

# POTENTIALLY TOXIC ELEMENTS (PTES) IN CIGARETTE AND MARIJUANA SMOKE IN NIGERIA: ECOLOGICAL, HEALTH, AND FEMALE REPRODUCTIVE RISKS ASSESSMENT

Muibat Adesola Adeniran<sup>1\*</sup>, Afeez Kolawole Oyeneye<sup>2</sup>, Zainab Temitope Yaqub<sup>2</sup>

<sup>1</sup>Department of Obstetrics and Gynecology, Ladoke Akintola University of Technology, Ogbomoso, Nigeria,

<sup>2</sup>Department of Chemical Engineering, University of Ilorin, Ilorin, Nigeria.

\*Corresponding author: maadeniran35@lautech.edu.ng

## Abstract

**Keywords:** Smoking machine, potentially toxic elements, Ecological risk, Human health risk

This study successfully quantified the ecological and health risks associated with cigarette and marijuana smoking by carrying out analysis on five samples of common cigarette and marijuana smoke brands. Findings showed that the mean concentration of Fe, As, Zn, Cu, Cr, Co and Ni in cigarettes were 1.5, 1.2, 1.7, 2.0 and 2.5 times higher than marijuana mean concentration respectively. Generally, the mean concentrations of PTEs in marijuana smoke followed the trend: Zn > As > Mn > Ni > Cd > Cu > Fe > Cr > Co > Pb. Similarly, the mean concentrations of PTEs in cigarette smoke followed the trend: Zn > As > Mn > Cu > Fe > Ni > Cr > Co > Pb > Cd. Enrichment factor estimates indicated an extremely high enrichment for both cigarette and marijuana samples for all PTEs except Pb in the marijuana sample which was found to be below the detectable limit. Geo-accumulation index results showed that the samples are practically uncontaminated. However, Cd indicated uncontaminated to moderately-contaminated in 80% of the marijuana samples. A similar trend was observed by contamination factor, all PTEs have a low contamination factor except for Cd which has a moderate contamination factor in 100% of the marijuana samples. Out of all studied PTEs, the NIPI and NIRI of Cd were the highest and are both consistent with other pollution indices (EF, Igeo, Cf, and ERI). The HI for children and adults from both marijuana and cigarette smoke for all potentially toxic elements was within the safe limit (HI < 1). However, children are at greater risk compared to adults. Among the five analyzed PTEs, Cd has the highest carcinogenic risks for marijuana smokes while As was found to have the highest carcinogenic risks for cigarette smoke. Ingestion pathway (CRing) was found to be responsible for 99.84% and 97.04% for children and adults respectively for both marijuana and cigarette smoke.

## 1. Introduction

Air pollution known as haze, is made up of ambient air pollution and household air pollution reported to about 252000 and 304000 lung cancer related deaths annually respectively. Fine particulates emanate from Tobacco and marijuana due to their incomplete combustion with characteristic similar carcinogens and cause similar diseases. Tobacco is the generic name for plants of the Nicotiana genus of the Solanaceae family. It is also commonly used to refer to anything made from the cured leaves of these plants. The principal constituent of tobacco, nicotine with a great physiological effect on humans has the general chemical formula  $C_{10}H_{14}N_2$ . Some examples of widely smoked tobacco include; cigarettes, cigars, hookahs (water pipe), bidis and kreteks. Tobacco smoke is the leading cause of lung cancer death, accounting for more than 85% of all lung cancer deaths (Bray et al., 2018)

*Cannabis sativa*, often known as Indian hemp, hemp, ganja, hashish, hemp, grass and marijuana, is a plant species belonging to the Cannabinaceae family. It contains the chemical compound THC (trans- $\Delta^9$ -tetrahydrocannabinol), with chemical formula  $C_{19}H_{26}O_2$  believed to be accountable for the characteristic psychoactive effects of cannabis that results in the "high sensation" observed when cannabis is consumed (Boonyayothin, Kobtrakul, Khositanon, Vimolmangkang, & Phoolcharoen, 2022). The dried leaves and flowers commonly referred to as marijuana can be hand-rolled or consumed in edibles such as cookies, rice, beans and gummies. Some of the health effects of cigarettes and marijuana include; increased pulse and heart rate; distorted perceptions of time and space (toxic psychosis); an altered state of consciousness; hallucinations and feelings of unreality. Carcinogens in marijuana can cause respiratory issues.

Models used for the exposure assessment and the health risk associated with smoking of cigarette and marijuana smoke constituents include the use of extract from tobacco particulate matter, extract from smokeless tobacco, inhalation of cigarette smoke and the cigarette smoke extract. Sophisticated smoking machines have been invented to make reproducibility samples of cigarette smoke extracts. However, the cost of acquiring this machine as well as the high technicality in their usage and maintenance necessitated the need for alternative, economical yet efficient smoking machine. This study investigated concentration levels of Potentially Toxic Elements (PTEs), ecological and human health risks associated with the consumption of cigarettes and marijuana available in Nigeria. The specific objectives of this study are to: (i) estimate and describe the distribution patterns of PTEs in cigarette and marijuana smokes (ii) evaluate the ecological risks of PTEs using existing and new contamination indices (iii) evaluate the potential human health risks associated with PTEs in cigarette and marijuana smokes.

## 2. Materials and Method

### 2.1 DESCRIPTION OF EXPERIMENTAL SET-UP

Five brands of filtered cigarettes and raw marijuana carefully selected based on their consumption rate in Nigeria were investigated to quantify particulate-bound PTE ecological and human health risks. Table 1 showed the sample code for the different brands of cigarettes and marijuana adopted for this research. Marijuana been contraband necessitated the application for ethical approval to undertake this research from the University of Ilorin ethical review committee. The protocol having identification code UERC/ENG/074 was submitted to the committee and having met the requirement, the research was fully approved by the ethical review committee with approval number UERC/ASN/2023/2459. Cigarette and marijuana samples were locally sourced and stored at room temperature but carefully placed in a zipper lock to avoid airborne contaminants.

