Source apportionment of respirable particulate matter using principal component analysis – a case study from India

Suman[1], Gurdeep Singh[2], Asim Kumar Pal[3]

[1]SRF, Dept. of Environmental Sc. & Engg., Indian School of Mines, Dhanbad, Jharkhand, India
[2]Professor & Head, Dept. of Environmental Sc. & Engg., Indian School of Mines, Dhanbad, Jharkhand, India
[3]Associate Professor, Dept. of Environmental Sc. & Engg., Indian School of Mines, Dhanbad, Jharkhand, India
sumanismd@gmail.com

Abstract: Principal Component based factor analysis (FA) is used to identify the sources of PM_{10} and to select source emission tracers by grouping the selected variables according to the common variations in order to adopt some control strategies. The development of air pollution control strategies is a wide preoccupation for human health. In order to achieve this purpose air pollution sources have to be accurately identified and quantified .Ambient air quality monitoring with particular reference to PM_{10} was carried over a period of one year in industrial and mining area of Angul –Talcher region. The identification of source profiles for Angul –Talcher industrial area is achieved by a Principal Component based factor analysis (FA) using SPSS followed by a Varimax rotation technique. The higher particulate pollution in this area may be attributed to industrial activities, automobile traffic, re suspension of road dust, soil dust, and smelter. The results from this statistical method have enabled us to characterize and apportion fine particulate matter emissions on the basis of dependence of the factors on the elements.

[Suman, Gurdeep Singh, Asim Kumar Pal. **Source apportionment of respirable particulate matter using principal component analysis – a case study from India.** *Rep Opinion* 2014;6(8):26-32]. (ISSN: 1553-9873). http://www.sciencepub.net/report. 7

Keywords: PM_{10}; source apportionment; principal component analysis; factor analysis; varimax rotation

1. Introduction

In India, major sources of urban air pollution include coal combustion, oil refineries and industrial manufacturing facilities (Murray et al., 2001). However, automobile exhaust, emission from small-scale workshop and soil derived aerosols are considered as other important contributing sources (Dubey and Pervez, 2008). In an industrial society that pollutes its air, a reliable and accurate pollution source apportionment model would allow regulating agencies to know which sources are contributing to the airshed and in what amounts. Therefore, it is essential to delineate the contributing airborne particulate sources in view of environmental quality management and human health perspectives. Also the application of effective abatement strategies to reduce particulate matter (PM) levels is only possible when the emission sources have been uniquely identified and characterized (Viana et al., 2006). Since air pollution has been linked to mortality (Dockery et al., 1993), knowledge of what is contributing to the problem is important. Several reports revealed significant correlations between PM levels and increased respiratory and cardiovascular diseases, and mortality (Pope et al., 2002). Exposure to fine particulate matter has been implicated as a contributor to adverse human health effects including increases in cardiovascular and pulmonary disease, which leads to elevated human mortality and morbidity (Pope, 2000; Schwartz *et al.,* 1996; United State Environmental Protection Agency [USEPA], 2002). Many studies on source apportionment of particulates have been conducted abroad (Chow et al., 1999; Watson et al., 1994), as well as in India (Sharma and Singh, 1992; Sharma and Patil, 1994; Chowdhury, 2004). A complementary approach is to examine associations between health outcomes and sources contributing to ambient PM2.5 (Laden et al., 2000; Manchester-Neesvig et al., 2003; Mar et al., 2000; Tsai et al., 2000).

There are several types of multivariate receptor models used in the source apportionment studies (Henry et al., 1984). Over the last two decades, multivariate analysis has been widely used to identify sources of ambient particles. In this study to identify and estimate the possible sources of coarse and fine size particles, PCA was applied (Srivastava et al., 2008). Principle Component Analysis (PCA) has been used generally as an exploratory tool to identify the major sources of aerosol emissions and to statistically select independent source tracers. The main objective of PCA is to reduce a large number of variables to a smaller set of factors that retain most of the information in the original data set (Hopke, 1985; Marcazzan et al., 2003) and this property of multivariate PCA method has also been explained by Karar et al., (2007). In PCA a set multiple inter correlated variables is replaced by a small number of

independent variables by orthogonal transformations (Salvador et al., 2003). Thus, the objective of this research paper is to present an argument for using corroborative information to augment and support results of factor analysis associating pollution sources.

2. Material and Methods

2.1 Sampling site

Angul-Talcher area lies between 20^0 37' to 21^0 10' N latitudes and 84^0 53' to 85^0 28'E longitudes. This area is one of the major industrial zones in the state of Orissa and is fast emerging as a big source of coal and thermal power in the country. The area is recognized as one of the 24 problem areas identified by Central Pollution Control Board, Delhi in respect of industrial pollution hazard. The study area includes Angul, Banarpal, Talcher and Kaniha blocks of Angul and Talcher subdivisions of Angul district. There is a heavy transportation flux in the study area. NH-42 and NH-23 passes through this region and are also well connected with kuttcha and pucca roads. A map of the study area and its sampling locations are given in Figure1 and Figure 2 respectively.

