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Full Length Research Paper

Assessment of heavy metal pollution in soils along major roadside areas in Botswana

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Assessment of heavy metal pollutants: Al, Co, Cu, Fe, Pb, Mn, Ni and Zn was conducted along major roadside soils of Botswana, lying between latitudes 18°S to 27°S and longitudes 20°E to 29°E using enrichment factor ratios (EF), contamination factor (CF), pollution load index (PLI) and geoaccumulation index (I_{geo}) methods. The studied sites were demarcated into five zones referred to as FN (Francistown-Nata), NM (Nata-Maun), MG (Maun-Ghanzi), GK (Ghanzi-Kang) and TS (Tshabong-Sekoma). All the four pollution assessment methods revealed that zones FN, NM and MG are pollution impacted as compared to GK and TS zones. Results of multivariate analysis suggest mixed origins of pollution sources including human activities, vehicular emissions and lithogenic occurrences. Al, Cu, Fe, Mn, Zn and Co is of mixed origins of pollutants, with Fe and Mn being predominantly lithogenic, and vehicular emissions characterised by Pb and Ni. The findings in this study will serve to create awareness of vehicular heavy metal pollution to Botswana policy makers in the mitigation of vehicular pollution, as it is barely monitored.

Key words: Heavy metal contamination, roadside soils, enrichment factors, contamination factor, pollution load index, geoaccumulation index, cluster analysis, factor analysis.

INTRODUCTION

Pollution of the natural environment by heavy metals is a universal problem because these metals are indestructible and most of them have toxic effects on living organisms, when permissible concentration levels are exceeded. Heavy metals frequently reported in literature with regards to potential hazards and occurrences in contaminated soils are Cd, Cr, Pb, Zn, Fe and Cu (Akoto et al., 2008; Alloway, 1995). Vehicle exhausts, as well as several industrial activities emit these heavy metals so that soils, plants and even residents along roads with heavy traffic loads are subjected to increasing levels of contamination with heavy metals (Ghrefat and Yusuf, 2006).

Road construction has been the main activity for development of industrial units. This has led to the loss of forest cover and subsequent loss of soil fertility. Roadside soils often show a high degree of contamination that can be attributed to motor vehicles. Various researchers have found that the concentrations of the metals Pb, Cu, Zn, Cd and Ni decrease rapidly within 10 to 50 m from the roadsides (Joshi et al., 2010; Pagotto et al., 2001). According to Panek and Zawodny (1993), pollution of roadside soils and plants by combustion of leaded petrol products is localized and usually limited to a belt of several metres wide on either side of the road, and that for similar topography and vegetation, the level of pollution decreases with the distance from the road. Due to their cation exchange capacity, complexing organic substances, oxides and carbonates have high retention capacity for heavy metals. Hence contamination levels increase continuously as long as the nearby sources remain active. Nevertheless, some heavy metals attached to the soil particles can be removed from the soil surfaces and get translocated elsewhere by the action of water and wind (Harrison et al., 1981; Ndiokwere, 1984; Ghrefat and Yusuf, 2006).

Mmolawa et al. (2010), demonstrated that heavy metal

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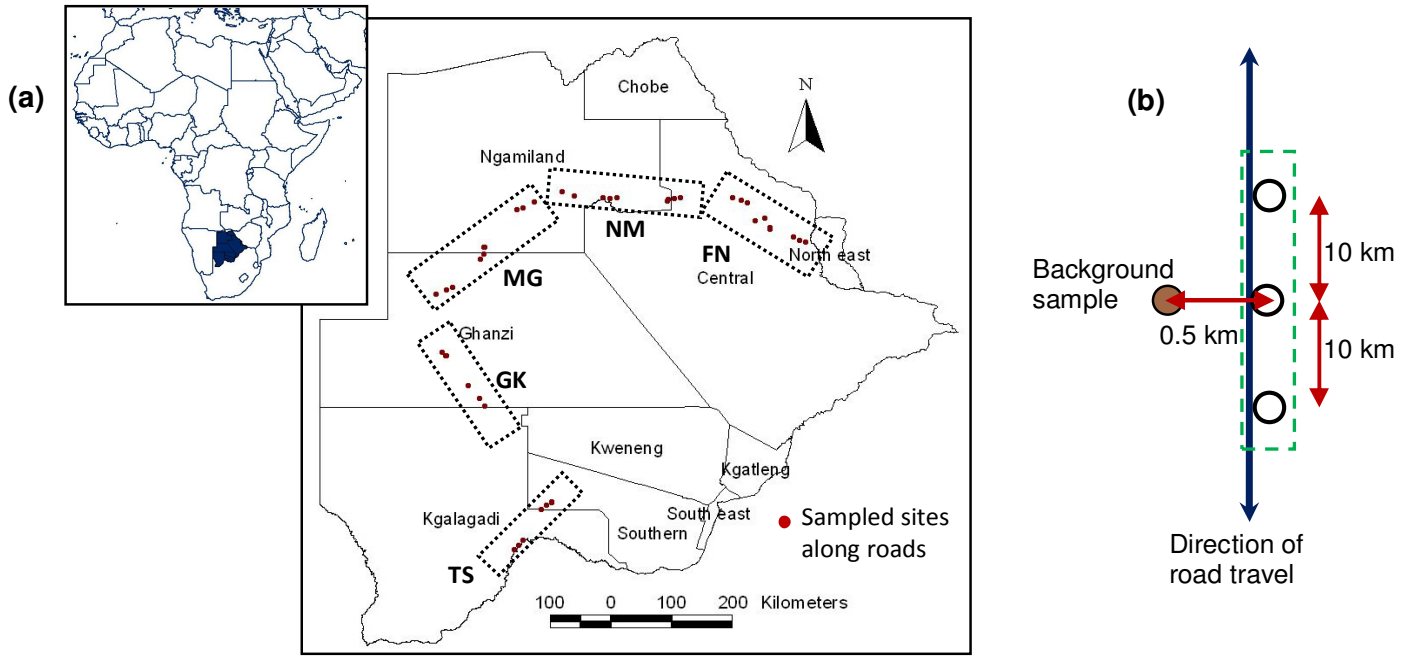

