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ORIGINAL ARTICLE

Contamination and Human Health Risk Due to Toxic Metals in Dust from Transport Stations in the Kumasi Metropolis, Ghana

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Abstract

The purpose of this study was to assess the contamination levels and human health risk that heavy metals in the dust from transport stations pose to the inhabitants of the Kumasi metropolis, Ghana. Dust samples were collected from 18 transport stations and analyzed for metals including As, Cd, Cr, Cu, Pb, Fe, Sb, Ni, and Zn using X-ray fluorescence spectrometer prior to confirmation on an inductively coupled plasma-mass spectrometer. Mercury concentrations were determined using Lumex RA-915M Zeeman automatic mercury analyzer. The average concentrations of As, Cd, Cr, Cu, Ni, Pb, Fe, Hg, Sb and Zn were 6, 10, 130, 54, 30, 22, 16,518, < 1, 15 and 120 mg/kg, respectively. All the measured metal concentrations were higher than their background concentrations and the dust were heavily polluted with the metals. Pollution load indices revealed metal pollution was high in the metropolis. However, hazard indices for all the metals across the three exposure pathways were < 1, indicating no non-carcinogenic risk for both adults and children. Exposure to multiple metals was the main potential non-carcinogenic risk to children. Cadmium showed high carcinogenic risk index exceeding the safe limit of 1E0-4 for children, indicating that children are at risk. The study generally observed a higher health risk to children via ingestion compared to adults.

Keywords Geo-accumulation · Enrichment factor · X-ray fluorescence · Pollution load index · Contamination factor

1 Introduction

Dust is a heterogeneous mixture of many tiny particles which exist in the form of dry solid powder. Dust particles that are emitted from different sources contribute significantly to the pollution of the urban environment. Dust is therefore viewed as a good indicator of heavy metal pollution in many urban areas such as transport stations, which are dominated by traffic activities. Human activities such as vehicular traffic, industrial activities, waste incineration, demolishing and construction works, coal combustion and welding activities together with disturbed soil surface contribute to the release of dust in urban areas. Dust particles can easily be distributed to a wide area in an urban setting via atmospheric transport aided by winds and vehicular movements. Human health can be affected from exposure to dust particles that contain toxic heavy metals.

Heavy metals originate from both natural crust and human activities [1]. Heavy metals, such as As, Hg, Cu, Zn, Ni, Sb, Fe, Cr, Cd, and Pb, are non-biodegradable and can bioaccumulate over time along the food chain [2]. Rapid urbanization and industrialization of urban cities accelerate the accumulation of heavy metals in the urban environment where humans can be exposed to entrained contaminants via ingestion, inhalation and skin contact. Heavy metals such as As, Cd, Pb and Hg, even at lower concentrations, affect human health and have no beneficial biological functions. Other metals such as Zn, Cu, and Fe are nutritionally essential for biological activities and healthy life; nevertheless, they become harmful when their concentrations exceed the maximum allowable limits [3]. Studies have

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clearly indicated the potential negative health effect of heavy metals on humans. For example, chronic exposure to Pb causes damage to the kidneys, liver, reproductive organs and the central nervous system as well as memory loss and decreased intellectual ability [4]. Cadmium is known to cause prostate cancer, hypertension, renal dysfunction, lung cancer and pulmonary diseases such as emphysema and bronchiectasis [5]. It is also documented that excessive exposure to As can cause lung, kidney and bladder cancers, damage to blood vessels, intestinal irritation, skin lesions and nerve damage [6]. On the other hand, exposure to Hg may result in neurological disorders and mental confusion such as nervousness, insomnia and shyness and visual field constriction [7]. At a high level of exposure, the other metals such as Ni, Sb, Cr, and Cu can also affect human health.

Heavy metal pollution emanating from anthropogenic sources have been documented to contribute significantly to pollution in urban areas [8]. For example, metals can be released from metal works such as auto-mechanical workshops, electronic repair shops, welding, energy production, coal combustion, metal smelting, construction and demolishing, domestic heating, wearing of paved surfaces and automobile emissions. Metals such as Zn, Cu, Sb, Pb, Cd, Cr, Ni and Fe in dust have been ascribed to traffic activities [9, 10]. Recently, dust from different areas such as roads and streets [11, 12], schools [13], fuel filling stations [14, 15] and topsoils [15–17] has been given attention as they are important sources for human exposure to toxic metals in major cities in Ghana.

Pollution indices such as geo-accumulation, pollution load index and enrichment have been applied in various studies to evaluate the heavy metal pollution in dust [18, 19]. Human health risk associated with exposure to heavy metals in dust has been successfully conducted with the risk assessment models [20–22]. Heavy metal pollution in street dust from transport stations has been recently studied in some major cities including Murcia (Spain) [23], Asansol (India) [24], Turin (Italy), Abadan and Mashhad (Iran) [25, 26] and in Nanjing, Xining and Xi'an (China) [9, 27, 28]. In Ghana, however, there exist only limited and old (more than 8 years old) records [11, 12] of metals in some selected streets in Accra, the capital city. Published information about contamination levels and associated human health risks of heavy metals in dust from the other cities in the country is lacking. Passengers spend significant amount of time at transport stations waiting for vehicles and may be directly exposed to heavy metals in the re-suspended and airborne dust particles found in these places. Also, workers in these areas, on a daily basis, are exposed to heavy metals in the dust particles. Therefore, it is extremely important to know the extent of heavy metal contamination in dust from transport stations in order to conduct health risk assessments and formulate appropriate measures to protect human life. The objective of the study is to investigate the concentrations, the pollution status as well as the human health risk of heavy metals including As, Cd, Cr, Cu, Fe, Hg, Pb, Ni, Sb and Zn in dust from transport stations within the Kumasi metropolis of Ghana.

2 Materials and Methods

2.1 Study Area

Kumasi is the second highest populated city in Ghana and covers about 254 km^2 of land area. The metropolis which lies between Latitude 6.35° N–6.4° S and Longitude 1.30° W–1.35° E has a population of 2.5 million with an annual growth rate of 5.4% [29]. Kumasi metropolis is a converging point of commercial activities with many commercial and economic centers.

