Assessment of selected Physicochemical Parameters and Trace Metals in Street Dust along roads in Enugu Metropolis, Nigeria

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ABSTRACT

T*race metals, present above permissible limits are an ever present threat to public health due to their toxicity and carcinogenic nature. They can also impair important biochemical processes in animals and affect plant growth. The assessment of these pollutants, commonly found in street dust, is important for environmental health quality. The present work investigated the level, sources and assessment of trace metal pollution in street dust along selected roads in Enugu metropolis. A total of 32 dust samples were collected from 10 major roads and analyzed for trace metal content with a Buck 210VGP AAS after strong tri-acid digestion. Values were obtained for 9 trace metals in the dust samples within the following ranges (in mg kg^{-1}): Cr (0.67 - 3.67), Mn (2.33 - 7.67), Fe (408.33 - 512.33), Co (3.00 - 61.75), Ni (39.67 - 193.67), Cu (11.50 - 90.00), Zn (1.00 - 31.67), Cd (0.00 - 1.33), and Pb (0.00 - 46.67). pH values, electrical conductivity (EC) and total organic matter (TOM) of the samples ranged from 6.75 - 8.39, 556 - 578.67 µS/cm and 1.27 - 10.35% respectively. The geo-accumulation index (I_{geo}) shows moderate pollution of Cd and Pb in the roads. The integrated pollution index (IPI) also showed moderate to high level of pollution of the metals in the following order: Cu<Pb<Ni<Cd. Multivariate statistical analysis identified the major sources of these trace metals along the roads as vehicles (from parts and emissions) and road infrastructure.*

Keywords: *street dust, Engu metropolis, environmental health,*

1. INTRODUCTION

Street dust, otherwise called street/road deposited sediments are found on road surfaces. It consists of depositions of vehicle and industrial exhausts, tyre and brake wears and dust from paved roads or potholes and construction sites. Its re-suspension by vehicles travelling along the roads generates particulate matter in the environment. This contributes to about 33% of air pollution (Sezgin, *et al*., 2003; Shi, *et al*., 2008; Faiz, *et al*., 2009). Street dust with its associated pollutants is part of street run-off that is deposited in nearby water bodies. This further contributes to the degradation of the aesthetic, recreational, biological, physical and chemical qualities of the receiving waters. A study showed that on the average, 46% of the fluvial suspended sediments originated from paved areas, 23%from unpaved roads, and 31% from the stream channel itself (Poleto, *et al*., 2009). A similar research to show the relationship between pollutants in the street dust and suspended sediment sample in river, discovered that concentrations of metals in rivers vary temporarily during storms due to input of street run-off containing elevated levels of metals (Poleto and Merten, 2008).

A lot of pollutants are associated with street dust. The visible signs of road pollution are litter and oil spills (Strenstrom, *et al*., 1984; Allison, *et al*., 1997; Walker and Wong, 1999; Kang, *et al*., 2009). The less visible pollutants include inorganic trace metals and de-icing salts and organic compounds such as polycyclic aromatic hydrocarbons (PAHs), perfluorinated surfactants (PFSs), polychlorinated biphenyls (PCBs), nutrients (e.g., phosphates and nitrates), and pesticides. Sources of trace metals on road surfaces include vehicular exhaust emissions, in situ road surfaces and pavements wear, brake and tyre wear, atmospheric deposition, and roadside soil erosion (Fergusson, 1984; Sutherland, 2003; Folkeson, 2008).

The wear of brake pad linings releases fine particles ranging from a few hundred nanometers to a few micrometers in diameter. The rate of wear and character of associated frictional debris is a function of vehicle speed, braking frequency, vehicle condition and the composition of brake lining materials (Thorpe and Harrison, 2008)Some of the trace metals found in break wear particles include: Cd, Cr, Cu, Fe, Mn, Ni, Pb, Sb and Zn (Thorpe and Harrison, 2008; Davis et al., 2000; McKenzie, et al., 2008).Similarly, tyre wear debris can be enriched with Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn (Thorpe and Harrison, 2008; Davis et al., 2000; McKenzie, *et al*., 2008; Duong and Lee, 2011).

