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Determination, Effects, and Health Risk Assessment of Heavy Metals and Polycyclic Aromatic Hydrocarbons Pollutants in Road Dust of Kaduna Metropolis, Nigeria

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Abstract- This study assessed the effects and health risk assessment of PAHs and heavy metals on six major roads in Kaduna metropolis using Gas chromatography-mass spectrometry (GC-MC) and atomic absorption spectrometer (AAS). **This study indicates that the areas around *Abuja Kaduna Zaria Express Way and Independence Way* recorded the highest mean concentrations of HMW-PAHs *(4–6 rings)*, with highly carcinogenic PAHs such as B(a)P being the most prevalent. C*hildren are found to be at a higher risk of cancer due to the exposure to contaminated particles, with the highest incremental lifetime cancer risk (ILCR) being 2.46E-01. The carcinogenic PAHs were found to be below the USEPA's 10−6 limit, indicating no cumulative carcinogenic risk. Cr and Sn observed in road dust samples was above the regulatory control limits of 1.10E+01 mg/kg as prescribed by USEPA and background concentrations, for the soils specified by the Nigerian regulatory body. Except for Cu, Fe, Ni, and Zn, the contamination factor index showed elevated level of potentially harmful metals.***

Indexed Terms- Heavy metals, PAHs, Pollutants, Risk assessment, Road dust

I. INTRODUCTION

Urban road dust re-suspension can be a source of pollution and a means of transporting pollutants between various environmental compartments, endangering human health [1]. This phenomenon, which is frequently seen in arid and semi-arid nations like Nigeria, is regarded as the most important environmental threat [2]. There are several ways that people can become exposed to potentially dangerous heavy metals and PAHs: direct contact with the metal, vehicle emissions, the burning of coal and oil to generate electricity, industrial facilities, and home heating all contribute significantly to atmospheric, ingestion through the air, contaminating surface and groundwater drinking supplies, and transfer to plants and animals, which then become part of the human food chain [3, 4]. According to [5], and [6], the urban environment's industrial and economic growth has led to an increase in the atmospheric concentrations of these pollutants. Road dust particles negatively impact the environment, the health of the local population, and their way of life since they contain contaminants such as polycyclic aromatic hydrocarbons and heavy metals [7]. Atmospheric airborne particles, such as heavy metals and PAHs, can pose a serious risk to human health [8]. It has been documented that exposure to potentially hazardous heavy metals and PAHs in road dust can affect human health through ingestion, skin contact, and inhalation over varying periods of time [9]. Accordingly, several studies have been conducted on the human health risks associated with toxic metal contamination in street dust and soil [10, 11]. However, there is a paucity of information about the toxicological properties and related health effects of road dust, which is partly explained by the differences in their chemical makeup, composition, and size distribution [12]. The purpose of this study is to investigate the levels of heavy metals and PAHs exposure through the dermal, ingestion, and inhalation by children and their adult parents in road dust, as well as the contamination level and pollution load index of heavy metals in the street dust of the Kaduna metropolis, which serves as a representative urban environment in northwest Nigeria.

II. MATERIALS AND METHODS

2.1 Description of the Study Area

The location of Kaduna city is situated between latitudes 100 22' 0" N and 100 40' 00" N and longitudes 70 20'00"E and 70 28' 00" (Figure 1). Situated at a height of 645 meters above sea level, the city spans around 260 km^2, with the distance between its eastern and western boundaries being around 14 km. The entire Kaduna north, the entire Kaduna south, and portions of Igabi and Chikun are the four local government areas that comprise the city [13]. According to statista.com, the population of Kaduna metropolis is close to two million now [14], put the population of Kaduna and its environs at 2,004, 282 in 2016 using the growth rate 2.47 as recommended in annual growth rate software world for population growth (2003), from the 2006 population census which was 1,570,331.

