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Ecological risk estimation of heavy metal pollution in roadside dust of Ado-Odo Ota, Southwestern Nigeria

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Abstract. Increased industrial, commercial and transport activities have constantly introduced air pollutants such as heavy metals in the atmosphere. Roadside dust samples were collected from 10 locations along Ota-Benin road, analysed for Cr, Cd, Co, Ni, Pb, Fe, Mn, Cu, As and Zn, and the ecological risk was evaluated for the heavy metals' concentration in the roadside dust particles using the Hakanson method. The results revealed that Cd (3.103 mg/kg) and Cu (mg/kg) surpassed the threshold effect level. Pollutant source identification analysis revealed possible origin from motor oil, plastics, metalliferous extraction, dyes, and paints industries. The contamination factor for Ni was found to be at a moderate level in location SM8, SM9 and SM10 and a similar category was observed for Pb in location SM7, SM8, SM9 and SM10. Zn concentration in location SM5, SM6, SM7, SM8, SM9 and SM10 fell within the moderate contamination factor zone as well. Furthermore, the mean E_r^i of the individual metals in the sample region followed the order of Cd > Ni > Pb > As > Cu > Zn > Cr indicating a high risk associated with cadmium within the sample region.

1. Introduction

The earth has continued to retain its ability to maintain life forms up to a certain level and standard for billions of years since its formation. Despite this, long-term consequences of various anthropogenic activities are on the rise, thereby making the physical and natural environment unfit for human habitation [1]. Industrial areas are often characterised with high concentrations of air pollutants (e.g. dust particles) which may lead to increased morbidity and mortality rates [2], depending on the type of pollutants and the concentration to which the population living in the region is exposed [3]. Industrial activities such as coal and fuel combustion, construction activities, emissions from vehicles, municipal solid waste disposal and various industrial processes emit harmful substances into the environment with adverse effects on the environment and human health when the pollutants are not adequately controlled [4,5]. Improper disposal of industrial by-products, waste materials and uncontrolled anthropogenic activities may result in the contamination of air, soil and water considering that they can be transported through natural processes such as wind and runoff [6–9].

Urban centres and cities promote the political, social, cultural and commercial life of most countries. However, concentrated habitation combined with energy consumption, industrial activities and automobile emissions has contributed to heightened environmental pollution and degradation [10]. Emerging economies are faced with this impediment because of the dependence on fossil fuels, old transportation fleet and rapid urbanisation [11,12]. Researchers have identified transport fleets and domestic energy consumption as prime contributors to air pollution [11,12]. Particularly, developing nations have continually experienced deteriorated urban air quality because of swift urbanisation, under-designed road network, increased commuters and the prevalence of old, poorly maintained vehicles [13,14].

In 1999, Ado-Odo Ota was identified as a city that harbours one of the largest concentrations of industries in Nigeria, consisting mainly of food industries, pharmaceuticals, agro-allied industries, breweries and packaging companies [15]. Thus, the industrial growth of the region gave rise to a steady increase in population [16]. Over the years, the region has experienced increased, commercial and industrial activities, urban building cluster and conjected traffic movements. These activities result in the resuspension of breathable dust particles composed of heavy metal fractions.
In this regard, the current research aims at identifying the heavy metal content present in urban road dust, to identify the potential origin of heavy metals contaminants, and to evaluate the ecological risk potential of heavy metal pollution in Ado-Odo region of Southwestern Nigeria.

2. Materials and Methods

2.1 Study Region
Ado-Odo Ota is a town in Ogun state located between latitude 6° 42' 0" North and longitude 3° 14' 0" East. Its elevation is 74.259 m above the sea level and has a large concentration of land space with a land mass of about 1460 sq. km [15]. The main inhabitants are the Yorubas, although other ethnic groups like the Egba settlers, Egun, and Yewas (Egbados) reside within the region. This town is about 542 km south-west from Abuja and 39.31 km inland from Lagos [17]. Over the years Ota has grown into an industrial city due to the economic development planning and lobbying by the Manufacturers Association of Nigeria which led to the official designation of Ota as an industrial town. Some of the industries located in the area are pharmaceutical industries, breweries, aluminium roofing sheet, iron, and steel companies. The study area is underlain by the Precambrian basement complex of South-Western Nigeria and is at the fringes of the border between Nigeria and the Republic of Benin [8].

