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RESEARCH

Health and ecological risk assessment of potentially toxic metals in road dust at Lalibela and Sekota towns, Ethiopia

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Abstract The ecological and health problems resulted from heavy metals (Mn, Fe, Ni, Co, Cu, Zn, Cd, Hg, Pb, As, and Cr) in the road dust in the towns of Sekota and Lalibela, Ethiopia were assessed. The average heavy metal concentrations were ranged from 0.088 (Cd) to 2.714 (Fe) mg/kg. Individual metal and cumulative metals pollution levels in both towns revealed that Lalibela is moderately polluted by Zn, Pb, and Ni and Sekota being moderately polluted by Zn, Pb, Ni, As, Hg, and Cu. Furthermore, the United States Environmental Protection Agency's health risk evaluation model showed that the total heavy metal health risk levels in the road dust ranged from 5.71×10^{-3} (adult) to 2.57×10^{-2} (children), with an average risk of 7.35×10^{-2}. Lalibela was found to have higher chance of risk than Sekota. The total lifetime cancer risk varied from 4.51×10^{-9} (for adults, Sekota) to 7.75×10^{-9} (for children, Lalibela), with a mean risk of 6.12×10^{-9} implying a low chance of getting cancer. The hazard quotient and hazard index of all the metals were below the limit. In general, children were found to be more susceptible than adults.

Keywords Heavy metal · Road dust · Environmental pollution · Ecological risk · Health risk assessment · Ethiopia

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Introduction

Heavy metals are found naturally in the Earth's crust, but they also come from anthropogenic sources. Heavy metals are pollutants that are persistent due to their inability to be degraded or eliminated. Consequently, they get accumulated in the soil, freshwater, seawater, and sediments (Sobhanardakani, 2018; Zhang et al., 2016). Even though some heavy metals, such as Cu, Zn, Fe, Co, Cr(III), and Mn, are beneficial for humans, four of the heavy metals of the public health concern are Hg, Cd, Pb and As (Sobhanardakani, 2018; H. Zhang et al., 2019a, b).

Studies have indicated that the principal sources of exposure to toxic metals constitute approximately 10% of particulate matter by mass (Morakinyo et al., 2021). Skin contact, ingestion, and inhalation of these particulate matters containing heavy metals are the three major pathways through that heavy metals can get into the human body. In addition to bone damage and neurodevelopmental deficits, reproductive toxicity, poor pulmonary function, cardiovascular disease, some of the health concerns resulting from heavy metals exposure are a fall in IQ, behavioral problems, and decreased reading skills (Denny et al., 2022; Khan & Strand, 2018; H. Zhang et al., 2019a, b). The level and kind of heavy metal, along with the total time of exposure, influence the health risks (Jeong & Ra, 2022; Khan & Strand, 2018; Vosoughi et al., 2021). The impacts of heavy metals on the health can sometimes be felt instantaneously or manifesting overtime. Moreover, studies have shown that children and the elderly are more vulnerable to heavy metal toxicity compared to adults (Rahman et al., 2021). Because most people in developing countries spend a lot of time on the roadside engaging in various activities, there is a rise on the health impact due to heavy metals (HMs) in the road dust (Denny et al., 2022; Khan & Strand, 2018; H. Zhang et al., 2019a, b).

Road dust is a complex mixture of inorganic and organic substances that are transported, deposited, and resuspended. The substances can originate from a variety of sources, involving anthropogenic and natural sources (Al-Shidi et al., 2022; Vosoughi et al., 2021). Road dust contains considerable amounts of heavy metals from many human activities. The chemical forms of heavy metals released to the environment are also altered by humans. By enabling a heavy metal to bioaccumulate in plants and animals, bioconcentrate in the food chain, or target particular biological organs, these modifications frequently affect a heavy metal's toxicity. Many human activities associated with rapid urbanization have brought considerable contaminants to the urban environment, resulting in serious road dust pollution (Al-Shidi et al., 2022; H. Zhang et al., 2019a, b; Q. Zhang et al., 2019a, b). Traffic emissions (e.g., brake lining-wear particles, vehicle exhaust aerosols, weathered street surface particles tire-wear particles), industrial emissions (e.g., petrochemical plants, chemical plants, oil refineries, metallurgical industry and coal combustion, mining), and municipal waste (e.g., improper waste disposal, cooking with biomass, and building material decomposition) are the major contributors of heavy metals in the road dust (Denny et al., 2022; Kreider et al., 2019; Rahman et al., 2021).

Road dust has the capacity to carry and disseminate toxic metals in urban areas. Since these toxic metals are the causes for health problems, measurements have to be taken. It is also important to understand the distribution, levels, and health and ecological risks of HMs in the road dust, to implement remedial measures (Denny et al., 2022; Rahman et al., 2021). Several studies have made progress in researching contamination sources, spatial and distribution characteristics, circulation, toxicity, health risk evaluation, contamination level assessment, and environmental impacts of heavy metals in urban dust around the world (Al-Shidi et al., 2022; Denny et al., 2022; Khan & Strand, 2018). However, in emerging nations like Ethiopia, only few preliminary studies on heavy metal pollution and its associated ecological and health risks has only been published (Endale et al., 2012; Getachew et al., 2019; Jeong & Ra, 2022; Rahman et al., 2021; Samuel et al., 2020; Woldetsadik et al., 2017). The present study focuses on quantifying heavy metals in road dust and evaluating the ecological and health threats in two selected Ethiopian towns (Sekota and Lalibela). This study is the first attempt to assess the potential risks to the environment and human well-being caused by road dust in Ethiopia. The present investigation also quantified the amount of HMs found in the road dust using the established US EPA guidelines.

Materials and Methods

Description of the sampling area

The sampling areas, Lalibala and Sekota, are found in North Wollo and Wag Himra administrative zones respectively. The town of Lalibela located between 12°01′54''N and 39°02′28''E, whereas Sekota town is between 12°01′54''N and 39°02′28''E in North part of Ethiopia. Lalibela town was found about 300 years ago by the King Lalibela and is one of the most important pilgrimage centers in Ethiopia. The town is also regarded as one of the most popular destination for both the domestic and international tourists, owing to its eleven most beautiful monolithic rock-hewn churches. Since 1978, the churches have been designated as UNESCO World Heritage sites (Fauvelle-Aymar et al., 2010). The second town, Sekota, is found in Wag Himra-zone with the elevation ranged from 1300 to 2000 m above sea level; its annual temperature ranges from 23–25 °C. Sekota is also used as the administration center for Wag Himra zone (Leta, 2008; Girma, 2017). The sampling locations in each town are shown in Fig. 1.

Sampling strategy and sample preparation

For sampling approximately 1–3 kg of composite sample made up of five sub-samples spaced 3 to 4 m apart, was collected from various points along the roadside of the selected towns. A small plastic brush and shovel were used during sampling. A new brush was used in each sampling point. Three rounds of sampling were conducted during the dry season (January 2 to April 30). On both sides of the main road, 16 samples were taken (10 from Sekota and 6 from Lalibela). The number of samples and locations were chosen by the area of the towns and population size, present and past land use, and traffic density. Polyethylene bags were used to transport the collected samples to the Woldia University laboratory.