Figure 1. (a) Map of Botswana locating the sampled sites (indicated by dots along major roads). Sites were zoned as follows; Francistown-Nata (FN); Nata-Maun (NM); Maun-Ghanzi (MG); Ghanzi-Kang (GK) and Tshabong-Sekoma (TS), and (b) schematic drawing of field procedure showing the sampling sites (empty circles) relative to the background sampled site (closed circle).

contamination by Al, Co, Cu, Fe, Mn, Ni, Pb and Zn was variable along major Botswana roadside soils with Pb being extremely enriched in the soils, mainly due to vehicular emissions. However, the authors in this study used world background reference values to determine enrichment factors due to unavailability of local background. Due to spatial variability in lithology and mineralogy, world reference has been known to be erractic when used to determine enrichment factors (Abrahim and Parker, 2008). The present study assessed heavy metal pollution in soils using locally determined background values for metal concentrations, employing in-depth heavy metal analysis using four different approaches.

The objectives of the present work were to: (1) Assess heavy metal contamination by Al, Co, Cu, Fe, Mn, Ni, Pb and Zn using background soils obtained some 0.5-1 km away from sampling sites; (2) Assess roadside soil contamination using four approaches, namely; (a) Enrichment factor (EF), (b) Contamination factor (CF), (c) Pollution load index (PLI), and (d) Geoaccumulation index (I_{geo}), and (3) Classify heavy metals by their similarities and establish their probable sources using both cluster and factor analysis, respectively.

MATERIALS AND METHODS

Study area

The study was conducted along major roadside areas of Botswana lying in latitudes 18 to 27°S and longitudes 20 to 29°E. The country has a semi-arid climate, with highly variable rainfall, both spatially and temporally. On annual averages, rainfall ranges from 250 mm in the extreme southwest and 650 mm in the extreme north (Batisani and Yarnal, 2010). The south-eastern part and the north is dominated by grassland and savannah trees whereas the Ghanzi, Kgalagadi and the west of Southern and Kweneng districts have sparse trees and grasses. The soils can be generally categorised according to the predominant physiographic units of the sandveld and hardveld. The hardveld is characterised by soils which have been weathered and alluvial deposits. On the other hand, the sandveld area is mostly covered by the Kgalagadi sands (Batisani and Yarnal, 2010).

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Site description and sampling techniques

Soils were randomly collected along major roadsides (Figure 1a), avoiding areas with obvious signs of disturbance such as animal burrowing and landfills. The distances between sampling sites were chosen to be about 50 or 100 km, depending on proximity of major settlements. Four samples were collected at each location as follows: One sample at about 10 km before the 50th (or 100th) km stretch, the second one at the site of concern and another one about 10 km after the site of concern. The fourth (background or control) sample was collected at least 500 m away from the direction of sampling locations (Figure 1b). All soils were sampled at the surface (0 to 10 cm in depth) using hand driven stainless steel augers. Exact locations for all sampled sites were determined using a global positioning system and entered into a geographical information system for data processing.

Sample preparation and analysis

Collected soil samples were air-dried to constant weight and then

sieved through a 500 µm stainless steel mesh wire. Samples of 0.5 g were digested in 20 ml freshly prepared aqua regia (1:3 HNO_3: HCl) on a hot plate for 3 h, then evaporated and analysed for metal concentration. Standard reference material was prepared using stock solution from SAARCHM and MERCH and was used to have a check on the accuracy of the results.

The total concentrations of Al, Co, Cu, Fe, Pb, Mn, Ni and Zn in filtrate were then determined using a flame atomic absorption spectrometer (Varian SpectrAA 220 FS) at wavelengths, λ: Al = 309.3 nm; Co = 240.7 nm; Cu = 324.8 nm; Fe = 372.0 nm; Pb = 217.0 nm; Mn = 279.5; Ni = 232.0 nm and Zn = 213.9 nm, using air acetylene flame.