2.2 Dust Sampling

Thirty-two dust samples were collected from 18 transport stations in the Kumasi metropolis. Control samples ($n = 3$) were collected from undisturbed portions of the Botanical Gardens of Kwame Nkrumah University of Science and Technology, Kumasi Ghana. The location of each site was recorded by using a hand-held global positioning system as presented in Fig. 1. At each sampling site, 5 sub-dust samples were collected at different points within an area of about 5 m^2 and mixed to form a composite sample. All dust samples were collected by sweeping the deposited dust on the ground surface using a small paint brush and a plastic dust pan. Large objects were removed from the collected samples on sites and the samples were packed into sealed and labeled polyethylene zip-lock bags. After collection of samples from each site, the dust pan and paint brush were wiped with tissue paper several times to avoid cross contamination of dust samples.

2.3 Sample Preparation

Dust samples were dried at room temperature (24–32 °C) in the laboratory for 24 h and non-dust objects such as grits were removed before grinding with porcelain mortar and pestle for homogenization. The ground samples were sieved through a < 250 µm mesh (ASTM E1, USA).

2.4 Sample Analysis

The concentrations of metals including As, Pb, Fe, Cd, Ni, Cr, Cu, Zn and Sb in the homogenised samples were determined using Thermo Scientific Niton XL3t GOLDD + X-ray fluorescence (XRF) spectrometer—a field-portable/

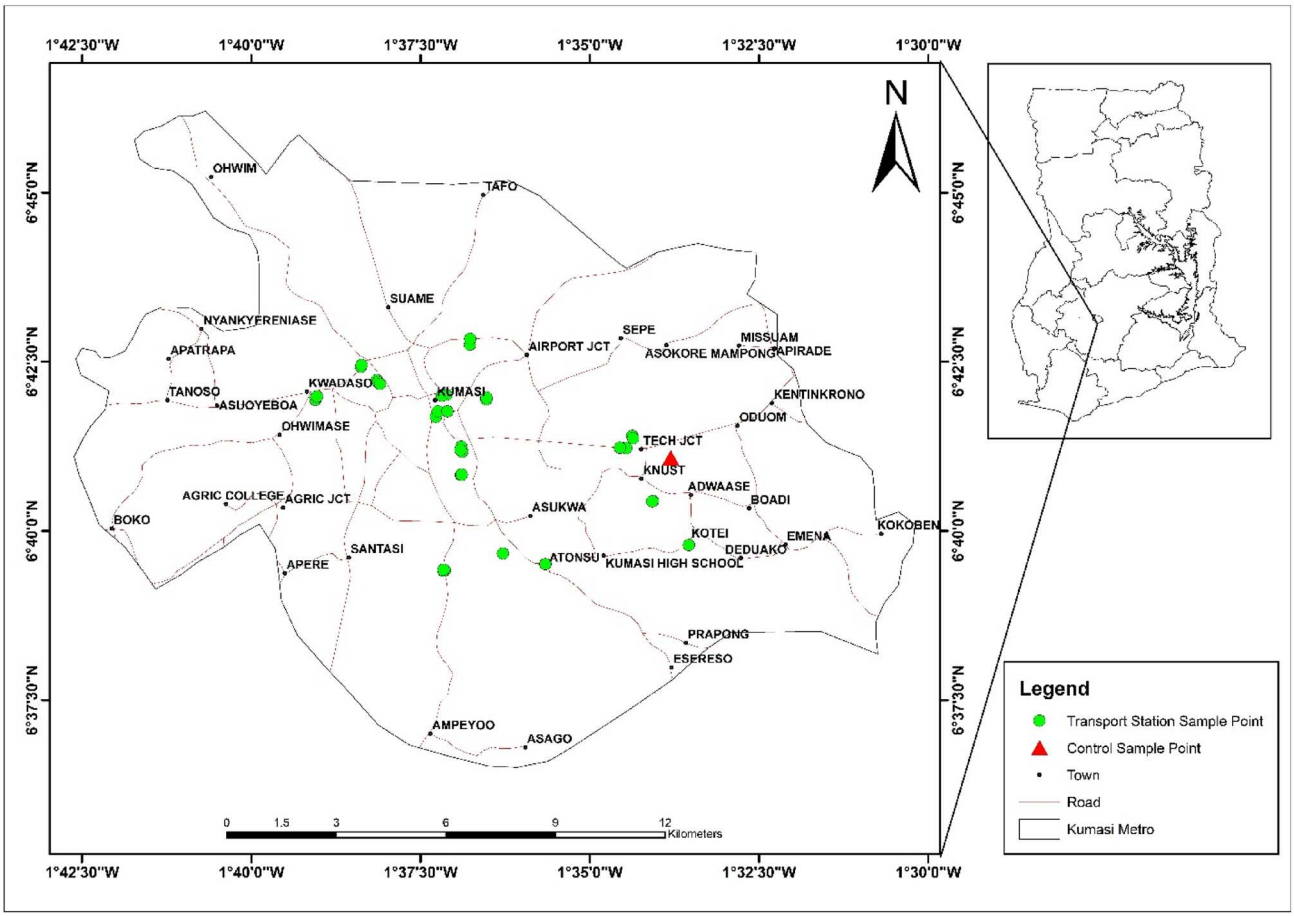

Fig. 1 Map of Kumasi metropolis showing sampled points

hand-held instrument. A NIST 2709a standard reference material was used as a standard for the accuracy and performance check of the analyzer. Satisfactory recoveries were obtained for three replicates of NIST 2709a analyses with average recovery of 86 ± 11% for As, 75 ± 5% for Cr, 104 ± 26% for Cu, 89 ± 8% for Ni and 99 ± 11% for Zn; the concentrations of Cd, Hg and Sb were below the limit of detection. Reproducibility was assessed through the analyses of 5 duplicate samples. The average relative percent difference between duplicate samples ranged from 3.5 to 34% indicating satisfactory reproducibility. During analysis, a polyethylene container (~ 3 cm) with openings on both ends was used to hold the sample after a Mylar film (polypropylene XRF thin film) was placed on one of the ends and secured with an open cup. The capped container was filled with the sieved dust sample to about three quarters full. The filled container was then place in the XRF shroud and the sample scan was conducted for 180 s. The XRF determines 24 elements but 9 toxicologically important ones were focused on in this work (See Supplentary table for raw data and method's limits of detection).

