Demonstrating $PM_{2.5}$ and road-side dust pollution by heavy metals along Thika superhighway in Kenya; sub-Saharan Africa

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Abstract

This study assessed the level of heavy metal in roadside dust and $PM_{2.5}$ mass concentrations along Thika superhighway in Kenya. Thika superhighway is one of the busiest roads in Kenya, linking Thika town with Nairobi. Triplicate road dust samples collected from twelve locations were analysed for lead (Pb), chromium (Cr), cadmium (Cd), nickel (Ni), zinc (Zn) and copper (Cu) using Atomic Absorption Spectrophotometry (AAS). $PM_{2.5}$ samples were collected on pre-weighed Teflon filters using a BGI personal sampler and the filters were then reweighed. The ranges of metal concentrations were 39 - 101 µg/g for Cu; 95 - 262 µg/g for Zn; 9 - 28 µg/g for Cd; 14 - 24 µg/g for Ni; 13 - 30 µg/g for Cr and 20 - 80 µg/g for Pb. The concentrations of heavy metals were generally highly correlated, indicating a common anthropogenic source of the pollutants. The results showed that the majority of the measured heavy metals were above the background concentration, and in particular Cd, Pb and Zn levels indicated moderate to high contamination. Though not directly comparable due to different sampling timeframes (8 hours in this study and 24 hours for guideline values), $PM_{2.5}$ for all sites exceed the daily WHO $PM_{2.5}$ guidelines of 25 µg/m^3. This poses a health risk to people using and working close to Thika superhighway, for example, local residents, traffic police, street vendors and people operating small businesses. $PM_{2.5}$ levels were higher for sites closer to Nairobi which could be attributed to increased vehicular traffic towards Nairobi from Thika. This study provides some evidence of the air pollution problem arising from vehicular traffic in developing countries and gives an indication of the potential health impacts. It also highlights the need for source apportionment studies to determine contributions of anthropogenic emissions to air pollution, as well as long-term sampling studies that can be used to fully understand spatiotemporal patterns in air pollution within developing regions.

Keywords: $PM_{2.5;}$ Heavy metals; Roadside dust; Air pollution; Health; Vehicular emission; Atomic absorption spectrophotometer; Geoaccumulation; Contamination factor; Africa

Introduction

Air pollution is a major environmental health problem, causing millions of deaths every year around the World (WHO, 2014; Cohen *et al*., 2017). Although air quality has significantly improved in some cities, particularly in high-income countries, many low- and middle-income countries (LMICs) still suffer from very poor air quality which increases the burden of non-communicable diseases (Robinson and Hammitt 2009; Cohen *et al*., 2017). Air pollution has been linked to negative health impacts including cardiovascular diseases, stroke, lung cancer as well as chronic obstructive pulmonary disease (USEPA, 2015; WHO, 2016). Common sources of air pollution (heavy metals and particulate matter (PM)) in LMICs include vehicular emissions, industrial plants, power generation plants, oil burning, waste incineration, biomass burning, electric power generators, tire friction, motor oils spills, construction and demolition activities as well as re-suspension of surrounding contaminated soils and dust (Al-Khashman, 2004; van Vliet and Kinney, 2007; Amato *et al* 2009). A significant increase in vehicle ownership implies that vehicle emissions (both exhaust and non-exhaust emissions) have grown significantly over time, as it is estimated that 30,000 vehicles are added yearly in Kenyan roads (UNEP, 2006). There were approximately 1.5 million vehicles and 110,000 motorcycles registered in 2009 by the Kenya revenue authority. It can be estimated that there were about 3 to 3.5 million vehicles in Kenya in the years 2016 and 2017. This number is estimated to grow to 5 million in the year 2030. This increase in vehicle and motorcycle population results in more air pollution even if we consider clean vehicles produced with better technology to reduce emissions. In addition, a huge percentage of the vehicles in Kenya are used and may be 8 years old or above (Kenya Bureau of Standards, 2014). This increases the burden of pollution when compared to new vehicles (Kenduiwo., 2014). Together, these sources contribute to road dust heavy metal content and $PM_{2.5}$ (particulate matter $\leq$ 2.5 µmin diameter) air pollution.

Road dust comprises of particles of various sizes; some fine particulate matter ($PM_{2.5}$; < 2.5 µm diameter), respirable coarse particulates (< 10 µm diameter) and non-respirable coarse particulates (> 10 µm diameter) derived from both anthropogenic (mobile and stationary) and natural sources. Previous roadside dust studies have highlighted enrichment of road dust with heavy metals like cadmium, lead and nickel due to traffic sources (Awadh, 2013). These heavy metals have been linked to adverse health effects including respiratory system disorders, nervous system interruptions, endocrine system malfunction, immune system suppression and the risk of cancer in later life (Atiemo *et al*., 2011). Road dust is important in health due to its composition. It may become airborne through suspension (or resuspension) by wind or vehicle movements (Amato *et al* 2009).

