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Research Article

Heavy Metal Concentrations in Road Dust in Abidjan, Côte d'Ivoire

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Abstract: The investigation of the anthropogenic contribution to heavy metals contamination on road surface 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 road dust from two locations being Northern Highway and Adjame Bus Station in Abidjan were sampled and analyzed using Atomic Absorption Spectrometer. The pollution status was assessed using Degree of Contamination (DC), Pollution Load Index (PLI) and Enrichment Factor (EF). The results obtained as compared with the alert values of the New Dutch List, showed that road dusts in Abidjan have elevated concentrations of Pb Cu and Ni. Results of DC, PLI and EF were in agreement with the heavy metal contamination levels of the two sites. The observed concentration levels show the need for mitigation measures to be applied to prevent ill-health effect.

Keywords: Abidjan, contamination assessment, Côte d'Ivoire, heavy metals, pollution, road dusts

INTRODUCTION

Roads are known to be the second largest non-point source of pollution in urban environment (Fakayode and Olu-Owolabi, 2003). Heavy metals found in roadside dust have been significant environmental pollutants of growing concern in recent years. Public attention and research works have increasingly focused on the related contamination effects on humans and other living bodies (Wang *et al*., 2005). Road dust is also one of the most important sources of atmospheric Particulate Matter (PM), especially in urban areas. Road dust can be generated from 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 (Al-Khashman, 2004).

Depending on the particulate size, road dust can have short or long resident time in the ambient air (Harrison *et al*., 1981). The composition and quantity of chemical matrix of road dust are indicators of environmental pollution (Banerjee, 2003).

Most common heavy metals found in road dust are lead (Pb), zinc (Zn) and copper (Cu) (Kim *et al*., 1998; Banerjee, 2003; Li *et al*., 2004)). Human exposure to heavy metals in road dust can occur through ingestion, inhalation or dermal contact. 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 (Ferreira-Baptista and De Miguel, 2005).

Abidjan, the capital city of Cote d'Ivoire, has experienced rapid growth in population and urbanization over the last few decades. Between the years 2002 and 2016, huge numbers of used (second-hand) vehicles were registered in Abidjan; majority of these vehicles are still in circulation. The rapid growth of industry, population and vehicular fleet exert a heavy pressure on the environmental resources of Abidjan.

This study aims to determine the concentration of heavy metals in road dust samples collected from selected roads in Abidjan in order to assess their contamination levels. The results obtained from this study will be useful information to the authorities concerned in formulating adequate pollution control measures.

MATERIALS AND METHODS

Study area: Abidjan, the capital city, is situated in the southeast of Côte d'Ivoire (5° 20' 11" north, 4° 01' 36" west). Abidjan has a tropical climate with rainy season from May to October; and a long dry season, with virtually no rainfall, from October to April.

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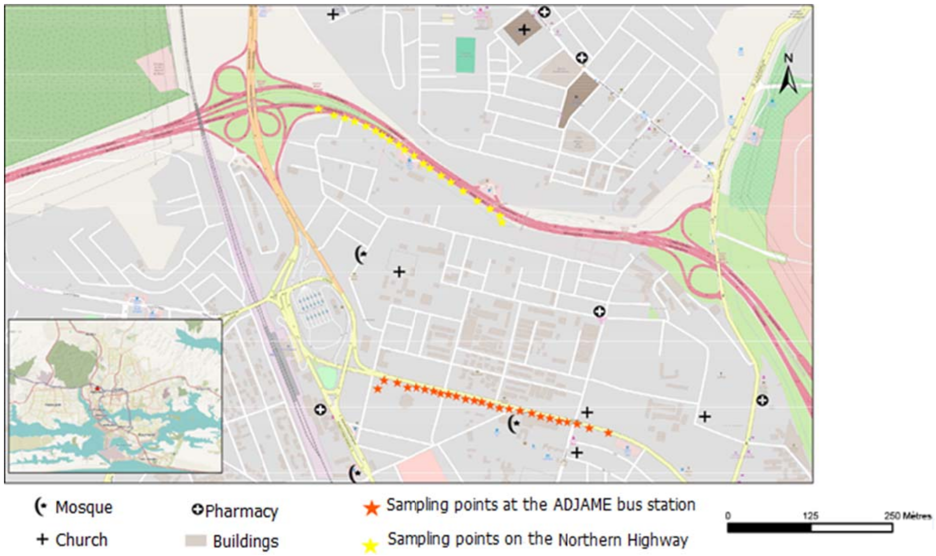