A study postulated that friction between the road surface and tyre treads results in an average tyre wear rate of between 6 and 90 mg/km, depending on driving speed, tyre age, and the road surface condition (Rogge, *et al*., 1993). Generally, higher speeds, older wheels and rougher surfaces result in more wear (Duong and Lee, 2011). Trace metal pollutants can also enter the environment by the combustion of fossil fuels including petrol and diesel fuels. Although leaded petrol is banned in many countries today including Nigeria, significant archives may still exist in the near-road environment as the low solubility of Pb allows it to have long residence times in the soil column (Turjoman and Fuller, 1987; Sutherland and Tolosa, 2001).

Small amounts of Bi, Cd, Cr, Cu, Ni, and V are used in petrol and diesel (Davis, *et al*., 2000), Trace amount of Zn isalso present in petroleum as an additive to reduce engine wear. Engine wear also releases Cr, Cu, Mn, and Ni. The wear of 3-way catalytic converters releases platinum group elements (Pd, Pt and Rh) to the road environment (Helmers, 1996; Sutherland, *et al*., 2008).Paint particles chipped from vehicle bodies and road lane markers are other sources of Pb (Deletic and Orr, 2005).

Mineral and stone materials used in road construction may contain Cd, Cu, Fe, Ni, Pb, V, and Zn, which are released into the environment as the road surface wears off (Lindgren, 1996). Galvanized-steel road equipment such as lamp posts, road signs and crash barriers may release Zn as they corrode (Table 1) (Folkeson, *et al*., 2008).

Soil, parent material and bedrock are natural sources of trace metals in the urban landscape, but levels are often elevated by anthropogenic activities (Carlosena, *et al*., 1998).Roadside soils contain elevated levels of trace metals. This makes them potential long-term sources of pollutants to the road surface through remobilization by wind, rain, vehicular turbulence and pedestrian movement (Sutherland and Tolosa, 2001; Jartun, *et al*., 2008).

Health safety awareness is increasing among the populations of developing countries. The need for a cleaner environment through reduction in pollutant levels has become imperative. In this regard, an assessment of these pollutants will help the relevant authorities to impose new and stricter regulations that are aimed at safeguarding human health. The objective of this paper is to present the assessment of selected physicochemical parameters and trace metals in street dust along roads in Enugu metropolis, Nigeria.

2. MATERIALS AND METHODS

2.1 Study Area

Enugu metropolis is made up of Enugu East, Enugu North, and Enugu South local government areas. The population of Enugu metropolis is 722,664 according to the 2006 census (Nigerian Population and Demographic Report). Enugu has a good network of paved roads. The study area falls within the humid tropical rain forest belt of southeast Nigeria. It is located within latitude 6.24°N and 6.30°N and longitude 7.27°E and 7.32°E. It has two seasons, the rainy season and the dry season. The rainy season, is characterized by heavy thunderstorms, and lasts from April to October with the southwesterly moisture accompanied by air mass moving northwards into the city. The turbulent runoffs result in leaching, sheet erosion and gullies (Akabuike, 1990). The mean temperature ranges from about 20.30ºC in the dry season to about 32.16º in the rainy season (Akabuike, 1990). The harmattan which occurs during the dry season between the months of November and February is generally accompanied by poor visibility especially at night and early in the morning. The city stands between 182.88 meters and 219.45 meters above sea level (Enete and Alabi, 2012).

2.2 Description of Sampling Sites

Ten major roads (with an average traffic density of 6000 vehicles/day) were selected in Enugu metropolis based on traffic load, population density and anthropogenic activities as described in Table 1.

Table 1: Description of the 10 selected roads within Enugu metropolis

Road Code	Road	Coordinates	Description
1	Chime Avenue	06°27'455" 007°30'726"	Major road within a residential area, filled with commercial activities and traffic.