Table 1: Sample codes for cigarette and marijuana

S/N	Sample	Sample Code	Brand Name	Brand Description
1	Cigarette	C1	Bohem	Imported/Filtered
2		C2	Gum	Imported/Filtered
3		C3	Oris	Imported/Filtered
4		C4	Rothmans	Imported/Filtered
5		C5	Royals	Imported/Filtered
1	Marijuana	M1	Arizona	Local/Unfiltered
2		M2	Colorado	Local/Unfiltered
3		M3	Jedi	Local/Unfiltered
4		M4	Local Igbo	Local/Unfiltered
5		M5	Loud	Local/Unfiltered

## 2.2 DESCRIPTION OF EXPERIMENTAL SET-UP

This study was conducted using a syringe-lung model (Figure 1) in the Environmental Engineering research laboratory of the Department of Chemical Engineering, University of Ilorin. The mainstream smoke of cigarette and marijuana were collected using the syringe lung model (an improvised smoking machine specifically designed for this research). The syringe model comprised of a 60 ml syringe, a pair of one-way air valve which prevents back-flow of smoke particles from and out of the smoking machine during sucking and puffing. A connecting hose and a cotton wool (representative lung) used as a medium to collect the mainstream smoke samples. For each experimental run, the smoking machine was carefully cleaned to avoid cross mixing of different smoke brands. Adopting the ISO standards, the machine drew puffs of cigarette smoke into the cotton wool, lasting 2 seconds at 60 seconds puff interval (Lu, H., &Zhu, L. (2007); ISO 1986). Similarly, the procedure was repeated for the marijuana samples and each experiment run lasted for about 5 minutes. All the 10 wool samples were wrapped with aluminum foil paper, stored in a tagged zipper lock nylons and transferred to the laboratory for digestion and elemental analysis.

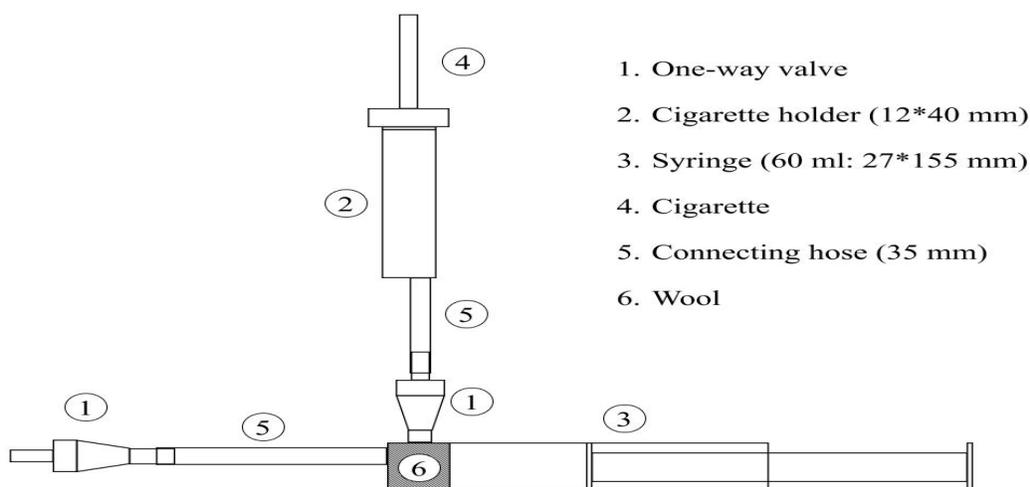


Figure 1: Smoking machine

## 2.3 PROCEDURE FOR AAS ANALYSIS

The preparation of all solutions was done using de-ionized distilled water (DDW). Aqua-regia (HCl and HNO<sub>3</sub> mix) was prepared using analytical reagent (AR) grade hydrochloric acid and hydrogen trioxonitrate (V) acid. Standard stock solutions for each metal at a concentration of 1000 mg/L were prepared using the respective analytical reagent (AR) grade metallic salts. Additionally, the pure solid forms of Cu, Ni, and Zn were utilized to create their 1000 mg/L standard solutions, dissolving them in either HCl or HNO<sub>3</sub> with distilled water.

1 g of the wool containing smoke particle was dissolved in 100 ml aqua-regia (HCL: HNO<sub>3</sub>; 3:1) in 250 ml conical flasks, the resulting solution was placed on a hot plate and heated to 70 °C for 30 minutes. This ensured leaching of all the particles in the wool into the aqua regia solution. The heated solution was allowed to cool in a fume cupboard until no brown fumes were observed. The digest was reduced to 50 ml by dryness. Dried solution of the digest was cooled at room temperature, and filtered by 5C 110-mm diameter Whatmann filter paper into a 100 mL volumetric flask.

Using Atomic Absorption Spectroscopy (AAS), the digested samples were analysed for elemental concentrations of ten PTEs: iron (Fe), zinc (Zn) arsenic (As), lead (Pb), manganese (Mn), cobalt (Co) chromium (Cr), copper (Cu), cadmium (Cd), and nickel (Ni) that were potentially toxic elements in urban environments (Adimalla, 2020; Cai *et al.*, 2019; D. Han

et al., 2017; Jiang, Cai, Wen, Hu, et al., 2020; Jiang, Cai, Wen, & Luo, 2020; Maeaba et al., 2019; Men, Liu, Xu, et al., 2019).

To ensure quality control, an analysis was conducted on Standard Reference Material (GSS-1/RDMIB2023), method blanks, and replicate samples to validate the accuracy of element determinations. No potentially toxic element (PTE) was detected in the blank samples. The recoveries of PTEs ranged from 93% to 109%, and the relative standard deviations of replicate samples did not surpass 5%.

## 2.4 ECOLOGICAL AND HEALTH RISK ASSESSMENT OF PARTICULATE BOUND PTEs

### 2.4.1 Capacity and throughput analysis

The particulate bound potentially toxic elements in cigarette and marijuana smoke were estimated using numerous existing and new pollution indices such as Geo-accumulation Index ( $I_{geo}$ ), Enrichment Factor (EF), Contamination Factor ( $C_f$ ), Potential Ecological Risks Index (ERI), Nemerov Integrated Pollution Index (NIPI) and Nemerov Integrated Risk Index (NIRI). The geo-accumulation index ( $I_{geo}$ ) compares the experimentally obtained PTE levels to a background levels used with sediments. The geo-accumulation index is a standard index used to estimate contamination from a single element (Odediran et al., 2021).  $I_{geo}$  Was estimated using Equation 1;

$$I_{geo} = \log_2 \left( \frac{C_n}{1.5B_n} \right) \quad (1)$$

The enrichment factor (EF) of PTEs was calculated using Equation 2;

$$EF = \frac{[C_n/R_{ref}]_{sample}}{[B_n/B_{ref}]_{background}} \quad (2)$$

Where  $[C_n/R_{ref}]_{sample}$  and  $[B_n/B_{ref}]_{background}$  are the target metal concentration ratio and the reference metal in the smoke samples respectively. For this study, iron was adopted as the reference element due to its low interactions with other PTEs, relative abundance in nature and minimal human related influence (Adimalla, Qian, & Wang, 2019)

The Potential Ecological Risks Index (ERI) to investigate the risk associated with PTEs present in cigarette and marijuana smoke was calculated using Equation 3 and 4 (Men et al., 2018).