After the researcher brought the samples to the laboratory, leaves, plastics, and large pieces of impurities, including broken pieces of bricks, and paving stones, were removed from the samples. The samples were then dried at 105 °C for 24 h and sieved through a 0.25 mm stainless steel sieve to remove larger particles. This size is chosen because the dust passed through it is expected to have high mobility and resuspension properties. A well-established technique was employed for determining toxic heavy metals (Taşpınar & Bozkurt, 2018). To make it brief, 1.25 g of the dried sample was put into to a beaker containing 20 mL Aqua regia (HCl/HNO_3, 3:1), and it was heated on a thermostatically controlled hot plate until near dryness. After the digested solution was cooled to ambient temperature, 5.0 mL of hydrogen peroxide was added in parts to complete the digestion, and the resulting mixture was heated again to near dryness in a fume hood. Next, 10 mL of ultrapure water (18.1 MΩ/cm) was used to wash the beaker, and 5 mL HCl was added, mixed, and heated again. The resulting solution was allowed to cool. Then it was put into a 100 mL standard flask, and made up to the mark with ultrapure water. Finally, Fe, Pb, Cu, Mn, Cr, Co, Ni, Zn, Hg, As, and Cd concentrations were measured using inductively coupled plasma-optical emission spectroscopy (ICP-OES). Triplicate analysis (n = 3) was done on all the samples. The method was validated by a recovery test using the standard spiking method while the precision was established using standard deviation.

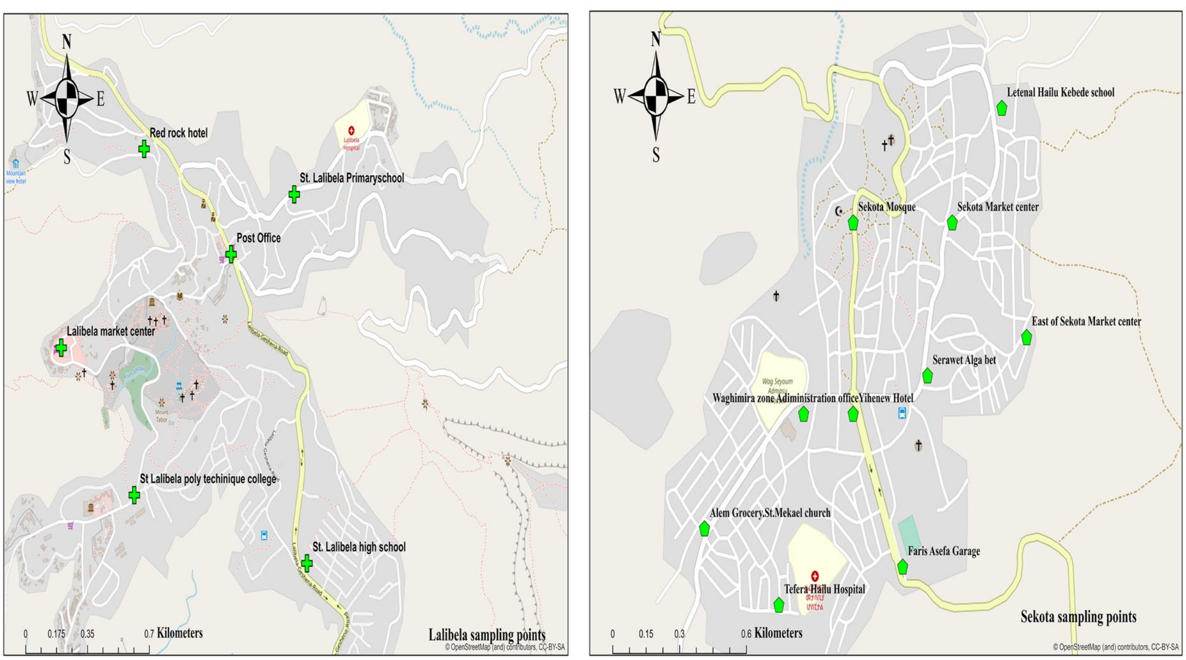

Fig. 1 Sampling locations in Sekota and Lalibela towns

The data quality was ensured by using the calibration and recovery test method. The correlation coefficient for the HMs was found in the range $R^2 = 0.9954$ for cobalt to $R^2 = 9999$ for manganese, which are in the acceptable range (Supplementary information 1). The accuracy of the method was checked using a standard spike method, and the percentage recovery values were found to be in the range of 88.5 (Fe) to 115% (As), which fall within the acceptable range of 80–120% (Supplementary information 2). Moreover, the laboratory blanks, filter blanks, and reagent blanks metal concentration were measured in the same manner as the sample measurement to evaluate external metal contamination, and no contamination was detected.

Statistical analysis

In this study, analysis of variance (ANOVA) and multivariate statistical analyses (hierarchical cluster analysis and principal component analysis) were used to estimate the associations between heavy metals and their geochemistry and/or origin (Kasozi et al., 2023; Otim et al., 2019, 2021). SPSS software (version 21), Origin software (version 2018), and Microsoft Office Excel, 2016 were used for all statistical analyses. The 95% confidence level of statistical value was used to evaluate the data in this study unless indicated.

Ecological risk assessment

The integrated pollution index (IPE), the geo-accumulation index (I_{geo}), the risk index (RI), the pollution index (PI), and the ecological risk index (ERI) are used to rank the potential toxic impacts of heavy metals in dust, soil, and sediment (Jahandari, 2020; Zhaoyong et al., 2019). This study also used these techniques for a similar application. As a result, the impact of single-element can be assessed by I_{geo}, PI, and ERI parameters. Furthermore, the risk and integrated pollution indexes can describe comprehensive potential ecological risks for various elements (Doabi et al., 2018; Hini et al., 2019; Ma & Singhirunnusorn, 2012; Taşpınar & Bozkurt, 2018). The formulas, types of equations, parameters and pollution level for each parameter are given in Table 1.

Evaluation of levels of exposure

The health risks arising from exposure to elements in road dust were estimated by the US Environmental Protection Agency method (USEPA, 1996). Skin contact, mouth ingestion and inhalation are the three main exposure pathways for road dust to get into the human body. The exposure dose received through skin/dermal contact, ingestion and inhalation routes can be calculated using the equations and parameters given in Table 2 (US EPA, 1989, 1996, 2001; Wei et al., 2015).

Risk characterization

Chronic or acute exposure to different levels of HMs might cause cancer and non-cancer risks. The elements' potential carcinogenic and non-carcinogenic risks were calculated using Eqs. 1–3. The potential non-carcinogenic impact of a single element can be assessed using HQ (hazard quotient) while the non-carcinogenic impact of multi-elements is assessed by HI (the hazard index). The HI or HQ values of less than 1 indicate no potential non-carcinogenic risk resulting from exposure, whereas HI or HQ values greater than 1 indicate the possibility of non-carcinogenic negative health consequence (US EPA, 2001; Vosoughi et al., 2021).