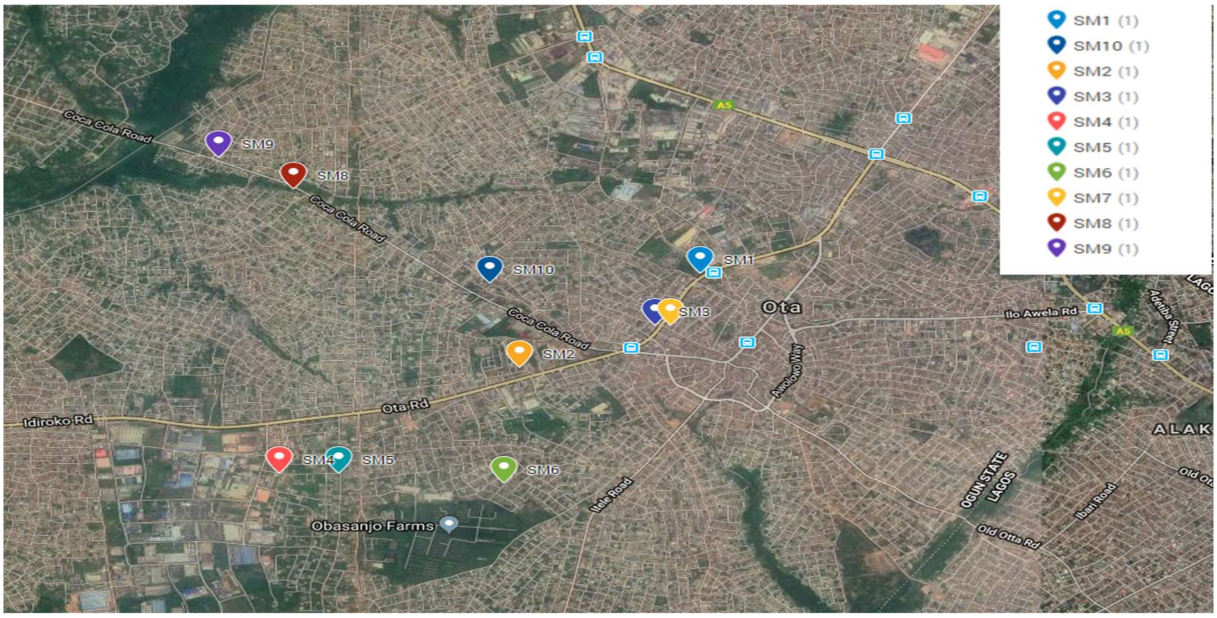


Figure 1: Map of sample location

2.2 Sample collection
Twenty street dust samples were collected from ten locations characterised by high traffic density and free from sites of contamination (Petrol stations, Mechanic workshops etc). Samples were collected during the dry season. At each sampling area, a composite sample was obtained composing of 200-250g roadside soil and 200-250 g of street dust. Before sampling, latex gloves, coveralls and face masks were worn. Before the samples were collected, brush and dustpan were used to sweep a 4-5m

radius, collecting samples of street dust from only impervious surfaces (gutters, roofs and road pavement). Thereafter, the samples were placed and in a sealed polyethylene zip locks. At the points were samples were collected, geographical identification was achieved by obtaining the GPS coordinates. This procedures were repeated at all sampling sites and the representative samples were transported to the lab for further heavy metal analysis.

2.3 Data Analysis

2.3.1 Statistical analysis

After the analysis of trace metals in the dust samples, descriptive statistics comprising of the mean, median, range, standard deviation, standard error of mean and percentile were obtained. The spatial analysis showing the concentration spread at each location was achieved using Surfer 15 software. Further statistical analysis, such as correlation analysis and factor analysis were conducted to identify the potential sources of the contaminants.

2.3.2 Ecological risk assessment

Hakanson technique [18] was used to derive the potential ecological risk index of heavy metals. The contamination factor (*CF*) for each trace metal was obtained with Equation 1, while the potential ecological risk index (E_r^i) was achieved with Equation 2 below.

$$CF = \frac{C_d}{C_r} \tag{1}$$

$$E_r^i = T_F \times CF \tag{2}$$

C_d represents the concentration of trace metal in the dust sample, C_r represents the reference value of trace metal in the study region, and T_F stands for the toxicity response factor. The criteria for evaluating the contamination factor and ecological risk index were presented in Table 1.