$$E_r^i = T_r^i \times C_f^i \quad (3)$$

$$C_f^i = \frac{C_{0-1}^i}{C_n^i} \quad (4)$$

Where  $E_r^i$ ,  $T_r^i$ ,  $C_f^i$ ,  $C_{0-1}^i$  and  $C_n^i$  are the potential ecological risk factor of a metal, the metal toxicity factor, contamination factor of single metal of interest, sample concentration measured and the soil's background concentration, respectively. The estimation of the degree of contamination was carried out by summing up the contamination factors for all the elements that were examined, this is shown in Equation 5 (Odediran et al., 2021).

$$C_{deg} = \sum C_f^i \quad (5)$$

Nemerov Integrated Pollution Index (NIPI) was used to estimate the level of contamination in a soil environment. This is given by (Ogunkunle & Fatoba, 2013).

$$NIPI = \sqrt{\frac{(PI_{ave}^2 + PI_{max}^2)}{2}} \quad (6)$$

Where  $PI(C_f^i)$ ,  $PI_{ave}$  and  $PI_{max}$  are the PTE pollution index, average PI value and maximum PI values, respectively. NIRI is evaluated using Equation 7.

$$NIRI = \sqrt{\frac{(E_{r_{ave}}^i + E_{r_{max}}^i)}{2}} \quad (7)$$

Where  $E_{r_{ave}}^i$ ,  $E_{r_{max}}^i$  are the mean value of  $E_r^i$  and the highest value of  $E_r^i$  respectively.

### 2.4.2 Health risk assessment

The Average Daily Dose (ADD) for children and adults were analyzed through the three exposure routes; ingestion ( $ADD_{ing}$ ), inhalation ( $ADD_{inh}$ ), and dermal contact ( $ADD_{dermal}$ ) (Han, Gao, Wei, Xu, & Gao, 2016; Men et al., 2018). These are shown in Equations 8 to 10.

$$ADD_{ing} = \frac{C \times IngR \times EF \times ED}{BW \times AT} \times 10^{-6} \quad (8)$$

$$ADD_{inh} = \frac{C \times InhR \times EF \times ED}{PEF \times BW \times AT} \quad (9)$$

$$ADD_{dermal} = \frac{C \times SA \times AF \times ABF \times EF \times ED}{BW \times AT} \times 10^{-6} \quad (10)$$

Where C, IngR, EF, ED, BW, AT, InhR, PEF, SA, AF and ABF are the heavy metal concentration in dust, the ingestion rate of soil, the exposure frequency, the exposure duration, the average body weight, the average time, the inhalation rate, the particle emission factor, the surface area of the skin that comes in contact with smoke particle, the skin adherence factor and the dermal absorption factor, respectively.

The non-carcinogenic PTEs probability risks of smoke sample are determined by estimating the Hazard Quotient (HQ) and Hazard Index (HI) using Equations 11 and 12 (Asvad et al., 2023; Li, Qian, Hu, Wang, & Gao, 2013).

$$HQ = \frac{ADD_i}{R_f D} \quad (11)$$

$$HI = \sum_{i=1}^3 HQ_i \quad (12)$$

Where  $R_f D$  is reference dose in  $mg \text{ kg}^{-1} \text{ day}$ .

Carcinogenic PTEs probability risks of smoke sample are determined using Equations 13 and 14 (Dehghani, Moore, Keshavarzi, & Beverley, 2017).

$$CR_i = ADD_i \times SF \quad (13)$$

$$CR = \sum_{i=1}^3 CR_i \quad (14)$$

Where  $CR_i$  and SF are carcinogenic risk for pathway  $i$  and carcinogenic slope factor.

## 3. Optimization Techniques for RIS-aided NOMA

### 3.1 Concentration of Potentially Toxic Elements (PTEs) in Cigarette and Marijuana Samples

The concentrations of PTEs (mg/kg) in cigarette and marijuana samples are as shown in Table 1. From the Ten PTEs analyzed, the mean concentration of cigarette was higher than marijuana for all the elements except for cadmium and manganese which have higher mean concentration in the marijuana sample. The mean concentrations of cigarette for Fe, As, Zn, Cu, Cr, Co and Ni in cigarette were 1.5, 1.2, 1.7, 2.0 and 2.5 times higher than marijuana while the mean concentrations of marijuana for Cd, Cu and Mn are 11.3, 1.02 and 2.1 times higher than the cigarette mean concentration respectively. In addition, Lead (Pb) concentration fell below the detectable limit in the marijuana samples. Generally, the mean concentrations of PTEs in marijuana smoke followed the trend:  $Zn > As > Mn > Ni > Cd > Cu > Fe > Cr > Co > Pb$ . Similarly, the mean concentrations of PTEs in cigarette smoke followed the trend:  $Zn > As > Mn > Cu > Fe > Ni > Cr > Co > Pb > Cd$ . The higher concentration of some of the PTEs in cigarette samples compared to the marijuana samples may be attributed to the difference in weight of the cigarette and marijuana samples. The sum of all the PTEs by sample showed that for the marijuana samples M4 had the highest concentration of total PTEs with value of 8.4 mg/kg while M3 had the least concentration with value of 4.37 mg/kg. Hence the concentration of PTEs present in marijuana samples followed the order  $M4 > M2 > M1 > M5 > M3$  (8.4, 7.6, 6.8, 5.1 and 4.4 mg/kg, respectively). Similarly, for the cigarette samples C2 had the highest concentration of total PTEs with value of 11.4 mg/kg while C5 had the least concentration with value of 4.1 mg/kg. Hence the concentration of PTEs present in cigarette samples followed the order  $C2 > C3 > C4 > C1 > C5$  (11.4, 8.5, 7.3, 6.3 and 4.1 mg/kg, respectively). Table 1: Descriptive statistics of PTEs concentration in cigarette and marijuana smoke (mg/kg).

