contributing pathways (ingestion and dermal contact).Consequently, to enable proper risk management, the contribution of each of each of the heavy metals to the total cancer risk for the ingestion and dermal contact pathways for the children and adults were presented in fig 5, 6, 7 and 8 in the appendix.

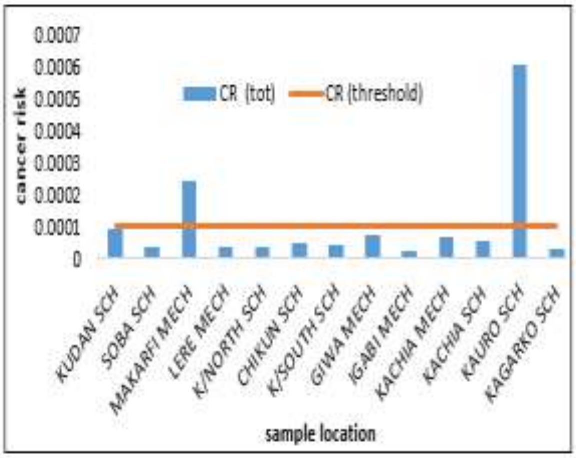

Fig 6. Comparison between total cancer risk in children and the acceptable threshold

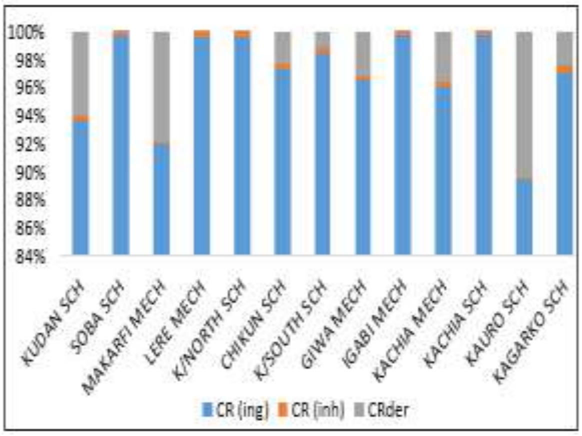

Fig 7. Contribution of the exposure pathways to the cancer risk in children

Comparing the cancer risks obtained in this study, our results for most of the study areas; were less than the acceptable limit for Soil of Major Cities in Mongolia (Sonomdagva *et al.*, 2019) and were greater in the case of automobile spare part and recycling market in Ilorin, Nigeria (Muyiwa *et al.*, 2020). Pollution effects of mechanic site activities in Nigeria have received limited attention even though these activities have been shown to produce harmful wastes.

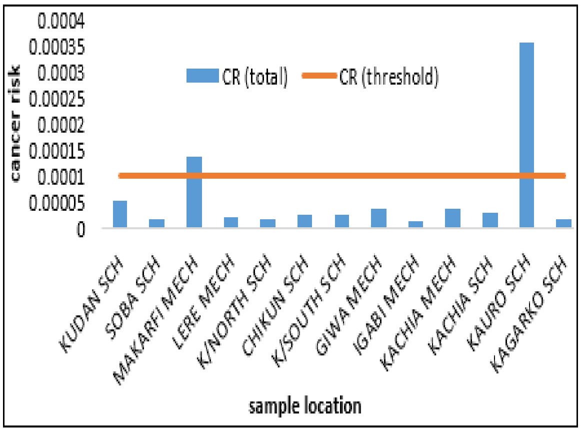

Fig 8: comparison between total cancer risk in adults and the acceptable threshold

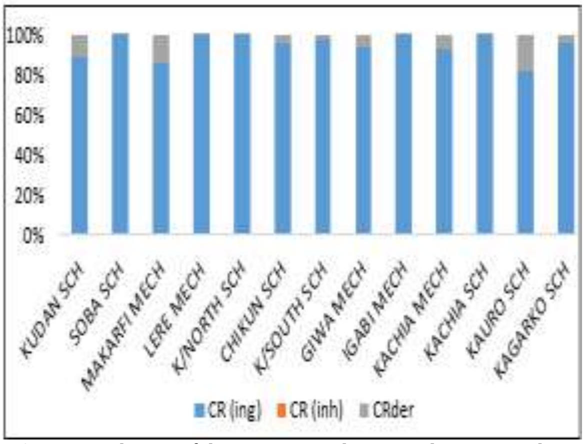

Fig 9. Contribution of the exposure pathways to the cancer risk in adults

Therefore, there is need to continually monitor their nature, volume, direct harmful effects and current methods of disposal as well as potential impacts on the environment (Bello *et al*. 2017 and 2019). The heavy metals most frequently encountered in this waste include copper, lead, cadmium, zinc, manganese and nickel, all of which pose risks for human health and the environment. It has therefore become imperative to monitor the levels of these heavy metals in soils in the vicinity of schools and auto mechanic workshops in Nigeria. Thus, this study is significant in that: The entire work is designed such that for the first time, data on heavy metals in the two mechanic sites are generated. This data obtained would provide an adequate idea of the pollution levels of these heavy metals on the environment and also, serve as a proactive vehicle for selection and design of remediation variables in modeling.

Conclusion: The carcinogenic and non-carcinogenic hazards associated with exposure for residents was greater than the US EPA acceptable thresholds. This indicated that the heavy metals may result to unacceptable carcinogenic and non-carcinogenic risks, which is an issue of concern in public health especially looking at the way school children play around these areas.

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