AN APPLICATION OF RECEPTOR MODELING TO IDENTIFY AIRBORNE PARTICULATE SOURCES IN LAGOS, NIGERIA

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Abstract
There have been no clear demarcations between industrial and residential areas of Lagos with focus on industry as the major source. There is need to identify potential source types in the study areas in order to have insight into the actual sources impacting the receptor sites. Elemental concentrations of airborne particulate matter sampled at three urban site classes in Lagos (an industrial city) in southwest Nigeria were subjected to statistical analysis to determine the number and nature of sources impacting the receptor sites. Inter-elemental Correlation, Principal Component Factor (PCFA) and Hierarchical Cluster Analyses (HCA) were the statistical tools used to infer the sources in the study areas. Soil re-suspension, automobile and residential fuel burning were observed to constitute the major sources.
Keywords: Abatement, dust entrainment, Industrial emission stacks, receptor sites, urban infrastructure.

1. Introduction

Urban areas are characterized by high population densities and activities meant to improve the quality of life. These activities are accompanied by some negative impacts. Among these is the emission of toxic elements into the atmosphere, leading to air quality deterioration and several categories of impacts. The sources of urban air pollution are as wide as the classes of urban infrastructure itself. However, these may be divided into three generic groups: point sources, which are mainly industrial emission stacks; area sources, which are several small point sources distributed over a large spatial area; and line sources, which are array of sources distributed along line segments. The relative contributions from point, area and line sources to total pollution load in any urban centre depend on the level of industrialization. Line sources in the form of transportation appear to account for greater percentages of the urban pollution problem in many urban centers. In Europe, US and other more industrialized countries, transportation accounts for 50-60% of urban air pollution (Oluwande, 1977; Wark and Warner, 1979). In Africa, urban air pollution is caused by a near equal mix of area and line sources (SSATP, 2001). However, the contribution of area and line sources to the urban air pollution load has not been adequately quantified. There have been so far, very few source apportionment studies in Nigeria. Ogunsola (1995) in the source apportionment of air particulates in Lagos and Ile-Ife reported a contribution of over 85 % of Pb, Br and Zn (marker elements for vehicular emissions) to have come from vehicular emissions in both cities. At the selected sites, Oluyemi (1997) in his study identified three major sources - soil, marine and vehicular traffic with some minor sources such as incineration, regional sulphate and unidentified industrial sources. In his work, the CMB model identified entrained soil as the major contributor at each of the sites in Lagos, accounting for 39.1-54.2% of the TSP load. This was followed by marine contribution (25.8-29.4%) and regional sulphate (5-7%) while each of the other sources contributed less than 4%. These studies were carried out with imported source profiles, which lacked representativeness of the sources impacting the sites. There are few sources, which may qualify as point sources in Nigerian cities. In Lagos (the most industrialized), some of the major sources are Breweries, Pharmaceutical and Paint Industries, Steel Industries, Domestic and Industrial Gas Industries, Beverages and Domestic Products Industries, and Thermal Station. However, the emission rate from the individual point sources has not yet been quantified. Air pollution in Lagos appears to be dominated by a mix of line (road traffic) and area sources (residential, commercial, small and medium scale industries).

The industrial contribution to Lagos air particulates has been reported to be below 10% of the total suspended particulates (Oluyemi, 1997; Jalal, 2001). The total number of vehicles on Nigerian roads showed steady increase from about 38,000 to 2.7Million between 1950 and 1985. (Obioh and Adegbulugbe, 1997). Though total number of vehicles per capital in the whole country is low, available vehicles tend to be concentrated in the urban areas. Of all the vehicles in the country, 40 % are concentrated in Lagos and its environs (Jalal, 2001).

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There have been no clear demarcations between industrial and residential areas in most urban cities in Nigeria. This has led to denial from various quarters on who contributes largely to the urban air pollution load whenever there is public outcry on air pollution. There has been focus on industry as the major culprit in this regard from the public but there has been no quantitative report revealing the actual sources in the study areas. There is still no clear agency responsible for traffic pollution in Nigeria despite high influx of used motor vehicles and deteriorating urban road-network in addition to past studies implication of traffic's high contribution to urban air pollution. There is need to identify potential source types for a developing country like Nigeria in order to put in place adequate air pollution monitoring.