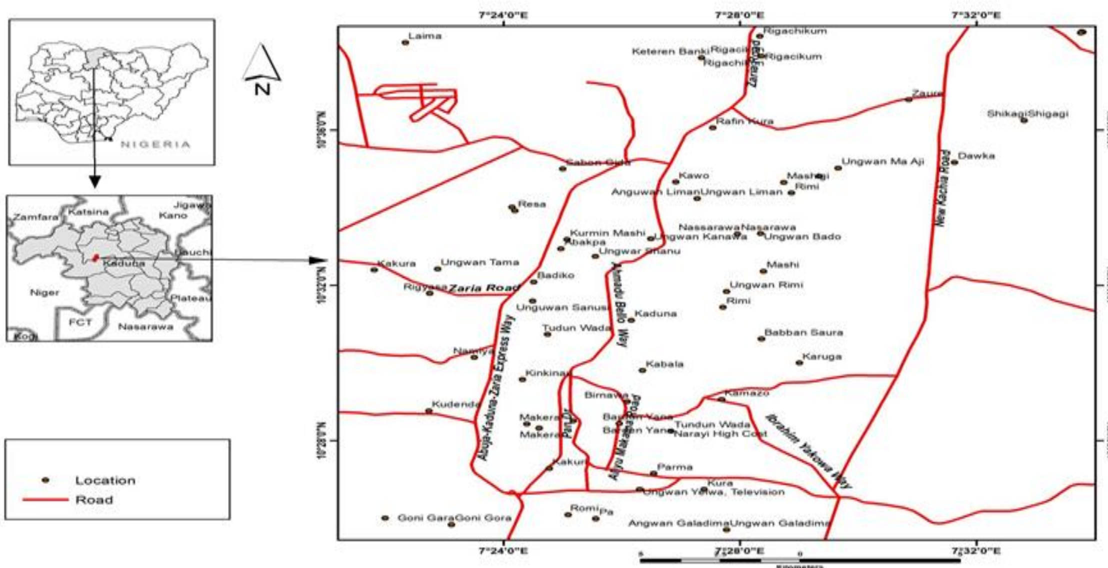

Figure 1: Map of Roads within Kaduna Metropolis (Kaduna State University (GIS), 2023)

2.2 Sample Collection and Preparation

Six (6) road dust composite samples (500 g) were collected in Kaduna state, selected in the driest months to avoid rain. The samples were collected near busy traffic zones and business areas. The samples were air-dried, passed through a mesh, and analyzed for heavy metals and PAHs.

2.3 Heavy Metals

The concentrations of seven (7) heavy metals (Cu, Cr, Fe, Pb, Ni, Sn, and Zn) were determined by adding concentrated HNO_3 and $HClO_4$ to a Teflon container, heating, drying, shaking, filtering, and dilution. The solutions were stored at 4 ºC until analysis day, and heavy metals analysis was performed using inductively coupled plasma mass spectrometry. The process involved heating, drying, shaking, filtering, and dilution [15].

2.4 Polycyclic Aromatic Hydrocarbons

Approximately, 2.5 mL of CH_3OH and 2.5 mL of CH_2Cl_2 were added to a Teflon container, which was then placed in an ultrasonic bath set at a 20 kHz frequency (Elmasonic S 80 H) for 30 minutes in order to solubilize the PAHs. The solution sample was filtered and PAHs analysis was conducted using a gas chromatography/mass selective detector and fused silica capillary column.

2.5 Human Risk Assessment of PAHs in Roads Dust

2.5.1 Evaluation of incremental lifetime cancer risk

The incremental lifetime cancer risk (ILCR) of PAHs exposure in road dust via dermal, inhalation and ingestion uptakes are evaluated using equations 1, 2 and 3 as stipulated by [16]. The BaPeq concentration of individual PAH analytes was estimated using C_i x TEF_i were Ci (g/g) is the concentration of each analyte in the road dust whilst TEFi is the toxicity equivalency factors of each analyte. The sum of BaPeq for all PAH analytes in each sample is represented as (ΣBaPeq).

$$ILCR_{dermal} = \frac{\sum BaP_{eq} \times CSF_{dermal} \times \left(\sqrt[3]{\frac{BW}{70}}\right) \times SA \times AF \times ABS \times EF \times ED}{BW \times AT \times 10^6} \quad (1)$$

$$ILCR_{Inhalation} = \frac{\sum BaP_{eq} \times CSF_{inhalation} \times \left(\sqrt[3]{\frac{BW}{70}}\right) \times IR_{Inhalation} \times EF \times ED}{BW \times AT \times PEF} \quad (2)$$

$$ILCR_{ingestion} = \frac{\sum BaP_{eq} \times CSF_{ingestion} \times \left(\sqrt[3]{\frac{BW}{70}}\right) \times IR_{Ingestion} \times EF \times ED}{BW \times AT \times 10^6} \quad (3)$$

2.5.2 Carcinogenic Risk (CR) Indices

Carcinogenic risks through ingestion of PAHs are typically predicted by the following equation using [17]. Under most regulatory programs, a CR value over 1.00E-05 indicates potential carcinogenic risk [18]. Where: CDI_{ing} = chronic daily intake of PAHs via ingestion (mg/kg day), SF = the carcinogenic slope factor of the contaminant (mg/kg/day) [19].