The risk tolerance for lifetime cancer risk (LCR) associated with exposure to a particular element is described in the range of 10^{-6}–10^{-4} (US EPA, 1989; Vosoughi et al., 2021). Here, it is assumed that one additional case in a population of one million, 1 in 10,000 people is acceptable. Risks below 10^{-6} is unlikely develop cancer. The slope factor (SF), average daily dose (D) and reference dose (RfD) for dermal contact, ingestion and inhalation routes are given in Table 3, where UEDERAIS (US Department of Energy's Risk Assessment Information System) and some other references have been used for the values (Gruszecka-Kosowska, 2016; Hini et al., 2019; Liang et al., 2017; RAIS, 2018; Vosoughi et al., 2021).

$$HQ = \frac{D}{RfD} \tag{1}$$

$$HI = \sum HQ_{ingestion,\ Inhalation,\ dermal} \tag{2}$$

$$LCR = LADDxSF \tag{3}$$

Table 1 The ecological risk analysis formulas and pollution level classification (Chen et al., 2022; Faisal et al., 2022; Jahandari, 2020; Raza Ahmad et al., 2019; Szczepaniak-Wnuk & Górka-Kostrubiec, 2016)

Equations	Scale	Definition	Values	Pollution level
$Igeo = \log_2(\frac{Cn}{1.5Bn})$	Cn	concentration (mg/kg)		
	Bn	background concentration (mg/kg)		
	I_{geo}	geo accumulation index	$I_{geo} < 0$	Unpolluted environments
			$0 < I_{geo} < 1$	Unpolluted to moderately polluted
			$1 < I_{geo} < 2$	Moderately polluted,
			$2 < I_{geo} < 3$	means moderately to strongly Polluted
			$3 < I_{geo} < 4$	Strongly polluted
			$4 < I_{geo} < 5$	Strongly to very strongly polluted
			$I_{geo} > 5$	Extremely polluted environment
$PI = \frac{Ci}{C0i}$	Ci	concentration of HMs in dust samples (mg/kg),		
	C0i	reference concentration (mg/kg)		
	PI	pollution index	$PI < 1$	Low pollution
			$1 < PI < 3$	Moderate pollution
			$PI > 3$	High levels pollution
Mean of PI	IPI	Integrated pollution index	$IPI < 1$	Low level of pollution,
			$1 < IPI < 2$	Moderate level pollution
			$IPI > 2$	High level pollution
$ERI = TrxPI$	Tr	Toxic response factor		
	ERI	Ecological risk index	$ERI < 40$	Low pollution
			$40 \leq ERI < 80$	Moderate pollution
			$80 \leq ERI < 160$	Higher pollution
			$160 \leq ERI < 320$	Serious pollution
			$ERI \geq 320$	Sever pollution
	RI	Risk index	$RI < 150$	Low pollution
$RI = \sum_1^n ERI$			$150 \leq RI < 300$	Moderate pollution
			$300 \leq RI < 600$	High pollution
			$RI \geq 600$	Very high pollution

Each element has its own Tr value, which is given as a standard, such that: *Mn = 10, Ni = 5, Cu = 5, Zn = 1, Cd = 30, Hg = 40, Pb = 5, As = 10, and Cr = 5*

Results and Discussion

Concentration of heavy metals in road dust

Table 4 provides the arithmetic mean and minimum to maximum concentrations of Mn, Fe, Ni, Co, Cu, Zn, Cd, Hg, Pb, As, and Cr metals with a standard deviation for all the road dust samples collected from Lalibela and Sekota towns. Mn, Fe, Ni, Co, Cu, Zn, Cd, Hg, Pb, As, and Cr levels were found to be within the ranges of 1.82–2.43, 2.02–3.37, 1.90–1.97, 0.88–2.64, 0.66–0.97, 1.35–1.57, 0.083–0.10, 0.15–0.19, 0.61–0.65, 0.12–0.151, and 0.92–1.42 (mg/kg), respectively. The ANOVA test for all the heavy metals showed a significant difference across each town, except Cd. The variation of HMs in Lalibela town was increased in the order of Cd < As < Hg < Pb < Cu < Zn < Cr < Mn < Ni < Co < Fe. The order in Sekota town, however, was Cd < As < Hg < Pb < Co < Cr < Cu < Zn < Ni < Fe < Mn. The variations in HM concentrations were most likely due to greater variation in mineralogy and is related to anthropogenic activities (Denny et al., 2022).

Regardless of the sampling site, the overall mean heavy metal content ranged from 0.088 (Cd) to 2.714 (Fe) mg/kg, and the order was Cd < As < Hg < Pb < Cu < Cr < Zn < Co < Ni < Mn < Fe. The result indicates

Table 2 Equations and parameter values for three exposure routes (Ali et al., 2017; Embiale et al., 2019; Wei et al., 2015)

Equation	Pathway	Scale	Definition	Unit	Value	
					Children	Adult
$Ding = Cx\frac{IngRxEFxED}{BWxAT}xCF$		C	Concentration	mg/kg	This study	This study
	Ingestion	D_{ing}	daily dose ingestion	mg/kg day		
		IngR	Ingestion rate	mg/day	200	100
		ED	Exposure duration	Years	24	6
		AT	Averaging time for non-cancer risk	Days	365 × ED	365 × ED
			Averaging time for cancer risk	Days	65 × 365	65 × 365
		BW	Body weight (site specific)	kg	60.7	15
		EF	Exposure frequency (site specific)	Days	350	350
$Dinh = Cx\frac{InhRxEFxED}{PEFxBWxAT}$	Inhalation	D_{inh}	daily dose through inhalation	mg/kg day		
		InhR	Inhalation rate	m^3/day	12.8	7.63
		PEF	Particle emission factor	mg/m^3	1.36×10^9	1.36×10^9
$Dder = Cx\frac{SLxSAxABSxEFxED}{BWxAT}XCF$	Dermal contact	D_{der}	daily intake through dermal contact	mg/kg day		
		SA	Exposed skin area	cm^2	5700	2800
		SL	Skin adherence factor	mg/cm^2day	0.07	0.02
		ABS	Dermal adsorption factor	Unitless	0.01	0.01
		CF	Conversion factor	kg/mg	10–6	10–6
$LADD = \frac{CxEFxEDxCR}{BWxATxPEF}$	All of the three routes	CR	Contact frequency	Mg/kg day	CR = IngR	CR = IngR
		LADD	Lifetime average daily dose			

AT = EF x ED, ED for adult for cancer risk is 65 year which is the average life expectancy of an Ethiopian

Table 3 The slope factor and reference dose for the three exposure routes (Embiale et al., 2019; Hini et al., 2019; Liang et al., 2017; RAIS, 2018)

Metals	RfD_{inh} (mg/kg day)	RfD_{der} (mg/kg day)	RfD_{ing} (mg/kg day)	SF_{ing}	SF_{der}	SF_{inh}
Fe	0.00022	0.07	0.84			
Cu	0.0402	0.012	0.04			
Mn	1.43E-05	0.00184	0.047			
Zn	0.3	0.06	0.3			
Pb	0.00352	0.000525	0.0035	0.085	0.0085	0.00008
Cr	2.86E-05	0.00005	0.003	42	0.0065	0.012
Cd	0.001	0.00001	0.001	6.3	6.3	0.0018
As	0.000301	0.000123	0.0003	0.151	1.5	0.0043
Ni	0.0206	0.0054	0.02	0.84	0.84	0.00024
Co	5.71E-06	0.016	0.02	9.8		
Hg	8.75E-05	0.000021	0.0003			