Assessment of metal contamination

Enrichment factor (EF)

Assessment of metal and level of contamination in soils require pre-anthropogenic knowledge of metal concentrations to act as pristine values. A number of different enrichment calculation methods and different reference material have been reported (Ogusola et al., 1994; Gaiero et al., 1997; Sutherland et al., 2000; Kamau, 2002; Valdés et al., 2005; Ghrefat and Yusuf, 2006; Abrahim and Parker, 2008; Akoto et al., 2008; Dragović et al., 2008; Charkravarty and Patgiri, 2009; Harikumar and Jisha, 2010; Sekabira, 2010; Olubunmi and Olorunsola, 2010). In this manuscript, the degree of anthropogenic pollution was established by adapting enrichment factor ratios (EF) used by Sutherland et al. (2000), as follows:

$$EF = \frac{C_{\mathrm{m}}\ \text{Sample}}{(\text{Median}\ C_{\mathrm{m}}\ \text{Background} + 2 \times \text{MAD}\ C_{\mathrm{m}}\ \text{Background})} \quad (1)$$

Where, C_{m} Sample is the concentration of a given metal along the roadside. Median C_{m} Background is median concentration of an element in the background soil sample and MAD C_{m} Background is the median absolute deviation from median, defined as:

$$\text{MAD} = \text{median}\left(\left| x_1 - \text{median}_j\left(x_j\right)\right|\right) \quad (2)$$

This method is less affected by extremes in the tail often encountered with geochemical data, because the data in the tails have less influence on the calculation of the median than they do on the mean (Chester et al., 1985; Gaiero et al., 1997). Enrichment factor categories for Equation 1 are outlined as follows:

EF < 2: Deficiently to minimal enrichment
2 ≤ EF < 5: Moderate enrichment
5 ≤ EF < 20: Significant enrichment
20 ≤ EF < 40: Very high enrichment
EF ≥ 40: Extremely high enrichment

Contamination factor (*CF*)

The level of contamination of soil by metal is expressed in terms of a contamination factor (CF) calculated as:

$$CF = \frac{C_{\mathrm{m}}\ \text{Sample}}{(C_{\mathrm{m}}\ \text{Background})} \quad (3)$$

where the 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.

Each site was evaluated for the extent of metal pollution by employing the method based on the pollution load index (PLI) developed by Thomilson et al. (1980), as follows:

$$PLI = \left(CF_1 \times CF_2 \times CF_3 \times \ldots \times CF_n\right)^{\frac{1}{n}} \quad (4)$$

where *n* is the number of metals studied (eight in this study) and *CF* is the contamination factor calculated as described in Equation 3. The PLI provides simple but comparative means for assessing a site quality, where a value of PLI < 1 denote perfection; PLI = 1 present that only baseline levels of pollutants are present and PLI > 1 would indicate deterioration of site quality (Thomilson et al., 1980).

This type of measure has however been defined by some authors in several ways, for example, as the numerical sum of eight specific contamination factors (Hakanson, 1980), whereas, Abrahim (2005) assessed the site quality as the arithmetic mean of the analysed pollutants. In this study, the authors found it appropriate to express the *PLI* as the geometric mean of the studied pollutants since this method tends to reduce the outliers, which might bias the reported results.

Geoaccumulation index (I_{geo})

Enrichment of metal concentration above baseline concentrations was calculated using the method proposed by Muller (1969), termed the geoaccumulation index *(I_{geo})*. This method assesses the metal pollution in terms of seven (0 to 6) enrichment classes ranging from background concentration to very heavily polluted, as follows:

$$I_{\mathrm{geo}} = \log_2\left[\frac{C_{\mathrm{m}}\ \text{Sample}}{(1.5 \times C_m\ \text{Background})}\right] \quad (5)$$

The factor 1.5 is introduced in this equation to minimise the effect of possible variations in the background values, C_{m} Background, which may be attributed to lithogenic variations in soils. The seven proposed descriptive classes for I_{geo} values are given in Table 1 (Muller, 1969).

Statistical analysis

In order to study the characteristics of roadside soils, the concentrations of heavy metals content in surface soils were subjected to correlation analysis, Principal Component Factor Analysis (*PCA*) and Hierarchical Cluster analysis (*CA*) by SPSS PASW Statistics 17 to determine association as well as the differences in the concentration between different zones.

RESULTS AND DISCUSSION

Heavy metal concentrations in soils

The mean heavy metal concentrations (in µg/g) along roadside soils ranged from (12.80 to 34.46) Al; (0.01 to 0.02) Co; (0.02 to 0.08) Cu; (25.36 to 87) Fe; (0.04 to 0.51) Mn; (0.37 to 0.48) Ni; (0.04 to 0.21) and (0.05 to

Table 1. The I_{geo} classes with respect to soil quality.