2	Abakaliki Road	06°27'891" 007°27'891"	Inter- state road, busy with heavy duty trucks and other vehicles.
3	Ogui Road	06°27'690" 007°30'607"	Long road with offices and commercial activities
4	Abakpa Nike Road	06°28'613" 007°31'033"	Major road within a densely populated area, very heavy vehicular and human traffic.
5	Obiagu Road	06°26'462" 007°29'648"	Heavy traffic with numerous commercial activities, dense human population
6	Zik Avenue	06°26'205" 007°29'648"	Road with heavy school children traffic, big buses and different business shops
7	Okpara Avenue	06°26'677" 007°29'436"	Major road in the central business district, heavy traffic and human activity
8	Onitsha Road	06°26'810" 007°28'957"	Moderate to heavy traffic, government offices and construction sites
9	Kenyatta-Ugwuaji Road	06°25'660" 007°29'620"	Heavy traffic, leading to a market, furniture shops, building materials shops.
10	Agbani Road	06°25'160" 007°29'206"	Major road from an industrial market through offices and commercial areas

Samples were collected in each road at intervals of 500 m by sweeping a 1 m^2 area on the road, near the curb. They were packed using a clean plastic dust pan and stored in polyethylene bags, carefully labeled and taken to the laboratory for analyses. At each sampling point, 3 sub-samples (1 m apart from each other) were taken, pooled and homogenized to obtain a composite sample (about 200 g) for each point. Thirty-two (32) dust samples were collected for analyses. In order to eliminate temporal variations, all samples were collected in February 2014. All the points were geo-referenced with a GPS unit (global positioning by satellite), *Garmin, E Trex.*

2.3 Sample Pretreatment and Analysis

After collection, the samples were taken to the analytical laboratory of Projects Development Institute (PRODA) Enugu. They were air-dried at room temperature and weighed prior to further analysis. The samples were dry-sieved using a 1 mm aperture metal sieve to remove large objects, litter, plants and leaves. The dried samples were further passed through a 230 mesh size (63 µm aperture) polyethylene sieve to obtain fine particles. 1 g each of the sieved samples was weighed with an analytical balance. Subsequently, the samples were placed in 50 cm^3 glass beakers and digested at 105℃ on a hot plate for 2 hours in a fume cupboard using 20 cm^3 of a mixture of concentrated HNO_3, HF and $HClO_4$ in the ratio of 2:2:1 by volume. The digested samples were cooled and filtered with Whatman No. 1 filter paper. The filtrates were made up to 100 cm^3 with distilled water in a volumetric flask. The total metal levels in the digested samples were determined using a Buck 210VGP atomic absorption spectrophotometer. The blanks and duplicates were similarly determined. pH and electrical conductivity was determined with a pH meter (LIDA Instruments) and EC meter (Sanxin, SX 723) using a 1:2 (w/v) sample/water suspension. The total organic matter of the samples was determined by the Walkley-Black chromic acidwet oxidation method (Walkley and Black, 1934).

2.4 Data Analysis

The trace metal data of the dust samples were analyzed to determine the Geo-accumulation Index (**I_{geo}**) and the Integrated Pollution Index (IPI) of the metals in the environment.

2.4.1 Geo-Accumulation Index (I_{geo})

The geo-accumulation Index (I_{geo}) was introduced by Muller (Muller, 1969). The method has been widely employed in European trace metal studies since the late 1960s. It is used to assess trace metal pollution in urban soils by comparing current and pre-industrial concentrations. It is also employed in pollution assessment of trace metals in urban street dust (Lu, *et al*., 2009; Lu, 2010; Gowd, *et al*., 2010). I_{geo} is mathematically expressed as:

$$I_{geo} = log_2 (C_n \div 1.5B_n) \quad (1)$$

Where C_n is the measured concentration of trace metal in the sediment, B_n is the geochemical background value in the street dust. In this study, the background geochemical concentrations of the trace metals (crustal average) (Taylor, 1964), were chosen as the background values for calculating the I_{geo} values. The constant, 1.5 allows for natural fluctuations in the content of a given substance in the environment and accommodates very small anthropogenic influences (Lu, *et al*., 2009). The geo-accumulation index (I_{geo}) scale in Table 2 consists of seven grades (0–6) ranging from unpolluted to highly polluted (Muller, 1969).