In this work, particulate samples were collected from thirteen locations categorized into Highway/ Motorway, Bus Stop and Residential site classes. The industrial sites are sandwiched between these three categories of sites. The aerosol samples were analyzed by total reflection x-ray fluorescence (TXRF) technique, details of which have been reported elsewhere (Olise, 2004). The data sets were then subjected to receptor models, based on principal component factor analysis (PCFA) and hierarchical cluster analysis (HCA) in order to have insight into the sources impacting the receptor sites.

2. Materials and Methods

In identifying the sources of urban suspended particulate matter, correlation matrix, factor and cluster analyses were carried out on the data. Though correlation coefficients of 0.5 is significant, this study made use of coefficients of 0.80 and above as cutoff in view of the dependence of common origin or influencing factor of two variables on relatively high correlation coefficients.

The Principal Component Factor analysis (PCFA) was the receptor model used in this work. Detailed descriptions of the model and its applications have been reported elsewhere (Roscoe *et al.*, 1982; Gao *et al.*., 1994; Huang *et al.*, 1999). This model starts with principal component analysis, using the correlation matrix of the elemental concentrations, followed by a VARIMAX rotation. The rotated component loadings in each factor are used to infer potential source/sources. Choosing the numbers of factors to retain in the analysis was guided by the Kaiser criterion, whose rule is to drop all components with eigenvalues less than unity (Harrison *et. al.*, 1997).

Cluster analysis (CA), a classification method, was used to establish a set of clusters such that cases within a cluster are more similar to each other than they are to cases in other clusters. The task, therefore, is to group observations (objects) that are close enough or have the same origin together as a cluster (Spyrou et al, 1992; Wongphatarakul et al, 1998). The divisive option of the hierarchical cluster analysis method was used in this work. The method employed Euclidean distance and complete linkage (Furthest neighbour) as a measure of correlation.

The statuses of elements from their correlation coefficients, their factor loadings from factor analysis as well as the clusters which they form from cluster analysis were used to infer a source. Although some elements serve as finger print elements for more than one source, the knowledge of sources around receptor sites gives a clear picture on the source or sources those finger- print elements represent. For example, Pb, Zn and Cu are source finger print elements for road traffic, non-ferrous metallurgical industries, petrochemical industry, battery industry and mineral extraction in mines.

3. Results and Discussion

(a) Elemental Correlation Coefficients

The results of inter-elemental coefficients for the highway/motorway, bus stops and residential site classes are presented in Tables 1a, b and c respectively. Along highways/motorways we found that K and Fe had correlation coefficients e" 0.80 with Cu and Zn while Cr had correlation coefficients e" 0.80 with Fe Ni and Br. Copper had the strongest correlation coefficients of 0.94 with Zn. At bus stops it was found that each pair of Ca had correlation coefficients e" 0.80 with Cr, Cu, Br and Pb while Cr had correlation coefficients e" 0.80 with Co, Cu, Br and Pb. Iron had correlation coefficients e" 0.80 with Ni and Br while Br had correlation coefficients e" 0.80 with Cu and Pb. In the residential areas, each pair of Ca, Ti, V, Cr, Fe, Co, Ni, Cu, Zn, Br, and Pb was highly correlated.

Lead and Br has a correlation coefficient of 0.56 in the highways/motorways site class. This weak correlation between Pb and Br along highways/ motorways suggests contributions to the two elements from other source/sources, which may include industry (Pb) and inland transport of marine aerosol-sea spray (Br). The high correlation between Ti, Fe and Ni in residential areas suggests soil entrainment contributions since most of the roads are unpaved. The high correlation between Cu and Zn in the residential areas and highways/motorways indicates industrial and/or open biomass combustion contributions (Chow *et al.*, 1995).

(b) Elemental Loadings of Factor Components

The results of factor analysis for each of the site classes are presented in Tables 2a, b and c. The factor analysis returned four, three and two factors for Highway/Motorway, Bus Stop, and Residential site classes respectively. It has been reported that K and Mn are tracer elements for biomass combustion and Mn can also be crustal in origin and it may be attributed to fugitive dust re-suspension by vehicles especially on unpaved roads (Chow *et al.*, 1995).

