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Distribution and Health Risk Assessment of Heavy Metals in Road Dust at Adjamé Bus Station in Abidjan, Côte d'Ivoire

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Abstract

Heavy metal concentration in roadside dusts are increasingly becoming of health concern. The investigation of the anthropogenic contamination by heavy metals on road dust is very necessary for environmental planning and monitoring in urban dwellings. In the present study, the concentration of four heavy metals (Pb, Cu, Zn and Ni) in dust at Adjamé Bus Station in Abidjan, were sieved below 112 μm and analyzed using atomic absorption spectrometer. The results show that the average concentrations of Cu, Zn, Cd and Pb in the dust samples are 403.26, 91.89, 2.46 and 279.76 mg/kg respectively. The observed concentration levels show that these heavy metals could be posing harmful-health effect. This study revealed that the elemental content were higher than their background value of the average continental crust. The pollution status was assessed using enrichment factor (EF). As recorded the highest EF value at 25.1 for Pb followed by Cd (13.97), Cu (8.32) and Zn (1.49). The health risk was assessed using Hazard Quotient (HQ) and Health Index (HI). The assessment of health risk indicated that there were mainly three exposure pathways for people: ingestion, dermal contact and inhalation. The main exposure pathway of heavy metals to both children and adults is ingestion. HQ and HI for all metals were lower than the safe level (=1), the cancer risk of Cd was low its threshold value, indicating no health risk exists in present condition.

Keywords: Heavy Metals, pollution, road dusts, contamination assessment, Côte d'Ivoire. Abidjan

1. Introduction

Road dust is among the major causes of pollution in the urban environment [1]. Road dust can be generated from the following processes: exhaust emissions, tyre wear, break wear, clutch wear, road surface wear, corrosion of vehicle components and corrosion of street furniture, signs, crash barriers and fencing [1]. Dust is the most pervasive and important factor affecting human health and well-being [2].
The most common heavy metals introduced to the environment by road transportation are lead (Pb), zinc (Zn), and copper (Cu) [3-4-5]. The use of leaded gasoline is primarily responsible for the Pb exposure [6], while tyre wear and corrosion of roadside safety fences contribute to Zn pollution [6]. Cu is mainly released from the wear of brake linings, which is also an important source of Pb and Zn. All three metals are deposited in the form of dust and can form aerosols when re-suspended [8]. The source of Ni and Cr in street dust is believed to be due to corrosion of vehicular parts [9].
Exposure to heavy metals in road dust can occur through ingestion, inhalation or dermal contact. Several prior studies have evaluated the concentration, distribution, pollution potential, and health risks of heavy metals in road dust [10-11].
Recent studies have shown that the direct soil exposure, through soil ingestion, dermal adsorption and inhalation exposure, is a major pathway of the intake of heavy metals and is particularly important for children [12]. Children's behavior can expose them to more toxic effects of soil heavy metals. The adverse effects of heavy metals in road dust include respiratory system disorders, nervous system interruptions, endocrine system malfunction, immune system suppression and the risk of cancer in later life [13].
Estimating the source and spatial distribution of pollutants is crucial to quantifying the level of environmental risks [14].The purposes of this work are to investigate concentration of four heavy metals (Cu, Zn, Cd and Pb) contents in road dust in Abidjan dust and to estimate the non-cancer health risk of theses heavy metals.

2. Materials and methods

2.1.Study area

The study area (Adjamé bus station) is situated in the southeast of Côte d'Ivoire (5° 20' 11" north, 4° 01' 36"west) (Figure 1). It was selected based purely on traffic density (an average of 5000 vehicles/day). A large number of people frequenting this site daily and are subjected to the dusty environment created by vehicular emissions.. Temperatures at the study area range between a maximum of 45 degrees in March / April and a minimum of 12°C in December.

2.2. Sample Collection, Preparation and Analysis

The sample collection was done from December 2014 to February 2015. During this dry season, from each selected location, samples were collected at 6 days intervals.