Fig. 1: Map of study area (northern highway and Adjame bus station)

The study areas for the road dust were the Northern Highway and the Adjame bus station (Fig. 1). These sampling sites were selected based purely on traffic density. They have an average traffic density of 5000 vehicles per day. The vehicles use either gasoline or diesel fuel. A large number of people frequenting these sites daily are subjected to the dusty environment created by vehicular emissions.

Sample collection, preparation and analysis: Samples were collected during the dry season from each selected location at 6 day intervals from December 2014 to February 2015. At the sampling sites, about 500 g of road dust composite samples were collected by sweeping using soft touch brush and plastic dust pan. A minimum of 19 samples were collected from each site for the period of sampling. In order to avoid cross contamination, different brushes and dust pans were used for each sampling day.

Sampling was not done on rainy days. The samples were collected between 6:30 am and 8:30 am on each sampling day because this interval is a peak traffic period. The road dust samples were stored in self-sealed polyethylene bags, carefully labelled and taken to the laboratories of the National Nuclear Research Institute of the Ghana Atomic Energy Commission for elemental analysis.

Samples collected from each spot (on each sampling day) were homogenously mixed to form a composite sample. The samples were sieved using two meshes (metric sieve test BS 410 and WS Tyler) with a geometric diameters of 250 μm and 112 μm respectively. 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 min 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 utilising 0.5 g 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°C for 15 min. After the program completion, 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°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°C until trace metal analysis by Atomic Absorption Spectrometry (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.

Contamination assessment of the samples:
Enrichment factor: The Enrichment Factor (EF) is a convenient measure of geochemical trends; it is used for making comparisons in metal contamination between different soil locations (Sinex and Helz, 1981). Enrichment factor can be used to differentiate between metals originating from human activities and those of natural sources and also to assess the degree of anthropogenic influence. The following equation can be

used to determine enrichment factors of metals in soil samples:

$$EF_X = \left[C_S / C_{S(ref)}\right] / \left[B_C / B_{C(ref)}\right] \quad (1)$$

where,

- EF_X = The enrichment factor for the element of interest 'x'
- C_S = The concentration of the element 'x' in the sample
- $C_{S(REF)}$ = The concentration of the reference element used for normalization in the sample
- B_C = The concentration of the element 'x' in the earth crust
- $B_{C(REF)}$ = The concentration of the reference element in the crust which is used for normalization

A reference element is a conservative element; commonly used reference elements include Aluminum (Al), Silicon (Si), iron (Fe), Manganese (Mn), Titanium (Ti), etc. (Manoli *et al*., 2002; Yongming *et al*., 2006). In this study, Silicon was used as reference element with reference elemental concentrations taken from the chemical composition of the average continental crust data (Taylor and McCLennan, 1985). Five categories of contaminations are recognized on the basis of the enrichment factor: EF<2 shows 'deficiency', EF = 2-5 indicates 'moderate enrichment', EF = 5-20 indicates 'significant enrichment', EF = 20-40 indicates 'very high enrichment' and EF>40 indicates 'extremely high enrichment' (Bai *et al*., 2009).