While the number of studies focused on air pollution and its impacts in Africa has increased over the last decade, (Victoria *et al* 2014: Gaita et al., 2014: Kinney *et al* 2011: van Vliet and Kinney 2007: Boman., 2013: Shinggu., 2010), there is still deficit in knowledge in African cities compared to other locations worldwide (Kinney *et al*., 2011; UNEP, 2016). This deficit is particularly acute given the high urbanisation and population growth rates observed in African countries (Ngo *et al*., 2015: Fengler., 2010). These urbanisation rates, combined with unregulated traffic activities, poorly maintained vehicles and limited air pollution control policies and or implementation, mean that air quality in sub-Saharan Africa (SSA) has deteriorated over time (Zachariadis *et al.*, 2001; Ngo *et al* 2015). Even though previous studies have addressed regional aerosols in SSA (e.g. Gaita *et al*., 2014), there is little work that has focused in monitoring urban roadside particulate matter concentrations and in road dust chemistry, particularly in East African

countries. Pollution concentrations near roadways are important in SSA cities because roadways are hubs of transport, commerce, and other pedestrian activities, meaning that in these spaces high pollutant concentrations coincide with high population exposure potential. Air pollutants tend to put a lot of pressure on the already weak medical system. Some professions, e.g. street vendors, '*boda boda*' riders and traffic police, as well as residents in houses close to highways, who spend their days along roads and on congested roadsides are particularly predisposed to air pollutant exposures (UNEP, 2006). In addition, Kinney *et al*. (2011) found that 49% of daily trips in Nairobi were either on foot or on bicycle placing members of the public at risk of high exposure and from respiratory diseases.

Many studies agree that the construction of highways has positive effects on population growth, by attracting immigrants, bringing an array of employment opportunities as well as housing developments (Boarnet and Chalermpong, 2001; Chi *et al*., 2006). The expansion of Thika superhighway is no different, it has led to the radical development of homes and businesses along the highway which has resulted in population growth along the superhighway. In addition, the increasing number of vehicles and motorcycles in the country is a growing concern due to their significant air pollutants input especially CO_x and particulate matter. (Kenduiwo, 2014; CAIP, 2000;).

In an attempt to address the effects of urbanisation, growth and development to the human population, this study aimed to generate new understanding of the influence of vehicle emissions to road dust chemistry and $PM_{2.5}$ concentrations in urban Kenya.

Methodology

Study area

The area of study was along Thika superhighway and in Thika town. Thika superhighway is a modern highway approximately 45 km long in length. It is part of an international trunk road connecting Nairobi city with Ethiopia to the north (Figure 1). It starts at Muthaiga roundabout, proceeds to Kasarani, Githurai Interchange, Kenyatta University, Ruiru Town, Juja Town and ends at the bridge near Blue Post Hotel in Thika. The land along the study site is experiencing radical developmental change as new building are constructed every day. Land close to Thika town is currently utilised for real-estate a shift from small scale agriculture. Whereas close to Nairobi, the land has been utilised for construction of commercial and domestic buildings. There are a few manufacturing industries in Ruiru and in Allsops, with most of them being in Ruiru. The population of towns/constituencies along Thika superhighway according to the 2009 census are estimated to be: 136,917 people for Thika, 40,446 for Juja, 238,858 for Ruiru, 191,690 for Roysambu, 194,120 for Ruaraka and 166,044 for Starehe. The human population of all these places increases every year (NCIDP, 2014; **Gicaci**, 2015; Kenya National Bureau of Statistics, 2013).

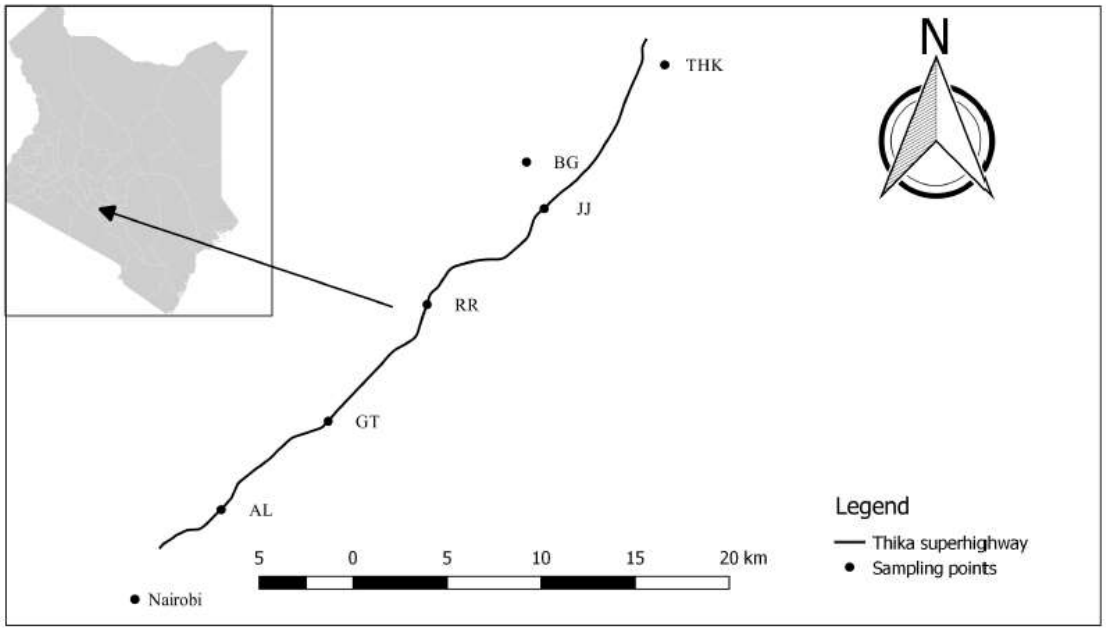

Figure 1: Map showing the locations of sampling sites along Thika superhighway. Further details about sampling sites are given in Table 1. (Thika superhighway. [Computer generated map]. Digitised from Google Earth using QGIS. [GIS software].Version2.18.17.2018).