3.2 Ecological Risk Assessment of PTEs from Marijuana and cigarette smoking  
 3.2.1 Enrichment Factor (EF)

S/N	Sample	Concentration (mg/kg)									
		Fe	As	Cd	Zn	Cu	Mn	Pb	Cr	Co	Ni
<b>Cigarette</b>											
1	C1	0.289	0.144	0.064	4.308	0.489	0.208	0.123	0.222	0.117	0.307
2	C2	0.362	0.704	0.033	8.225	0.518	0.885	0.000	0.243	0.138	0.301
3	C3	0.289	1.065	0.048	5.533	0.607	0.163	0.000	0.295	0.174	0.396
4	C4	0.434	1.264	0.109	3.878	0.459	0.355	0.000	0.295	0.206	0.283
5	C5	0.362	1.769	0.003	0.217	0.607	0.237	0.000	0.318	0.204	0.357
	Mean	0.347	0.989	0.051	4.432	0.536	0.370	0.025	0.274	0.168	0.329
	Minimum	0.289	0.144	0.003	0.217	0.459	0.163	0.000	0.222	0.117	0.283
	Maximum	0.434	1.769	0.109	8.225	0.607	0.885	0.123	0.318	0.206	0.396
	Median	0.362	1.065	0.048	4.308	0.518	0.237	0.000	0.295	0.174	0.307
	SD	0.061	0.609	0.039	2.902	0.068	0.297	0.055	0.040	0.040	0.047
	Skewness	0.495	-0.242	0.505	-0.327	0.198	1.938	2.236	-0.493	-0.363	0.819
	Kurtosis	-0.660	0.093	0.742	1.238	-2.710	3.828	5.000	-2.053	-2.266	-0.995
	CV%	0.004	0.371	0.002	8.422	0.005	0.088	0.003	0.002	0.002	0.002
<b>Marijuana Mix</b>											
1	M1	0.199	0.758	0.608	3.676	0.533	0.664	0.000	0.087	0.037	0.315
2	M2	0.271	0.199	0.699	4.402	0.622	0.988	0.000	0.086	0.052	0.361
3	M3	0.235	1.300	0.442	0.000	0.489	0.753	0.000	0.154	0.104	0.893
4	M4	0.307	0.614	0.669	4.133	0.666	1.150	0.000	0.190	0.065	0.628
5	M5	0.145	1.300	0.487	1.078	0.430	0.355	0.000	0.173	0.078	1.072
	Mean	0.231	0.834	0.581	2.658	0.548	0.782	0.000	0.138	0.067	0.654
	Minimum	0.145	0.199	0.442	0.000	0.430	0.355	0.000	0.086	0.037	0.315
	Maximum	0.307	1.300	0.699	4.402	0.666	1.150	0.000	0.190	0.104	1.072
	Median	0.235	0.758	0.608	3.676	0.533	0.753	0.000	0.154	0.065	0.628
	SD	0.063	0.472	0.112	1.988	0.096	0.306	0.000	0.049	0.026	0.329
	Skewness	-0.310	-0.258	-0.344	-0.697	0.092	-0.304	0.000	-0.309	0.498	0.267
	Kurtosis	-0.644	-1.477	-2.477	-2.307	-1.730	-0.378	0.000	-2.902	-0.030	-2.206
	CV%	0.004	0.223	0.013	3.954	0.009	0.094	0.000	0.002	0.001	0.108

The degree of increase in PTEs in smoking media relative to mean natural abundance showed an enrichment value above 40, this indicated an extremely high enrichment for both cigarette and marijuana smoke respectively. Although, lead was found to be deficient to minimal enrichment in the marijuana sample as it was below the detectable limit. The mean enrichment value of all studied PTEs in cigarette followed the trend: Cd > As > Zn > Cu > Co > Ni > Cr > Pb > Mn. Cd had the highest enrichment value of 25097 while Mn had the lowest enrichment value of 59. The sum of all the PTEs by sample showed that for the cigarette samples C4 had the highest enrichment factor of total PTEs with value of 62720 while C5 had the least enrichment factor with value of 25411. Hence the enrichment factors of PTEs present in cigarette samples followed the trend; C4 > C3 > C1 > C2 > C5 (62720, 59575, 53726, 40379, 25411, respectively). Similarly, The mean enrichment value of all studied PTEs in marijuana followed the trend: Cd > As > Zn > Ni > Cu > Co > Cr > Mn > Pb. Cd had the highest enrichment value of 570965.5 while Pb had the lowest enrichment value of 0. The sum value of all the PTEs by sample showed that for the marijuana samples M5 had the highest enrichment factor of total PTEs with value of 622028 while M3

had the least enrichment factor with value of 348445. Hence the enrichment factors of PTEs present in marijuana samples followed the order  $M5 > M1 > M2 > M4 > M3$  (622028, 550388, 457115, 391400, 348445, respectively).

### 3.2.2 Geo-accumulation Index ( $I_{geo}$ )

The analysis of  $I_{geo}$  using the statistical analysis (Table 2) showed values for geo-accumulation index of PTEs to be less than zero for both marijuana and cigarette smoke samples. This indicated that the samples are practically uncontaminated. However Cd indicated uncontaminated to moderately contaminated in 80% of the marijuana samples.

### 3.2.3 Contamination factor ( $C_f$ )

The contamination factors of PTEs from marijuana and cigarette smoke is shown in table 2. Using the contamination factor indices in Table S1, all PTEs have a low contamination factor with the exception of Cd which has moderate contamination factor in 100% of the marijuana sample. The contamination degree of the cigarette samples followed the order  $C4 > C3 > C1 > C2 > C5$  with values of (0.53, 0.34, 0.33, 0.29, 0.18, respectively) comparing the contamination degree with the ecological index showed low degree of contamination. Similarly, the contamination degree of the marijuana samples followed the order  $M2 > M4 > M1 > M5 > M3$  with values of (2.42, 2.36, 2.15, 1.77, 1.61, respectively) comparing the contamination degree with the ecological index showed low degree of contamination.

### 3.2.4 Potential ecological risk

The potential ecological risk of PTEs from marijuana and cigarette smoke shown in table 2 ranged from low to moderate potential ecological risk. Using the potential ecological risk index in Table S1, for the cigarette samples, all PTEs showed low ecological risk however for the marijuana samples all the PTEs showed low ecological risk except Cd which had moderate potential ecological risk with a maximum of 69.9. Cd showed moderate potential ecological risk in 60% of the marijuana sample.

### 3.2.5 Integrated ecological risk assessment of NIPI and NIRI

The NIPI and NIRI of PTEs in cigarette and marijuana smoke samples are as shown in Figure 2 and 3, respectively. The NIPI values for both cigarette and marijuana showed no pollution for all studied PTEs except Cd which showed moderate pollution. All studied PTE's NIRI values are less than 40 which showed low risk except for Cd with a NIRI value of 64.3 which showed moderate risk.