Contamination factor and pollution load index: To assess the extent of contamination of heavy metals in road dust and also provide a measure of the degree of overall contamination at a particular sampling site, contamination factor and pollution load index have been applied. The Contamination Factor (CF) parameter is expressed as:

$$CF = C_{metal} / C_{background} \quad (2)$$

where,

- CF = The contamination factor
- C_{metal} = The concentration of pollutant (metal) in sediment
- $C_{background}$ = The background value for the metal (Aktaruzzaman *et al*., 2014)

The geochemical background values in continental crust averages of the trace metals under consideration reported by Taylor and McCLennan were used as background values for the metal (Taylor and McCLennan, 1985). Contamination Factor CF < 1 refers to 'low contamination'; 1≤ CF < 3 means 'moderate contamination'; 3 ≤ CF ≤ 6 indicates 'considerable contamination' and CF > 6 indicates 'very high contamination'.

The road dust was assessed for the extent of metal pollution by employing the method based on the pollution load index (Tomlinson *et al*., 1980; Afrifa *et al*., 2013) as follows:

$$PLI = \left(CF_1 \times CF_2 \times CF_3 \times \ldots \times CF_n\right)^{\frac{1}{n}} \quad (3)$$

where, *n* is the number of metals studied and *CF* is the contamination factor calculated as described in Eq. (2). The PLI provides comparative simple purpose means for assessing a site quality. PLI values vary from 0 (unpolluted) to 10 (highly polluted) as follows: PLI = 0 (background concentration); 0 < PLI ≤ 1 (unpolluted); 1 < PLI ≤ 2 (moderately unpolluted); 2 < PLI ≤ 3 (moderately polluted); 3 < PLI ≤ 4 (moderately to highly polluted); 4 < PLI ≤ 5 (highly polluted) and PLI > 5 (very highly polluted) (Zhang *et al*., 2011).

RESULTS AND DISCUSSION

Heavy metal concentration in road dust: A summary of concentrations of heavy metals measured in the road dust samples are presented in Table 1. The results generally show higher concentrations at the northern highway than were observed at the Adjame bus station for the heavy metals (Cu, Zn, Ni and Pb) detected in the road dust. The northern highway is characterized by both light and heavy-duty vehicular traffic during morning and evening rush hours.

From Table 1, the mean metal concentration values were in the following order: Cu > Pb > Ni > Zn for the Adjame bus station and Pb> Cu>Ni>Zn for the Northern Highway. The levels of Cu, Pb and Ni observed on the Adjame bus station and the Northern Highway were above the recommended alert levels of the New Dutch List. The New Dutch list is a guideline regarding tolerable contamination of soil. Significantly high levels of these metals could pose potential threat to humans and critical environmental media such as air and water bodies.

The highest mean Pb concentration was recorded at Northern Highway (452.84 mg/kg), as shown in Table 1. Pb comes mainly from automobile exhaust, tyre wear, bearing wear and wearing of brake linings (Poggio *et al*., 2009). The highest mean Cu concentration was measured at Northern Highway (409.34 mg/kg) as seen in Table 1. Cu is a common element in automobile thrust bearing, brake lining and other parts of the engine. Cu replaced asbestos and has been used as a friction brake material since the 1930's (Hopke *et al*., 1980). Zinc also recorded its highest mean concentration at Northern Highway (125.42 mg/kg). This value is below the alert value of 300 mg/kg of the New Duch List. The use of old and weak engines with low combustion efficiency could contribute significantly to Zn in the road dust. Vehicle brake linings and tyre wear have been identified as possible sources of Zn (Bai *et al*., 2009). Adjame bus

Table 1: Heavy metal concentrations (mg/kg) in road dust from the selected sites and the alert values of New Dutch list for comparison

	Adjame bus station				Northern highway				
Element	Min	Mean	Max	SD	Min	Mean	Max	SD	*Alert value
Cu	86,5	403,26	530,50	125,06	105,50	409,34	516,50	125,06	100
Zn	63,5	91,89	113,00	14,90	58,50	125,42	440,00	14,90	300
Pb	151,5	279,76	316,50	42,64	144,00	452,84	4757,50	42,64	50
Ni	123,5	140,42	165,00	11,92	120,00	137,71	163,00	11,92	75

* Alert values of the New Dutch List

Table 2: Results of Contamination Factor (CF), Degree of Contamination (CD) and Pollution Load Index (PLI) for the sampling sites