The sampling points selected for this study were Allsops (AL), Githurai (GT), Ruiru bus terminus (RR), Jomo Kenyatta University bus terminus (JJ), Commercial Street Thika (THK) and Jomo Kenyatta University as a rural background (BG) site (Table 1). Thika superhighway is one of the busiest roads in Kenya, which was expanded in 2012 into a superhighway. In a study done in 2015, it was reported that the traffic volume in this highway was 1998 vehicles/hour/lane during peak hours and 1300 vehicles/hour/lane in off-peak hours (Kabui, 2015).

Table 1: Sample locations and codes, where W designates western side of the highway while E is eastern side

Sample location code	Area	Longitude	Latitude	Elevation (m)
BG	Jomo Kenyatta University	37° 0'34.14"E	1° 4'58.57"S	1531
THK W	Thika	37° 4'31.14"E	1° 2'12.00"S	1507
THK E	Thika	37° 4'31.87"E	1° 2'11.83"S	1507
JJ W	Jomo Kenyatta bus terminus	37° 1'3.17"E	1° 6'16.88"S	1518
JJ E	Jomo Kenyatta bus terminus	37° 1'4.48"E	1° 6'18.31"S	1518
RR W	Ruiru	36°57'40.77"E	1° 9'5.95"S	1525
RR E	Ruiru	36°57'43.05"E	1° 9'3.08"S	1525
GT W	Githurai	36°54'52.07"E	1°12'22.62"S	1540
GT E	Githurai	36°54'52.92"E	1°12'23.45"S	1540
AL W	Allsops	36°51'47.23"E	1°14'54.11"S	1630

AL E	Allsops	36°51'48.94"E	1°14'55.27"S	1630

At each site (Figure 1, Table 1), road dust samples were collected and analysed to determine the level of heavy metals contamination, relative to the background site. Furthermore, at each site, $PM_{2.5}$ mass concentrations were measured to determine the contribution of road traffic to atmospheric $PM_{2.5}$.

Road dust chemistry

Sampling process

The collection of road dust samples was comparable to previous work undertaken elsewhere (e.g. in Europe; Amato *et al*., 2009 and Africa; Abah *et al*., 2014). Half a meter from the pavement edge, two sub-samples from each sampling site were collected within a $1m^2$ area. Dust was obtained by sweeping the pavement with a plastic brush and a plastic dustpan, put in a clean polyethylene bag which was sealed, labelled and transported to the laboratory for analysis (Raj and Ram, 2013).

Sample preparation, digestion and analysis

To determine the level of heavy metals (Pb, Cr, Fe, Cu, Ni and Zn), the collected road dust samples were air dried at room temperature for 5 days to a constant weight and then sieved through a 125 µm stainless steel mesh wire (Abah *et al*., 2014). 1g of the sample was weighed to the nearest 0.001 g and transferred to a round-bottomed flask. 10 ml of 50% (v/v) HNO_3 was added to the sample and the sample was mixed. The flask containing the mixture was covered with a watch glass. The sample was heated to 95^0C and then refluxed for 10 to 15 minutes without boiling. The sample was cooled and 5 ml of concentrated HNO_3 was added. The cover was replaced followed by refluxing for 30 minutes. In case brown fumes were generated due to oxidation of the sample, this step was repeated continuously until there was no further formation of the brown fumes. The resulting solution was heated at 95^0C without boiling for two hours. The sample was cooled and then 2 ml of water and 3 ml of 30% H_2O_2 was added to the solution. The vessel was covered using a watch glass and returned to the heat source for warming, to start the peroxide reaction. The sample was heated until the effervescence subsided after which the vessel was cooled. 1 ml aliquots of 30% H_2O_2 were added continuously with warming until the sample appearance remained unchanged. The sample was covered using an allihn condenser to recover the vapour. The heating of the acid-peroxide digestate was left to continue until the volume reduced to approximately 5 ml. 10 ml concentrated HCl was added to the sample digestate. A vapour recovery device was used to cover the sample. The sample was placed in the heating source and refluxed at 95^0C for 15 minutes. The resulting digestate was filtered through Whatman filter paper No. 41 (USEPA, 1996) and the filtrate transferred into a 100ml volumetric flask and distilled water added to 100ml mark. The solutions were aspirated into the FAAS instrument, Shimadzu AA-6200 (experimental conditions are outlined in Table 2). The detection limits for the metals were found to be; Zn 0.01459 µg/g, Cu 0.1836 µg/g, Cd 0.02795 µg/g, Ni 0.0854 µg/g, Cr 0.0474 µg/g and Pb 0.2612 µg/g.