Table 2: Pollution Grades of Geo-Accumulation Index of Metals

I_{geo} Class	I_{geo} Value	Pollution Grade
0	$I_{geo} \leq 0$	Practically unpolluted
1	$0 < I_{geo} < 1$	Unpolluted to moderately polluted
2	$1 < I_{geo} < 2$	Moderately polluted
3	$2 < I_{geo} < 3$	Moderately to heavily polluted
4	$3 < I_{geo} < 4$	Heavily polluted
5	$4 < I_{geo} < 5$	Heavily to extremely polluted
6	$5 \leq I_{geo}$	Extremely polluted

2.4.2 Integrated Pollution Index (IPI)

To further assess the pollution levels of the metals in the dust on road surfaces in Enugu, an integrated pollution index (IPI) of the metals was calculated in this study. The IPI is defined as the mean value of the pollution index (PI) of a trace metal. In this study, the PI of each metal is defined as the ratio of the metal concentration in the street to the background concentration of the corresponding metal as the following formulation: (Wei, *et al*., 2009; Chen, *et al*., 2005).

$$PI_n = C_n \div B_n \quad (2)$$

Where, C_n is the concentration of element in environment, B_n is the background value. In this study, the background geochemical concentrations of the metals (crustal average) (Taylor, 1964), were chosen as the background values for calculating the IPI values.

Table 3: Classification of Integrated Pollution Index of Metals

IPI Class	IPI value	Classification
1	IPI≤ 0	Low level of pollution
2	1<IP1≤ 2	Moderate level of pollution
3	2< IPI≤5	High level of pollution
4	IPI>5	Extreme high pollution

2.4.3 Statistical Analysis

Correlation of different trace metals and the physico-chemical parameters were calculated by the Pearson correlation matrix method. Strong correlations signify that each paired parameter have common pollution sources. To help in the identification of different metal types, Principal Component Analysis (PCA) was performed to establish possible factors that contribute towards the metal concentrations and source apportionment. The number of significant principal components was selected on the basis of Varimax orthogonal rotation with Kaiser Normalisation at eigen values greater than 1. Hierarchical cluster analysis (HCA) was also performed to group the metals and the physico-chemical parameters into sub-groups. This shows metals that are of common sources in the street dust. These statistical analyses were done using IBM-SPSS 20.0

3. RESULTS AND DISCUSSION

3.1 Heavy Metal Concentrations

The trace metal concentrations in the selected roads are given in the table below. The earth crustal average values and the Nigerian soil quality standards (NESREA) are also shown.

Table 4: Mean levels (mg/kg dry weight) of trace metals in dust samples

Road/ Metal	Cr	Mn	Fe	Co	Ni	Cu	Zn	Cd	Pb
1	2.67	4.33	483.00	8.33	116.00	66.67	19.67	1.00	26.67
2	3.67	4.33	501.67	11.33	39.67	53.67	4.00	1.33	16.67
3	2.25	4.00	455.25	61.75	87.75	11.50	1.50	1.00	15.00
4	2.33	7.67	495.67	9.00	193.67	56.67	5.67	0.67	13.33
5	0.67	6.67	470.67	35.00	177.00	73.33	1.33	1.33	3.33
6	1.33	3.67	512.33	10.67	134.33	90.00	31.67	1.00	16.67
7	2.00	4.67	431.33	4.00	112.00	46.67	1.67	1.33	6.67
8	1.00	2.33	443.33	9.67	85.33	56.67	1.00	0.67	46.67
9	1.33	3.00	408.33	3.00	55.67	70.00	1.00	0.00	23.33
10	2.25	5.25	463.50	3.00	40.50	77.50	9.50	0.00	0.00
Range	0.67-3.67	2.33 - 7.67	408.33 -512.33	3.00 - 61.75	39.67-193.67	11.50 - 90.00	1.00 - 31.67	0.00-1.33	0.00-46.67
Mean	**1.97**	**4.59**	**466.06**	**16.63**	**101.69**	**59.28**	**7.56**	**0.81**	**16.25**
Continental Crustal Average*	**100**	**950**	**56300**	**25**	**76**	**55**	**70**	**0.2**	**12.5**
Nigerian Soil Quality Standard**	**100**	**NA**	**NA**	**50**	**70**	**100**	**421**	**3**	**164**