CR = CDing x SF (4)

Table 1: Applicable Parameters for the Incremental Lifetime Cancer Risk Evaluation of PAHs

Parameters	Units	Adult	Children
Body weight (BW)	[kg]	70	15
Exposure frequency (EF)	[day $year^{-1}$]	180	180
Exposure duration (ED)	[year]	24	6
Inhalation rate (IRinhalation)	[m^3 day^{-1}]	20	10
Dust ingestion rate (IRingestion)	[mg day^{-1}]	100	200
Dermal exposure area (SA)	[cm^2]	5700	2800
Dermal adherence factor (AF)	[mg cm^{-2}]	0.07	0.2
Dermal adsorption fraction (ABS)	[unit less]	0.13	0.13
Particle emission factor (PEF)	[m^3 kg^{-1}]	1.36E+09	1.36E+10
Carcinogenic slope factor ingestion (CSFingestion) of BaP	[mg kg^{-1} day^{-1}]	7.3	7.3
Carcinogenic slope factor dermal uptake (CSFdermal) of BaP	[mg kg^{-1} day^{-1}]	25	25
Carcinogenic slope factor inhalation (CSFinhalation) of BaP	[mg kg^{-1} day^{-1}]	3.85	3.85
Averaging life span (AT)	[years]	64.2	64.2

2.6 Heavy Metal Pollution and Ecological Risk Assessment

2.6.1 Contamination factor (CF)

The ratio of each measured heavy metal's concentration (Cn) to its background value (Cbn) is known as the contamination factor, and it was used to characterize the pollution level of road dust with a particular heavy metal [20]. Based on the results obtained for CF, the level of heavy metal contamination was established according to CF < 1, low; 1 ≤ CF ≤ 3, moderate; 3 ≤ CF < 6, considerable; and CF ≥ 6, very high.

$$CF = \frac{Cn}{Cbn} \quad (5)$$

III. RESULTS AND DISCUSSION

Table 1: Mean Concentrations (mg/kg) of Some Polycyclic Aromatic Hydrocarbons in Some Selected Roads Dust in Kaduna Metropolis, Kaduna State, Nigeria

PAHs	EF	ABKZEW	NKR	IW	ABW	AMR	IYR
Naphthalene	0.001	2.21E-03	ND	ND	1.43E-02	3.90E-01	3.75E-03
Acenaphthylene	0.001	ND	2.57E-02	4.29E-09	2.81E-01	7.00E-01	7.70E-03
Acenaphthene	0.001	6.11E-02	5.00E-02	8.60E-02	7.80E-09	ND	3.18E-07
Fluorene	0.001	2.62E-07	ND	4.84E-01	3.00E-02	8.29E-07	7.10E-04
Phenanthrene	0.001	ND	ND	3.18E-02	8.21E-01	ND	5.30E-02
Anthracene	0.01	1.09E-07	1.56E-07	2.16E-02	1.61E-07	1.32E-9	1.02E-05
Fluoranthene	0.001	7.52E-04	1.50E-01	7.90E-04	9.00E-03	4.84E-09	7.20E-09
Pyrene	0.001	1.04E-03	7.20E-01	2.68E-02	2.29E-03	1.49E-01	1.22E-01
Benzo(a)anthracene	0.1	2.68E-03	ND	3.76E-01	4.84E-01	5.50E-01	1.24E-09
Chrysene	0.01	3.00E-02	6.14E-06	1.09E-07	8.65E-06	9.30E-03	2.10E-02
Benzo(b)fluoranthene	0.1	ND	1.88E-02	2.40E-09	1.40E-01	6.30E-04	7.90E-08
Benzo(k)fluoranthene	0.1	7.10E-02	1.54E-01	ND	8.45E-01	4.60E-01	ND
Benzo(a)pyrene	1	9.90E-01	1.08E-01	9.30E-01	4.10E-01	9.38E-05	ND
Dibenz(a,h)anthracene	0.1	6.11E-01	1.68E-01	2.86E-04	4.00E-02	ND	7.70E-01
Indeno(1,2,3-cd)pyrene	1	4.84E-07	6.00E-02	1.50E-02	2.13E-01	5.50E-05	4.00E-02
Benzo(g,h,i)perylene	0.01	5.30E-01	1.54E-01	7.80E-09	2.07E-01	2.88E-05	ND
Σ16PAH		2.30E+00	1.61E+00	1.97E+00	3.50E+00	2.26E+00	1.02+00