Table 1: Ecological risk criteria and toxicity response values of heavy metals

Ecological Risk			Toxic response values
Contamination Factor (*CF*)	$CF < 1$	Low contamination factor	The T_F of Cu, As, Cd, Pb, Ni, Cr, and Zn are given as 5, 10, 30, 5, 5, 2, and 1 respectively [18–20].
	$1 \leq CF \leq 3$	Moderate contamination factor	
	$3 \leq CF \leq 6$	Considerable contamination factor	
	$6 \leq CF$	Very high contamination factor	
Risk Index (E_r^i)	$Er < 40$	Low ecological risk	
	$40 < Er \leq 80$	Moderate ecological risk	
	$80 < Er \leq 160$	Considerable ecological risk	
	$160 < Er \leq 320$	High ecological risk	
	$Er > 320$	Serious ecological risk	

3. Results and Discussion

3.1 Trace metal concentration in roadside dust

Table 2 represents the concentration of toxic HM in the road dust from the different sample locations. The concentration of Zn in the dust samples varied from 14.98 to 136.20 mg/kg (mean value of 62.27mg/kg). Pb varied from 0.62 to 30.15 mg/kg (mean value of 14.53 mg/kg), Cr varied from 0.05 to 57.54 mg/kg (average value of 23.75 mg/kg), Cd ranged from 1.16 to 8.64 mg/kg, Ni varied from 1.01 to 28.47 mg/kg (mean value of 10.89 mg/kg), Cu varied from 4.57 to 50.42 mg/kg (average value of 21.88 mg/kg), As ranged from 0.05 to 8.35 mg/kg (average value of 3.86 mg/kg), and Co varied from 6.61 to 14.49 mg/kg (mean value of 12.27 mg/kg). Spatial representation of some heavy metals concentration in the dust samples are represented in Figure 2.