I_{geo}value	I_{geo}class	Designation of soil quality
> 5	6	Extremely contaminated
4 - 5	5	Strongly to extremely contaminated
3 - 4	4	Strongly contaminated
2 - 3	3	Moderately to strongly contaminated
1 - 2	2	Moderately contaminated
0 - 1	1	Uncontaminated to moderately contaminated
0	0	Uncontaminated

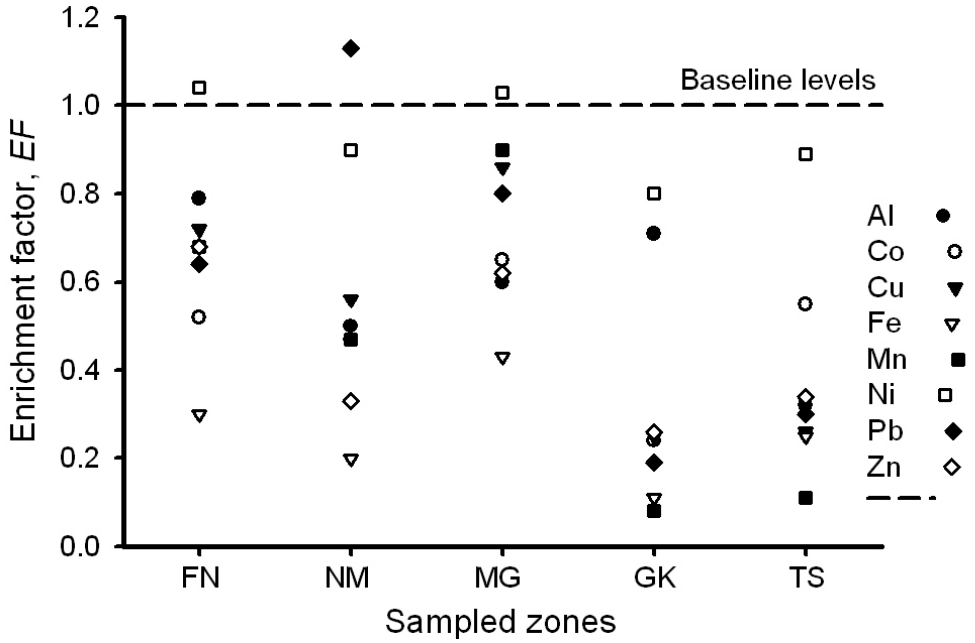

Figure 2. Enrichment factors for heavy metals along roadside soils for each sampled zone.

0.14) Zn. Since this study is the first of its kind for Botswana major roadside soils, there is no local information in literature available for comparison. Data reported here were therefore used to examine the extent of contamination by Al, Co, Cu, Fe, Pb, Mn, Ni and Zn using comparable pristine samples obtained at least 0.5 km from the roadside sampled sites. Concentrations of individual heavy metal elements and their background data are given in the appendix.

Enrichment factor

Enrichment factors of various metals in the roadside soils in sampled zones are presented in Figure 2.

According to Figure 2, EF ratios suggest that all metals are deficiently to minimally enriched. These results are contrary to those previously reported by Mmolawa et al. (2010). In their preliminary study, the authors reported moderate (Co, Cu, Fe and Ni) to extreme (Pb) enrichment in most roadside soils studied here. The dissimilarities may however, be ascribed to the different approaches used in the enrichment factor calculation methods. The previous study employed a normalised enrichment factor approach for metal concentrations using world uncontaminated background soils values, and iron as a metal of normalization, an approach which is less reliable since it ignores the fact that some geologic materials may have naturally high element concentrations and that the world reference values could be higher or lower compared to local conditions.

Contamination factor (*CF*)

Contamination factors of various metals in the roadside soils in sampled zones are presented in Table 2.

Using the contamination factor categories previously described, zones FN and MG suffered moderate contamination by all metals except Co and Zn, respectively. On the other hand, zones GK and TS

Table 2. Contamination factors for heavy metals along roadside soils for each sampled zone.

	Al	Co	Cu	Fe	Mn	Ni	Pb	Zn
FN	1.46	0.86	1.30	1.05	1.95	1.18	1.21	1.01
NM	0.93	0.78	1.01	0.69	1.36	1.02	2.14	0.50
MG	1.10	1.07	1.56	1.52	2.60	1.16	1.51	0.93
GK	1.30	0.39	0.44	0.39	0.22	0.91	0.37	0.38
TS	0.59	0.91	0.47	0.88	0.30	1.01	0.57	0.52

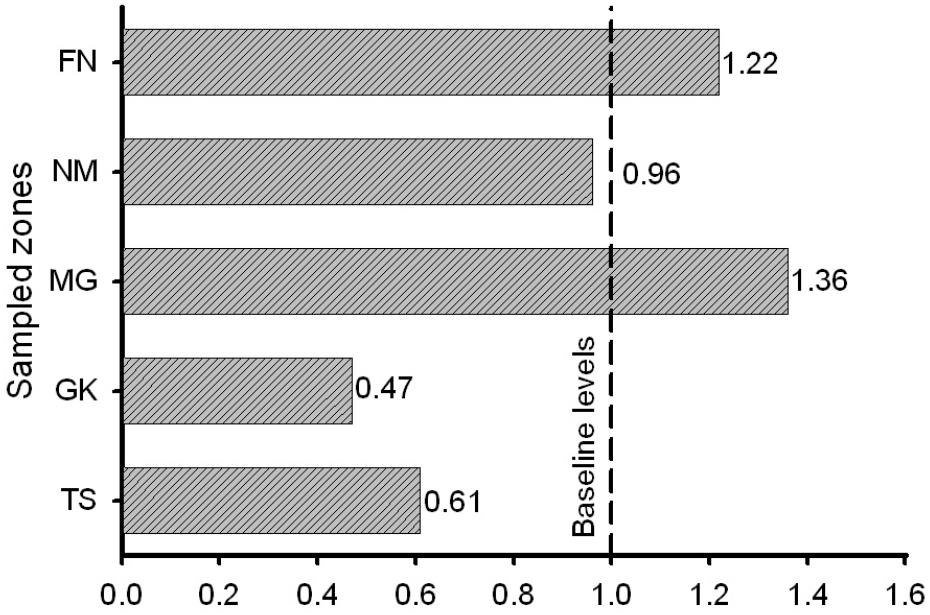

Figure 3. Pollution load index, *PLI* for the eight metals studied at the sites.