Keys: ABKZEW; Abuja Kaduna Zaria Exprees Way, NKR; New Kachia Road, IW; Independence Way, ABW; Ahmadu Bello Way, AMR; Aliyu Makama Road, IYR; Ibrahim Yakowa Road, TEF;Toxic Equivalent Factor, ND; Not Detected

Table 2: Incremental lifetime Cancer Risk (ILCR) for Adults and Children in Kaduna Roads Dust

ADULTS			CHILDREN		
ILCRsInhalation		Roads	ILCRsInhalation		Roads
Mean	9.41E-12	AMR	Mean	1.57E-27	IW
Max	2.42E-07	ABKZEW	Max	4.61E-19	ABKZEW
Min	8.52E-24	IYR	Min	9.90E-35	AMR
Cancer Risk			Cancer Risk		
Mean	3.62E-11		Mean	6.04E-27	
Max	9.32E-07		Max	1.78E-18	
Min	3.28E-23		Min	3.81E-34	
ILCRsIngestion		Roads	ILCRsIngestion		Roads
Mean	2.42E-12	IW	Mean	1.59E-12	ABW
Max	7.10E-04	ABKZEW	Max	9.72E-04	ABKZEW

Min	2.50E-20	IYR	Min	3.42E-20	IYR
ILCRsDermal		Roads	ILCRsDermal		Roads
Mean	4.18E-12	IW	Mean	3.08E-12	AMR
Max	1.23E-03	ABKZEW	Max	1.23E-04	ABKZEW
Min	4.32E-20	IYR	Min	4.32E-21	IYR

Table 3: Mean Concentrations of Some Heavy Metals (mg/kg) in the Major Roads in Kaduna Metropolis

ROADS	Cu	Cr	Fe	Pb	Ni	Sn	Zn
ABKZEW	2.29E-01	6.20E-02	2.00E-03	6.30E-02	1.00E-01	1.66E+01	1.00E-01
NKR	3.10E-02	1.60E-01	5.64E-02	1.99E-03	5.20E-02	8.00E-02	7.24E-02
IW	2.10E-02	2.80E-01	8.70E-02	6.00E-02	5.10E-02	4.08E-01	3.06E-02
ABW	1.80E-03	3.00E-01	5.80E-02	5.10E-02	2.70E-02	9.20E-01	4.50E-03
AMR	2.00E-03	8.84E+00	2.13E-02	9.23E-01	2.04E-02	3.20E-02	9.80E-03
IYR	2.00E-03	1.77E+00	4.25E-03	9.23E-01	2.04E-02	6.40E-01	1.96E-03
∑HEAVY METALS	2.87E-01	1.86E+00	2.29E-01	2.02E+00	2.71E-01	1.87E+01	2.19E-01
Background	1.40E-01	2.30E-01	0.41E+01	2.41E+01	4.11E+00	1.40E-01	5.56E+01
USEPA, (2002)	2.70E+02	1.10E+01	6.20E+03	2.00E+02	7.20E+01	-	1.10E+03

Keys: USEPA, United State Environmental Protection Agency

Table 4: Contamination Level of Some Heavy Metals in Kaduna Metropolis

ROADS	Cu	Cr	Fe	Pb	Ni	Sn	Zn
ABKZEW	2.29	-	-	-	0.02	4.29	0.01
NKR	0.31	0.01	0.01	-	0.01	0.57	-
IW	0.21	0.01	0.02	-	0.01	2.91	-
ABW	0.02	0.01	0.01	-	0.01	6.57	-
AMR	0.02	0.38	0.01	0.04	-	0.23	-
IYR	0.02	7.70	-	0.04	-	4.57	-