$RfD_{inh,}$ is reference dose for inhalation route, $RfD_{ing,}$ is reference dose for ingestion route, RfD_{der} is reference dose for dermal contact route, SF_{inh} is slop factor for inhalation route, SF_{ing} is slop factor for ingestion route and SF_{der} is slop factor for dermal contact route

Table 4 The arithmetic mean, maximum, minimum and standard deviations (mg/kg) of HMs in road dust sample from Lalibela and Sekota towns

Sampling place		Mn	Fe	Ni	Co	Cu	Zn	Cd	Hg	Pb	As	Cr
Lalibela	Maximum	1.840	3.370	1.910	2.640	0.670	1.370	0.090	0.170	0.630	0.140	1.420
	Minimum	1.800	3.290	1.900	2.610	0.660	1.350	0.080	0.150	0.610	0.120	1.400
	Mean	1.820	3.330	1.903	2.623	0.663	1.363	0.083	0.157	0.623	0.130	1.407
	SD	0.020	0.040	0.006	0.015	0.006	0.011	0.006	0.012	0.012	0.010	0.012
Sekota	Maximum	2.430	2.140	1.970	0.890	0.970	1.570	0.100	0.190	0.651	0.151	0.940
	Minimum	2.370	2.020	1.940	0.880	0.950	1.540	0.090	0.180	0.650	0.150	0.920
	Mean	2.410	2.097	1.957	0.883	0.960	1.557	0.093	0.183	0.650	0.150	0.933
	SD	0.035	0.067	0.015	0.006	0.010	0.015	0.006	0.006	0.0001	0.0001	0.012
Total	Maximum	2.430	3.370	1.970	2.640	0.970	1.570	0.100	0.190	0.650	0.150	1.420
	Minimum	1.800	2.020	1.900	0.880	0.660	1.350	0.080	0.150	0.610	0.120	0.920
	Mean	2.115	2.713	1.930	1.753	0.812	1.460	0.088	0.170	0.637	0.140	1.170
	SD	0.323	0.677	0.031	0.953	0.163	0.107	0.008	0.017	0.016	0.013	0.259

SD means standard deviation

that Fe is the highest, which might be due to its large abundance in the earth crust. Furthermore, all the HMs concentrations are found to be lower than the world average concentration of HMs, except Hg in both towns, which was found higher than the world average values (0.1 mg/kg) (Alloway, 2010). This elevated level of Hg concentration compared to the background levels, may be due to the emission Hg from discharge of motor oils, grease, fossil fuel burning and car batteries in the towns. The result is consistent with the study conducted by (Al-Shidi et al., 2022). A similar comparison was done with the FAO/WHO standards, which indicated that the concentration of all the metals are found to be below the standards. The total percentage account for WHO/FAO standard in Lalibela town was found in the range of 0.007% (Fe) to 62.3% (Hg), whereas in Sekota town it was ranged from 0.004 (Fe) to 61% (Hg). The mean value of all the HMs investigated in this study is less than the reported mean concentration in other studies (Jahandari, 2020; Shabbaj et al., 2017).

The percentage contribution of each heavy metal across the town was investigated and given in Fig. 2. The findings showed that all the metals in Sekota

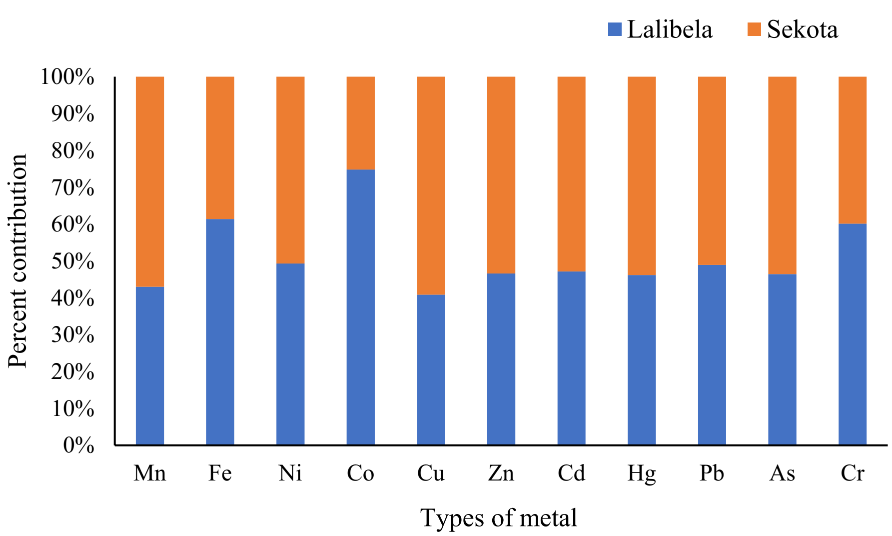

Fig. 2 The heavy metal percent contribution in Lalibela and Sekota towns

contributed more in terms of percent than in Lalibela, with the exception of Fe, Co, and Cr. The change in contribution in the two towns may be caused by the variations of the soil composition in the areas, paving materials for roads, emissions from cars brake systems, tires, bodies, the burning of biomass and fossil fuels, and air particle resuspension (Al-Shidi et al., 2022; Zhaoyong et al., 2019).

Estimating of human health impact

The health risk assessment model utilized by the US EPA was employed to assess the health risks for children and adults in the towns of Sekota and Lalibela. The various exposure routes, including inhalation, ingestion, and dermal contact, were used to evaluate the health impact of HMs. Table 5 shows the amount of HMs ingested via the three different exposure routes (hand-to-mouth intake (D_{ing}), respiration intake (D_{inh}), and dermal intake (D_{der}). Furthermore, for both towns, the HM intake amount was calculated using four scenarios: (1) each metal intake by each exposure route, (2) each metal intake by all three exposure routes, (3) all metal intake by every exposure route, and (4) all metal intake by any of the three exposure routes (Embiale et al., 2020; Rabinovitch et al., 2016).

Table 5 The exposure intake of HMs amount through ingestion, inhalation and dermal contact routes for adults and children at Sekota and Lalibela towns