	Contamination factor	
Element	Northern highway	Adjame bus station
Cu	7.44	7.33
Zn	1.79	1.31
Pb	36.23	22.38
Ni	1.84	1.87
DC	47.30	32.90
PLI	4.56	4.38

Table 3: Results of the enrichment factor

	Enrichment factor	
Element	Northern highway	Adjame bus station
Cu	8.77	8.38
Zn	2.12	1.50
Pb	43.74	25,36
Ni	2.19	2.13

NB: Silicon used as reference element

station recorded the highest level of Ni (140.42 mg/kg). The source of Ni in road dust could be corrosion of vehicular body parts (Lu *et al*., 2009). The rate of high corrosion and wear from old vehicles (as a result of high patronage of imported used vehicles) plying the roads could account for the significant levels of anthropogenic contributions to Ni in the roadside dust.

Contamination Factor (CF), Degree of Contamination (DC) and Pollution Load Index (PLI): The CF, DC and PLI values for the sampling site are shown in Table 2. Moderate contamination was observed for Zn and Ni at both sampling sites, while Cu and Pb values were higher than 6 indicating very high contamination. The highest contamination factors for Cu, Zn and Pb were observed at the Northern Highway.

The DC values were found to be greater than 24 at both sampling sites, implying very high degree of contamination. Northern Highway recorded the highest degree of contamination which is worrying because a lot of hawking activities take place at this site during rush hours of the day. Also, long term exposure within the neighbourhood could lead to adverse health effects particularly on the more vulnerable groups (children, pregnant women and the aged). The results of the PLI in Table 2 show that the two sampling sites could be classified as highly polluted.

Enrichment Factor (EF): The Enrichment factor values obtained for the metals measured in the road dust are presented in Table 3 (Kim *et al*., 2016) 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 sites. The results of the mean EFs were in the following order: Pb > Cu> Ni> Zn. An increase in EF values indicates an increase in the contributions from anthropogenic origins (Sutherland *et al*., 2000). Zn and Ni generally showed moderate enrichment at the sampling sites. Cu was significantly enriched at Northern Highway sites in comparison to the Adjame sites. The mean EF value of Pb showed very high enrichment at Adjame bus station and extremely high enrichment at Northern Highway, indicating anthropogenic influx, which could largely be coming from vehicular activities. This could be expected as speeding and breaking on the highways can cause high rates of break and tyre to wear. The elements Cu, Zn, Pb and Ni are present in break, tyre and exhaust emissions.

CONCLUSION

Heavy metals (Cu, Pb, Zn and Ni) concentrations in road soil dust and their contamination levels in Abidjan, Côte d'Ivoire, have been studied in this study. Contamination indexes namely, Enrichment Factor (EF), Contamination Factor (CF), Degree of Contamination (CD) and pollution load index (fold) were used in the assessment of level of metal contamination in the study area.

The mean concentration of Cu, Pb and Ni exceeded the alert values of the New Dutch at the sampling sites. The results show that road dust in Abidjan has elevated metal concentrations greatly contributed by vehicular emissions. The two sampling sites considered in this study were found to be moderately contaminated with respect to Zn and Ni and very highly contaminated in Cu and Pb. The results of the degree of contamination show that Northern Highway was relatively the more contaminated of the two sampling sites. The assessment results of the PLI also support the observation that Pb, Zn, Ni and Cu levels in road dust present significant pollution problem. The EF vlues of heavy the metals of interest in this study ranked as follows: Pb > Cu > Ni > Zn. These EFs indicated that there was considerable Pb and Cu pollution, which mainly originate from vehicular traffic.

The observed levels call for more attention to be focused on heavy metal contamination in road dust in

Abidjan. With the rapid population growth, an expected increased vehicular fleet in Abidjan could aggravate the situation. There is therefore the need for the necessary mitigation methods to be applied.

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CONFLICT OF INTEREST

The author(s) have not declared any conflict of interests.

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