Table 2: Atomic absorption spectrophotometer conditions

Element	**Wavelength (nm)**	**Fuel gas flow rate (L/min)**	**Lamp current (mA)**	**Slit width (nm)**

Pb	**283.3**	**2.0**	**10**	**0.7**
Cr	**357.9**	**2.8**	**10**	**0.7**
Cu	**324.8**	**1.8**	**6**	**0.7**
Cd	**228.8**	**1.8**	**8**	**0.7**
Ni	**232.0**	**1.6**	**12**	**0.2**
Zn	**213.9**	**2.0**	**8**	**0.7**

Assessment of contamination

There are several indices that may be used to assess the level of contamination of heavy metals in road dust. For this study, the Geo-accumulation index (I-geo) and the contamination factor (CF) were selected to evaluate the contamination level of Zn, Cu, Cd, Ni, Cr and Pb in the roadside dust, based on their common usage in similar work (e.g. Addo *et al.*, 2012; Awadh, 2013). The index of Geo-accumulation (I-geo) assessed the level of contamination by comparing the concentration of heavy metals obtained to background levels which are bottom sediments in this case. The Geo-accumulation (I-geo) index was calculated using the following equation:

$$I_{geo} = \log_2 \left(\frac{Cn}{1.5\,Bn}\right) \qquad \text{eq. 1}$$

In the I-geo index, Cn is the measured concentration of the heavy metal in the road dust sample and Bn is the geochemical background concentration of the heavy metal (Robertson *et al* 2003; Taylor, 1964). The constant 1.5 in equation 1 minimizes the effect of possible variations in the background values which may be attributed to lithologic variations in the sediments. The values of this index vary from sub-zero to more than 5. The highest grade (6) reflects a 100-fold enrichment and (0) reflects the background concentration. 0-1 indicate unpolluted to moderate pollution, 1-2 indicate moderate pollution, 2-3 indicate moderate to strong pollution, 3-4 indicate strong pollution, 4-5 indicate strong to extreme pollution while values >5 indicate extreme pollution.

For comparison with the I-geo index, the contamination factor (CF) was also calculated for all samples. The CF was calculated as:

$$CF = \frac{Cm_{\,sample}}{Cm_{\,background}} \qquad \text{eq. 2}$$

CF is the contamination factor, $Cm_{\,sample}$ is the concentration of the metal in the sample and $Cm_{\,background}$ is the metal concentration in the background sample. The CF reflects the metal enrichment in the sediment; a $CF < 1$ indicates low contamination, $1 \leq CF < 3$ indicates moderate contamination, $3 \leq CF \leq 6$ indicates high contamination and $CF > 6$ indicates very high contamination.

$PM_{2.5}$ sampling procedure

Sampling of $PM_{2.5}$ was carried out at the five sampling sites along Thika superhighway during the months of March and April 2017 (dry season). The background and roadway monitoring of $PM_{2.5}$ were undertaken using a portable air sampling system, BGI (Kinney *et al.,* 2011). Samples were collected on pre-weighed teflon filters for 8h per sample at a flow rate of 4L per minute, with air being drawn by a calibrated BGI personal sampling pump. At each site,

sampling was conducted between 06:30 hrs and 14:30 hrs local time, for five non-consecutive weekdays. During the sampling period, humidity ranged from 57 % to 69 %, temperature 21^0C to 23^0C and wind 8 Km/h to 14 Km/h.

Results and discussion

Road dust chemistry

The heavy metals (Zn, Cu, Cd, Cr, Ni and Pb) concentrations in road dust are listed in Table 3 and the spatial distribution of these metals in road dust are illustrated in Figure 2.

181 Table 3: Mean heavy metal concentrations in the roadside dust (n= 3) with standard deviations given in brackets.

Sampling Points		Cu N-T	Cu T-N	Zn N-T	Zn T-N	Cd N-T	Cd T-N	Ni N-T	Ni T-N	Cr N-T	Cr T-N	Pb N-T	Pb T-N
AL	Mean	101.40	85.11	262.18	254.89	25.52	27.68	14.34	14.34	22.73	17.95	49.16	51.59
	N	3	3	3	3	3	3	3	3	3	3	3	3
	Std. Deviation	1.80	4.12	2.23	2.26	0.21	0.44	0.84	2.33	1.09	0.86	3.03	3.03
BG	Mean	39.19	40.99	94.91	94.98	8.68	10.69	16.43	17.69	14.70	12.98	20.49	20.49
	N	3	3	3	3	3	3	3	3	3	3	3	3
	Std. Deviation	2.57	2.35	1.28	0.85	0.48	0.39	1.11	1.83	1.16	0.72	1.46	2.53
JJ	Mean	57.29	54.12	154.24	203.88	15.38	18.78	16.85	23.54	17.09	17.28	46.24	56.93
	N	3	3	3	3	3	3	3	3	3	3	3	3
	Std. Deviation	0.68	0.79	1.18	3.11	0.37	0.43	1.11	2.33	0.57	1.36	3.04	2.92
RR	Mean	72.67	82.62	168.41	238.22	20.03	20.59	19.36	17.96	13.27	17.95	41.87	43.33
	N	3	3	3	3	3	3	3	3	3	3	3	3
	Std. Deviation	3.21	2.18	2.18	0.50	0.78	1.16	0.42	1.34	0.44	0.86	4.45	1.68
GT	Mean	85.57	98.69	227.22	198.28	22.39	23.72	19.22	16.57	17.19	17.28	49.16	39.93
	N	3	3	3	3	3	3	3	3	3	3	3	3
	Std. Deviation	3.73	2.45	1.18	0.74	0.55	1.15	2.79	1.74	0.33	0.92	2.23	2.23
THK	Mean	74.70	75.16	197.69	241.15	11.93	15.70	20.89	21.03	22.92	29.13	80.26	72.48
	N	3	3	3	3	3	3	3	3	3	3	3	3
	Std. Deviation	1.04	1.42	2.52	0.37	0.24	0.37	1.69	2.17	2.60	0.86	1.46	0.84