Type of metal	Sekota				Lalibela			
	D_{inh}	D_{der}	D_{ing}	TD*	D_{inh}	D_{der}	D_{ing}	TD*
	Adults							
Fe	4.87E-10	1.32E-07	3.31E-06	3.44E-06	7.74E-10	2.10E-07	5.26E-06	5.47E-06
Cu	2.23E-10	6.05E-08	1.52E-06	1.58E-06	1.54E-10	4.18E-08	1.05E-06	1.09E-06
Mn	5.60E-10	1.52E-07	3.81E-06	3.96E-06	4.23E-10	1.15E-07	2.88E-06	3.00E-06
Zn	3.62E-10	9.83E-08	2.46E-06	2.56E-06	3.17E-10	8.59E-08	2.15E-06	2.24E-06
Pb	1.51E-10	4.10E-08	1.03E-06	1.07E-06	1.45E-10	3.93E-08	9.84E-07	1.02E-06
Cr	2.17E-10	5.88E-08	1.47E-06	1.53E-06	3.27E-10	8.87E-08	2.22E-06	2.31E-06
Cd	2.16E-11	5.86E-09	1.47E-07	1.53E-07	1.93E-11	5.23E-09	1.31E-07	1.36E-07
As	3.48E-11	9.45E-09	2.37E-07	2.46E-07	3.02E-11	8.19E-09	2.05E-07	2.13E-07
Ni	4.55E-10	1.23E-07	3.09E-06	3.21E-06	4.42E-10	1.20E-07	3.01E-06	3.13E-06
Co	2.05E-10	5.57E-08	1.39E-06	1.45E-06	6.09E-10	1.65E-07	4.14E-06	4.31E-06
Hg	4.25E-11	1.15E-08	2.89E-07	3.01E-07	3.65E-11	9.90E-09	2.48E-07	2.58E-07
TD **	2.76E-09	7.48E-07	1.88E-05	**1.95E-05**	3.28E-09	8.89E-07	2.23E-05	**2.32E-05**
Children								
Fe	7.49E-10	7.51E-09	2.68E-05	2.68E-05	1.19E-09	1.19E-07	4.26E-05	4.27E-05
Cu	3.43E-10	3.44E-09	1.23E-05	1.23E-05	2.37E-10	2.37E-08	8.48E-06	8.50E-06
Mn	8.61E-10	8.63E-09	3.08E-05	3.08E-05	6.50E-10	6.52E-08	2.33E-05	2.34E-05
Zn	5.57E-10	5.58E-09	1.99E-05	1.99E-05	4.87E-10	4.88E-08	1.74E-05	1.74E-05
Pb	2.32E-10	2.33E-09	8.31E-06	8.31E-06	2.23E-10	2.23E-08	7.97E-06	7.99E-06
Cr	3.33E-10	3.34E-09	1.19E-05	1.19E-05	5.03E-10	5.04E-08	1.80E-05	1.81E-05
Cd	3.32E-11	3.33E-10	1.19E-06	1.19E-06	2.97E-11	2.97E-09	1.06E-06	1.06E-06
As	5.36E-11	5.37E-10	1.92E-06	1.92E-06	4.64E-11	4.65E-09	1.66E-06	1.66E-06
Ni	6.99E-10	7.01E-09	2.50E-05	2.50E-05	6.80E-10	6.81E-08	2.43E-05	2.44E-05
Co	3.15E-10	3.16E-09	1.13E-05	1.13E-05	9.37E-10	9.39E-08	3.35E-05	3.36E-05
Hg	6.54E-11	6.55E-10	2.34E-06	2.34E-06	5.61E-11	5.62E-09	2.01E-06	2.02E-06
TD **	4.24E-09	4.25E-08	1.52E-04	**1.52E-04**	5.04E-09	5.05E-07	1.80E-04	**1.81E-04**

D_{inh} means inhalation dose, D_{der} means dermal dose and D_{ing} means ingestion dose, TD is total individual HMs dose in any the three exposure routes and TD** is total metal intake in each exposure route and the bold indicates all HMs intake in any of the exposure routes*

The result revealed that the D_{ing} and D_{inh} values of Fe, Cu, Mn, Zn, Pb, Cr, Cd, As, Ni, Co, and Hg for the children are greater than adults. This could be due to the high rate of respiration and children suck their finger into their mouth. The D_{der} for adults for all the metals exceeded the children. The higher value of D_{der} for the adults may be due to the large surface area covered by the adults compared to the children. The result of the present work is consistent with the work done by (Shabbaj et al., 2017; Szczepaniak-Wnuk & Górka-Kostrubiec, 2016; Vosoughi et al., 2021).

Regarding, the second scenario, the amount of intake of each metal by all the three exposure routes for the adults in Sekota and Lalibela ranged from 1.53×10^{-07} (Cd) to 3.96×10^{-06} (Mn) and 1.36×10^{-07} (Cd) to 5.47×10^{-06} (Fe), respectively. On the other hand, in Sekota and Lalibela, the intake of the children was found to be between 1.19×10^{-06} (Cd) and 3.08×10^{-05} (Mn) and 1.06×10^{-06} (Cd) and 4.27×10^{-05} (Fe), respectively. The third scenario revealed that the overall metal intake for the adults live in Sekota and Lalibela through inhalation, dermal contact, and ingestion exposure routes was found to be 2.76×10^{-09}, 7.48×10^{-07}, 1.88×10^{-05} and 3.28×10^{-09}, 8.89×10^{-07}, 2.23×10^{-05}, respectively. However, the intake levels for the children were 4.24×10^{-09}, 4.25×10^{-08}, 1.52×10^{-04} and 5.04×10^{-09}, 5.05×10^{-07}, 1.8×10^{-04} by inhalation, dermal contact, and ingestion exposure routes in Sekota and Lalibela, respectively. Furthermore, the overall metal intake dose by any of the three exposure routes was also calculated. The results revealed that the amount of intake by adults and children live in Sekota were 1.95×10^{-05} and 1.52×10^{-04} respectively. In relation to the inhabitants of Lalibela, 2.32×10^{-05} and 1.81×10^{-04} mg/kg of metals were taken by adults and children respectively. From this result, one can conclude that the inhabitants in Sekota town have taken relatively higher amounts of HMs than the residents of Lalibela town. The general pattern observed in both towns are: ingestion > dermal contact > inhalation exposure routes. Similar results has been observed with the previous study (Al-Shidi et al., 2022; Jeong & Ra, 2022).

The HQ for the non-carcinogenic risks of Fe, Cu, Mn, Zn, Pb, Cr, Cd, As, Ni, Co and Hg for adults and children was calculated through the three exposure routes by considering (1) HQ for each metal intake by each exposure route, (2) HI for each metal intake by all of the three exposure routes, (3) HI for all metal intake by each exposure route, and (4) HI for all metal intake by all of the three exposure routes. The HQ for each metal in dermal contact, inhalation and ingestion exposure routes for adults and children are given in Table 6. The highest value of HQ at Lalibela and Sekota was due to Hg. Thus, by considering all the three exposure routes in Sekota and Lalibela towns, the total adult HI values for each HMs were found in the range 1.28×10^{-06} (Fe) to 1.68×10^{-03} (Cr), respectively whereas the corresponding HI values for children were found between 3.54×10^{-05} (Fe) to 7.83×10^{-03} (Hg) and 5.03×10^{-05} (Fe) to 6.72×10^{-03} (Hg). Although the HI values for each HMs through any of the three exposure routes were below the US EPA standards (< 1), Cr has a relatively high non-carcinogenic risk than other HMs for adults while Hg is high for the children. Regarding the HI value of all the HMs intake by each exposure route, HI value for Sekota and Lalibela adult inhabitants through any of the three exposure routes varied from 8.56×10^{-05} to 2.58×10^{-03} and 1.52×10^{-04}, 3.12×10^{-03}, respectively. The children HI value for all the HMs intake through the three of exposure routes were found in between 1.32×10^{-04} and 2.46×10^{-02} for Sekota and 1.58×10^{-04} and 2.53×10^{-02} for Lalibela inhabitants. The dermal contact and ingestion exposure routes were the predominant routes for both the adults and children. The overall hazard risk of the examined HMs was also assessed by considering the overall intake of all the HMs by any of the exposure routes, and the findings demonstrated that the HI values for the adults and children live in Sekota were found to be 5.71×10^{-03} and 2.49×10^{-02}, respectively. Similarly, the HI value for the adults and children live in Lalibela was 6.29×10^{-03} to 2.57×10^{-02}, respectively.