*(Taylor, 1964) ** (National Environmental Standards and Regulations Enforcement Agency, NESREA), NA (Not available)

The concentrations of Cr, Mn, Fe, Co, Ni, Cu, Zn, Cd and Pb in the dust samples varied from 0.67 - 3.67, 2.33 - 7.67, 408.33 - 512.33, 3.00 - 61.75, 39.67 - 193.67, 11.50 - 90.00, 1.00 - 31.67, 0 - 1.33, 0 - 46.67 mg/kg, respectively. The mean concentrations were 1.97, 4.49, 466.06, 16.63, 101.69, 59.28, 7.56, 0.81 and 16.25 mg/kg, respectively. The sequence in the average levels of the trace metals is as follows:
Fe>Ni>Cu>Co>Pb>Zn>Mn>Cr>Cd. The mean level of Ni at 101.69 mg/kg exceeded its background value of 76 mg/kg as well as the NESREA soil quality limit of 70 mg/kg. The mean levels of Cu, Cd and Pb were all higher than their background values but within their NESREA limits. The rest of the metals were within limits.

3.2 Physico-chemical properties

The pH, electrical conductivity (EC) and total organic matter (TOM) of the dust samples are shown in Table 5.

Table 5: Physicochemical parameters of street dust on selected roads in Enugu Metropolis

Road Code	Location	pH	EC(μS/cm)	TOM (%)
1	Chime Avenue	7.31±0.54	567.67±26.58	7.00±1.01
2	Abakaliki Road	7.66±0.62	573.00±16.82	5.51±2.23
3	Ogui Road	7.31±0.22	556.50±23.74	6.45±0.85
4	Abakpa Nike Road	7.76±0.32	556.00±26.21	5.65±4.40
5	Obiagu Road	7.54±0.35	572.00±24.02	6.67±2.77
6	Zik Avenue	7.37±0.23	572.33±6.81	7.09±1.06
7	Okpara Avenue	7.75±0.44	573.67±16.17	5.30±2.07
8	Onitsha Road	7.50±0.21	558.00±23.64	4.38±0.70
9	Kenyatta-Ugwuaji	7.93±0.41	578.67±16.29	6.67±1.46
10	Agbani Road	7.60±0.13	574.50±7.42	4.89±2.46

The pH and EC are considered as indicators of the chemical nature of street dust. The pH values of the street dust samples along the roads were within the neutral-alkaline range: 7.31-7.93. The pH has a major effect on metal dynamics because it controls adsorption and precipitation which are the main mechanisms of metal adsorption to street dust (Evans, *et al*., 1995). The mobility of trace metals within the dust profile decreases with increasing soil pH (8 and above) due to precipitation of hydroxides, carbonates or formation of insoluble organic complexes (Smith and Giller, 1992). The pH values of the samples therefore suggest decreased mobility and solubility of trace metals in the samples. The mean EC values measured ranged from 556 - 578.67µS/cm. EC of soils is classified as: non saline < 2; moderately saline 2 - 8; very saline 8 - 16; extremely saline > 16 (Smith and Giller, 1992). The result of the present study shows that the EC of the street dust is extremely saline. The mean values of total organic matter, TOM ranged from 4.38 - 7.09%. It has been shown that organic matter is important in the binding of metals to dust particles. It has also been reported that metals such as Cd, Ni and Zn may be influenced in their solubility characteristics by TOM (Fotovat, *et al*., 1996)