displayed low contamination by all metals except for Al and Ni, respectively, which showed moderate contamination. Zone NM displayed moderate contamination by Cu, Mn, Ni and Pb, and low contamination by Al, Co, Fe and Zn.

Pollution load index (PLI)

To effectively compare whether the five stations suffer contamination or not, the pollution load index, PLI, described in Equation 4, was used. The PLI is aimed at providing a measure of the degree of overall contamination at a sampling site. Figure 3 shows results of the PLI for the eight metals studied at these zones.

Based on results presented in Figure 3, the overall degree of contamination by the 8 metals is of the order MG > FN > NM > TS > GK. MG and FN show strong signs of pollution or deterioration of site quality, whereas NM is almost at baseline level. Sites GK and TS suggest perfection (or no overall pollution). Relatively high PLI values at MG, FN and, to some degree, NM suggest input from anthropogenic sources attributed to increased human activities and/or vehicular emissions. These sites are along a major highway connecting a number of townships and villages having higher populations and establishments. Furthermore, FN zone is along the highway which is frequently used by commercial trucks for transportation of goods to and from Zambia and other countries into central Africa.

Geoaccumulation index (I_{geo})

The calculated geoaccumulation (I_{geo}) values are presented in Figure 4. It is evident from Figure 4 that the uncontaminated to moderately contaminated I_{geo} value of '0 to 1' is observed at zone MG by Cu, Fe, Mn and Pb, at zone NM by Pb and at zone FN by Mn.

As revealed from the four pollution assessment methods; I_{geo}, PLI, CF and to a less degree, EF, roadside soils of zones FN, NM and MG are pollution impacted, as compared to GK and TS zones. Statistical tests were

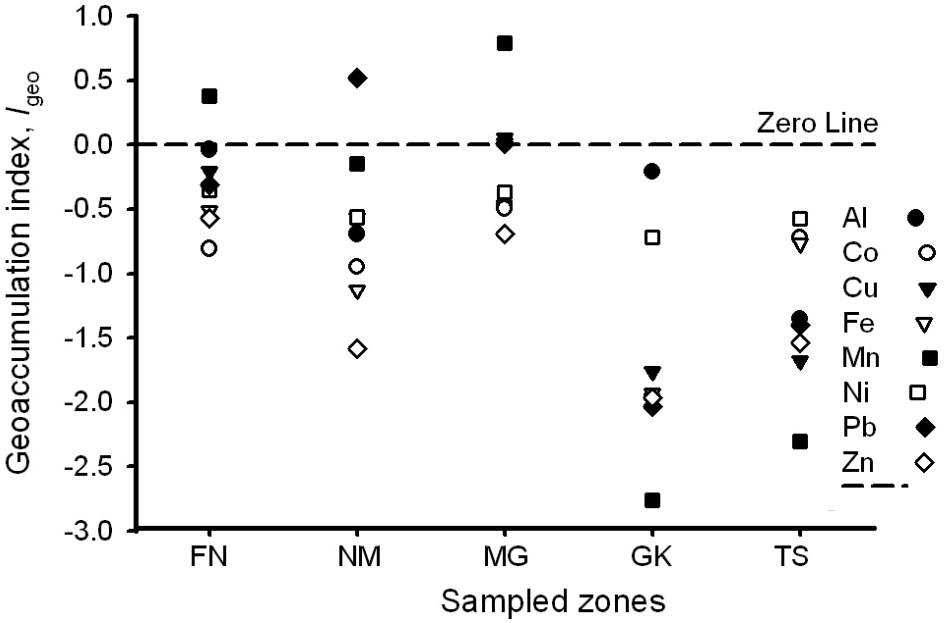

Figure 4. Geoaccumulation indices of heavy metals along the roadside soils.

Table 3. The Spearman's rank correlation coefficient, ρ, between concentrations of metals in FN, NM, MG, GK and TS zones.

	Al	Co	Cu	Fe	Mn	Ni	Pb	Zn
Al	1.000							
Co	0.013	1.000						
Cu	0.324*	0.291	1.000					
Fe	0.110	0.268	0.342*	1.000				
Mn	0.506**	0.361*	0.811**	0.307	1.000			
Ni	0.338*	0.091	0.484**	0.240	0.556**	1.000		
Pb	0.056	0.253	0.649**	0.385*	0.602**	0.170	1.000	
Zn	0.350*	0.323*	0.434**	0.335*	0.593**	0.421**	0.293	1.000

* Correlation is significant at the 0.05 level (2-tail)..** Correlation is significant at the 0.01 level (2-tail).

then performed to establish the inter-metal relationships, and classify metals.