To sum up, the HI value for all of the four scenarios were below 1; this indicated that the non-cariogenic risks occur low likely to the exposed inhabitants (adults and children). However, the value of HI for the children is relatively higher than the HI value for the adults in all scenarios. The general trend of HI showed that dermal contact for the adult and ingestion for the children are the highest contributor of inhabitant's dust exposure. The results of this research are comparable with that found in the previous findings (Shabbaj et al., 2017).

The cumulative (either all HMs by single route or all HMs by all routes) and individual (single HM

Table 6 HI and HQ value of heavy metal through dermal contact, ingestion and inhalation routes for children and adult inhabitants in Sekota and Lalibela towns

		Fe	Cu	Mn	Zn	Pb	Cr	Cd	As	Ni	Co	Hg	Total HI
Adults													
Lalibela	HQ_{inh}	3.52E-06	3.83E-09	2.96E-05	1.06E-09	4.11E-08	1.14E-05	1.93E-08	1E-07	2.15E-08	0.000107	4.17E-07	0.000152
	HQder	6.26E-06	2.62E-05	6.12E-05	7.18E-06	0.000281	0.000741	0.000131	0.000685	0.00015	0.000207	0.000827	0.003123
	HQ_{ing}	0.000003	3.48E-06	6.23E-05	1.43E-06	7.48E-05	0.001774	0.000523	6.66E-05	2.22E-05	1.03E-05	0.000471	0.003012
Sekota	HQ_{inh}	2.21E-06	5.55E-09	3.92E-05	1.21E-09	4.29E-08	7.58E-06	2.16E-08	1.16E-07	2.21E-08	3.59E-05	4.86E-07	8.56E-05
	HQ_{der}	1.89E-06	5.04E-06	8.26E-05	1.64E-06	0.000078	0.001176	0.000586	7.69E-05	2.28E-05	3.48E-06	0.000549	0.002583
	HQ_{ing}	3.94E-06	3.79E-05	0.000081	8.21E-06	0.000293	0.000491	0.000147	0.00079	0.000155	6.97E-05	0.000964	0.003041
HI	Lalibela	1.28E-05	2.97E-05	0.000153	8.61E-06	0.000356	0.002526	0.000654	0.000752	0.000172	0.000324	0.001298	0.006287
	Sekota	8.04E-06	4.29E-05	0.000203	9.85E-06	0.000371	0.001675	0.000733	0.000867	0.000178	0.000109	0.001513	0.00571
Children													
Lalibela	HQ_{inh}	5.41E-06	5.89E-09	4.55E-05	1.62E-09	6.32E-08	1.76E-05	2.97E-08	1.54E-07	3.3E-08	0.000164	6.41E-07	0.000233
	HQ_{der}	1.57E-07	1.83E-07	3.27E-06	7.51E-08	3.92E-06	0.000093	2.74E-05	3.49E-06	1.16E-06	5.42E-07	2.47E-05	0.000158
	HQ_{ing}	5.07E-05	0.000212	0.000495	5.81E-05	0.002276	0.005996	0.001061	0.00554	0.001217	0.001677	0.006691	0.025274
Sekota	HQ_{inh}	3.41E-06	8.53E-09	6.02E-05	1.86E-09	6.6E-08	1.17E-05	3.32E-08	1.78E-07	3.39E-08	5.52E-05	7.47E-07	0.000132
	HQ_{der}	1.07E-07	2.86E-07	4.69E-06	9.31E-08	4.43E-06	6.68E-05	3.33E-05	4.37E-06	1.3E-06	1.98E-07	3.12E-05	0.000147
	HQ_{ing}	3.19E-05	0.000307	0.000656	6.65E-05	0.002374	0.003976	0.001189	0.006393	0.001251	0.000564	0.007799	0.024607
HI	Lalibela	5.63E-05	0.000212	0.000544	5.82E-05	0.00228	0.006107	0.001088	0.005544	0.001218	0.001842	0.006716	0.025665
	Sekota	3.54E-05	0.000307	0.000721	6.66E-05	0.002378	0.004055	0.001222	0.006398	0.001252	0.000619	0.007831	0.024886

HQ_{inh} is hazard quotient for inhalation; HQ_{der} is hazard quotient for dermal contact; HQ_{ing} is hazard quotient for ingestion exposure routes and HI is hazard index

at each route or single HM by three routes) lifetime cancer risk due to Pb, Cr, Cd, As, Ni and Co HMs for the adults and children were investigated, and it is given in Table 7. The results revealed that the cumulative cancer risk due to all the HMs in each exposure routes for the adults and children in Sekota town was: 4.30×10^{-09} (ingestion) to 1.07×10^{-12} (inhalation) and 4.35×10^{-09} (ingestion) to 1.09×10^{-12} (inhalation), whereas for the adults and children in Lalibela, they were found in the range of 7.46×10^{-09} (ingestion) to 1.55×10^{-12} (inhalation) and 7.55×10^{-09}(ingestion) to 1.52×10^{-12} (inhalation) respectively. Thus, the highest and the lowest non-carcinogenic risk were seen in the ingestion and inhalation exposure routes. A study by (Vosoughi et al., 2021) supported the findings of the present study. In addition, the cumulative LCR of all the HMs entered by all of the three exposure routes were found in the range of 4.51×10^{-09} (adults) and 4.57×10^{-09} (children) in Sekota. For Lalibela town inhabitants, they were found in the range of 7.66×10^{-09} (adults) to 7.75×10^{-09} (children). On the other hand, the individual metal cancer risk that enters into the body by all the three routes was evaluated, and the LCR for the adults and children live in Sekota were found in the range 5.22×10^{-12} (Pb) to 3.36×10^{-09}(Cr) and 5.27×10^{-12} (Pb) to 3.40×10^{-09}(Cr), respectively. Similarly, 5.00×10^{-12} (Pb) to 5.07×10^{-09}(Cr) to 5.06×10^{-12} (Pb) to 5.13×10^{-09}(Cr) was the corresponding LCR value for the adults and children in Lalibela town. Furthermore, the predominant exposure routes for the individual metal follows the pattern of ingestion > dermal contact > inhalation for both inhabitants in both towns.

Generally, all the risk values (cumulative and individual HMs) for the children and adults were lower than the US EPA recommended value range (10×10^{-6} to 10×10^{-4}) and the International Commission on Radiation Protection (ICRP) (5.0×10^{-5}); this indicates the occurrence of cancer risk due to the road dust metals are relatively low. Although the calculated value of LCR in each exposure route is below the threshold value of the US EPA, the overall results showed that the children are relatively at higher risk as compared to the adults. Moreover, the percent contribution of each metal for the total cancer risk was calculated, and Cr, Ni and Co are accounted for 74.4%, 6.26% and 16.5 of the total for the children and adults in Sekota, and 66.2%, 3.9% and 28.7% for the children in Lalibela town.