3.1 Concentration of PAHs in Roads Dust

In Table 1, B(a)P has recorded the highest mean concentrations of 9.30E-01 mg/kg and 9.90E-01 mg/kg in Independence Way and Abuja Kaduna Zaria Express Way. The highest concentration of PAHs recorded in these expressways may be possibly due to the heavy load of car emissions, indicating the impact of road activities in the study area [21]. This reveals that HMW-PAHs (5–6 rings) contribute the highest percentage of PAH carcinogenicity in road dust due to their higher TEFs values compared to LMW-PAHs (2–3 rings). HMW-PAHs have a higher tendency to adhere to street dust [22, 23]. Poor engine maintenance and fuel quality have a major impact on HMW-PAH emissions [5]. The concentrations of PAHs in road dusts from Kaduna metropolis were comparable to levels reported for Warri in Nigeria [24]; however, lower levels of PAHs were found in dusts from Kaduna metropolis than those of street dusts from Lagos, Nigeria [25], and Kumasi, Ghana [16].

3.2 HEALTH RISK ASSESSMENT OF PAHS

3.2.1 Carcinogenic Risk Assessment for Human Health

The cancer risk levels via the inhalation pathway (9.72E-04) and dermal contact (1.23E-04) for children were recorded as the highest in all the dust samples. Both inhalation and dermal contact greatly contribute to cancer. Therefore, inhalation and dermal are the main pathways for exposure to PAHs and bear a high risk. Also, other studies show similar results [26]. Children have smaller bodies than adults; it is thought that a child's daily consumption of PAHs (mg/kg body weight) is higher [23]. Cancer risks observed in this study were less than 10^{-6}, with 10^{-7} representing no possible cancer risk (ILCR) being the highest recorded risk. Reduced traffic volume in Kaduna's city may be the cause of the reduced cancer risk. It is important to note that every road in the city (with little traffic) has a low individual cancer risk (below 10^{-6}).

3.3 Concentrations of Some Heavy Metals in the Road Dust

Table 3 revealed that Pb had the highest total mean concentrations (2.02E+00 mg/kg) in the street dust samples; this value is below the [17], acceptable limit (2.00E+01 mg/kg), while Fe had the lowest (2.29E-01 mg/kg). Given that Pb is the primary consequence of burning gasoline, this could be the case [27]. Previous studies showed that automobile exhaust emissions from gasoline combustion accounted for a sizable amount of the Pb detected in urban roadside soil [28]. Similarly, the mean concentration of Cr and Sn observed in road dust samples was above the regulatory control limits of 1.10E+01 mg/kg as prescribed by [17], for the soils specified by the Nigerian regulatory body. It was observed that these findings were above those presented by [29, 30].

3.3.1 Contamination Level of Some Heavy Metals in the Street Dust

The contamination factor (CF) for all measured individual metals is presented in Table 4. The mean CF values of all metals were found in the following order: IYR (7.70: very high)>ABW (6.57: very high)>ABKZEW (2.29: moderate) AMR > (0.04: low), IW > (0.02: low), and NKR> (0.01: low) the study quantified that the street dust of the investigated areas was inclined with heavy metals. Most of the metals and sampling sites in Kaduna city's street dust showed moderate to substantial contamination, suggesting a potential risk to the surrounding ecosystems {31].

CONCLUSION

The highest percentage of PAH carcinogenicity in road dust was found in the concentration of HMW-PAHs (5–6 rings) on Independence Way and Abuja Kaduna Zaria Express Way. *C*hildren are found to be at a higher risk of cancer due to exposure to contaminated particles, with the highest incremental lifetime cancer risk (ILCR). The carcinogenic PAHs were found to be below the USEPA's limit, indicating no cumulative carcinogenic risk. The concentration of Pb in road dust samples was found to be below the acceptable limit, while Cr and Sn were found to be above the regulatory control limits. The contamination factor index showed elevated levels of potentially toxic metals in road dust samples, except for Cu, Fe, Ni, and Zn, which were below the acceptable limit set by the Nigerian regulatory body.

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