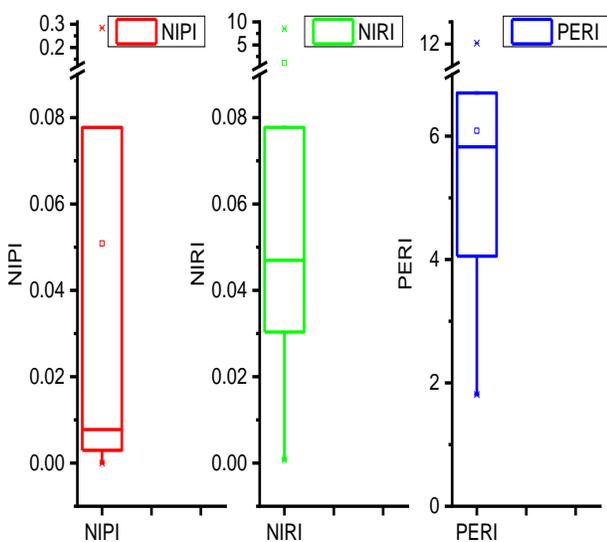


Figure 2: Risk indexes of PTEs in smoke samples of Cigarette

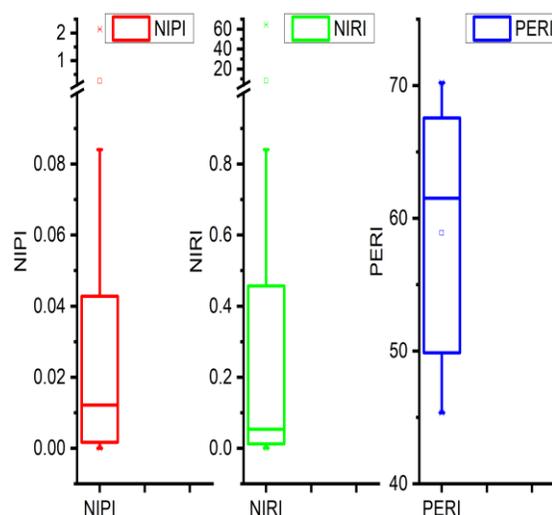


Figure 3: Risk indexes of PTEs in smoke samples of Marijuana

Heavy Metals	Statistics	Conc. (mg/kg)	Marijuana				Cigarette				
			EF	Igeo	Cf	Er	EF	Igeo	Cf	Er	
As	Mean	0.8342	16508.93	-4.821	0.064	0.642	0.989	10927.59	-4.695	0.076	0.761
	Minimum	0.199	2880.783	-6.615	0.015	0.153	0.144	1954.751	-7.081	0.011	0.111
	Maximum	1.3	35172.41	-3.907	0.1	1	1.769	19171.06	-3.462	0.136	1.361
Cd	Mean	0.581	443810.1	0.3586	1.937	58.1	0.051	25096.86	-3.817	0.171	5.14
	Minimum	0.442	319744.7	-0.026	1.473	44.2	0.003	1408.84	-7.229	0.01	0.3
	Maximum	0.699	570965.5	0.635	2.33	69.9	0.109	42695.85	-2.046	0.363	10.9
Zn	Mean	2.6578	6673.551	-5.429	0.031	0.039	4.432	7956.939	-5.521	0.052	0.052
	Minimum	0	0	-6.886	0	0.013	0.217	359.669	-9.199	0.003	0.0025
	Maximum	4.402	11083.42	-4.856	0.052	0.052	8.225	13632.6	-3.954	0.097	0.097
Cu	Mean	0.548	2486.626	-7.134	0.011	0.055	0.536	1623.376	-7.138	0.011	0.054
	Minimum	0.43	2122.468	-7.446	0.009	0.043	0.459	1078.756	-7.352	0.009	0.046
	Maximum	0.666	3024.828	-6.914	0.013	0.066	0.607	2142.353	-6.949	0.012	0.061
Mn	Mean	0.782	185.650	-10.905	0.000	0.000	0.3696	58.946	-12.125	0.000	0.0004
	Minimum	0.355	138.736	-11.893	0.000	0.000	0.163	31.961	-13.016	0.000	0.0002
	Maximum	1.15	212.269	-10.416	0.001	0.001	0.885	138.536	-10.575	0.001	0.0010
Pb	Mean	0	0	0	0	0	0.025	217.059	-7.930	0.006	0.031
	Minimum	0	0	0	0	0	0	0	-7.930	0.006	0.031
	Maximum	0	0	0	0	0	0.123	1085.294	-7.930	0.006	0.031
Cr	Mean	0.138	328.6281	-10.395	0.001	0.002	0.274	409.299	-9.108	0.002	0.005
	Minimum	0.086	161.845	-10.768	0.001	0.001	0.222	341.644	-9.400	0.002	0.004
	Maximum	0.19	608.4828	-9.760	0.001	0.003	0.318	519.706	-8.884	0.003	0.006
Co	Mean	0.0672	800.7113	-8.953	0.003	0.016	0.1678	1237.426	-7.517	0.008	0.042
	Minimum	0.037	474.1206	-9.663	0.002	0.009	0.117	972.099	-8.002	0.005	0.029
	Maximum	0.104	1371.724	-8.172	0.005	0.026	0.206	1535.294	-7.186	0.010	0.052
Ni	Mean	0.6538	3079.86	-7.426	0.011	0.054	0.329	833.388	-8.108	0.005	0.027
	Minimum	0.315	1345.477	-8.158	0.005	0.026	0.283	554.263	-8.313	0.004	0.024
	Maximum	1.072	6284.138	-6.392	0.018	0.089	0.396	1164.706	-7.828	0.006	0.033

### 3.3 Health Risk Assessment

The assessment of the health risks caused by exposure of children and adults to potentially toxic elements in cigarette and marijuana smoke through the three exposure pathways (that is; ingestion, inhalation and dermal) were estimated using equations (12-18). From the ten PTE's studied, five were found to be associated with both carcinogenic and non-carcinogenic risks (Pb, As, Cr, Cd and Ni) and four additional elements (Zn, Co, Cu and Mn) were associated with non-carcinogenic risks.

### 3.3.1 Non-carcinogenic risk assessment

The percentage risk contribution through ingestion (HQing) in HI for marijuana was 94.36% and 68.52% in children and adults respectively. Likewise the percentage risk contribution through ingestion (HQing) in HI for cigarette was 94.59% and 68.66% in children and adults respectively. Hence, from this study, it could be inferred that the main exposure pathway of potentially toxic elements from cigarette and marijuana is through ingestion, followed by dermal and inhalation. Similar trends have been reported in previous studies (Odediran et al., 2021; Chen et al., 2019; Men et al., 2018). In addition, the overall percentage risk contribution through ingestion (HQing) and CRing for marijuana smoke for both children and adults was estimated to be 81.62% and 98.44% respectively. Similarly, the overall percentage risk contribution through ingestion (HQing) and CRing for cigarette smoke for both children and adult was estimated to be 81.63% and 98.44% indicating that the carcinogenic risks associated with ingestion pathway is higher than the non-carcinogenic risks. The hazard quotient for children through the ingestion, inhalation and dermal pathways were 9.33, 2.78 and 0.49 times that of Adults respectively for both cigarette and marijuana. The HI for children and adults from both marijuana and cigarette smoke for all potentially toxic elements were within the safe limit ( $HI < 1$ ). The concentration levels for lead in all the marijuana and cigarette samples were below the detectable limits except only one of the cigarette sample.