Table 7 Lifetime cancer risk values for dermal contact ingestion, and inhalation exposure routes for inhabitants of Sekota and Lalibela towns

		Pb	Cr	Cd	As	Ni	Co	TLCR*
Adults								
Sekota	LCR_{Ing}	4.74E-12	3.36E-09	5.03E-11	1.94E-12	1.41E-10	7.42E-10	4.30E-09
	LCR_{Der}	4.74E-13	5.20E-13	5.03E-11	1.93E-11	1.41E-10		2.12E-10
	LCR_{Inh}	4.46E-15	9.60E-13	1.44E-14	5.53E-14	4.03E-14		1.07E-12
	TLCR**	5.22E-12	3.36E-09	1.01E-10	2.13E-11	2.82E-10		**4.51E-09**
Lalibela	LCR_{Ing}	4.54E-12	5.07E-09	4.49E-11	1.68E-12	1.37E-10	2.20E-09	7.46E-09
	LCR_{Der}	4.54E-13	7.84E-13	4.49E-11	1.67E-11	1.37E-10		2.00E-10
	LCR_{Inh}	4.28E-15	1.45E-12	1.28E-14	4.79E-14	3.92E-14		1.55E-12
	TLCR**	5.00E-12	5.07E-09	8.98E-11	1.84E-11	2.74E-10		**7.66E-09**
Children								
Sekota	LCR_{Ing}	4.79E-12	3.40E-09	5.08E-11	1.97E-12	1.43E-10	7.51E-10	4.35E-09
	LCR_{Der}	4.79E-13	5.26E-13	5.08E-11	1.95E-11	1.43E-10		2.14E-10
	LCR_{Inh}	4.51E-15	9.72E-13	1.45E-14	5.60E-14	4.08E-14		1.09E-12
	TLCR**	5.27E-12	3.40E-09	1.02E-10	2.15E-11	2.86E-10		**4.57E-09**
Lalibela	LCR_{Ing}	4.60E-12	5.13E-09	4.54E-11	1.70E-12	1.39E-10	2.23E-09	7.55E-09
	LCR_{Der}	4.60E-13	7.94E-13	4.54E-11	1.69E-11	1.39E-10		2.03E-10
	LCR_{Inh}	4.33E-15	1.47E-12	1.30E-14	4.85E-14	3.96E-14		1.58E-12
	TLCR**	5.06E-12	5.13E-09	9.08E-11	1.86E-11	2.78E-10		**7.75E-09**

*LCR_{ing} is life time cancer risk for ingestion, LCR_{inh} is life time cancer risk for inhalation and LCR_{Der} is life time cancer risk for dermal contact exposure routes; TLCR** is total life time cancer risk for each metal taken by all of the three routes, TLCR* is total life time cancer due to intake of all HMs by each route and bold font is total LCR due to all HMs intake by all routes*

Ecological risk assessment

The cumulative ecological risk of the HMs was assessed using RI and IPI parameters whereas the individual metal ecological risk was evaluated using the I_{geo} index, PI, and ERI, parameters. The results of each parameter for Lalibela and Sekota towns was given in Table 8. The I_{geo} index, PI, and ERI values for Lalibela town varied from -1.175 (Mn) to -0.34 (Zn), 0.664 (Mn) to 1.185 (Zn) and 1.185 (Zn) to 36.94 (Hg), respectively, while -1.836 (Fe) to 1.356 (Zn), 0.315 (Co) to 1.356 (Zn) and 1.357 (Zn) to 43 (Hg), are the corresponding value of I_{geo} index, PI, and ERI for Sekota town. These results revealed that the road dust pollution is relatively low in both towns. However, Lalibela town was moderately polluted by Pb, Ni, and Zn while Sekota town is moderately pollute by Hg, Pb, Ni, As, Zn, and Cu. During the dry season, the temperature of the towns become high, which might accelerate the corrosion processes, cause wear of the wares, walls, lamps, and railings that often contain heavy metals such as Zn, Cu, Cd, and Cr, resulting in the release of the metals to the urban environment and their accumulation in the urban street dust (Shabbaj et al., 2017). The IPI and RI values for Lalibela town were found to be 0.899 and 95.84, respectively, whereas 0.898 and 109 were the IPI and RI values of Sekota towns. Thus, the result of the commutative risk assessment showed that both towns were found to have low levels of pollution.

Generally, most of the parameters have showed that the pollution level of the towns are ranked at low pollution state; both towns are ranked in moderate pollution by some selected heavy metals, which needs action to minimize the further increment. The moderate pollution level might be due to the improper disposal of large municipal wastes and availability of too many garages along the streets, which are the most common phenomena observed seen in the towns. Therefore, the towns' administrators should create an awareness and set an appropriate guideline for the proper disposal of wastes, maintain the alarmingly increment of three-wheel Bajajs and give proper work places to the garages since they are the most expected anthropogenic source of the HMs in the study area (Shabbaj et al., 2017).

Hierarchical cluster analysis (HCA) and principal component analysis (PCA)

Principal component analysis and hierarchical cluster analysis are the two approaches which are commonly employed for the identification of potential sources of heavy metals (Denny et al., 2022; Kasozi et al., 2023; Otim et al., 2019). Thus, HCA was performed for HMs in the road dust by using Euclidean distance as a measure of similarity, and the result is given in Fig. 3. The results indicated via Euclidean distance 1; there are five clusters: cluster 1 includes Mn and Ni; Cluster 2 includes Zn and Cr; Cluster 3 includes Fe only;

Table 8 The heavy metals ecological risk assessment using different pollution index parameters at Lalibela and Sekota towns

	Lalibela			Sekota		
Metal	I_{geo}	PI	ERI	I_{geo}	PI	ERI
Mn	-1.175	0.664	6.642	-0.77	0.88	8.8
Fe	-1.168	0.667		-1.836	0.42	
Ni	-0.528	1.04	5.199	-0.529	1.069	5.347
Co	-0.679	0.937		-0.679	0.315	
Cu	-0.96	0.771	3.855	-0.96	1.116	5.581
Zn	-0.34	1.185	1.185	-0.34	1.356	1.357
Cd	-0.991	0.755	22.636	-0.991	0.845	25.363
Hg	-0.7	0.924	36.941	-0.699	1.076	43.06
Pb	-0.555	1.021	5.107	-0.555	1.066	5.328
As	-0.691	0.929	9.286	-0.692	1.071	10.71
Cr	-0.588	0.998	4.989	-0.588	0.661	3.309
IPE		0.899			0.898	
RI			95.84			109

I_{geo} is geo accommmulation index, PI is pollution index, ERI is ecilogical risk index, IPE is integrated pollution index and RI is risk index