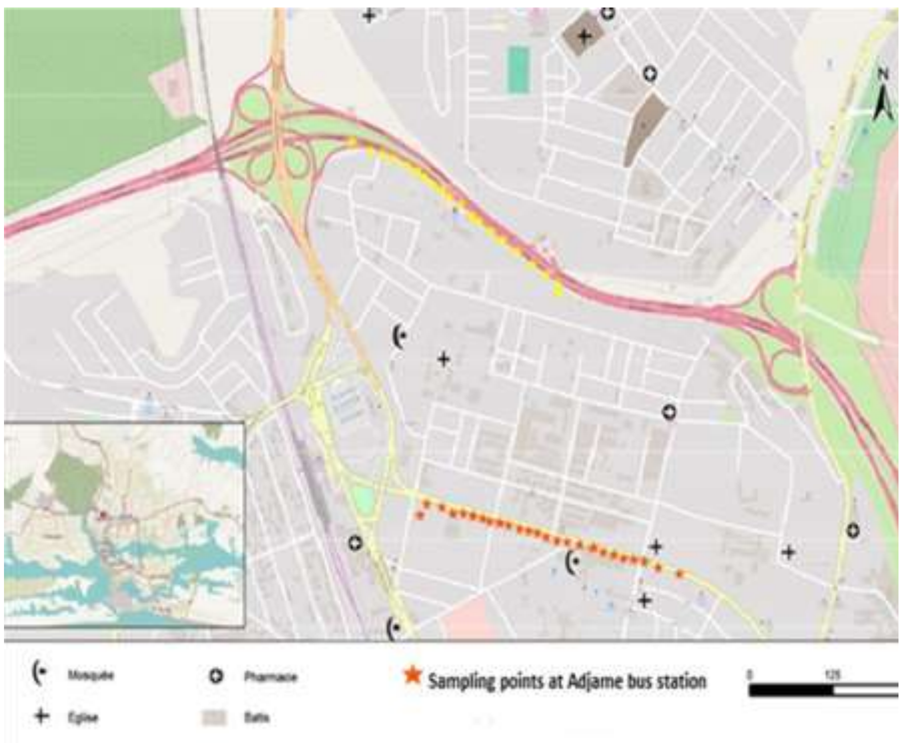

Figure 1: Map of study area (Adjamé bus station)

A total of 19 samples were collected for the period of sampling. The dust samples were gathered and collected into self-sealed polythene bags. The self-sealed polythene bags were pre-cleaned with acetone.

At the sampling sites, about 500 g of road dust composite sample was collected by sweeping using soft touch brush and plastic dust pan. In order to avoid cross contamination, different brushes and dust pans were used for each sampling day.

The dust was sampled from different areas within the study area. Sampling was not done on rainy days. The samples were collected between 16.30 am and 18.30 am on each sampling day because of heavy traffic.

Samples collected from each spot (on each sampling day) were homogenously mixed to form a composite sample. The samples were sieved using a mesh (metric sieve test Bs 410, WS Tyler) with a geometric diameter of 250 µm and 112 µm. As a measure of avoiding cross contamination, the sieves were cleaned with acetone between samples. The size fraction between 250 µm and 112 µm was labelled as +112 µm and those less than 112 µm were labelled as "-112 µm". The analyses were restricted to the size fractions below 112 µm because particles of such sizes are easily resuspended. The samples were then pulverized for 15 minutes into fine powder using the Fritsch Pulverisette-2 to ensure homogeneity and also to avoid particle size effect.

Microwave Acid Digestion Procedure:

The digestion was carried out by using 0.5g of the pulverised samples in an acid mixture (4 mL of 65% HNO_3, 1 mL of 37% HCl, 4 mL of 40% HF). The digestion was carried out at an operation pressure of 200 psi and temperature of 210^{o}C for 15 min. After the program completion in 15 min, the vessels were removed from the microwave oven and were left to cool for 30 min. They were then opened and 25 mL H_3BO_3 was added to the solution. The vessels were then sealed again and irradiated for another 15 min at 210 ^{o}C. After the acid digestion, the samples were transferred into a 100 ml measuring cylinder and toped to the 20 ml mark with double distilled water. The obtained digests were stored in polyethylene bottles at 4 ^{o}C until trace metal analysis by Atomic absorption spectrometer (AAS).

The concentrations of trace metals (Pb, Ni, Cu, and Zn) in the filtrate were determined using Varian AA 240FS- Atomic absorption spectrometer in an acetylene- air flame.

2.3 Enrichment Factors

The Enrichment Factors (EF) is a convenient measure of geochemical trends and is used for making comparisons between areas [15]..