In accordance with USEPA methodology which recommends a minimum of 1 in 20 samples be analyzed for comparison, 8 of the 32 dust samples were analyzed for total metals by inductively-coupled plasma mass spectrometry (ICP-MS) after digestion following procedures described in Darko and coworkers [30, 31]. Briefly, 1 g of sample was added to 10 ml of 1:1:1 HCl-HNO_3-H_2O (Fisher Scientific, trace metal grade) mixture in a digestion tube and heated at 95 °C for 1 h in a heating block. The digestate was centrifuged at 5000 g for 20 min. An aliquot was pipetted, made to volume with 0.5% HCl and analyzed using an Agilent 7800 ICP-MS. QA/QC included a blank, a NIST 2710 SRM and a duplicate. The percent recoveries for 3 replicates of the SRM were 92 ± 5% for As, 86 ± 2% for Cd, 55 ± 9% for Cr, 95 ± 6% for Cu, 80 ± 10% for Ni, 95 ± 8% for Pb, 46 ± 3% for Sb and 86 ± 5% for Zn. The relative percent difference for the duplicate indicated good reproducibility: As—2.3%, Cd—15.5%, Cr—2.4%, Cu—3.0%, Ni—3.8%, Pb—2.6%, Sb—8.1 and Zn—0.8%.

Concentration of mercury was determined using Zeeman automatic mercury analyzer equipped with a pyro

RA-915 + (Lumex, Russia) [32]. A known mass (~ 0.3 g) of dry dust sample was and placed in the sample cell of the Pyro-915 + operating at a heating temperature of 450 °C. Analytical peaks develop after 45 s of the instrument run at an air flow rate of 1 L/min while detection limit was found to be 0.0005 mg/kg. The concentration of mercury (in mg/kg) was obtained by integrating the obtained peak height and area with reference to the calibration from an activated charcoal reference material (Cat: 500292: Lumex, St Petersburg, Russia). Accuracy of the measurements, expressed as relative error between the certified value of 2 ng/kg of the reference material and the observed values, was < 5%. Moreover, precision of the measurements, expressed as percentage relative standard deviation on 5 independent determinations, was also satisfactory, being lower than 10%.

2.5 Estimation of Heavy Metals Contamination through Pollution indices

2.5.1 Geoaccumulation Index (Igeo)

The Igeo is calculated by comparing the level of the heavy metals contaminant in the dust with its concentration in the background sample. Geoaccumulation index was calculated using Eq. 1.

$$\text{Igeo} = \log_2\left[\frac{\text{C}n}{1.5 \times \text{Bn}}\right] \tag{1}$$

where C_n is the measured concentration of metal in the dust samples (mg/kg) and Bn is the metal concentration in the reference sample (mg/kg). The background or reference concentrations of the metals used for calculation of Igeo values were adopted from an earlier study [30]. A constant factor of 1.5 was introduced to correct the effects of likely variations in the background values due to lithogenic effects [33]. The Igeo classification was used to evaluate the pollution status of each metal in the dust samples [31].

2.5.2 Enrichment Factor

Enrichment factor was used to distinguish between the heavy metal contaminants originating from natural sources and those from human activities. The concentrations in the background samples were used as the standard for comparison. Enrichment factor (EF) was calculated using Eq. 2:

$$\text{EF} = \frac{\text{Ms} \times \text{Fer}}{\text{Mr} \times \text{Fes}} \tag{2}$$

where Ms and Fes represent measured metal and Fe concentrations in the analyzed dust sample respectively while Mr and Fer are concentrations of measured metal and Fe in the background sample. EF > 1 indicates that the metal concentration is enriched in the dust sample relative to the background and may originate from anthropogenic activities. EF < 1 shows that metals originate from natural source. Based on the values of EF, 5 contamination classess are proposed. EF < 2 indicates minimum enrichment, EF = 2–5 moderate enrichment, $5 < \text{EF} \leq 20$ significant enrichment, $20 < EF \leq 40$ very high enrichment and EF > 40 extremely high enrichment [32].

2.5.3 Contamination Factor

Contamination factor (CF) was used to evaluate the level of heavy metal contamination in the dust sample. The contamination factor for the individual metal was calculated using Eq. 3.

$$\text{CF} = \frac{\text{C}_{\text{sample}}}{\text{C}_{\text{reference}}} \tag{3}$$

where C_{sample} is the measured concentration of a metal in the dust (mg/kg) and $C_{reference}$ represents the concentration of the metal in the reference sample (mg/kg). Decision on the level of contamination was based on classification classes of CF: low contamination (CF < 1), moderate contamination ($1 \leq \text{CF} < 3$), considerable contamination ($3 \leq \text{CF} \leq 6$) and very high contamination (CF > 6).

2.5.4 Pollution Load Index

The pollution load index (PLI) of metal pollutants is used to assess the overall degree of pollution for a dust sample. The PLI was calculated using Eq. 4.

$$\text{PLI} = \left(\text{CF}_1 \times \text{CF}_2 \times \text{CF}_3 \times \ldots \times \text{CF}_n\right)^{1/n} \tag{4}$$

where *n* represents the number of metals studied and CF is the contamination factor of a metal. The PLI values are into three classes as PLI < 1 (denotes no pollution load), PLI = 1 (only baseline level of pollutants is present) and PLI > 1 (progressive deterioration of site quality).