Statistical analysis

Analysis of variance was employed to determine whether groups of variables have the same mean. Sites showed no significant effect on variation between group means of the heavy metals at different zones except for copper ($P < 0.001$), manganese ($P < 0.003$) and zinc ($P < 0.05$). This suggests that there is some degree of input of these (Cu, Mn and Zn) metals between sites. Inter-elemental association was also evaluated by Spearman's rank correlation coefficient, ρ and the results are presented in Table 3.

Table 3 indicates that some elemental pairs, for example Al/Mn ($r = 0.51$, $df = 28$, $P < 0.001$), Cu/Mn ($r = 0.81$, $df = 28$, $P < 0.0001$), and Cu/Pb ($r = 0.65$, $df = 28$, $P < 0.0001$) etc, have strong correlations with each other. On the other hand, pairs such as Al/Cu ($r = 0.22$, $df = 28$, $P < 0.05$), Al/Ni ($r = 0.34$, $df = 28$, $P < 0.05$), and Al/Zn ($r = 0.35$, $df = 28$, $P < 0.05$) are moderately significant, whereas the rest of elemental pairs show no significant correlation with each other. Strong correlations signify that each paired elements have common contamination sources. Physico-chemical properties and metal associations were however not performed in the present study, to help in ascertaining these results.

Agglomeration schedule of cluster analysis (CA) was performed on data using nearest neighbour linkage and Euclidean distance as a measure of proximity between

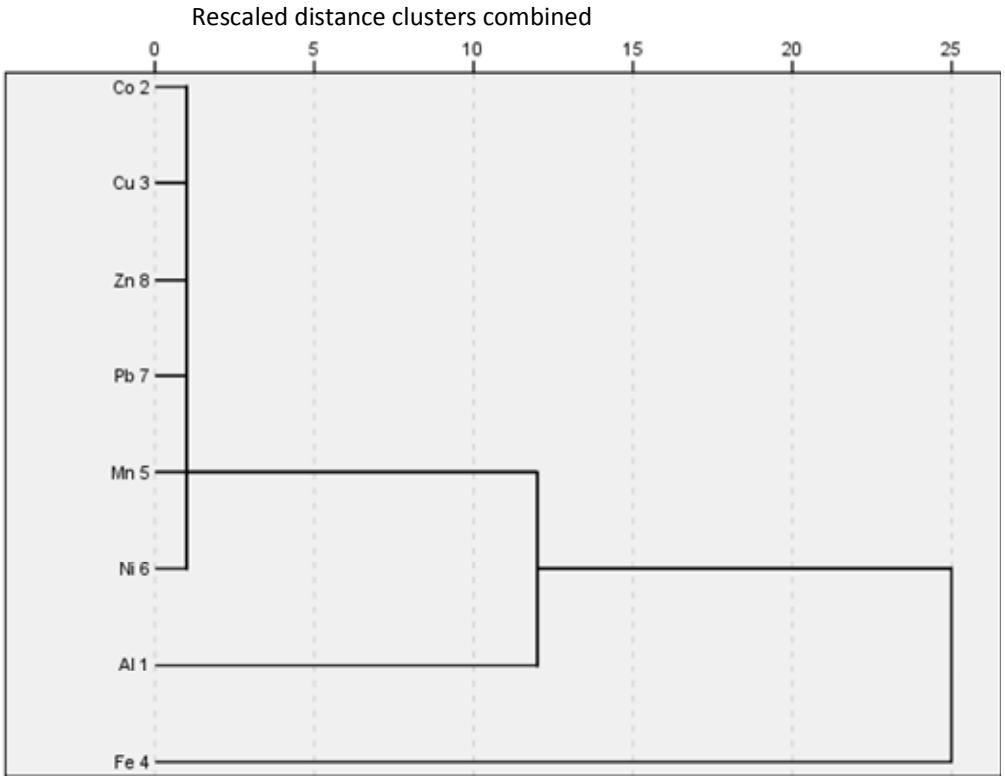

Figure 5. Dendrogram derived from hierarchical cluster analysis of heavy metals content in analysed soils.

samples. Results of CA are shown in Figure 5.

The hierarchical cluster analysis using nearest neighbour method produced two clusters, between which the variables were significantly ($P < 0.05$) different. The first cluster contained Co, Cu, Zn, Pb, Mn, Ni and Al. These elements were classified as anthropogenic in origin, leaving Mn and Al as originating from mixed (anthropogenic and lithogenic) sources. The second cluster discriminated the lithogenic Fe. Similar studies by Al-Momani (2009) found Pb to be strongly associated with vehicular emissions and Zn to be associated with various industries and metal smelting processes. According to Fergusson and Kim (1991), Co, Mn, Al, Cu, Ni and Cu are associated with traffic related sources such as corrosion of metallic part, concrete materials, re-entrained dust from roads and tear and wear of tyres and engine parts

Principal component analysis (PCA) was performed to establish possible factors that contribute towards the metal concentrations and source apportionment. All data set was subjected to factor analysis (*FA*). The number of significant principal components (*PC*) was selected on the basis of Varimax orthogonal rotation with Kaiser normalisation with eigenvalue greater than 1. The rotated component matrix is given in Table 4, and illustrated in Figure 6.