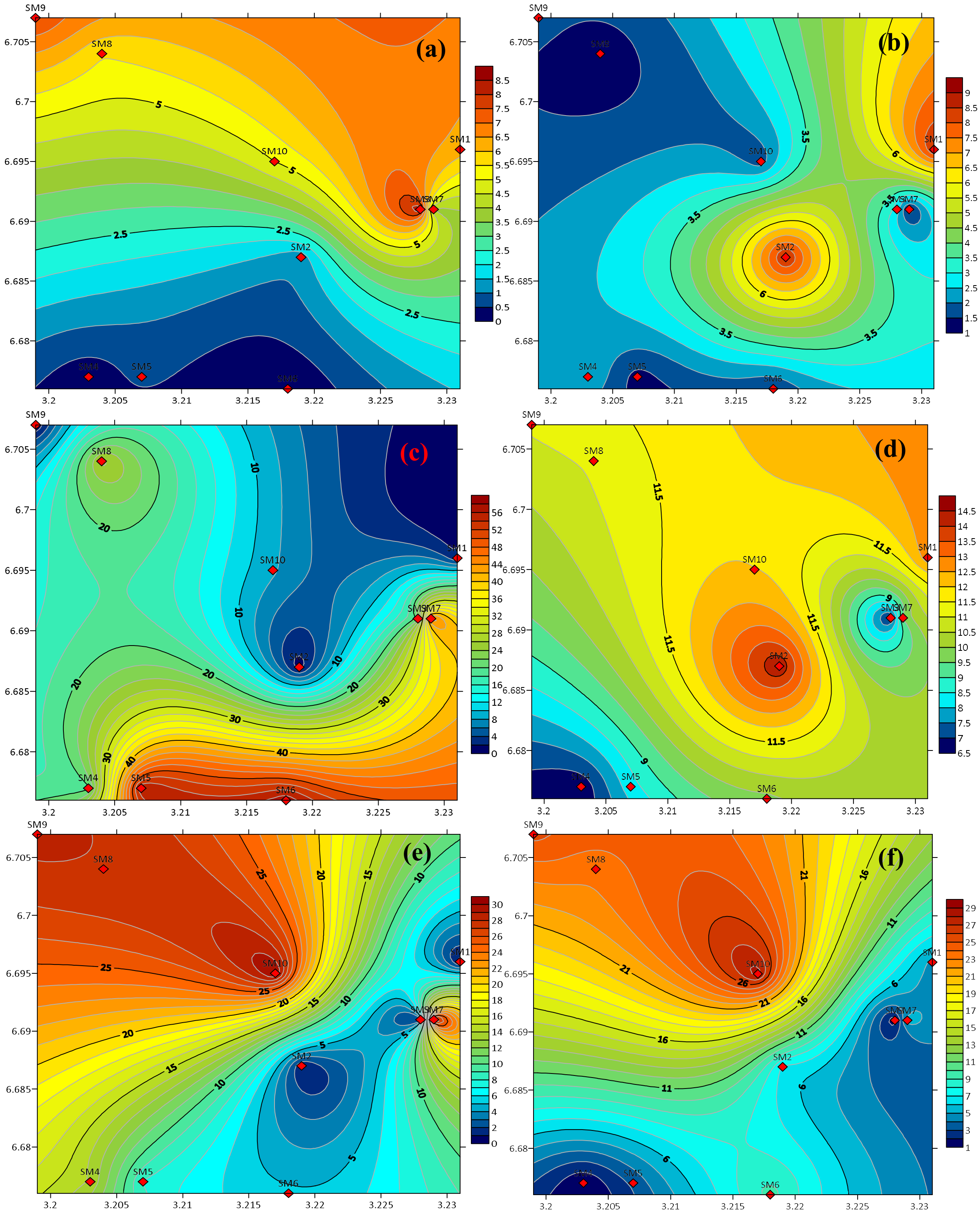


Figure 2: Spatial distribution of heavy metals (a) As (b) Cd (c) Cr (d) Co (e) Pb and (f) Ni

Comparing the concentration of trace metals found in the roadside dust with the threshold effect level (TEL) and the probable effect level (PEL) [21], the value of Zn in most dust samples was within the TEL/PEL standards. However, SM8 exceeded the TEL limit (124 mg/kg). Concerning Pb in the dust samples, none exceeded the TEL/PEL standards (30.2/112 mg/kg). For Cr, 100% of the samples were within the PEL standard, and 30% of the samples exceeded the TEL limit. Concerning Cd, 100% of the samples surpassed the TEL standard, while 80% of the samples were within the PEL stipulated value. Ni concentration in the dust samples was relatively low when compared with the PEL value as no sample surpassed the standard. However, 30% of the samples surpassed the TEL value for Ni. For Cu concentration in the dust samples, the PEL standard was not exceeded, but 30% of the samples were higher than the TEL limit.

Furthermore, the PEL threshold for As was not exceeded in all samples investigated, but only 20% of the samples were below the TEL standard. It is noteworthy to mention that no TEL/PEL limit has been identified for Co. In general, the presence and level of heavy metal concentration in roadside dust depend on the wind patterns, industrial activities, weather conditions and traffic intensity [22].

Table 2: Descriptive statistics of heavy metal concentration (mg/kg) in roadside dust

	Zn	**Pb**	**Cr**	**Cd**	**Ni**	**Fe**	**Mn**	**Cu**	**As**	**Co**
Minimum	14.98	0.62	0.05	1.155	1.005	2792	85.86	4.565	0.05	6.61
25% Percentile	30.52	1.529	1.999	1.284	2.748	4150	109.5	6.351	0.525	7.908
Median	57.95	10.89	20.16	1.718	6.158	4796	170.6	7.743	4.45	10.47
75% Percentile	90.38	28.44	48.03	4.244	23.76	4919	196.5	42.78	6.538	12.21
Maximum	136.2	30.15	57.54	8.635	28.47	5050	228	50.42	8.35	14.49
Range	121.3	29.53	57.49	7.48	27.46	2258	142.2	45.85	8.3	7.88
5% Percentile	14.98	0.62	0.05	1.155	1.005	2792	85.86	4.565	0.05	6.61
95% Percentile	136.2	30.15	57.54	8.635	28.47	5050	228	50.42	8.35	14.49
Mean	62.27	14.53	23.75	**3.102**	10.89	4431	158.1	**21.88**	3.86	10.27
Std. Deviation	38.68	12.84	22.23	2.933	10.57	806.8	51.48	20.08	3.146	2.55
Std. Error of Mean	12.23	4.059	7.031	0.928	3.342	255.1	16.28	6.348	0.995	0.806
TEL	**124**	**30.2**	**37.3**	**0.7**	**16**	**-**	**-**	**18.7**	**5.9**	**-**
PEL	**271**	**112**	**90**	**4.2**	**36**	**-**	**-**	**108**	**17**	**-**