Table 1a: Highway/Motorway Inter-elemental Correlation Trend

	K	*Ca*	*Ti*	*V*	*Cr*	*Mn*	*Fe*	*Co*	*Ni*	*Cu*	*Zn*	*Se*	*Br*	*Sr*	*Y*	*Pb*
K	1.00															
Ca	.170	1.000														
Ti	.172	.205	1.000													
V	.429	.640	.547	1.000												
Cr	.432	.271	.211	.557	1.00											
Mn	.414	.346	.725	.779	.587	1.000										
Fe	.601	.429	.146	.520	**.858**	.380	1.000									
Co	.106	.533	.417	.537	.373	.255	.468	1.000								
Ni	.438	.431	.331	.715	**.835**	.604	.775	.441	1.00							
Cu	**.864**	.294	.286	.643	.658	.529	**.824**	.369	.664	1.000						
Zn	**.828**	.395	.279	.612	.641	.453	**.826**	.498	.595	**.939**	1.000					
Se	.699	.353	.365	.659	.755	.745	.713	.331	.595	.762	.709	1.000				
Br	.376	.174	.180	.539	**.808**	.720	.552	-.014	.689	.476	.337	.782	1.00			
Sr	.122	-.035	-.075	.225	.680	.471	.366	-.158	.423	.206	.073	.552	**.848**	1.000		
Y	.046	.201	.243	.467	.762	.603	.455	.299	.736	.287	.264	.434	.691	.605	1.000	
Pb	.339	.605	.450	.699	.748	.604	.721	.616	.642	.527	.618	.725	.561	.382	.487	1.000

Table 1b: Bus Stop Inter-elemental Correlation Trend

	K	*Ca*	*Ti*	*V*	*Cr*	*Mn*	*Fe*	*Co*	*Ni*	*Cu*	*Zn*	*Se*	*Br*	*Sr*	*Y*	*Pb*
K	1.00															
Ca	.415	1.00														
Ti	-.273	.434	1.00													
V	-.287	-.155	.499	1.00												
Cr	.421	**.890**	.246	-.421	1.00											
Mn	.064	.657	.786	.214	.579	1.00										
Fe	-.242	.646	.750	.366	.456	.559	1.00									
Co	.585	.794	-.014	-.411	**.816**	.369	.137	1.00								
Ni	-.281	.548	.749	.346	.342	.650	**.859**	.000	1.00							
Cu	.516	**.861**	.377	-.201	**.813**	.721	.469	.624	.460	1.00						
Zn	.689	.311	.151	.148	.110	.230	-.004	.222	.063	.510	1.00					
Se	-.033	**.833**	.652	.143	.720	.698	**.924**	.415	.790	.721	.049	1.00				
Br	.159	**.917**	.659	-.036	**.813**	.764	**.815**	.518	.768	**.831**	.192	**.930**	1.00			
Sr	-.220	.475	.489	.403	.296	.239	**.877**	.092	.547	.286	-.060	.781	.563	1.00		
Y	-.165	.555	.777	.435	.265	.545	**.899**	-.028	**.931**	.431	.199	.768	.754	.671	1.000	
Pb	.220	**.821**	.365	-.081	**.840**	.449	.756	.562	.483	.677	.028	**.876**	**.827**	.733	.512	1.000

Table 1c: Residential Inter-elemental Correlation Trend

	K	Ca	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Se	Br	Sr	Y	Pb
K	1.00															
Ca	.942	1.000														
Ti	.999	.945	1.000													
V	.780	.779	.799	1.000												
Cr	.994	.930	.996	.836	1.00											
Mn	.370	.141	.352	.184	.395	1.000										
Fe	.882	.982	.891	.811	.877	.006	1.000									
Co	.673	.789	.699	.877	.707	-.106	.878	1.000								
Ni	.794	.877	.816	.894	.815	-.081	.937	.974	1.00							
Cu	.969	.938	.979	.877	.979	.246	.920	.816	.908	1.000						
Zn	.978	.981	.983	.839	.976	.220	.957	.801	.897	.987	1.000					
Se	.707	.766	.715	.796	.745	.284	.777	.763	.741	.740	.759	1.000				
Br	.817	.909	.836	.884	.834	-.040	.961	.970	.995	.916	.916	.776	1.00			
Sr	.513	.551	.522	.723	.556	-.103	.569	.520	.572	.556	.558	.642	.563	1.000		
Y	-.315	-.337	-.309	-.079	-.279	.269	-.309	-.074	-.217	-.274	-.310	-.065	-.213	-.382	1.000	
Pb	.859	.960	.868	.787	.858	.074	.978	.878	.915	.896	.934	.803	.951	.515	-.245	1.000