EF_X = [CS/CS (ref)] / [BC/BC (ref)]   (1)

Where EF_X is the enrichment factor for the element X; CS is the concentration of element of interest in sample; CS (ref) is the concentration of the reference element used for normalization in the sample; BC is the concentration of the element in the crust; BC (ref) is the concentration of the reference element used for normalization in the crust. A reference element is a conservative element; commonly used reference elements include aluminum (Al), silicon (Si), iron (Fe), manganese (Mn), scandium (Sc), titanium (Ti), [16-17]. In this study, Si was used as a reference element and reference elemental concentrations were taken from the chemical composition of the average continental crust data [18]. Five contamination categories are recognized on the basis of the enrichment factor: EF < 2 states deficiency to minimal enrichment, EF = 2–5 moderate enrichment, EF = 5–20 significant enrichment, EF = 20–40 very high enrichment and EF > 40 extremely high enrichment [19].

2.4. Health risk assessment method

In this study, the risk assessment model developed by the Environmental Protection Agency of the United States (US EPA) was used to evaluate the health risks posed by heavy metals in road dust. The average daily dose (ADD) (mg/kg/day) of a pollutant via ingestion, dermal contact and inhalation as exposure pathways can be estimated using Eqs. (1), (2) and (3) [20]:

$$ADDinh = (C \times Rinh \times EF \times ED) / (PEF \times BW \times AT) \quad (1)$$

$$ADDing = (C \times Ring \times EF \times ED \times CF) / (BW \times AT) \quad (2)$$

$$ADDderm = (C \times SL \times SA \times ABS \times EF \times ED \times CF) / (BW \times AT) \quad (3)$$

Where, ADDing is daily exposure amount of metals through ingestion (mg/kg/day); ADDinh is daily exposure amount of metals through inhalation (mg/kg/day); ADDderm is daily exposure amount of metals through inhalation (mg/kg/day).

The life time average daily dose LADD for cancer elements via inhalation exposure route was calculated by:

$$LADD\ (mg/kg^{-1}day^{-1}) = \frac{C \times EF}{AT \times PEF}\left(\frac{InhRchild \times EDchild}{BWchild} + \frac{InhRadult \times EDadult}{BWadult}\right)$$

Where C is the upper limit of the 95% confidence interval for the mean (95% UCL), which is considered as a conservative estimate of the “reasonable maximum exposure”. The exposure factors for these models are showed in Table 1.

For non-carcinogenic risks, the doses calculated for each element and exposure pathway are subsequently divided by the corresponding reference dose (RfD) to yield a hazard quotient (HQ). HQ=D/RfD (7)

Where RfD is the corresponding reference dose. An HQ<1 indicates no adverse health effects, while HQ>1 indicates that adverse health effects are likely to occur.

Hazard index (HI) is equal to the sum of HQ. If the value of HQ or HI is less than one, it is believed that there is no significant risk of non-carcinogenic effects. If HQ or HI exceeds one, then there is a chance that non-carcinogenic effects may occur, with a probability which tends to increase as the value of HQ or HI increases [23].

In the case of carcinogenic risks, the life time cancer risk can be estimated by:

R=LADD/Sf (8)

Where Sf is the corresponding slope factor.

The level of cancer risk associated with exposure to an element in street dust is the range of threshold values (10^{-6}, 10^{-4}), above which environmental and regulatory agencies consider the risk unacceptable [24]. Hazard Index method and cancer risk method were used to assess human health risk of heavy metals exposure to surface dusts in Abidjan city.

Table 1. Exposure factors for dose models.

Factor	Definition	Unit	Value		Reference
			Children	Adult	
C	concentration of the contaminant in dusts	mg/kg			This study
Ring	ingestion rate	mg/day	200	100	[21]
Rinh	inhalation rate	m^3/day	10	20	[22]
EF	exposure frequency	days/year	250	250	[13]
ED	exposure duration	years	6	25	[23]
BW	average body weight	kg	15	70	[24]
AT	average time	days	365×ED	365×ED	[24]
CF	conversion factor	kg/mg	1×10^{-6}	1×10^{-6}	
PEF	particle emission factor	m^3/kg	1.32×10^9	1.32×10^9	[23]
SA	surface area of the skin that contacts the dust	cm^2	2800	3800	[23]
SL	skin adherence factor for dust	mg/(cm^2h)	0.2	0.2	[23]
ABS	dermal absorption factor (chemical specific)		0.001	0.001	[23]