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The concentration of most of the metals (e.g. Zn, Cu and Pb) are higher in sites closer to the urban areas of Nairobi city and Thika town (Figure 2), which is attributable to the greater volume of vehicular traffic near the highly-populated conurbations. All these metals were suspected to originate from vehicular emissions since there was the absence of any close industries near the sampling sites (Victoria *et al.*, 2014; Nabulo *et al*., 2006). In the case of Allsops (AL) sampling site, it had the highest Zn concentration with an average of 262.2 µg/g which is comparable to Dhaka and Amman studies (Ahmed *et al.*, 2006; Al-Khashman 2004), whereas Juja (JJ) had lower concentration with an average of 154.2 µg/g. The background site had lowest Zn concentrations (94.9 µg/g) when compared to the other roadside sites. AL site had the highest Cu concentration, with an average of 101.4 µg/g, and JJ was lower with an average of 54.1 µg/g, compared to 39.2 µg/g at the background site. These results are above those obtained in Ketu-south, Ghana (60.53 µg/g) showing that the sites in this study are highly polluted (Addo *et al.*, 2012). The site with the highest concentration of Cd was AL with a concentration of 277.0 µg/g, while the lowest concentration of 11.9 µg/g was measured at Commercial Street Thika (THK). For comparison, the background site had a concentration of 8.7 µg/g. In the case of Ni, JJ had the highest mean concentration of 23.5 µg/g while THK had the lowest concentration of 14.3 µg/g. The background Ni concentration was slightly higher than THK at 16.4 µg/g. In terms of Cr concentration, THK was highest with an average concentration of 29.1 µg/g, this was close to the concentration obtained in Luanda, Angola reported as 26 µg/g (Ordonez *et al.*, 2003). The lowest concentration was at Ruiru (RR) with an average of 13.3 µg/g, which was slightly above the background site concentration (13.0 µg/g). The site with the highest Pb concentration was THK with an average of 72.5 µg/g and the lowest was RR (average of 39.9 µg/g), while the background site had an average concentration of 20.5 µg/g. This is comparable to Kampala, Uganda reported as 45.3 µg/g (Nabulo *et al.*, 2006).

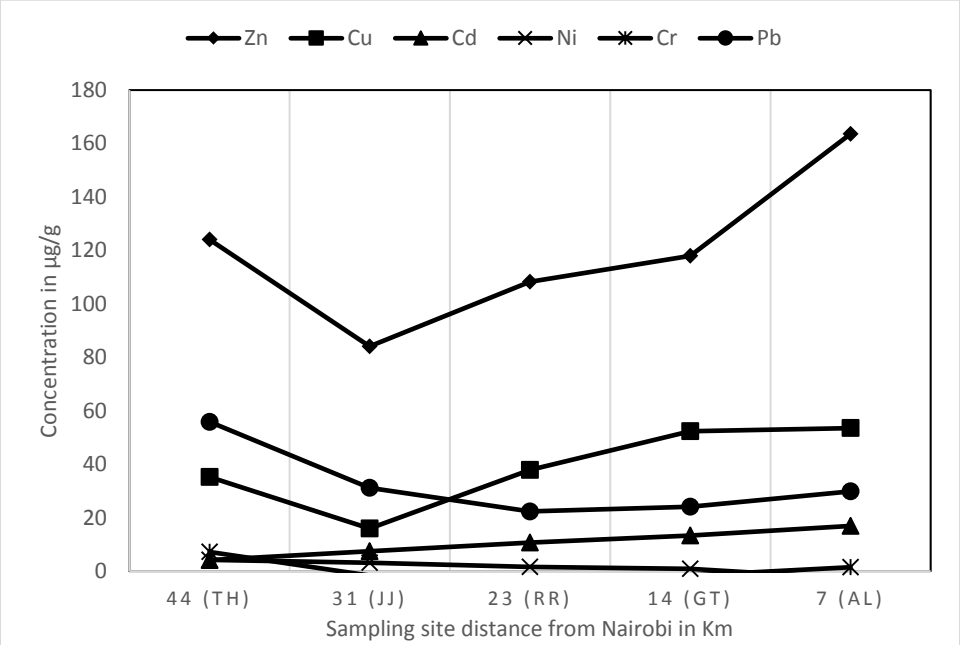

Figure 2: Concentration of heavy metals (Zn, Cu, Cd, Ni, Cr and Pb) along Thika superhighway in µg/g. The background concentration of each metal has been subtracted, implying that the concentration level is the enrichment of that metal at the site.