Copper and Zn are components of plant tissues. They may equally originate from open waste burning especially those containing used food cans. Nickel (Ni) and Cr are source signature elements for metal works (Chow, 1995). Vanadium (V) is found in petroleum in high abundance and is released into the atmosphere during residual oil combustion (Chow *et al.*, 1995). Calcium is crustal in origin and there is strong indication from factor and cluster analyses, in this work, that it has sources attributable to dust entrainment. For Highway/Motorway site class, factor 1 has a variance (eigenvalue) of 4.44, representing 27.73 % of the total system variance explained. It has high loading in Cr, Mn, Ni, Se, Br, Sr and Y and these elements have strong inter-elemental correlations except that between Mn and Cr which is only slightly above 0.5. This factor suggests contributions from entrained soil dust and/ or metal work. Factor 2 has a variance of 4.18 and this accounted for 26.14 % of the total system variance. It is highly loaded in K, Zn and Cu and moderately loaded in Fe and the elements correlated well. This factor suggests possible contributions from biomass combustion and/or industrial sources. Factor 3 exhibited a variance of 3.09 accounting for 19.24% of the total variance explained. It is loaded in Ca, V, Co and Pb and it is observed that all the elements has inter-elemental correlation coefficients higher than 0.50. This factor suggests contribution from automotive activities. Factor 4 has a variance of 2.19 representing 13.70% of the system variance. It is highly loaded in Mn and Ti. This factor suggests contributions from soil. For bus stop site class factor 1 has a variance of 6.59 and accounts for 41.22% of the total system variance. It is highly loaded in Ti, Fe, Ni, Se, Br, Sr, Y and moderately loaded in V, Mn and Pb and all the elements has inter-elemental correlation coefficients higher than 0.50. This factor suggests automobile/ soil dust sources. Factor 2 has a variance of 5.14 and represents 32.10 % of the total system variance explained. It is heavily loaded in Pb, Ca, Cr, Co and Cu and moderately loaded in Se and Br and all the elements correlated strongly. Automotive sources could be inferred from this factor. Factor 3 has a variance of 2.03 and accounts for 12.71 % of the total system variance. It is highly loaded in K and Zn and these elements are well correlated. This factor indicates possible contributions from biomass combustion. For the residential site class, factor 1 has a variance of 10.74 and accounts for 67.14 % of the total system variance. It is highly loaded in K, Ca, Ti, V, Cr, Fe, Co, Ni, Cu, Zn, Se, Br and Pb and moderately loaded in Sr. This factor suggests well-mixed sources, which may include automobile and residential fuel burning. Factor 2 has a variance of 2.12 and represents 13.27 % of the total system variance explained. It is heavily loaded in Mn and moderately loaded in K and Cr and these elements are fairly correlated. Biomass combustion sources could be inferred from this factor.

The percentage of the total system variance explained equals the cumulative variance and this equals 86.86 %, 86.03 % and 80.41 % for highway/ motorway, bus stop, and residential site classes respectively. The optimum percentage total system variance expected to be explained for the adequacy of the model being 80 % (Harrison *et al.,* 1997). The communalities were high (>0.700) for all the elements except Ca (0.631) for highway/motorway site class and Mn (0.672) for bus stop site class indicating the adequacy of the component model for this data set.

(c) Elemental Components of Clusters

The results of identified clusters with their elemental memberships for each of the three-receptor sites are shown in Figures 1, 2 and 3 for Highway/Motorway,