The RfD and Sf values [13-10] of all investigated metals are presented in Table 2

Table 2: RfD and Sf values of elements

	Zn	Cu	Cd	Pb
RfDing	3.00E-01	4.00E-02	1.00E-03	3.50E-03
RfDinh	3.00E-01	4.00E-02	1.00E-03	3.52E-03
RfDdermal	6.00E-02	1.20E-02	5.00E-05	5.25E-04
Sfinh			6.30E+00	

3. Results and discussions

3.1. Heavy metal concentration (mg/kg) in road dust from the selected site

The concentrations of metals in road dust samples, as well as their background values are showed in Table 3. The background values of the metals are the average continental crust data [25-26]. The concentration of Cu, Zn, Cd and Pb in road dust ranged from 86.50 to 530.50, 63.50 to 113.00, 1.50 to 5.00, 151.50 to 316.50 mg/kg, with means of 403.26, 91.89, 2.46 and 279.76 mg/kg, respectively. The concentrations of 4 metals varied widely in this selected site and followed the order of Cu>>Pb> > Zn>>Cd. Compared to their background values, the elements Cu, Zn, Cd and Pb had evidently elevated, indicating pollution of anthropogenic activities. Cu copper which has high average concentration would come from tire abrasion, corrosion of metal parts of cars, lubricants, industrial emissions and incinerators [1]. Pb also had high average concentrations compared to the background value. (Pb) comes mainly from automobile exhaust and vehicle emissions, such as tire wear, bearing wear, and brake lining wear [1]. The presence of Zn is due to high frequency of intermittent braking, Zn is a product of brake and tyre wear. Zn is used as a vulcanization agent in vehicle tyres and tyre wear has been reported to contribute significantly to Zn in street dust [27]. The cadmium is released as a combustion product in the accumulators of motor vehicles or in carburetors [28-29].

Table 3: Heavy metal concentration of road dust at Adjamé bus station in Abidjan (mg/kg)

Element	Min	Mean	Max	SD	Background
Cu	86.50	403.26	530.50	125.06	55
Zn	63.50	91.89	113.00	14.90	70
Cd	1.50	2.46	5.00	1.03	0.2
Pb	151.50	279.76	316.50	42.64	12.5

3.2. Assessment According to Enrichment Factor (EF)

Enrichment factors of various metals in the road dust in sampled area are presented in Table 4. Silicon was used as a reference element because there is no indication of any human activity that could contribute to silicon within the vicinity of the sampling site. According to Table 4, the results of the mean EFs were in the following order: Pb> Cd> Cu> Zn.

An increase in EF values indicates an increase in the contributions from anthropogenic origins [30]. Zn generally showed minimal enrichment at the sampling site. Cu and Cd were significantly enriched at Adjamé bus station site. The mean EF value of Pb showed very high enrichment at Adjamé bus station, indicating anthropogenic influx, which could largely be coming from vehicular activities. This could be attributed to the automobile emission, where the wind direction played a key role in transfer the pollutants. The elements Cu, Zn, Pb and Cd are present in break, tyre and exhaust emissions.

Table 4: Result of the Enrichment Factor

Element	Mean (EF _Si) value
Cu	8.32
Zn	1.49
Cd	13.97
Pb	25.41

NB: Silicon used as reference element

3.3.Health risk assessment of heavy metals exposure to surface dusts

The results of the risk assessment are shown in Table 5.

Average daily dose of ingestion of dust particles for all metals were much higher than those of inhalation of re-suspended dust particles and dermal absorption with dust particles. Among three different exposure pathways, the HQing values were the highest and contributed the most to HIs for both children and adults, indicating that ingestion of road dust appears to be the most threatening exposure way to human health at Adjamé Bus station (Figure 1). The inhalation of re-suspended through mouth and nose seemed to be negligible due to inhalation of dust particles is 2-4 orders of magnitude lower than the other two paths. Similar results were obtained by previous studies [13-10]. The highest levels of risks were associated with the route of ingestion of dust particles to children and adults for all metals, followed by dermal contact.