The I-geo shows that most of the road sites are moderately polluted by Zn and Pb, with I-geo scores ranging from 0 to 2, except for Cd which had all I-geo values greater than 5, indicating extreme pollution in the road dust. In the case of Ni, Cr and Cu, nominal or negative values for most sites indicated that the sites were not enriched with those metals when compared to the background site. The contamination factors (CFs) for Zn, Cu, Cd, Ni, Cr and Pb were calculated for the study area (Table 4). In most of the sites, there was moderate contamination of all metals with CF values ranging between 1 and 3. Cd and Pb had some CF values which were over 3, indicating the road dust samples were more contaminated with these metals, for example, Al site had a CF of 3.1 for Cd, while THK site had CF value of 3.9 for Pb. The lowest contamination factor of all the metals was at JJ site whose CF was 0.6 for Cr, which indicated low contamination. The source of these pollutants could be attributed to exhaust and non-exhaust vehicular emission since there are no industries close to Thika superhighway except at RR. No anomaly was observed in the RR results that could be attributable to industrial emissions (Xia *et al.*,2011).

Table 4. Enrichment factors for heavy metals in Thika superhighway road dust using the geo-accumulation index (I-geo) and Contamination Factor (CF) analysis

Sampling site	Zn		Cu		Cd		Ni		Cr		Pb	
	I-geo	CF	I-geo	CF	I-geo	CF	I-geo	CF	I-geo	CF	I-geo	CF
THK W	0.9	2.1	-0.1	1.9	5.7	1.4	-2.4	1.3	-2.7	1.6	2.1	3.9
THK E	1.2	2.5	-0.1	1.9	6.1	1.8	-2.4	1.2	-2.4	2.2	2.0	3.5
JJ W	0.6	1.6	-0.5	1.5	6.1	1.8	-2.7	0.8	-3.1	0.7	1.3	2.3
JJ E	1.0	2.1	-0.6	1.4	6.4	2.2	-2.3	1.1	-3.1	0.6	1.6	2.8
RR W	0.7	1.8	-0.2	1.9	6.5	2.3	-2.5	1.1	-3.5	0.8	1.2	2.0
RR E	1.2	2.5	0.0	2.1	6.5	2.4	-2.6	0.8	-3.1	1.0	1.2	2.1
GT W	1.1	2.4	0.1	2.2	6.6	2.6	-2.5	1.0	-3.1	1.3	1.4	2.4
GT E	0.9	0.8	0.3	2.5	6.7	2.7	-2.8	0.9	-3.1	1.0	1.1	1.9
AL W	1.3	2.8	0.3	2.6	6.8	2.9	-3.0	0.7	-2.7	1.3	1.4	2.4
AL E	1.3	2.7	0.0	2.2	6.9	3.2	-3.0	0.9	-3.1	1.0	1.5	2.5

Pearson's Correlation Coefficient (r) identified that there was a positive correlation between most of the measured heavy metals in the road dust (Table 5), which indicated a common source of the metals (Victoria *et al.*, 2014). Elemental pairs Cu/Zn (r=0.986), Cu/Cd (r=0.908), and Zn/Cd (r=0.830), had r values above 0.5 indicating strong correlation with each other. On the other hand, pairs such as Cu/Cr (r=0.291), Cd/Pb (r=0.107) and Pb/Ni (r=0.356) showed moderate relationships. Elemental pairs Cu/Ni (r=-0.054), Zn/Ni (r=-0.061), Ni/Cd (r=-0.258) and Cd/Cr (r=-0.111) indicated inverse relationship. The results showing positive correlation indicate that these metals originated from a common anthropogenic source most probably vehicular emission (Abah *et al* 2014; Addo *et al* 2012). This was expected as Zn, Cu, Ni, Cr and Cd are commonly produced from brake wear and tyre wear **(**Shinggu *et al.*, 2010). Similarly, Cu and Cr have been reported to originate from exhaust emissions (Yu *et al.*, 2003).

229 **Table 5.** The correlation coefficient, r, between concentrations of heavy metal along Thika superhighway (Kenya).

	Cu N-T	Cu T-N	ZnN-T	Zn T-N	Cd N-T	Cd T-N	Ni N-T	Ni T-N	Cr N-T	Cr T-N	Pb N-T	Pb T-N
Cu N-T	1											
Cu T-N	.884*	1										
Zn N-T	.986**	.854*	1									
Zn T-N	.810	.707	.783	1								
Cd N-T	.872*	.810	.833*	.650	1							
Cd T-N	.908*	.793	.891*	.717	.984**	1						
Ni N-T	-.054	.305	-.061	.190	-.258	-.274	1					
Ni T-N	-.512	-.456	-.440	-.015	-.597	-.507	.416	1				
Cr N-T	.594	.291	.670	.532	.197	.341	-.089	-.028	1			
Cr T-N	.332	.314	.364	.604	-.111	-.007	.629	.400	.665	1		
Pb N-T	.510	.477	.561	.722	.107	.225	.553	.344	.736	.959**	1	
Pb T-N	.438	.306	.487	.782	.116	.256	.356	.500	.698	.870*	.924**	1