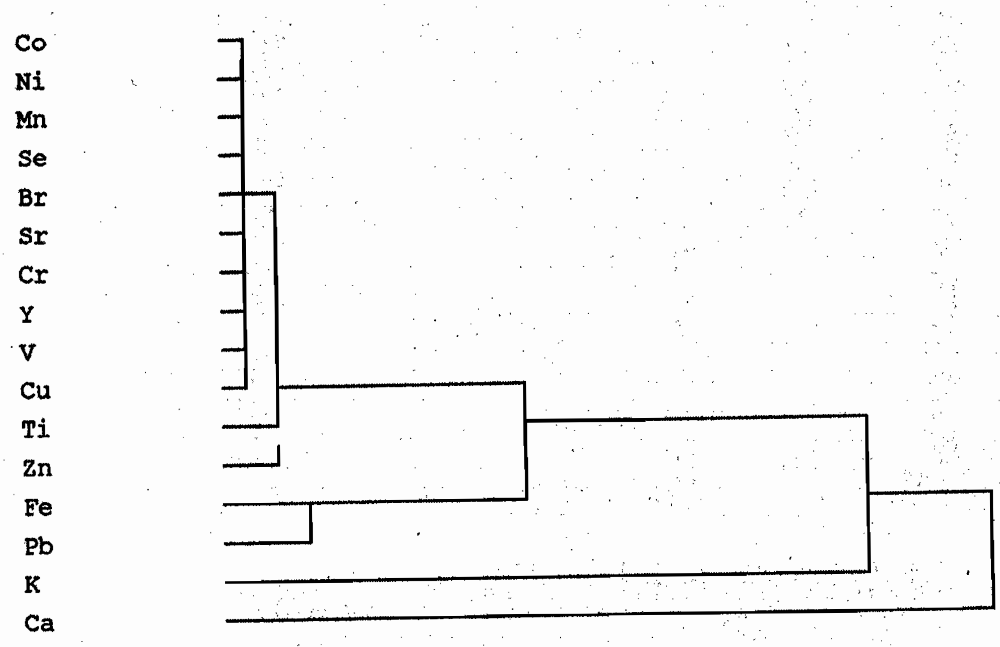

Figure 1: Highway/Motorway Site Class Cluster Analysis Result

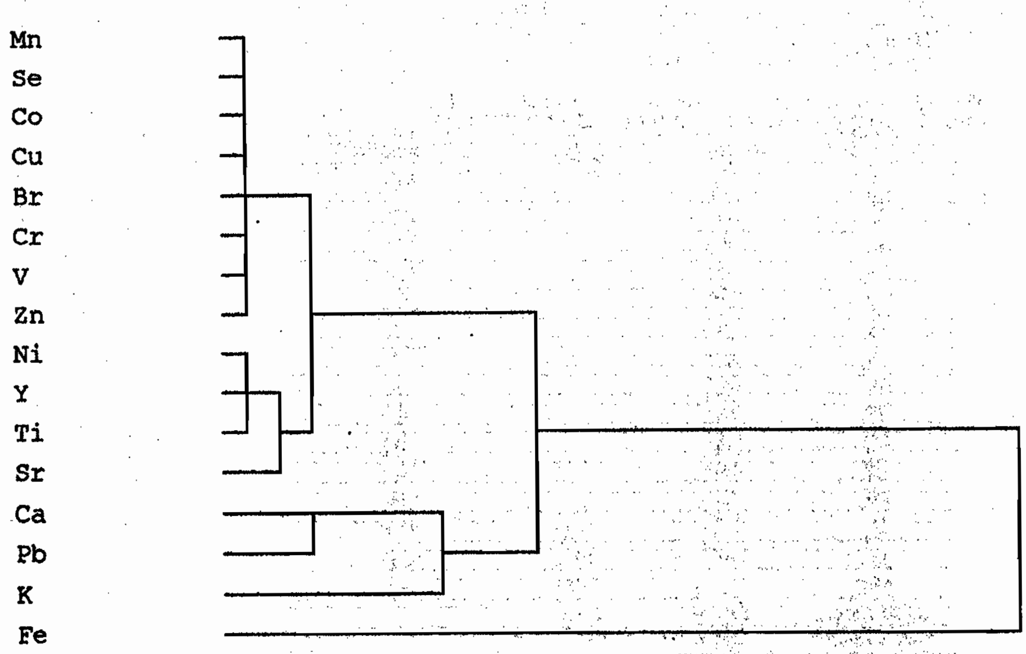

Figure 2: Bus Stop Site Class Cluster Analysis Result

Table 2a: Factor Analysis Result for Highway/Motorway Site Class

Variables	Factor 1	Factor 2	Factor 3	Factor 4	Communalities
Ti				.787	.866
Mn	.510			.892	.974
Cr	.791				.944
Ni	.616				.792
Se	.526				.858
Br	.895				.948
Sr	.927				.897
Y	.814				.791
Zn		.874			.951
Cu		.904			.950
Fe		.687			.928
K		.953			.940
Ca			.765		.631
V			.526		.822
Co			.874		.813
Pb			.637		.795
Variance	4.44	4.18	3.09	2.19	
% Variance	27.73	26.14	19.24	13.70	