The HQs and HIs for all heavy metals were lower than 1, which indicated that the adverse health impact on children and adults exposure to heavy metals in road dusts was relatively light at Adjamé bus station. Children were found to experience higher health risks through ingestion compared with adults. The values of HQing for children were 9.33 times higher than those for adults in this study. This result may be partially attributed to the special behavior patterns of children, particularly frequent hand-to-mouth contact. The orders of non-cancer hazard indexes of metals were Pb>Cu>Cd>Zn to children and adults. The HI values for all metals tested in this study were within the safe level (=1), suggesting minimal non-carcinogenic risk to children and adults from exposure to road dust metals. The cancer risks according to inhalation exposure to Cd, is presented in Table 5.

Table 5: Exposure dose, hazard quotient and risk for each element and exposure pathway (mg/kg* d)

	Zn	Cu	Cd	Pb
RfDing	3.00E-01	4.00E-02	1.00E-03	3.50E-03
RfDinh	3.00E-01	4.00E-02	1.00E-03	3.52E-03
RfDdermal	6.00E-02	1.20E-02	5.00E-05	5.25E-04
Sfinh			6.30E+00	
CHILD				
Ding	6.04E-04	2.65E-03	1.62E-05	1.84E-03
Dinh	1.74E-08	7.66E-08	4.67E-10	5.31E-08
Ddermal	1.69E-06	7.42E-06	4.53E-08	5.15E-06
LADD			2.4305E-09	
HQing	2.01E-03	6.63E-02	1.62E-02	5.26E-01
HQinh	5.80E-08	1.92E-06	4.67E-07	1.51E-05
HQdermal	2.82E-05	6.18E-04	9.06E-04	9.81E-03
HI = ∑HQi	2.04E-03	6.69E-02	1.71E-02	5.36E-01
Cancer Risk			3.86E-10	

Table 5 (continued): Exposure dose, hazard quotient and risk for each element and exposure pathway (mg/kg* d)

ADULT				
Ding	6.47E-05	2.84E-04	1.73E-06	1.97E-04
Dinh	9.84E-09	4.32E-08	2.64E-10	3.00E-08
Ddermal	2.58E-06	1.13E-05	6.92E-08	7.86E-06
LADD			2.4305E-09	
HQing	2.16E-04	7.10E-03	1.73E-03	5.63E-02
HQinh	3.28E-08	1.08E-06	2.64E-07	8.52E-06
HQdermal	4.30E-05	9.42E-04	1.38E-03	1.50E-02
HI = ∑HQi	2.59E-04	8.04E-03	3.11E-03	7.13E-02
Cancer Risk			3.8579E-10	

The level of cancer risk associated with exposure to this element in road dust (i.e. 3.86E-10) falls within the range of threshold values (10^{-6} - 10^{-4}) above which environmental and regulatory agencies consider the risk unacceptable, it means there was no cancer risk at Adjamé bus station.

4. Conclusions

This work investigated the elemental contents of road dust and human health risk due to exposure at Adjamé bus station in Abidjan. The road dusts were examined for four elemental contents Cu, Pb, Zn and Cd. The dust particles of size fractions less than 112 mm were considered in this study for the reason that they are more aerodynamic and can therefore be carried far when resuspended. The result generally showed that the concentrations of the metal are higher than their background value of the average continental crust data. The pattern of the total mean concentration in the road dust followed Cu>>Pb>> Zn>>Cd. The enrichment factor showed minimal enrichment for Zn, significantly enrichment for Cu and Cd, and very high enrichment for Pb. Human health risk assessment was a useful tool to identify toxic metals. The results of the risk assessment showed that people are exposed to pollutant via ingestion, dermal contact and inhalation. The exposure pathway which resulted in the highest levels of risk for human exposed to road dust was ingestion of this material, which was followed by dermal contact. In this study, the values of HQ for those pathways decrease in the order of ingestion>dermal contact>inhalation. The Hazard Quotient values and the Hazard Index values for all studied metals are far lower than the safe level for children and adults, indicating no risk from these metals. The Hazard Quotient values for single metals and the Hazard Index value for all studied metals are far lower than the safe level for children and adults, indicating no risk from these metals. The cancer risk of Cd was low its threshold value, indicating without health hazards and cancer risk in Adjamé bus station. We conclude that there is no human health risk for selected heavy metals in road dust at Adjamé bus station.

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