2.6 Human Health Risk Assessment

The potential health risk associated with human exposure to heavy metals in dust from transport stations was evaluated based on the exposure guidelines of the United States Environmental Protection Agency [34]. Health risk assessment was conducted on carcinogenic and non-carcinogenic metals via three exposure pathways namely ingestion, inhalation and dermal contact for both adults and children. The average daily dose in mg/kg/day which expresses the daily exposure level of heavy metals without any substantial risk via ingestion (ADDing), dermal contact (ADDderm) and

inhalation (ADDinh) of dust particles were calculated using Eqs. 5, 6 and 7.

$$\text{ADDing} = \text{Cdust} \times \frac{\text{IngR} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}} 10^{-6} \quad (5)$$

$$\text{ADDinh} = \text{Cdust} \times \frac{\text{InhR} \times \text{EF} \times \text{ED}}{\text{PEF} \times \text{BW} \times \text{AT}} \quad (6)$$

$$\text{ADDderm} = \text{Cdust} \times \frac{\text{SA} \times \text{AF} \times \text{ABS} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}} \times 10^{-6} \quad (7)$$

Exposure parameters used in the model employed to estimate average daily dose and human risk are shown in Table 1.

2.6.1 Non-carcinogenic health risk

The non-carcinogenic health risk was assessed by means of hazard quotient (HQ) and Hazard index (HI).

$$\text{HQ} = \frac{\text{ADD}}{\text{RfD}} \quad (8)$$

$\text{HQ} \leq 1$, shows that there will be no adverse non-carcinogenic health effects to human, and $\text{HQ} > 1$, indicates the likelihood of a metal to negatively affect human health by non-carcinogenic effects.

Hazard index (HI) was applied to evaluate the additive adverse health effects of non-carcinogenic risk of heavy metals in dust [35]. HI was obtained as the sum of HQ values for each metal via the three exposure pathways (Eq. 9).

$$\text{HI} = \sum \text{HQ} = \text{HQingestion} + \text{HQdermal} + \text{HQinhalation} \quad (9)$$

HI value < 1, designates no non-carcinogenic risk, and $\text{HI} > 1$ indicates the likelihood of non-carcinogenic health effects to occur [35].

2.6.2 Carcinogenic Health Risk

The carcinogenic risk is considered as the incremental probability of a person to develop any kind of cancer at some point in a life time following the exposure to carcinogenic metals [14, 38]. Carcinogenic risk (CRI) was calculated using Eq. 10.

$$\text{CRI} = \sum \text{ADDc} \times \text{SF} \quad (10)$$

where ADDc is the estimated average daily dose for carcinogenic effects in mg/kg/day and SF represents slope factor in $(\text{mg/kg/day})^{-1}$. The slope factor represents the chance of developing cancer per unit exposure level in $(\text{mg/kg/day})^{-1}$. Values of SF and RfD are presented in Table 2. Among the heavy metals studied, carcinogenic risk assessment was conducted on Cd, As, Ni and Pb based on the accessibility of slope factors. The acceptable range for carcinogenic risks is set between 1×10^{-6} and 1×10^{-4} [38]. CRI below 1×10^{-6} signifies a negligible carcinogenic risk to human health and $\text{CRI} > 1 \times 10^{-4}$ indicates the likelihood to develop cancer.

3 Results and Discussion

3.1 Concentrations of Heavy Metals in Dust from Transport Stations

The concentrations of heavy metals in dust samples from transport stations are summarized as boxplots in Fig. 2.

Table 1 Exposure parameter and values used for human health risk assessment for heavy metals in transport stations in the Kumasi metropolis

Factor	Description	Value		References
		Children	Adults	
C	Metal concentration in dust (mg/kg)			This study
IngR	Ingestion rate of dust (mg/kg)	200	100	[36]
EF	Exposure frequency (Days/year)	350	350	[36]
ED	Exposure duration (years)	6	30	[36]
Bw	Body weight of exposed individual (kg)	15	70	[36, 37]
AT	Average time for: Carcinogens Non-carcinogens	365ED 365×70	365ED 365×70	[36, 38]
InhR	Inhalation rate of dust (m^3/day)	7.6	20	[38]
PEF	Particle emission factor (m^3/kg)	1.32×109	1.32 ×109	[39]
SA	Exposed skin surface area (cm^2)	2800	5700	[36]
AF	Skin adherent factor (mg/cm^2/day)	0.2	0.07	[36]
ABS	Dermal absorption factor	0.001 for all metals except As is 0.03	0.001 for all metals except As is 0.03	[40]

Table 2 Cancer slope factors (SF) in $(mg/kg/day)^{-1}$ and reference dose (RfD) in mg/kg/day for the different heavy metals via ingestion, inhalation and dermal contact [41–44]

Heavy Metal	Cr	Fe	Ni	Cu	Zn	Pb	As	Cd	Sb	Hg
R_fDing	3.0E–3	0.7	0.02	0.040	0.3	1.4E–3	3.00E–4	5.0E-4	4.2E–4	3.0E–4
R_fDderm	1.5 E–5	0.7	5.40E–3	0.012	0.06	4.2E–4	1.23E–4	5.0E–5		2.10E–5
R_fDihn	3.0E–5	0.7	2.06E–5	4.02E–2	0.30	3.52E–3	3.00E–4	5.7E–5		8.6E–5
SFing	–		0.91	–	–	0.042	1.50	15.0		–
SFderm	–		0.91	–	–	0.042	3.66	15.0		–
SFinh	–		0.84	–	–	0.042	15	6.3		–