Table 2b: Factor Analysis Result for Bus Stop Site Class

Variable	Factor 1	Factor 2	Factor 3	Communalities
Ti	.885			.805
V	.595			.728
Mn	.657			.672
Fe	.924			.971
Ni	.906			.837
Sr	.733			.685
Y	.934			.884
Se	.798	.582		.981
Br	.707	.671		.964
Pb	.505	.774		.872
Ca		.824		.963
Cr		.950		.960
Co		.870		.816
Cu		.729		.899
K			.716	.854
Zn			.928	.873
Variance	6.59	5.14	2.03	
% Variance	41.22	32.10	12.71	

Table 2c: Factor Analysis Result for Residential Site Class

Variable	Factor 1	Factor 2	Communalities
Ca	.876		.948
Ti	.799		.984
V	.916		.864
Fe	.935		.956
Co	.976		.969
Ni	.978		.972
Cu	.884		.970
Zn	.883		.987
Se	.828		.742
Br	.984		.983
Sr	.614		.512
Pb	.927		.916
K	.779	.511	.984
Cr	.807	.506	.990
Mn		.949	.947
Variance	10.74	2.12	
% Variance	64.14	13.27	

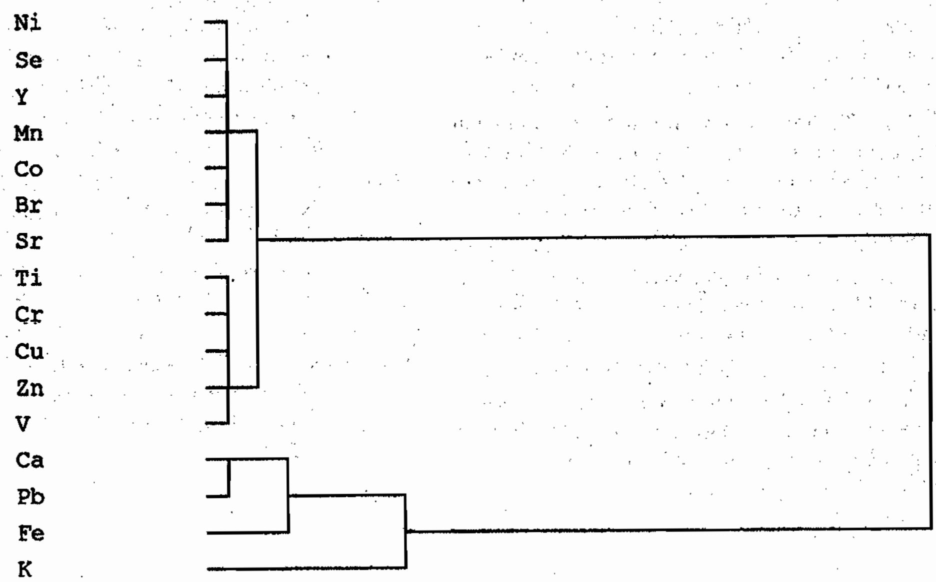

Figure 3: Residential Site Class Cluster Analysis Result

Bus Stop, and Residential site classes respectively. For highway/motorway site class, cluster 1 contains Co, Ni, Mn, Se, Br, Sr, Cr, Y, V, and Cu which are mixed finger print elements for biomass combustion and metal work sources. Cluster 2 contains Fe, Pb, K, and Ca, which are source finger print elements for automobile and entrained soil sources. For bus stop site class, cluster 1 contains Mn, Se, Co, Cu, Br, Cr, V and Zn, which are mixed finger print elements for biomass combustion and industrial sources. Cluster 2 contains Ni, Y, Ti and Sr, which are source finger print elements for soil and cluster 3, contains Ca, Pb, K and Fe which are finger print elements for automobile/entrained soil sources. For residential site class, Cluster 1 contains Se, Y, Mn, Co, Br and Sr which are finger print elements for biomass combustion while cluster 2 contains Ti, Cr, Cu, Zn and V which are source finger print elements for residential fuel burning. Cluster 3 contains Ca, Pb, Fe and K, which are mixed finger print elements for automobile/entrained soil sources.

4. Conclusion

Source identification of urban airborne particulate matter has been carried out using multi-variate statistical tools: factor and cluster analyses. Four, three and two factors were, respectively resolved for the categorized Highway/Motorway, Bus Stop and Residential site classes in the study areas. The factors showed signatures of both natural and anthropogenic sources including entrained soil, automobile, industry, metal works, biomass and residential fuel combustion sources.

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