3.2 Multivariate Statistical Evaluation

3.2.1 Correlation analysis

Correlation assessment helps to determine the relationship existing between the trace metals in the dust samples. The current study utilized three parametric limits to show the level of relativity between different heavy metals; (i) $r > 0.7$ is considered a strong relationship (ii) r varying from 0.3 – 0.7 is considered moderate relationship and (iii) $r < 0.3$ is termed a weak relationship [23–25]. However, values having moderate and strong relationship were further discussed. From Table 3, moderate relationship exist between Cd and Co ($r = 0.6017$), Fe and Pb ($r = 0.6801$), Cr and Fe ($r = 0.5291$), Mn and Cr ($r = 0.6053$), Fe and Ni ($r = 0.3804$), Mn and Ni ($r = 0.4364$), and Cu and Fe ($r = 0.5590$). Furthermore, a strong relationship was observed between Zn – Pb ($r = 0.8658$), Zn – Ni ($r = 0.7493$), Zn – Fe ($r = 0.7694$), Zn – Mn ($r = 0.8668$), Zn – Cu ($r = 0.8747$), Pb – Ni ($r = 0.7370$), Pb – Mn ($r = 0.7036$), Pb – Cu ($r = 0.9332$), Ni – Cu ($r = 0.7194$), and Fe – Mn ($r = 0.7985$). The results derived from the positive relationships is an indication that the emission of trace elements emanate from a common anthropogenic origin [22].

Table 3: Correlation matrix of heavy metals in roadside dust around the study location

	Co	Zn	Pb	Cr	Cd	Ni	Fe	Mn	Cu
Co	1								
Zn	0.0100	1							
Pb	0.0439	0.8658	1						
Cr	-0.5058	0.2035	-0.0412	1					
Cd	0.6017	-0.7218	-0.6245	-0.5849	1				
Ni	0.4471	0.7493	0.7370	-0.3275	-0.3201	1			
Fe	-0.5623	0.7694	0.6801	0.5291	-0.9924	0.3804	1		
Mn	-0.1206	0.8668	0.7036	0.6053	-0.7755	0.4364	0.7985	1	
Cu	0.2172	0.8747	0.9332	-0.0438	-0.4881	0.7194	0.5590	0.7444	1

3.2.2 Factor analysis

To further investigate the sources of these heavy metals, factor analysis using varimax rotation was applied to extract latent variables that are related to a particular source. The factor analysis identified two principal factors that explained 82.9% of the entire variation of which their eigenvalues were greater than 1 (Figure 3 (a)). In addition, factor 1 explains 51.8% of the total variance with strong positive additions from Cu (r = 0.969), Pb (r = 0.944), Zn (r = 0.924), Ni (r = 0.799), and Mn (r = 0.768) and moderated contributions from Fe (r = 0.629) (Figure 3 (b) and Table 4). The strong positive contributions from Cu, Pb, Zn, Ni, and Mn suggest an anthropogenic origin from plastics, metalliferous extraction, and metal corrosion [20,26]. To add, the samples contributing to factor 1 are mainly from location SM10, SM9, SM8, and SM7 (Figure 3 (c)). Factor 2 describes 31.1% of the total variation with high positive contributions from Co (r = 0.874) and Cd (r = 0.822). High contributions from Cd and Co suggests that contaminants emanate from dyes and paints industries. A report by Alloway [27] and Soltani et al. [28] revealed that traffic emissions from vehicle exhaust, tire particles and eroding brake pads might contribute Pb, Cu, Zn, and Cd to the atmosphere. In a similar report, leakage of motor oil and physical abrasion of cars are common contributors of Zn to urban road dust [29–31].