3.3 Correlations among the heavy metal pollutants and physico-chemical parameters

Table 6: Pearson Correlation Matrix

		pH	EC	TOM%	Cr	Mn	Fe	Co	Ni	Cu	Zn	Cd	Pb
Ph	Pearson Correlation	1											
	Sig. (2-tailed)												
EC	Pearson Correlation	-.025	1										
	Sig. (2-tailed)	.893											
TOM %	Pearson Correlation	-.308	.005	1									
	Sig. (2-tailed)	.087	.979										
Cr	Pearson Correlation	.088	-.111	-.023	1								
	Sig. (2-tailed)	.632	.546	.900									
Mn	Pearson Correlation	-.135	.080	.114	-.097	1							
	Sig. (2-tailed)	.461	.664	.535	.597								
Fe	Pearson Correlation	-.014	-.194	-.103	-.208	-.157	1						
	Sig. (2-tailed)	.939	.286	.575	.253	.392							
Co	Pearson Correlation	.072	-.285	-.109	.140	.076	-.019	1					
	Sig. (2-tailed)	.697	.114	.551	.446	.680	.916						
Ni	Pearson Correlation	-.306	.138	-.042	-.192	.129	.410*	-.171	1				
	Sig. (2-tailed)	.088	.450	.821	.293	.482	.020	.348					
Cu	Pearson Correlation	-.208	.366*	.210	-.069	.019	.136	-.287	.415*	1			
	Sig. (2-tailed)	.254	.039	.249	.706	.918	.459	.112	.018				
Zn	Pearson Correlation	-.090	-.144	.094	.215	-.357*	.112	-.054	-.034	.202	1		
	Sig. (2-tailed)	.625	.431	.610	.237	.045	.540	.770	.852	.267			
Cd	Pearson Correlation	.172	-.028	.084	.093	-.048	.178	-.015	.082	-.131	.124	1	
	Sig. (2-tailed)	.346	.878	.649	.612	.794	.330	.936	.654	.473	.500		
Pb	Pearson Correlation	-.379*	-.104	-.036	-.094	.086	-.154	-.113	.284	.222	-.045	-.202	1
	Sig. (2-tailed)	.032	.570	.846	.608	.640	.400	.540	.116	.223	.807	.267	

The result of the analysis presented in Table 6 shows that Cu is significantly correlated with Ni and EC at < 0.05 significance level indicating that these metal pollutants share common sources: brake, tyre and engine wear, fuel/oil additives and road infrastructure wear. This could also mean that the presence of these trace metals is enhanced by the electrical conductivity (EC) of the samples. Also there is a significant correlation at < 0.05 significance level between Zn and Mn, Pb and pH, TOM. This indicates that the retention of the metals in street dust is affected by the TOM while their mobility and solubility is affected by the pH.

3.4 Index of Geo– accumulation

The results of the calculated I_{geo} for the metals are shown in Table 7.

Table 7: Index of geo-accumulation

Road	Metal								
	Cr	Mn	Fe	Co	Ni	Cu	Zn	Cd	Pb
1	-5.81	-8.38	-7.45	-2.17	0.02	-0.31	-2.42	1.74	0.51
2	-5.38	-8.38	-7.41	-1.73	-1.52	-0.62	-4.72	2.15	-0.17
3	-6.06	-8.48	-7.53	0.72	-0.38	-2.85	-6.14	1.74	-0.36
4	-6.01	-7.53	-7.41	-2.06	0.76	-0.54	-4.21	1.16	-0.49
5	-7.97	-7.73	-7.48	-0.10	0.63	-0.17	-6.31	2.15	-2.49
6	-6.83	-8.59	-7.38	-1.82	0.24	0.12	-1.73	1.74	-0.17
7	-6.23	-8.29	-7.62	-3.24	-0.03	-0.82	-5.97	2.15	-1.49
8	-7.24	-9.29	-7.59	-1.96	-0.42	-0.54	-6.80	1.16	1.32
9	-6.83	-8.90	-7.70	-3.64	-1.04	-0.24	-6.80	0	0.31
10	-6.06	-8.12	-7.51	-3.64	-1.49	-0.09	-3.47	0	0

The ranges of the values of the metals are as follows: Cr (-5.38) -(-7.97), Mn (-7.53) --(-9.29), Fe (-7.38) – (-7.70), Co (-3.64) - (0.72), Ni (-1.52) – (0.76), Cu (-2.85) – (0.12), Zn (-6.80) – (-1.73), Cd (0) - (2.15) and Pb (-2.49) – (1.32). Their mean values are as follows: -6.44, -8.37, -7.51, -1.96, -0.32, -0.61, -4.86, 1.40, -0.30. The mean value of Cd showed moderate pollution of the metal in Enugu metropolis. There was moderate to heavy Cd pollution in street dust at Okpara Avenue (7), Abakaliki Road (2) and Obiagu Road (5). The maximum I_{geo} value of 2.15 was observed for Cd in these roads. They experience heavy vehicular, human and commercial activities. This indicates that this pollution is from human and commercial activities. Chime Avenue (1), Onitsha Road (8) and Kenyatta-Ugwuaji (9) showed moderate Pb pollution with values of 0.51, 1.32 and 0.31 respectively. These roads experience heavy human and vehicular traffic as well as commercial activities.