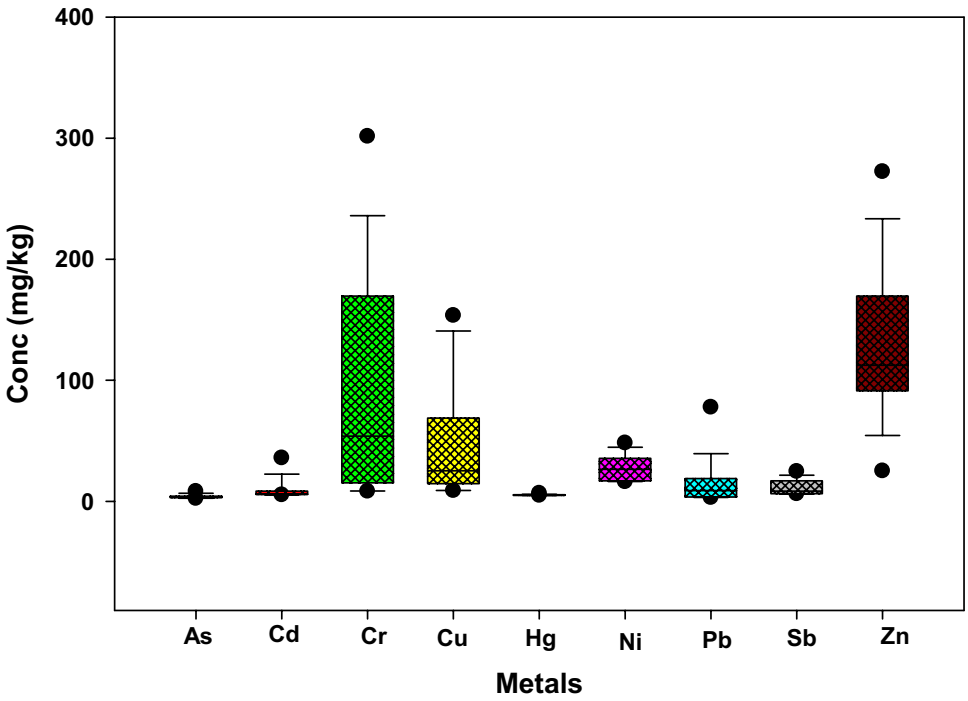

Fig. 2 Concentrations of heavy metals (mg/kg) in dust samples from transport stations within the Kumasi metropolis

3.1.1 Arsenic

The mean As concentration recorded in this study is in agreement with earlier work [15] who reported a mean of 6.2 mg/kg from the fuel filling stations in the Kumasi metropolis. The dust sample from Krofrom had the highest As concentration of 9.66 mg/kg followed by Metro Mass transport which contained 9.55 mg/kg. The average As concentration obtained in this study was 20 times higher than the concentration in the background sample indicating that dust from transport stations was polluted. The potential source of As pollution could be attributed to traffic activities due to the combustion of fossil fuel [45].

3.1.2 Cadmium

The mean concentration of Cd in this study was higher than the mean value reported in other studies, 8.13 mg/kg [46], 1.04 mg/kg [47] and 2.46 mg/kg [48]. All the reported concentrations of Cd in this study exceeded the background concentration of 0.01 mg/kg. This signifies the anthropogenic pollution of Cd in transport station dust. Cadmium is used as an additive in automobile lubricating oils and vulcanization of tyres, therefore the high levels of cadmium in the dust may have been released from oil spillage, car components, break lining wear, tyre wear and engine exhausts of motor vehicles [49].

3.1.3 Chromium

The mean concentration of Cr obtained in this study was lower than the average concentration of 210 mg/kg reported [11] for road dust in major highways of Accra, Ghana and the average concentration of Cr of 128 mg/kg from Beijing Bus stations [48]. The mean concetration in this study was however 6 times higher than the average concentration of 21.5 mg/kg for a similar study conducted in Kayseri, Turkey [46]. All the Cr concentrations in transport stations exceeded

that of the reference sample (4.67 mg/kg) suggesting the anthropogenic contribution of Cr in transport stations. The possible sources of Cr could be vehicular activities. Corrosion of car components which are plated with chrome material containing Cr and Ni contributes to the release of Cr into urban dust.

3.1.4 Copper

The highest copper concentration was measured from Ahodwo station (143.77 mg/kg) followed by Atonsu (141.11 mg/kg). The mean concentration of copper obtained in this study was 2 times lower than the average value of 27.8 mg/kg reported for a car park in Kayseri, Turkey [46] and 3.8 times lower than that (208.9 mg/kg) reported for Beijing bus stations [48]. A similar trend was observed in a study conducted in Adamawa State, Nigeria [47]. The average Cu concentration in this study exceeded the background value. This suggests the anthropogenic input to Cu pollution in transport stations. Copper is a common pollutant in the urban environment and is associated with heavy traffic [50]. The elevated level of Cu in the transport station dust samples could be linked to corrosion car components, leakage of rubricanting oils, break lining wear, tyre wear and engine exhausts.

3.1.5 Mercury

Mercury is one of the major toxic metals in the environment. The release of mercury in the environment is a result of anthropogenic activities such as gold mining, industrial production of cement and natural processes such as weathering of Hg-containing rocks [51]. The natural level of Hg in soil normally ranges from 0.001 to 0.08 mg/kg and does not exceed 0.1 mg/kg [52]. Therefore, the values of Hg in dust samples reported from Dr. Mensah and Asafo exceeded expected amounts in soil. The possible sources of Hg pollution in these places could be associated with gasoline combustion from motor vehicles, atmospheric deposition of mercury particles and industrial emissions such as coal burning [51, 53].

3.1.6 Nickel

The average concentration of nickel in the dust samples was lower than the mean value of 44.05 mg/kg reported for fuel filling station dust in the Kumasi Metropolis [15] and higher than the mean value (23 mg/kg) for road dust in Islamabad Expressway, Pakistan [54]. A similar study conducted in Kayseri, Turkey [46] reported the average concentration of Ni as 38 mg/kg which is lower than the mean value reported in this study whereas a a higher mean value (56.68 mg/kg) was found in Beijing bus stations [48]. The average concentration of Ni obtained in this study was higher than the background. Nickel concentration observed in this study could be attributed to anthropogenic activities such as automobiles [49] and incineration of municipal waste.