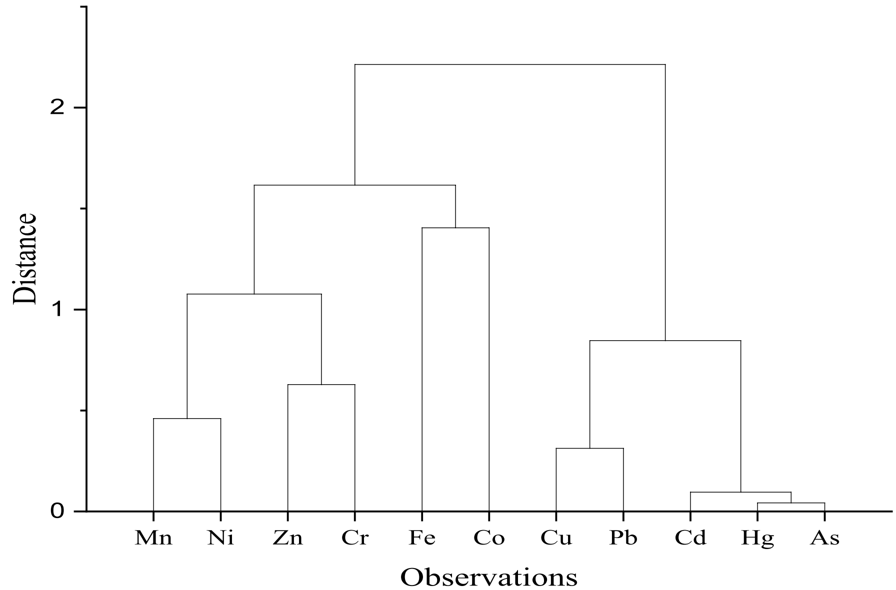

Fig. 3 Dendogram obtained from hierarchical cluster analysis of heavy metals contents in street dust samples

Cluster 4 includes Cu and Pb; Cluster 5 includes Cd, Hg, and As; cluster 5 include only Co, which indicates the pairs of these HMs under the same cluster that might have the similar or common sources, whereas Fe and Co grouped in a separate cluster show the likelihood that they originated from a source different from the other heavy metals.

The PCA for heavy metals across the sampling towns were carried out, and the result showed that the first two principal components (PCs) explained 99.98% of the total variance based on PCA. The PC1 explained up to 88.19% of the total variance and was characterized by high loadings of Zn, Ni, and Mn. The PC2 explained 11.79% of the total variance and was dominated by weighted values for Co and Fe. The relationships between the elemental content of the road dust and the PC1 and PC2 components are presented in Fig. 4. The results obtained using PCA showed similar results to HCA. Thus, Cd, As and Hg are highly correlated which indicates. This could be because they may come from a common source (mostly from traffic related activities). Similarly, Zn, Ni and Mn; Pb and Cu have also showed good correlation which might have common sources (Aguilera et al., 2021). Co and Fe has loosely relation with other metals that might have their own possible sources.

Conclusion and recommendation

In this study, the concentration of HMs (Fe, Ni, Mn, Co, Cd, Cr, Zn, Cu, Pb, Hg and As) in the road dust in Lalibela and Sekota towns were investigated. The result of the determination of HMs in the road dust revealed that the mean concentration of Fe, Ni, Mn, Co, Cd, Cr, Zn, Cu, Pb, Hg, and As were found in the range of 0.083 mg/kg (Cd) to 3.29 mg/kg (Fe) in Lalibela town and 0.09 mg/kg (Cd) to 2.410 mg/kg (Mn) in Sekota town. The result of this study showed that all the HMs in Lalibela and Sekota towns had a lower concentration of HMs than the world's average HMs concentration. I_{geo}, IP, IPI, RI, and ERI methods were employed for the ecological risk analysis, and the result obtained indicates that Lalibela town is moderately polluted by Ni, Pb, and Zn whereas Sekota town is also polluted moderately by Pb, As, Ni, Hg, Zn, and Cu. The total intake of each HMs by the children is higher than by the adults. Ingestion exposure routes are the predominant exposure routes compared to the inhalation and dermal contact. Cancer and non-cancer risk for inhabitants in Lalibela and Sekota towns were assessed using LCR and HQ or HI. The obtained result showed that all the values of LCR, HQ, and HI are below the standard set by the US EPA. This indicates that the likelihood of non-carcinogenic and the probability of developing cancer risks for the exposed inhabitants were insignificant. However, the possibility that HMs can cause

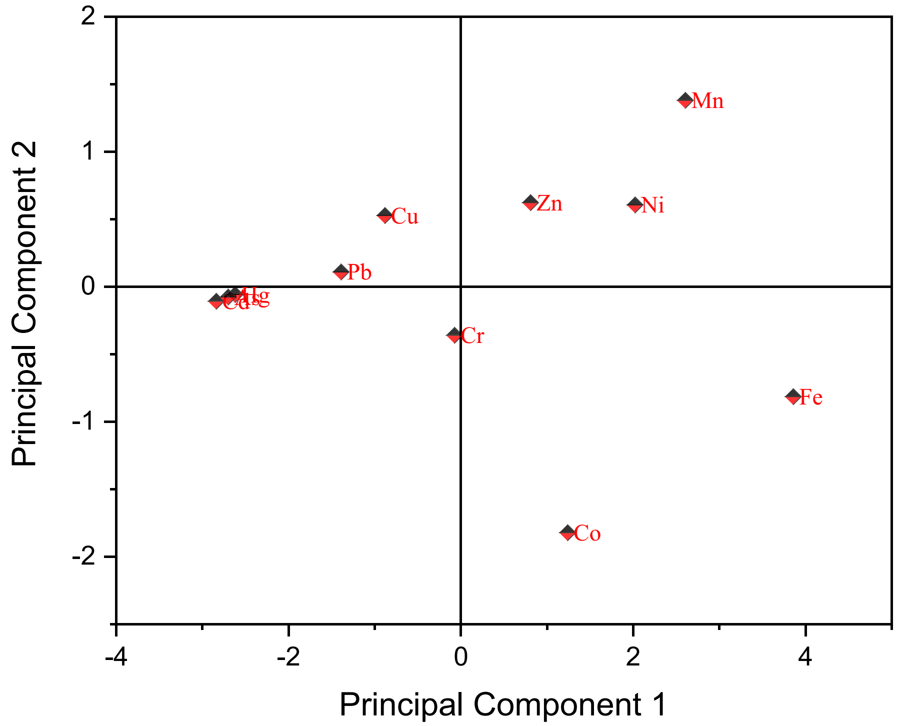

Fig. 4 Score plot for PCA analysis

serious health effects by accumulating in body tissues persists. Although the LCR value is low, Cr, Ni, and Co are accounted for more than 90% of the total LCR for children and adults in both towns. Moreover, a human can be exposed to heavy metals through drinking water, vegetables, cereals, and animal products such as milk, meat, and others; considering these routes should be mandatory to get a full health risk assessment of the inhabitants in the study towns.

The analysis of this work did not include spatiotemporal variation within the towns, making it challenging to enable the highest polluted location in the towns and to help take site-specific remedial actions. Moreover, the presence of many vehicles, especially the three-wheel Bajaj's, improper disposal of municipal waste (the most observable practice seen in the town) are rapidly increasing besides to the rapid growth of towns. Thus, doing a continuous measurement analysis for heavy metals as well as other toxic pollutants is mandatory to prevent further increment of street dust pollution. The town stakeholders can reduce the health impact due to road dust by employing regularly cleaning road surfaces using sweeping machines and vehicles to manage atmospheric pollution quality. Furthermore, urban greenbelts play a critical role in the phytoremediation of heavy metal pollution, so the towns' stakeholders are highly recommended to implement of urban greenbelts along with the growth of the towns.

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Data availability The data used to support the findings of this study are included in this study and its supplementary information file.

Declarations

Ethical Responsibilities of Authors All authors have read, understood, and have complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the Instructions for Authors.

Competing of interest The authors declare that they have no conflict of interest.

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