Only the first two components comprising of 60.87% of the total cumulative variances were retained. The first principal component, *PC*-1 explains that 44.68% of the total variance is highly loaded by Al, Cu, Fe, Mn, Zn and moderately loaded by Co. This factor is a source of mixed sources including human activity and vehicular emissions, which is evident from the fact that the soils were excavated alongside major highways connecting a number of townships and villages having higher

Table 4. Factor analysis (after Varimax rotation) showing contribution of statistically dominant variables measured in this study.

Variable	PC-1	PC-2
Al	0.742	-0.039
Co	0.562	0.185
Cu	0.783	-0.032
Fe	0.701	0.128
Mn	0.872	-0.007
Ni	0.456	0.614
Pb	0.146	-0.917
Zn	0.784	0.155
Eigenvalue	3.574	1.295
% of total variance	44.680	16.188
Cumulative (%)	44.680	60.867

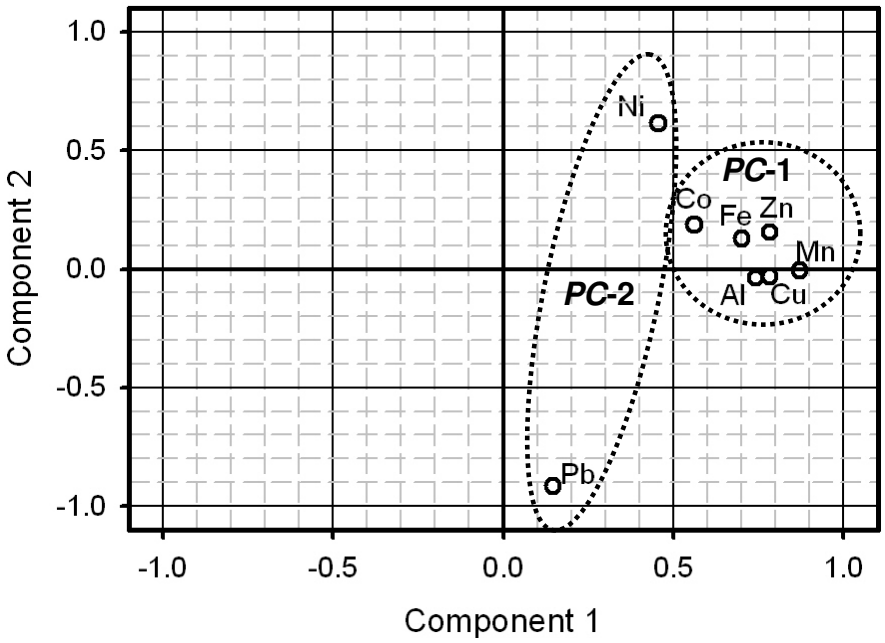

Figure 6. Loading plots of PCA analysis of heavy metals concentration for roadside soils of Botswana.

populations and establishments. Close association of these metals is supported by their significant correlation (Table 3) and cluster 1 from *CA* results. The association of Mn and Fe could also be due to their common occurrence in the basic rock, since the concentrations of these elements were lower than that the background values ($I_{geo} < 0$) except for FN and MG zones whose I_{geo} class category for Mn was '1' and again, I_{geo} class = 1 for Al just for zone MG.

The second component *PC*-2 accounts for 16.19% of the total variance and contains Ni and Pb. *PC*-2 is strongly loaded by Pb indicating that its source is from vehicular emissions. It has been proven that leaded gasoline contributes to Pb concentrations in soils. The moderate loading of Ni in *PC*-2, shared in between, to a lesser extent, *PC*-1 suggests both vehicular and industrial origins.

Conclusions

Anthropogenically impacted and background soils on major roadsides were assessed using enrichment factors, contamination factors, pollution load index and geoaccumulation index for Al, Co, Cu, Fe, Mn, Ni, Pb and Zn. Enrichment factor ratios showed that all elements were deficiently to minimally enriched.

The contamination factor showed that generally there is low and moderate contamination of the heavy metals across the zones FN, NM, MG, GK, and TS.

The geoaccumulation index showed that zones FN, NM, and MG are uncontaminated to moderately contaminated, whereas zones GK and TS are uncontaminated.

The measure of the degree of overall contamination (PLI) at a site indicated strong signs of pollution deterioration by the eight measured metals at zones MG and FN, no overall contamination at TS and GK and a baseline level contamination category for NM.

Cluster analysis revealed two groups of metals having close similarities: firstly Co, Cu, Zn, Pb, Mn, Ni and Al, classified as anthropogenic and secondly lithogenic Fe.

Factor analysis generated two sources of pollutants; firstly mixed origin of sources including human activities, vehicular emissions and lithogenic occurrences characterised by Al, Cu, Fe, Mn, Zn and Co, and secondly vehicular emissions characterised by Pb and Ni.

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Appendix 1. Concentrations of heavy metals in roadside and background soils (µg/g).