### 3.3.2 Carcinogenic Risks

The slope factor being a very important determinant for estimating carcinogenic risk is only available for As, Cd, Pb, Cr and Ni. Hence the carcinogenic risks of only the five potentially toxic elements were determined using Equations (2.17 and 2.18). Among the five analyzed PTE's, Cd has the highest carcinogenic risks for marijuana smokes while As was found to have the highest carcinogenic risks for cigarette smoke (Figure 7). Ingestion pathway (CRing) was found to be responsible for 99.84% and 97.04% for children and adult respectively for both marijuana and cigarette smoke. HQing, HQinh and HQdermal for children were 9.33, 2.78 and 0.49 times that of Adults respectively for both cigarette and marijuana. The cancer risks for the five PTE's studied for both marijuana and cigarette fall below the  $10^{-4}$  range indicating that the global statutory limit recommended by the United State Environmental Protection Agency as well as the International Agency for Research on Cancer (IARC) were not exceeded. (Odediran et al., 2021; Du et al., 2013; IARC 2011; USEPA 2011) In general, based on the study, the risk assessment results showed that children are at higher risk (both carcinogenic and non-carcinogenic) from smokes from both cigarette and marijuana.

### 3.4 Impact on Female Reproduction

The presence of potentially toxic elements (PTEs) in cigarette and marijuana smoke, as quantified in this study, raises significant concerns for female reproductive health, particularly regarding fertility and pregnancy outcomes. Women of reproductive age exposed to these PTEs through smoking may experience disruptions in ovarian function, hormonal balance, and fetal development. Key PTEs identified in higher concentrations such as cadmium (Cd) in marijuana smoke and arsenic (As) in cigarette smoke have been linked to adverse reproductive effects in epidemiological and toxicological studies.

Cadmium, found at markedly higher mean concentrations in marijuana smoke (0.581 mg/kg) compared to cigarette smoke (0.051 mg/kg), is a well-documented reproductive toxicant. Chronic exposure to Cd can impair ovarian steroidogenesis by altering enzymes like  $3\beta$ -hydroxysteroid dehydrogenase and  $17\beta$ -hydroxysteroid dehydrogenase, leading to reduced levels of gonadotropins such as luteinizing hormone (LH), follicle-stimulating hormone (FSH), and estradiol. This hormonal disruption contributes to ovulatory dysfunction, delayed menarche, and reduced fertility, with studies showing that women with elevated Cd levels experience longer time-to-pregnancy and higher rates of infertility. During pregnancy, Cd readily crosses the placenta, accumulating in fetal tissues and causing morphological damage to the placenta, which restricts nutrient and oxygen transfer. This results in adverse outcomes including low birth weight, preterm birth, fetal growth restriction, and increased risk of spontaneous abortion or stillbirth. Female fetuses appear particularly vulnerable, with evidence of sex-specific effects such as congenital cardiac anomalies and reduced gestational age. Given the extremely high enrichment factor for Cd in marijuana samples (mean 443,810) and its moderate ecological risk, women using marijuana may face amplified risks compared to cigarette smokers.

Arsenic, present at higher mean levels in cigarette smoke (0.989 mg/kg) than in marijuana smoke (0.834 mg/kg), also exerts detrimental effects on female reproduction. As exposure interferes with the hypothalamic-pituitary-ovarian axis, reducing gonadotropin secretion and altering neurotransmitter levels, which can lead to menstrual irregularities and infertility. Epidemiological data indicate associations with delayed conception and increased risks of primary and secondary infertility. In pregnancy, As is linked to adverse outcomes such as spontaneous abortion, stillbirth, preterm delivery, and low birth weight, with meta-analyses confirming dose-dependent relationships. The placenta acts as a partial barrier, but As still reaches the fetus, potentially causing developmental delays and congenital malformations. The high enrichment of As in both smoke types (mean EF >10,000) underscores its potential to exacerbate these risks, particularly for cigarette users.

Other PTEs, such as lead (Pb) detected in cigarette smoke (mean 0.025 mg/kg) but below detectable limits in marijuana, and manganese (Mn) higher in marijuana (mean 0.782 mg/kg), further compound reproductive hazards. Pb exposure is associated with impaired spermatogenesis in partners but directly affects women by causing menstrual disturbances, reduced fertility, and elevated risks of miscarriage, preeclampsia, and preterm birth. Mn, while essential in trace amounts, can disrupt endocrine function at higher levels, potentially contributing to ovulatory issues. The ingestion pathway, responsible for the majority of PTE exposure in this study (~99% for children and 97% for adults), aligns with mechanisms where PTEs accumulate in reproductive tissues over time.

These findings are particularly relevant in Nigeria, where cultural and socioeconomic factors may increase women's exposure through secondhand smoke or shared environments. Although the overall hazard indices (HI <1) suggest low non-carcinogenic risks, the carcinogenic potential of Cd and As highest in marijuana and cigarette smoke, respectively warrants caution for reproductive-age women. Smoking cessation, especially preconception and during pregnancy, to mitigate these risks should be advised.