3.1.7 Lead

The highest concentration of Pb was measured from Asafo station (61.73 mg/kg) which is over three times the maximum allowable limit of 20 mg/kg in dust [55]. The average concentration of Pb recorded in this study was 3.66 times lower than the mean value of 80 mg/kg reported [46] and 11 times lower than the mean value of 241 mg/kg reported [47] and apprximatley 5 times lower than the mean concentration for Beijing bus stations [48]. This indicates that transport stations in the Kumasi metropolis were less polluted with Pb compared to other cities. Pb concentration obtained in this study exceeded the background concentration in uncontaminated surface soil [45]. Combustion of leaded gasoline in motor vehicles, and leaks and spills from batteries and radiators could be the potential sources of detected Pb [56].

3.1.8 Zinc

The mean concentration of Zn obtained in this study was lower than that of 280 mg/kg reported from the fuel filling station dust in the Kumasi metropolis [15]. A similar study [48] reported the average Zn concentration of 525 mg/kg which is over four times higher that what was obtained in this study. All the sample sites had zinc concentrations that were higher than that of the reference sample suggesting the anthropogenic contribution to zinc contamination of dust at the transport stations. The observed concentration of zinc is thought to be emitted from automobiles [57].

3.1.9 Iron

The concentration of Fe ranged from 3769 to 40,936 mg/kg, with a mean value of 16517 mg/kg. The average value of Fe was the highest compared to the mean values of other metals. This may be due to the reason that Fe has higher natural content in soil compared to other heavy metals [46]. The reported mean value of Fe in this study was lower than the mean value of 20,500 mg/kg reported from car parks in Mubi, Adamawa State, Nigeria [47]. The highest value of Fe was recorded at Metro Mass transport yard (40,936 mg/kg) followed by Abinkyi (28,733 mg/kg), Krofrom (27,330 mg/kg), Mayanka (27,323 mg/kg) and Roman Hill (21,682 mg/kg). All the sample sites had Fe concentrations that were higher than the value recorded for the control dust sample (8216 mg/kg) except Adum which had the lowest value (3787 mg/kg). Iron contamination may be considered to be due to corrosion of some parts of motor vehicles as indicated

in the study conducted in Nigeria [58]. On the other hand, human activities which involved metal grinding, cutting and fubrication and auto mechanical workshops which were dotted around some car stations such as Roman Hill, Metro Mass transport and Krofrom could also be linked to Fe pollution in dust found in these areas.

3.1.10 Antimony

Antimony is one of the potential hazardous metals to human health and its distribution in the environment is by anthropogenic activities and natural processes. Its natural content in the earth crust is about 0.3 mg/kg [59]. The mean concentration was about 22.7 times higher than reported [53] from roadside dust in Japan. The average Sb concentration exceeded the background concentration which indicates anthropogenic pollution of Sb in transport stations. A study [53] showed that automobiles contribute greatly to the release of Sb in the urban dust. Other studies revealed that the use of antimony-containing compounds such as dialkyldithiol carbamate in motor oil and grease, Sb_2S_3 in brake linings and antimony trioxide as flame retardant in the process of vulcanization contribute to the emission of Sb into the environment [57, 59]. Therefore, break lining wear, oil leaks, tyres wear and combustion of fossil fuel may be considered to be the major potential sources of Sb pollution in transport stations.

3.2 Correlations Between Metals

The relationship between heavy metals in dust from transport stations was conducted using Pearson's correlation at $p < 0.05$. Arsenic showed a strong negative correlation with Ni ($r = -0.722$, $p < 0.05$) and a moderate positive correlation with Zn ($r = 0.643$, $p < 0.05$) signifying that As originated from the same anthropogenic source with Ni and Zn. Litterature indicates that As, Ni and Zn may be released into the environment from anthropogenic activities such as combustion of fossil fuel, tyre wear and corrosion of car parts [53, 57]. Cadmium showed a strong positive correlation with Sb ($r = 0.732$, $p < 0.05$), which indicates they have a similar source of origin. Similarly, a moderate negative correlation was found between Cr and Pb ($r = -0.63$, $p < 0.05$) but the other metals did not show any significant correlations amongst them.

3.3 Heavy Metal Pollution in Dust

The descriptive statistics of the calculated Igeo and EF values of heavy metals in dust from transport stations are presented in Table 3.

The average Igeo values decreased in the following sequence: Cd > Cr > As > Zn > Ni > Hg > Cu > Pb > Sb > Fe. The mean Igeo value of Pb, Fe and Sb which ranged between 0 and 1, showed that dust from transport stations were unpolluted to moderately polluted. The mean Igeo of Cu and Hg indicated that dust samples were moderately polluted by these metals wheress the mean Igeo of Ni signified moderately to strongely polluted. On the other hand, mean Igeo of As, Cr and Zn designate dust to be strongly polluted with the metal. The mean Igeo value of Cd signifies very strongly polluted. Among the heavy metals studied, dust samples were signficantly polluted by Cd, Cr, Zn and As and least polluted by Pb, Fe and Sb. Comparing to other studies [14] reported the Igeo values of Zn, Cu, Cr and Ni in soil dust of fuel filling stations in Accra, Ghana which are lower than the values reported in this study. Similarly, Hg and As showed higher Igeo values compared to those reported elsewhere [60].