Zone FN	**Al**	**Co**	**Cu**	**Fe**	**Mn**	**Ni**	**Pb**	**Zn**
FN1A	54.70	0.01	0.08	109.98	0.43	0.51	0.13	0.10
FN	38.32	0.01	0.08	39.75	0.37	0.46	0.10	0.10
FN1B	33.92	0.04	0.15	256.04	0.41	0.55	0.13	0.12
FN2A	38.70	0.01	0.12	14.82	0.69	0.46	0.13	0.14
FN	68.39	0.05	0.04	12.19	0.71	0.62	0.06	0.29
FN2B	30.75	0.01	0.04	13.33	0.35	0.50	0.08	0.09
FN3A	24.52	0.02	0.02	78.07	0.28	0.42	0.03	0.29
FN	14.63	0.00	0.02	46.67	0.11	0.40	0.34	0.07
FN3B	6.17	0.03	0.01	39.00	0.07	0.38	0.09	0.06
Mean	34.46	0.02	0.06	67.76	0.38	0.48	0.12	0.14
S.D	19.04	0.02	0.05	77.66	0.22	0.08	0.09	0.09
FBb	47.99	0.02	0.11	280.52	0.97	0.50	0.01	0.34
Zone NM								
NM1A	14.20	0.03	0.04	40.36	0.18	0.42	0.07	0.10
NM	40.76	0.01	0.05	51.78	0.33	0.31	1.30	0.06
NM1B	16.03	0.02	0.04	48.32	0.27	0.39	0.14	0.05
NM2A	14.82	0.01	0.04	32.35	0.22	0.42	0.06	0.11
NM	17.96	0.02	0.04	40.16	0.31	0.38	0.06	0.06
NM2B	50.38	0.01	0.06	90.80	0.42	0.47	0.07	0.07
NM3A	22.53	0.03	0.06	49.18	0.31	0.43	0.10	0.07
NM	8.34	0.02	0.06	22.59	0.20	0.47	0.07	0.05
NM3B	11.84	0.00	0.06	23.12	0.16	0.42	0.06	0.05
Mean	**21.87**	**0.02**	**0.05**	**44.30**	**0.26**	**0.41**	**0.21**	**0.07**
S.D	**14.19**	**0.01**	**0.01**	**20.47**	**0.08**	**0.05**	**0.41**	**0.02**
NMb	23.58	0.01	0.05	47.17	0.20	0.41	0.19	0.14
Zone MG								
MG1A	15.09	0.03	0.05	34.56	0.22	0.52	0.07	0.06
MG	14.06	0.01	0.07	52.98	0.17	0.21	0.49	0.10
MG1B	0.00	0.02	0.06	19.92	0.14	0.41	0.07	0.04
MG2A	15.78	0.01	0.06	79.16	0.19	0.45	0.08	0.06
MG	74.50	0.06	0.12	274.94	0.93	0.51	0.08	0.32
MG2B	50.80	0.02	0.09	43.06	1.46	0.45	0.12	0.27
MG3A	15.63	0.03	0.08	76.62	0.42	0.45	0.23	0.08
MG	25.03	0.00	0.07	115.24	0.29	0.73	0.09	0.07
MG3B	21.53	0.04	0.09	184.16	0.75	0.51	0.13	0.16
Mean	25.60	0.02	0.07	92.78	0.48	0.46	0.16	0.13
SD	21.45	0.02	0.02	79.80	0.44	0.13	0.13	0.10
MGb	63.18	0.06	0.11	488.76	0.75	0.51	0.10	0.13
Zone GK								
GK1A	24.34	0.01	0.02	32.62	0.03	0.38	0.04	0.11
GK	31.33	0.02	0.02	30.74	0.02	0.29	0.04	0.05
GK1B	32.06	0.00	0.03	31.89	0.10	0.30	0.03	0.03
GK2A	30.23	0.00	0.01	19.97	0.08	0.42	0.04	0.04
GK	32.06	0.01	0.02	21.08	0.01	0.38	0.03	0.04
GK2B	33.42	0.00	0.02	15.84	0.01	0.44	0.04	0.05
Mean	35.23	0.02	0.03	91.56	0.14	0.39	0.05	0.06
S.D	12.67	0.02	0.03	175.27	0.27	0.08	0.02	0.04
GKb	6.32	0.02	0.02	27.67	0.07	0.40	0.31	0.15

Appendix 1. Contd.

Zone TS								
TS1A	20.43	0.06	0.03	92.48	0.07	0.41	0.06	0.09
TS	15.39	0.00	0.02	63.03	0.07	0.48	0.04	0.07
TS1B	15.17	0.00	0.02	58.51	0.05	0.52	0.05	0.06
TS2A	9.53	0.03	0.02	56.32	0.05	0.33	0.08	0.05
TS	13.28	0.03	0.03	43.91	0.08	0.32	0.06	0.06
TS2B	9.45	0.00	0.02	27.23	0.03	0.39	0.05	0.10
Mean	12.80	0.02	0.02	52.74	0.06	0.41	0.09	0.08
S.D	4.74	0.02	0.00	22.69	0.02	0.07	0.10	0.04
TSb	13.29	0.02	0.02	64.57	0.02	0.38	0.08	0.06

SD = standard deviation; FBb, NMb, MGb, GKb and TSb are background sites for the five zones, respectively.