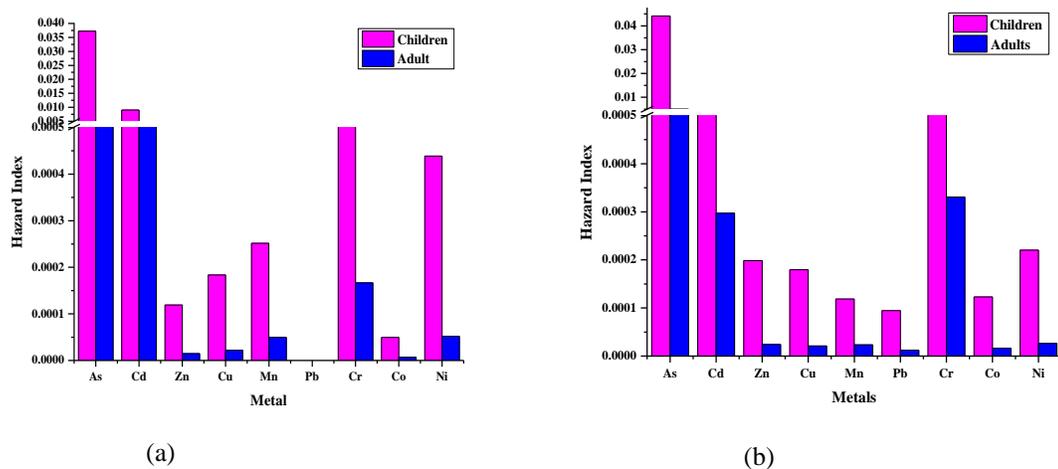


Figure 6: Hazard Index of PTEs in (a) marijuana samples (b) cigarette samples

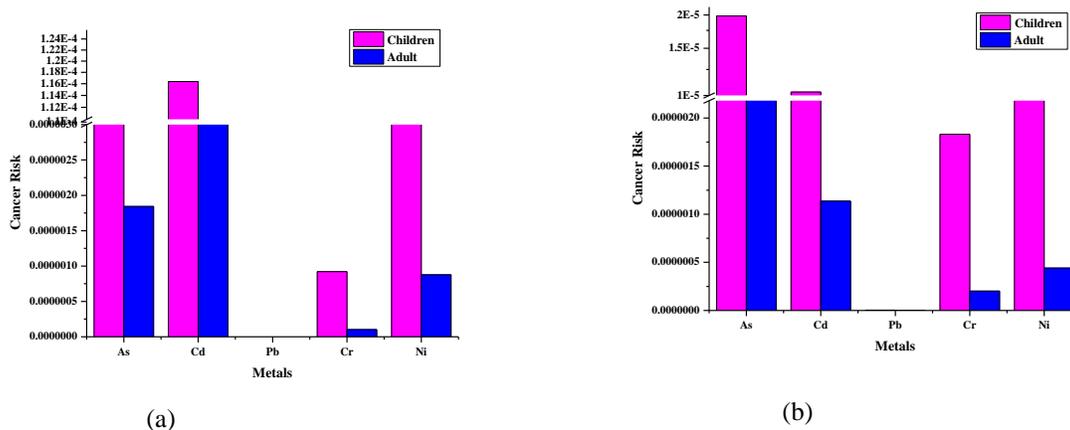


Figure 7: Cancer risk associated with PTEs in (a) marijuana sample (b) cigarette samples

#### 4. Conclusion

This study successfully quantified the ecological and health risk associated with cigarette and marijuana smoking by carrying out analysis on five samples each of common cigarette and marijuana smoke brands. Findings showed that the mean concentration of Fe, As, Zn, Cu, Cr, Co and Ni in cigarette were 1.5, 1.2, 1.7, 2.0 and 2.5 times higher than marijuana mean concentration respectively. While the mean concentration of Cd, Cu and Mn in the marijuana smoke samples are 11.3, 1.02 and 2.1 times higher than the mean concentration observed in the cigarette respectively. Generally, the mean concentrations of PTEs in marijuana smoke followed the trend: Zn > As > Mn > Ni > Cd > Cu > Fe > Cr > Co > Pb. Similarly, the mean concentrations of PTEs in cigarette smoke followed the trend: Zn > As > Mn > Cu > Fe > Ni > Cr > Co > Pb > Cd.

Enrichment factor estimates indicated an extremely high enrichment for both cigarette and marijuana samples for all PTEs except Pb in the marijuana sample which was found to be below the detectable limit. Geo-accumulation index results showed that the samples are practically uncontaminated. However Cd indicated uncontaminated to moderately-contaminated in 80% of the marijuana samples. Similar trend was indicated by contamination factor all PTEs have a low contamination factor with the exception of Cd which has moderate contamination factor in 100% of the marijuana samples. . Out of all studied PTEs, the NIPI and NIRI of Cd were the highest. The NIPI and NIRI results are consistent with other pollution indices (EF,  $I_{geo}$ ,  $C_f$ , and ERI).

The Hazard index for children and adults from both marijuana and cigarette smoke for all potentially toxic elements were within the safe limit ( $HI < 1$ ). However children are at greater risk compared to adults. Among the five analyzed PTE's, Cd has the highest carcinogenic risks for marijuana smokes while As was found to have the highest carcinogenic risks for cigarette smoke. Ingestion pathway (CRing) was found to be responsible for 99.84% and 97.04% for children and adult respectively for both marijuana and cigarette smoke. The cancer risks for the five PTE's studied for both marijuana and cigarette fell below the  $10^{-4}$  range indicating that the global statutory limit recommended by the United State Environmental Protection Agency as well as the International Agency for Research on Cancer (IARC) were not exceeded. In general, based on the study, the risk assessment results showed that children are at higher risk (both carcinogenic and non-carcinogenic) from smokes from both cigarette and marijuana.

From the results obtained, it is highly recommended that government and other stakeholders should work together and come up with measures to curb the use of drugs most especially the adolescence. Future research should incorporate biomarkers of exposure in women to better quantify PTE impacts on fertility metrics and pregnancy outcomes These measures may include but not limited to smoking cessation strategies, public health campaigns as well as strict regulatory measures.

#### Acknowledgement

The author acknowledges the support of the Ethical review committee of the University of Ilorin that provided the ethical backing to carry out this research work.

#### Funding

The author specially recognize the Petroleum Technology Development Fund (PTDF) for the funding provided for this research.

#### Declaration of Competing Interest

The authors declare that they have no known financial interests or interpersonal relationships that might have influenced the research presented in this study.

#### References

Adeniran, J., Yusuf, R., & Olajire, A. (2017). Exposure to coarse and fine particulate matter at and around major intra-urban traffic intersections of Ilorin metropolis, Nigeria. *Atmospheric Environment*, 166, 383-392.