The mean enrichment factors (EF) of Cd, Cr, As and Zn showed high enrichments of these elements in the dust samples while Pb, Sb and Fe showed the least enrichment which are equally described by the Igeo pollution indices. The EF of Cd which ranged from 2758.80 to 175.61, with a mean

Table 3 Summary of pollution indeces of heavy metals in dust across transport stations in the Kumasi Metropolis

	Geoaccumulation index			Enrichment factor			Concentration factor		
Element	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean
As	3.04	4.42	3.68	4.69	34.66	10.30	12.37	32.20	20.34
Cd	9.10	11.27	10.12	175.61	2758.80	1099.30	821.00	3713.00	1998.89
Cr	1.06	5.21	3.92	2.91	58.78	16.14	3.12	55.70	27.92
Cu	− 0.60	2.93	1.07	0.46	7.79	2.71	0.99	11. 41	4.31
Hg	0.24	6.36	1.69	0.93	68.69	7.62	1.77	123.26	13.04
Ni	1.45	2.89	2.16	2.20	19.14	4.40	4.10	11.13	7.00
Pb	− 1.41	2.38	0.57	0.11	4.99	1.82	0.57	7.80	2.76
Zn	2.12	4.28	3.26	2.12	40.09	10.25	6.53	29.19	16.03
Fe	− 1.71	1.73	0.22	1.00	1.00	1.00	0.46	4.98	2.01
Sb	− 0.50	1.48	0.52	0.51	3.52	1.50	1.06	4.20	2.35

value of 1099.30 indicated that Cd was extremely enriched in the dust. The EF of Pb and Sb were less than 2 which indicated minimal enrichment. The EF of Cu and Ni signify moderately enrichment whereas the EF of the other metals including As, Cr and Zn showed very high enrichment. The mean EF values of As, Cd, Cr, Cu, Hg, Ni, Pb, Zn and Sb in the dust samples exceeded 1, which indicated the anthropogenic contribution to the pollution of these metals in dust.

The contamination factors (CF) varied significantly among the metals due to defferences in the levels of their pollution and sources. Cadmium exhibited the highest mean CF of 1998.89 signifying very high contamination of dust samples. Other metals such as Fe, Sb and Pb had the lowest mean CF values which fall between 1 and 3 and were considered as moderately contaminated to considerable contaminated. The CF values of Hg varied greatly between sample sites and ranged from 1.77 to 123.26. This indicates that sample sites were moderately contaminated ($1 \leq CF < 3$), considerable contaminated ($3 \leq CF \leq 6$) while others were very highly contaminated ($CF > 6$). The other metals including As, Cr, Zn, Ni and Cu exhibited mean CFs which indicated that sample sites were significantly contaminated by these metals. The results of CFs also indicated Cd, Cr, As and Zn as the major metal pollutants in the transport stations within the Kumasi metropolis.

Pollution load index (PLI) of the samples ranged between 1.39 and 12.57 with a mean value of 6.14 (Fig. 3), indicating that the quality of sample sites were deteriorated ($PLI > 1$) by heavy metals. Among the transport stations studied, Krofrom (close to the city centre) showed the highest pollution load while Kotei (city outskirts) displayed the least heavy metals pollution load. Most of the transport stations within the Kumasi metropolis appeared to have high metal pollution load compared to fuel filling stations which were reported to be moderately polluted [15].

3.4 Human Health Risk Assessment

The results of carcinogenic and non-carcinogenic risks for As, Cd, Pb and Ni for both children and adults are presented in Table 4.

3.4.1 Estimation of Non-carcinogenic Risk

The results of hazard quotients for all the studied heavy metals in transport stations were less than acceptable safe limit of 1 (Table 5).

The results show non-carcinogenic effects for both children and adults is not likely to occur from exposure to heavy metals in dust from transport stations. Similarly, hazard index for each metal across the three exposure pathways were less than 1, signifying no potential non-carcinogenic risk for both groups; children and adults. However, Cr (with a hazard index of 0.87 is more likely to trigger non-carcinogenic health risk for children. This was equally reported by Du and coworkers [40] who observed hazard index of 0.805 for Cr in children due to exposure in road dust. A study [61] also reported the non-carcinogenic health risk of Cr (hazard index of 0.919) for children which is higher than the value obtained in this study. Although the hazard index of other metals was comparatively lower, their regular monitoring is necessary. The hazard index of the heavy metals for children decreased in the following order: $Cr > Cd > As > Fe > Pb > Ni > Cu, Zn > Hg$.

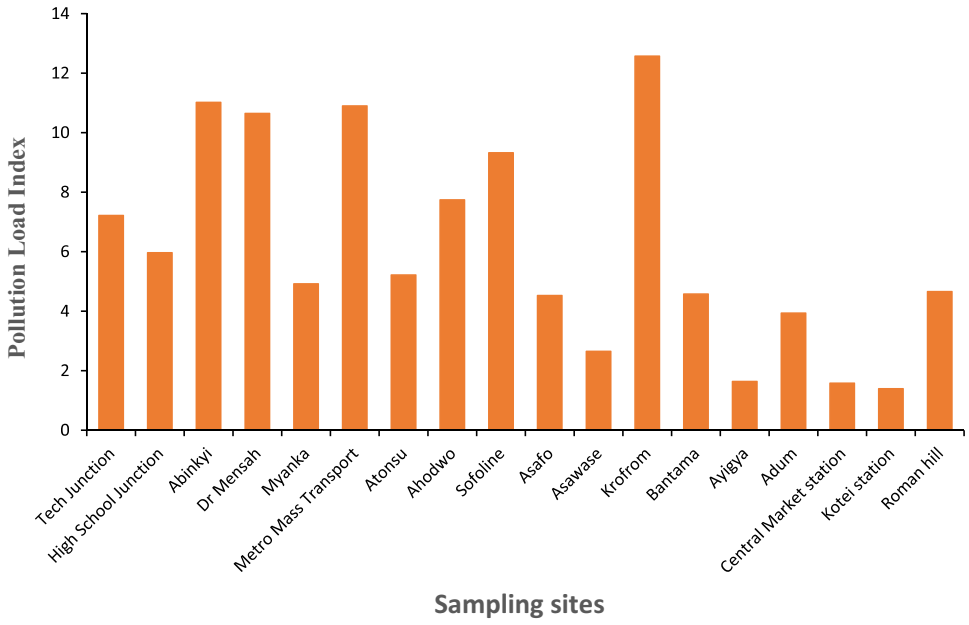

Fig. 3 Pollution load index for heavy metals in transport station dust of Kumasi metropolis

Table 4 Non-carcinogenic risk; Hazard quotients (HQ) and hazard index (HI)