3.5 Integrated Pollution Index (IPI)

The values in table 9 show the Integrated Pollution Indices (IPI) of the trace metals in the street dust of selected roads in Enugu metropolis.

Table 8: Integrated Pollution Index of metals in street dust of selected roads in Enugu

Code	Road	Cr	Mn	Fe	Co	Ni	Cu	Zn	Cd	Pb
1	Chime Avenue	0.03	0.00	0.01	0.33	1.53	1.21	0.28	5.00	2.13
2	Abakaliki Road	0.04	0.00	0.01	0.45	0.52	0.98	0.06	6.67	1.33
3	Ogui Road	0.02	0.00	0.01	2.47	1.15	0.21	0.02	5.00	1.20
4	Abakpa Nike Road	0.02	0.01	0.01	0.36	2.55	1.03	0.08	3.33	1.07
5	Obiagu Road	0.01	0.01	0.01	1.40	2.33	1.33	0.02	6.67	0.27
6	Zik Avenue	0.01	0.00	0.01	0.43	1.77	1.64	0.45	5.00	1.33
7	Okpara Avenue	0.02	0.00	0.01	0.16	1.47	0.85	0.02	6.67	0.53
8	Onitsha Road	0.01	0.00	0.01	0.39	1.12	1.03	0.01	3.33	3.73
9	Kenyatta-Ugwuaji	0.01	0.00	0.01	0.12	0.73	1.27	0.01	0.00	1.87
10	Agbani Road	0.02	0.01	0.01	0.12	0.53	1.41	0.14	0.00	0.00

According to its classification, Cr, Mn, Fe and Zn have low level of pollution in all the selected roads. The sequence of moderate to extremely high pollution in the roads is Cu<Pb<Ni<Cd. There is extremely high pollution of the roads by Cd. Since this metal is toxic, regulatory agencies should impose stricter laws on common sources of this metal: tyre wear debris, brake pad linings wear and fuel and oils additives.

3.6 Source Identification based on PCA and HCA analyses

In this study, PCA was applied to identify possible sources of the 9 kinds of trace metal pollutants in street dust in Enugu metropolis. The factor loadings after varimax rotation as well as eigen values are listed in Table 9.

Table 9: Principal Component Analysis

	Initial Eigen values			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %

1	1.960	21.775	21.775	1.960	21.775	21.775	1.882	20.913	20.913
2	1.628	18.093	39.868	1.628	18.093	39.868	1.553	17.253	38.165
3	1.324	14.715	54.583	1.324	14.715	54.583	1.478	16.418	54.583
4	.980	10.892	65.475						
5	.912	10.130	75.605						
6	.763	8.480	84.085						
7	.615	6.836	90.922						
8	.469	5.213	96.135						
9	.348	3.865	100.000						

Table 10:
The component matrix and rotated component matrix of the 9 trace metals in Enugu metropolis street dust

	Component Matrix[a]			Rotated Component Matrix[a]		
	Component			Component		
	1	2	3	1	2	3
Cr	-.427	.279	-.397	-.251	.545	-.240
Mn	.081	-.656	.262	-.039	-.687	-.179
Fe	.452	.469	.546	.250	-.039	.811
Co	-.472	-.088	.255	-.534	-.100	.017
Ni	.802	.026	.219	.676	-.292	.387
Cu	.705	.102	-.355	.788	.111	-.024
Zn	.043	.712	-.419	.212	.790	.126
Cd	-.070	.473	.445	-.204	.145	.603
Pb	.445	-.386	-.434	.554	-.172	-.446
	Extraction Method: Principal Component Analysis.			a. 3 components extract a. Rotation converged in 6 iterations.		