230 ** Significant correlation at 0.01 level

Particulate matter ($PM_{2.5}$)

$PM_{2.5}$ concentrations generally increased towards Nairobi town (Figure 3), with the highest mean concentration being at JJ with 509 µg/m^3. This was attributable to dust storms (Al-Khashman, 2004; Amato et al 2009; Lindén *et al*., 2012), which were experienced on one sampling day at JJ which skewed the site average (Figure 4), and therefore the mean $PM_{2.5}$ concentration was recalculated for the four remaining sampling days giving 36.24 µg/m^3 (Figure 3). Most of the study sites had high $PM_{2.5}$ concentrations during Monday, Wednesday and on Friday (Figure 4), which could be attributed to the high human-related activities along the road/highway as people are coming back to the city from their rural home and as well going back to their rural homes on Mondays and Fridays respectively (Kinney *et al.*, 2011).

$PM_{2.5}$ concentrations were higher than those observed in many European and American studies, but was similar to studies undertaken in other African countries; Accra, Ghana (Aboh et al., 2009), Ouagadougou, Burkina Faso (Boman et al., 2009) and Cairo, Egypt (Boman et al., 2013). All the sites in this study had lower $PM_{2.5}$ concentrations when compared to a study completed in February 2006 between Nairobi and Ruiru, Kenya, which was conducted by van Vliet *et al*., 2007 who reported $PM_{2.5}$ concentrations of 414 µg/m^3. This difference may be due to the different sampling protocols and sampling periods employed in the two studies. However, the average $PM_{2.5}$ concentration for Thika town measured in this study (69 µg/m^3) was higher than observed Gaita et al.'s 2014 study in Nairobi who reported an average concentration of 21 µg/m^3, but it was lower when compared to the results (98.1 µg/m^3) reported by Kinney et al 2011 in a side walk within Nairobi central business district. Even though the results obtained cannot be compared with WHO daily guidelines since sampling was done for only 8hrs, all the roadside sampling sites had $PM_{2.5}$ levels higher than daily WHO guideline of 25 µg/m^3.

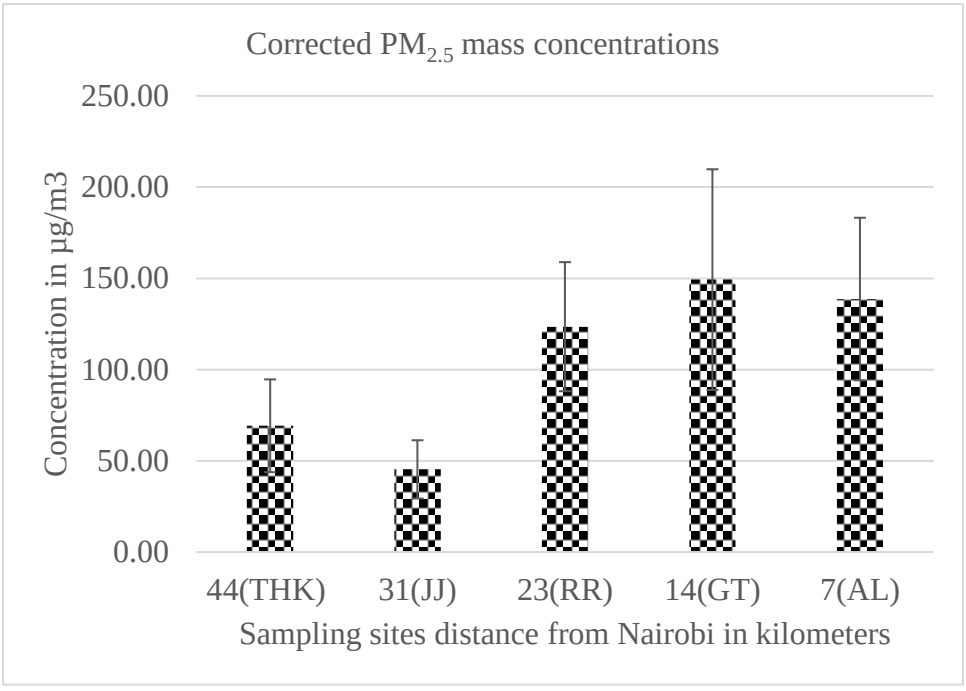

Figure 3: Mean $PM_{2.5}$ concentrations at five sites along Thika superhighway. All bar graphs show the average $PM_{2.5}$ of five sampling days, except JJ where one sampling day has been omitted from the calculation due to a dust storm which caused an 8-hour average of 2365 µg/m^3 on that day.