Metals	Children				Adults			
	HQing	HQinh	HQderm	HI	HQing	HQinh	HQderm	HI
As	2.28E–01	6.56E–06	4.67E–02	0.27	7.64E–04	1.16E–06	7.44E–03	0.01
Cd	3.09E–01	7.79E–05	8.64E–03	0.32	1.03E–03	1.38E–05	1.38E–03	0.00
Cr	5.59E–01	1.61E–03	3.13E–01	0.87	1.87E–03	2.84E–04	4.98E–02	0.05
Cu	9.33E–03	2.67E–07	8.71E–05	0.01	3.13E–05	4.72E–08	1.39E–05	0.00
Hg	8.52E–04	8.56E–08	3.41E–05	0.00	2.86E–06	1.51E–08	5.43E–06	0.00
Ni	1.90E–02	5.31E–04	1.97E–04	0.02	6.37E–05	9.37E–05	3.14E–05	0.00
Pb	1.68E–01	1.93E–06	1.57E–03	0.17	5.64E–04	3.40E–07	2.50E–04	0.00
Zn	5.48E–03	1.58E–07	7.67E–05	0.01	1.84E–05	2.78E–08	1.22E–05	0.00
Fe	2.41E–01	6.93E–06	6.74E–04	0.24	8.07E–04	1.22E–06	1.07E–04	0.00
Sb	–	–	–	–	–	–	–	–
HI	1.54E+00	2.23E–03	3.71E–01	1.91	5.16E–03	3.94E–04	5.90E–02	0.06

Table 5 Average daily dose for carcinogenic risks for adults and children

Metals	Children				Adults			
	ADDc				ADDc			
	Ingestion	Inhalation	Dermal	CRI	Ingestion	Inhalation	Dermal	CRI
As	5.86E–06	1.69E–10	1.64E–06	1.48E–05	2.09E–06	3.17E–10	2.51E–07	4.06E–06
Cd	1.32E–05	3.81E–10	1.23E–07	2.00E–04	4.72E–06	7.16E–10	1.88E–08	7.11E–05
Ni	3.26E–05	9.37E–10	3.04E–07	2.99E–05	1.16E–05	1.76E–09	4.64E–08	1.06E–05
Pb	2.02E–05	5.82E–10	1.89E–07	8.16E–07	7.22E–06	1.09E–09	2.88E–08	3.04E–07

The total hazard index across the three exposure routes for both children and adults were 1.91 and 0.06, respectively. For children, total HI exceeded 1 (safe limit), indicating that cumulative effect of metals is a major concern of non-carcinogenic risk to this sensitive group than adults. It was observed that heavy metals may pose more health risk to children via ingestion (HI = 80.6%) followed by skin contact (19.4%) and inhalation. Young children (1–6 years) are the most sensitive group likely to suffer from heavy metal poisoning due to their active hand to mouth activities, and for that case they can easily ingest a significant amount soil dust than adults [62]. For adults, a different trend of exposure pathways was observed, dermal contact > ingestion > inhalation. This findings is consistent with a study conducted by Zheng et al. [63] who observed dermal contact (for adults) and ingestion (for children) as the dominant exposure pathways of heavy metals in street dust.

3.4.2 Estimation of Carcinogenic Risk

With respect to the results of this study (Table 5), the carcinogenic risk index ranged from 3.04E–07 to 1.06E–05 for adults and 8.16E–07 to 2.00E–04 for children. The acceptable range for carcinogenic risk is set between 1×10^{-6} and 1×10^{-4} [38]. The carcinogenic risk index of As, Cd, and Ni for adults were within the acceptable limits, indicating no carcinogenic risk. Also, the indices of As, Ni and Pb for children were within the acceptable range. However, the indice for Cd (2.00E–04) was above the maximum acceptable value (1×10^{-4}). This indicates that children are likely to suffer from cancer associated with exposure to Cd-contaminated transport station dust in the Kumasi metropolis. The results of carcinogenic health risk assessment indicated ingestion as the principal exposure pathway that contributes to carcinogenic risk followed by dermal contact and inhalation for both children and adults.

4 Conclusion

This study has systematically investigated the concentration, pollution levels and human health risk associated with heavy metal contamination in dust from transport stations within the Kumasi metropolis, Ghana. The concentrations of As, Cd, Cr, Hg, Cu, Pb, Zn, Fe and Sb varied significantly in the dust samples. All the studied metals recorded the average concentrations higher than their corresponding background concentrations which signifies anthropogenic pollution. These pollution indices showed that dust samples were significantly polluted by Cd, As, Cr and Zn. The elevated levels of heavy metals in dust from transport stations could be attributed to emissions from vehicular activities.

The pollution loads indicated that the sample sites were deteriorated by heavy metals. From the health risk assessment, both HQ and HI of all the metals were below the safe limit (1) for both children and adults, indicating no non-carcinogenic risk. However, Cr with HI = 0.87 which is more closer to safe limit for children requires regular monitoring. The total HI for children were > 1, signifying a major concern of cumulative hazards of heavy metals in children. Ingestion route (HI = 80.6%) was a major exposure pathway for children while dermal contact (HI = 98.3%) was dominant for adults. For carcinogenic risk, As, Ni and Pb were seen to pose no risk for both children and adults. Cadmium with CRI of 2.00E–04 exceeded the safe limit of 1E0–4 for children, indicating children to be at risk of Cd-causing cancer when exposed to dust from transport stations within the Kumasi metropolis. Exposure pathways for both adults and children for carcinogenic risk followed the order: ingestion > dermal contact > inhalation. This study has offered the baseline of current pollution levels of heavy metals and associated health risk, therefore appropriate measures need to be taken by environmental regulatory bodies of the Kumasi Metropolis. Regular monitoring of heavy metals in transport stations is recommended to safe-guard the environment and human life.

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Compliance with Ethical Standards

Conflict of interest The authors certify that they have NO affiliations with or involvement in any organization or entity with any financial or non-financial interests in the subject matter or materials discussed in this manuscript.

Ethical approval Ethical clearance was not required for this study as no human participants were involved.

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