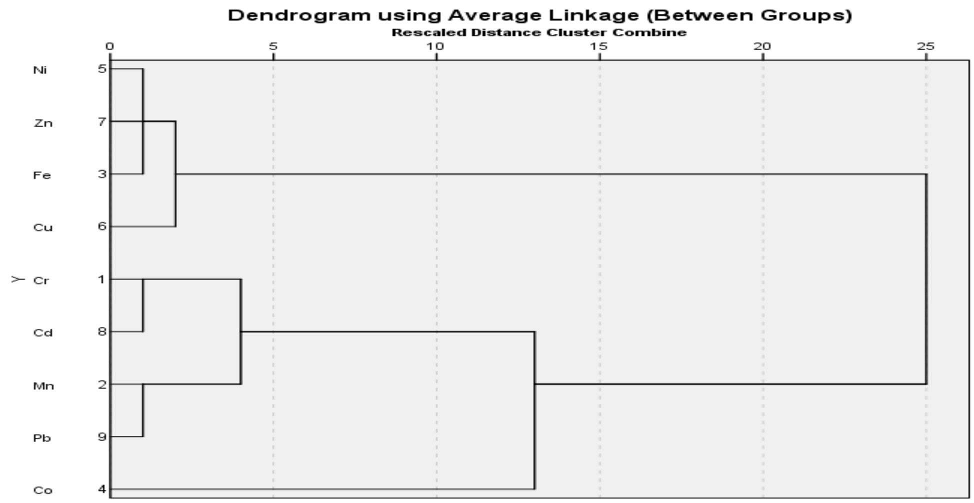
Principal factors extracted from the variables with eigenvalues greater than1 were selected. The component matrix and rotated component matrix of all the 9 kinds of metal pollutants are shown in the Table 9. Three factors were obtained accounting for 54.583% of the total variance. The first component is dominated by Ni and Cu (with high variation value of 0.676 and 0.788) accounting for 21.775% while the second component is dominated by Zn and Mn (with high variation value of 0.790 and -0.687) accounting for 18.039%. However, the third component is dominated by Fe and Cd with variation value of 0.811 and 0.603 respectively accounting for 14.715%. There is a close association of Ni and Cu in the first component. These metals are also significantly correlated indicating that they are from the same source: vehicular emission. In the second component, Mn is negatively correlated with Zn. This shows that they are not of the same source. While Zn is a fuel additive, Mn is a brake pad component. The third Component which is dominated by Fe and Cd may be from a mixed source: vehicular emissions and road infrastructure wear.

3.7 Hierarchical Cluster Analysis (HCA)

In previous studies, cluster analysis was used to classify the trace metals and help identify their sources, whether anthropogenic or natural (Lee *et al*., 2006; Li and Feng, 2012; Wang and Sun, 2009). Herein, HCA was performed to cross check the results of the PCA for the metals. HCA was carried out in this study with the Ward's Method, and the distances reflect the degree of correlation between different trace metals.

The results of HCA are shown in a dendogram in Fig. 2. Five subgroups are identified: (1) Ni, Zn, and Fe (2) Cu (3) Cr, Cd and Mn (4) Pb and (5) Co. These subgroups which are indicative of the common sources of these metals are consistent with those identified in Table 1. This result is also consistent with that of the PCA as discussed in Section 3.6.

Figure 2: Hierarchical clustering of trace metals in the street dust



4. CONCLUSION

The levels and sources of the trace metals in street dust collected from selected roads in Enugu were investigated. There is an elevation of the levels of some of these metals above their background levels. This is attributable to anthropogenic activities. The multivariate statistical analysis shows that the sources of these trace metals in street in Enugu metropolis are vehicular emissions and road infrastructure wear.

This study has provided empirical evidence about the level of trace metal pollution in Enugu street dust. The current effort of the government at manual and mechanical street sweeping is commendable. In this regard, the government is encouraged not to relent but to extend this service to other roads within the metropolis. This will help in the effort to safeguard human health.

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