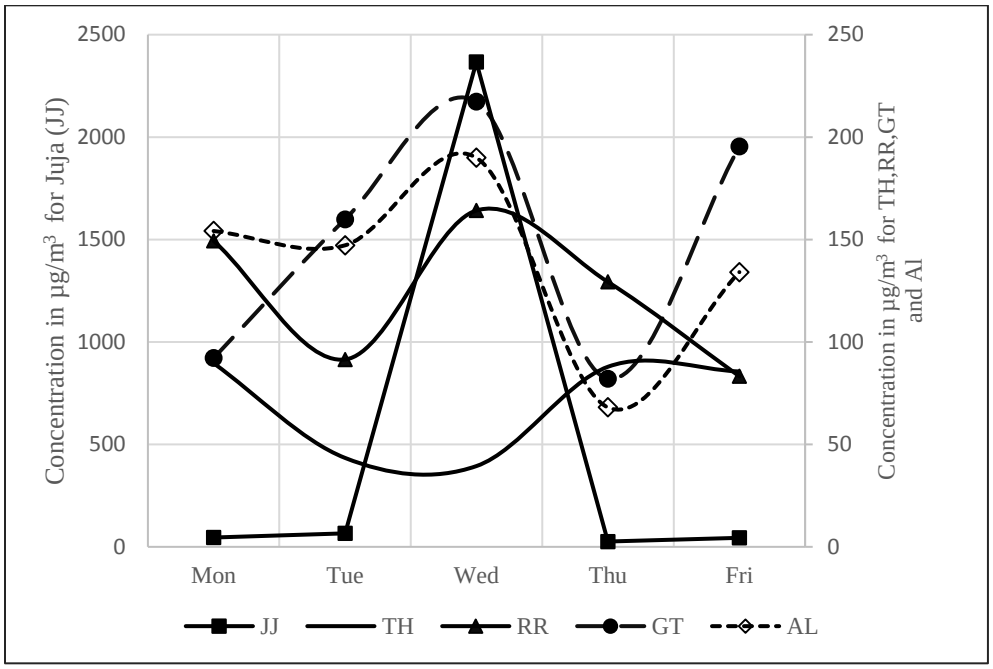

Figure 4: 8-hour $PM_{2.5}$ concentrations at five sites along Thika superhighway from Monday to Friday.

Health implications

Exposure to heavy metals in roadside dust occurs by skin contact, inhalation and/or ingestion. The 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 (Atiemo *et al.,* 2011). The high levels of heavy metals as evident in this study, and particularly Pb and Cr which are known to be carcinogenic are of concern in relation to human health, chiefly to children, the vulnerable old and pregnant women living close to and/or using busy roads (Du *et al.,* 2013; Atiemo *et al.,* 2011)

A great number of scientific studies have linked exposure to particle pollution with a variety of problems including premature death in people with heart or lung disease, nonfatal heart attacks, irregular heartbeat, aggravated asthma and decreased lung function (USEPA, 2014**).** In addition, increased respiratory symptoms such as irritation of the airways, coughing or difficulty in breathing have also been linked to PM exposure (USEPA, 2015**)**. For those people who spend a significant portion of their day on (or adjacent to) the road, e.g. residential homes, street vendors, traffic police, touts and public vehicles drivers, the health consequences of $PM_{2.5}$ exposures are even greater (Ngo *et al,* 2015**)**.

Study limitations

The study only covered a short period in the dry season and a more comprehensive study needs to be executed along the highway and in adjacent residential area by the highway. It is important to acknowledge that the roadside dust chemistry results only represent part of the dry season.

Similarly, $PM_{2.5}$ results reported in this study are just representative of a portion of the dry season. Regardless of these, the results shows that Thika town as well as Thika superhighway is polluted by $PM_{2.5}$ and poses a health risk to people working in the town and along the highway respectively, who are exposed for long hours and long periods of time (USEPA, 2015; USEPA, 2014; WHO, 2014; WHO, 2016).

The sampling time for $PM_{2.5}$ was done for only 8 hours a day and not 24 hours at each location and so the results of are not fully comparable to WHO guidelines.

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Conclusion

This study has highlighted the influence of vehicular traffic on road dust chemistry and $PM_{2.5}$ concentrations along Thika superhighway in Kenya. All the heavy metals analysed (Cu, Zn, Ni, Cd, Ni and Pb) in the road dust samples were above the background concentrations at the sampled sites (except Nickel at one sampling site), highlighting the importance of anthropogenic emissions from vehicular traffic. Since roadside dust may be resuspended, these metals especially Cd, Pb and Cr which had higher I-geo and CF values, pose a significant health risk to people along the highway who may inhale the resuspended polluted dust (Adna *et al.,* 2002). Though not directly comparable, as an indication of air pollution levels, all the sites had $PM_{2.5}$ 8-hour concentrations above the 24-hour WHO guideline value of 25 $\mu g/m^3$, meaning that some individuals may experience adverse health impacts which include respiratory and cardiovascular morbidity plus mortality from cardiovascular, respiratory diseases and from lung cancer (WHO 2013). Those that use the road frequently, including traffic police, street vendors and local residents along the highway may experience the greatest health impacts due to higher exposures. While this study provides some evidence of the problem, further work needs to include source apportionment studies to quantify the contribution of vehicular traffic to road dust and $PM_{2.5}$ at the sites in Kenya. Further, while this study has provided initial evidence of $PM_{2.5}$ concentrations above guideline values, long-term $PM_{2.5}$ measurements at key sites in Kenya (e.g. important roadways such as Thika superhighway) are needed to more fully understand spatial and temporal variations in particulate air pollution in SSA countries.

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