- Adewuya, A. O., Oladipo, O. E., Imarah, T., Asmal, L., & Emsley, R. (2023). The 3-year progression of clinically significant psychotic-like experiences in a general adult population in Lagos, Nigeria. *Social Psychiatry and Psychiatric Epidemiology*, 58(1), 91-103.
- Adimalla, N., Qian, H., & Wang, H. (2019). Assessment of heavy metal (HM) contamination in agricultural soil lands in northern Telangana, India: an approach of spatial distribution and multivariate statistical analysis. *Environmental Monitoring and Assessment*, 191, 1-15.
- Asvad, S. R., Esmaili-Sari, A., Bahramifar, N., Behrooz, R. D., Paschalidou, A. K., & Kaskaoutis, D. G. (2023). Heavy metals contamination status and health risk assessment of indoor and outdoor dust in Ahvaz and Zabol cities, Iran. *Atmospheric Pollution Research*, 101727.
- Boonyayothin, W., Kobtrakul, K., Khositanon, P., Vimolmangkang, S., & Phoolcharoen, W. (2022). Development of a plant-produced recombinant monoclonal antibody against  $\Delta$ -9-tetrahydrocannabinol ( $\Delta$ 9-THC) for immunoassay application. *Biotechnology Reports*, 34, e00725.
- Bray, F., Ferlay, J., Soerjomataram, I., Siegel, R. L., Torre, L. A., & Jemal, A. (2018). Global cancer statistics 2018: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries. *CA Cancer J Clin*, 68(6), 394-424. doi:10.3322/caac.21492
- Cai, L.-M., Jiang, H.-H., & Luo, J. (2019). Metals in soils from a typical rapidly developing county, Southern China: levels, distribution, and source apportionment. *Environmental Science and Pollution Research*, 26(19), 19282-19293. <https://doi.org/10.1007/s11356-019-05329-1>
- Dehghani, S., Moore, F., Keshavarzi, B., & Beverley, A. H. (2017). Health risk implications of potentially toxic metals in street dust and surface soil of Tehran, Iran. *Ecotoxicology and Environmental Safety*, 136, 92-103.
- Galán-Madruga, D., Cárdenas-Escudero, J., Broomandi, P., Cáceres, J., & González, M. D. C. (2023). Evaluating urban indoor and outdoor PM10-bound organochlorine pesticides. Air quality status and health impact. *Building and Environment*, 228, 109818.
- Han, L., Gao, B., Wei, X., Xu, D., & Gao, L. (2016). Spatial distribution, health risk assessment, and isotopic composition of lead contamination of street dusts in different functional areas of Beijing, China. *Environmental Science and Pollution Research*, 23, 3247-3255.
- International Standard Organization, Interntion Standard: Cigarette-Routine Analytical Cigarette Smoking Conditions 1986
- Jiang, H.-H., Cai, L.-M., Wen, H.-H., Hu, G.-C., Chen, L.-G., & Luo, J. (2020). An integrated approach to quantifying ecological and human health risks from different sources of soil heavy metals. *Science of the Total Environment*, 701, 134466. <https://doi.org/10.1016/j.scitotenv.2019.134466>
- Keshavarzi, A., & Kumar, V. (2019). Ecological risk assessment and source apportionment of heavy metal contamination in agricultural soils of Northeastern Iran. *International Journal of Environmental Health Research*, 29(5), 544-560.
- Kowalska, J., Mazurek, R., Gąsiorek, M., Setlak, M., Zaleski, T., & Waroszewski, J. (2016). Soil pollution indices conditioned by medieval metallurgical activity—A case study from Krakow (Poland). *Environmental Pollution*, 218, 1023-1036.
- Lee, P.-K., Chang, H. J., Yu, S., Chae, K. H., Bae, J.-H., Kang, M.-J., & Chae, G. (2018). Characterization of Cr (VI)–containing solid phase particles in dry dust deposition in Daejeon, South Korea. *Environmental Pollution*, 243, 1637-1647.
- Li, H., Qian, X., Hu, W., Wang, Y., & Gao, H. (2013). Chemical speciation and human health risk of trace metals in urban street dusts from a metropolitan city, Nanjing, SE China. *Science of The Total Environment*, 456, 212-221.
- Lu, H., & Zhu, L. (2007). Pollution patterns of polycyclic aromatic hydrocarbons in tobacco smoke. *Journal of hazardous materials*, 139(2), 193-198.
- Lu, J., Lin, Y., Wu, J., & Zhang, C. (2021). Continental-scale spatial distribution, sources, and health risks of heavy metals in seafood: challenge for the water-food-energy nexus sustainability in coastal regions? *Environmental Science and Pollution Research*, 1-14.
- Maeaba, W., Prasad, S., & Chandra, S. (2019). First Assessment of Metals Contamination in Road Dust and Roadside Soil of Suva City, Fiji. *Archives of environmental contamination and toxicology*, 77(2), 249-262. <https://doi.org/10.1007/s00244-019-00635-8>
- Men, C., Liu, R., Xu, F., Wang, Q., Guo, L., & Shen, Z. (2018). Pollution characteristics, risk assessment, and source apportionment of heavy metals in road dust in Beijing, China. *Science of the Total Environment*, 612, 138-147.

- Men, C., Liu, R., Xu, L., Wang, Q., Guo, L., Miao, Y., & Shen, Z. (2020). Source-specific ecological risk analysis and critical source identification of heavy metals in road dust in Beijing, China. *Journal of Hazardous Materials*, 388, 121763.
- Odediran, E. T., Adeniran, J. A., Yusuf, R. O., Abdulraheem, K. A., Adesina, O. A., Sonibare, J. A., & Du, M. (2021). Contamination levels, health risks and source apportionment of potentially toxic elements in road dusts of a densely populated African City. *Environmental Nanotechnology, Monitoring & Management*, 15, 100445.
- Ogunkunle, C. O., & Fatoba, P. O. (2013). Pollution Loads and the Ecological Risk Assessment of Soil Heavy Metals around a Mega Cement Factory in Southwest Nigeria. *Polish Journal of Environmental Studies*, 22(2).
- Pourgholam-Amiji, M., & Khoshravesht, M. (2022). The Effect of Irrigation with Magnetically Treated Effluent on Uptake of Some Heavy Metals in Maize Cultivation. *Iranian Journal of Soil and Water Research ISNN*, 2423, 7833.
- Saud, B., Adhikari, S., Amatya, N., Thapa, H. S., Paudel, G., Shahi, S., & Yadav, P. K. (2023). Smoking Turnover Intention Among Active Tobacco Smokers During the COVID-19 Pandemic in Kathmandu, Nepal.
- Uduku, O., Lawanson, T., & Ogodu, O. (2021). Lagos: City scoping study. *Manchester, UK: African Cities Research Consortium, The University of Manchester. Available at: www.african-cities.org.*
- Williams, J. A., & Antoine, J. (2020). Evaluation of the elemental pollution status of Jamaican surface sediments using enrichment factor, geoaccumulation index, ecological risk and potential ecological risk index. *Marine Pollution Bulletin*, 157, 111288.
- Zhang, Y., Cao, S., Xu, X., Qiu, J., Chen, M., Wang, D., Guan, D., Wang, C., Wang, X., & Dong, B. (2016). Metals compositions of indoor PM 2.5, health risk assessment, and birth outcomes in Lanzhou, China. *Environmental monitoring and assessment*, 188, 1-13.
- Zhao, K., Fu, W., Qiu, Q., Ye, Z., Li, Y., Tunney, H., Dou, C., Zhou, K., & Qian, X. (2019). Spatial patterns of potentially hazardous metals in paddy soils in a typical electrical waste dismantling area and their pollution characteristics. *Geoderma*, 337, 453-462.
- Zhao, R., Guan, Q., Luo, H., Lin, J., Yang, L., Wang, F., Pan, N., & Yang, Y. (2019). Fuzzy synthetic evaluation and health risk assessment quantification of heavy metals in Zhangye agricultural soil from the perspective of sources. *Science of the Total Environment*, 697, 134126.