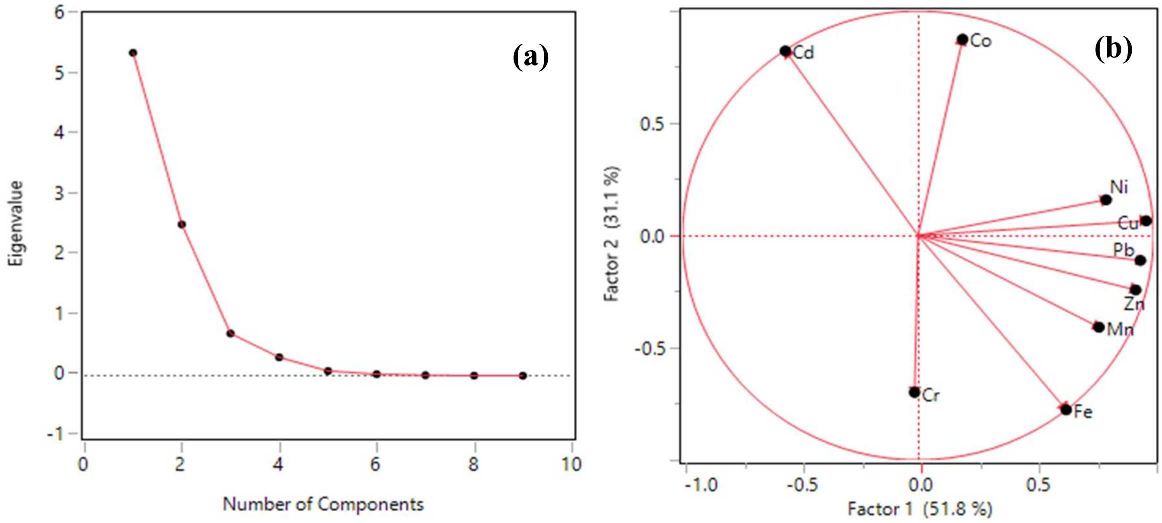
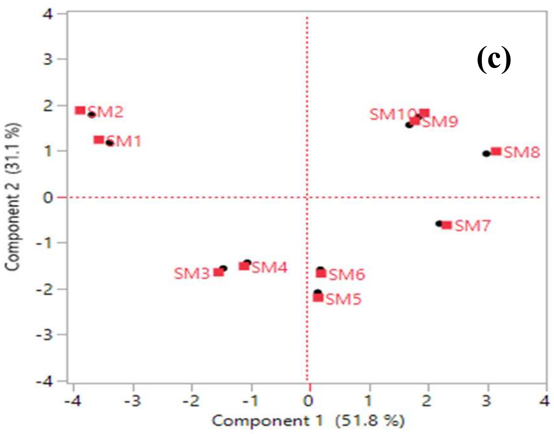


Figure 3: Factor analysis plot showing (a) Scree plot (b) loading plot (c) Biplot

Table 4: Factor loading of heavy metals in dust samples

	Factor 1	Factor 2	community estimates
Co	0.189	**0.874**	0.799
Zn	**0.924**	-0.243	0.913
Pb	**0.944**	-0.111	0.903
Cr	-0.015	-0.699	0.489
Cd	-0.563	**0.822**	0.993
Ni	**0.799**	0.159	0.663
Fe	0.629	-0.776	0.999
Mn	**0.768**	-0.409	0.757
Cu	**0.969**	0.065	0.942



3.2.3 Ecological risk assessment

The ecological risk level of trace metals in roadside dust within the sample region were calculated using potential ecological risk assessment. The assessment incorporated results derived from the contamination factor and risk potential of the individual toxic metal. Based on the results obtained from the contamination factor calculation, Cu was observed to be above the low contamination factor zone (Figure 4) in location SM7 and SM8, As was observed to be above the low contamination zone in SM1 and SM2, and Zn was observed to be above the low contamination zone in location SM5, SM6, SM7, SM8, SM9 and SM10. Nickel in the roadside dust samples fell within the moderate contamination factor zone in SM8, SM9 and SM10. Also, Pb in the roadside samples fell within the moderate contamination factor zone in SM7, SM8, SM9 and SM10. It is essential to mention that all trace metals analysed for the roadside dust samples were within the low contamination factor zone in location SM3 and SM4.

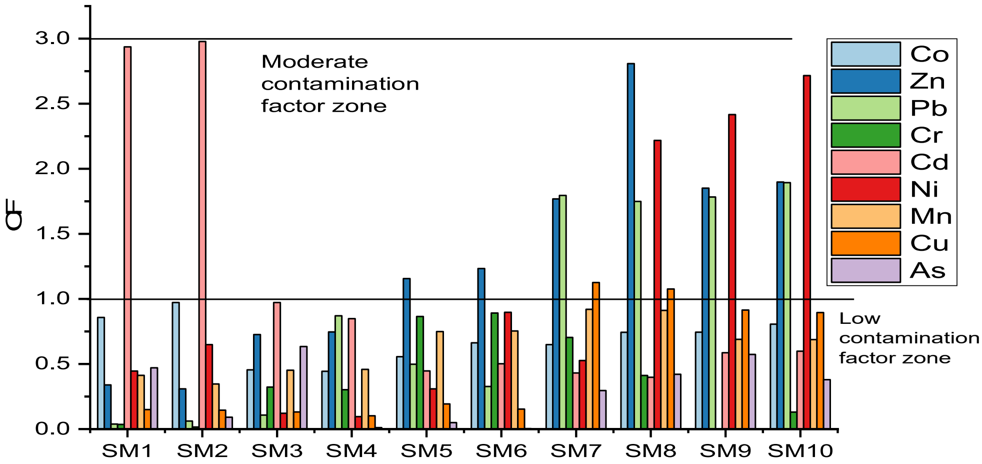


Figure 4: Contamination factor of heavy metals in the study region

After computing the potential ecological risk assessment, the ecological risk criteria (E_r^i) identified cadmium as problematic heavy metal in the roadside dust samples (Figure 5). Sample SM1 and SM1 were categorized in the considerable ecological risk zone due to their high E_r^i values. Meanwhile, other samples investigated were categorized in the low ecological risk section. Based on the results, the mean E_r^i of the individual metals in the sample region followed the order of Cd > Ni > Pb > As > Cu > Zn > Cr. The results further buttressed that Cd may cause significant health damage to the inhabitants within the region. In comparison, the average E_r^i value for Cd obtained from the current study exceeded the mean values obtained from Tehran in Iran [32], Beijing in China [33], and Shiraz in Iran [34].

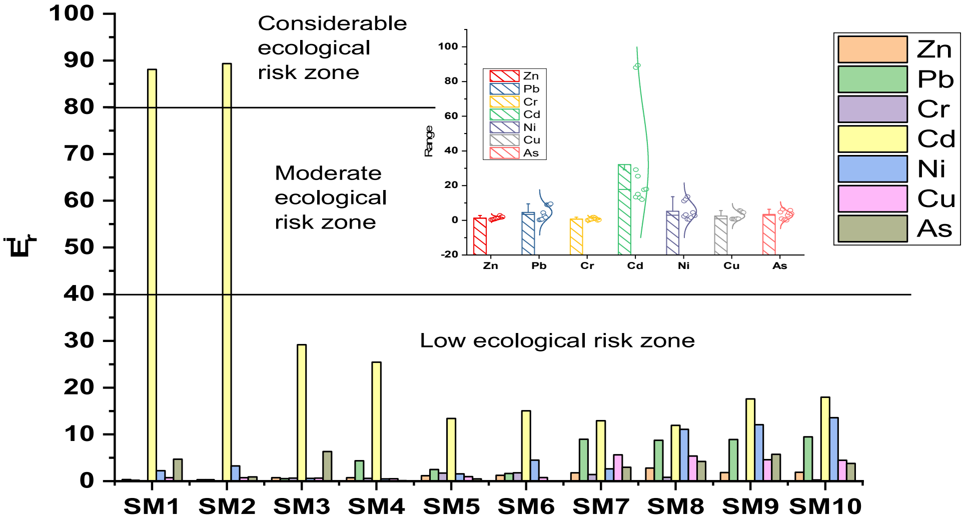


Figure 5: Ecological risk index of heavy metals at different locations

4. Conclusion

According to the results of the present investigation, Pb values were within the threshold effect level and the probable effect level. Several metals surpassed the TEL values in some locations; they include Cd, Cr, Ni, As and Cu. Heavy metal sources were possibly traced to induced activities such as leakage of motor oil, plastics, metalliferous extraction, dyes, and paints industries. Metals such as Cd, Ni, Pb, Zn and Cu were characterised by high contamination factor, thereby categorised under the moderate contamination factor zone. Furthermore, all metals were categorised under the low ecological risk zone except for Cd that was categorised under the considerable ecological risk zone in location SM1 and SM2. Therefore, there is a need for further investigation of the health impact of inhabitants within the region.

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