Coal reserves in lb valley and Talcher area are the major factors for setting up of thermal power plants in this area. There are many captive power plants established with major industries to meet the industrial power requirements. The lists of thermal power plants are:

i. Talcher Thermal Power Station, Talcher
ii. Captive Power Plant, NALCO
iii. NALCO Smelter Plant
iv. Talcher Super Thermal Power Plant, Kaniha

Besides these, there are few medium and small scale industries operating in the industrial estate of the Angul-Talcher area.

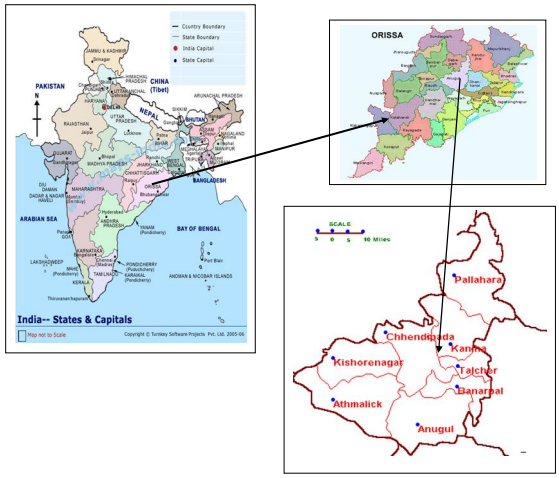

Figure 1. Location map of the study area

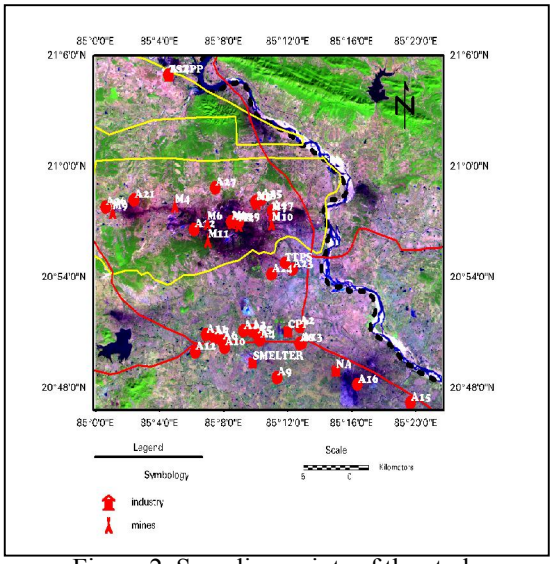

Figure 2. Sampling points of the study area

A1-NALCO Township	A10- Angul Township	A19- Ananta OCP
A2- Gotamara Village	A11-Vikashnagar, Angul	A20- Jagannath OCP
A3-NALCO Commercial area	A12- RSPCB Office, Angul	A21- Gopal Prasad Village
A4- Kuladh Village	A13- Banarpal Junction	A22- Donara Village
A5- Girang Village	A14-TSTPP(Kaniha) main gate	A23-TTPS (Talcher) Resid area
A6- Kandasar Village	A15- Meramundali Village	A24- Sharma Chawk, Talcher
A7- Turang Village	A16- Shivpur Village	A25- Dera Chawk
A8- Bonda Village	A17-LingarajOCP-New Balanda	A26- Ananta Guest House
A9-Tulsipal Village	A18-Bhubaneshwari Mines	A27- Rakash Village

2.2 Sampling and Analysis

PM_{10} measurement was carried out at 27 locations in Angul –Talcher area in Orissa .24 hour filter samples of PM_{10} were collected using an EPM 2000 filter paper in Respirable Dust Sampler. After sampling, each filter containing particulate matter was cut into two halves; one was digested in 4:1 (v/v) $HNO_3/HClO_4$ mixture (NIOSH, 1984). The

components and elements analyzed were selected to provide as much information as possible for source identification. Based on the chemical analysis and trace elements identified from the GBC Avanta Beam Atomic Absorption Spectrophotometer coupled with Graphite furnace, hydride generator and computer data station, factor analysis was performed to detect and quantify various source contributions. Principal component analysis was used in the present study.

SPSS software extracted factors with eigen values greater or equal to 1 as a principle component or factor (Ho et al., 2006; Gupta et al., 2007) is used for estimating the sources contributing to the pollution load. Factor analysis proceeds in following 3steps:

(1) Correlation matrix for all the variables are computed

(2) Factor extraction and

(3) Factor rotation between the original values and the extracted factors.

To maximise the source identification power of factor analysis, variables were selected with precise source information. The variables used in the factor analysis were Pb, Cu, Zn, Fe, Ni, Mn, Al and Fl. In PCA a set multiple inter correlated variables is replaced by a small number of independent variables by orthogonal transformations (Salvador et al., 2003). Principal Components (PCs) are linear combinations of the original variables and are attained in such a way that the first PC explains the largest fraction of the original data variability. The second PC explains a lesser fraction of the data variance than the first PC and so forth (Abdul-Wahab et al., 2005; Sousa et al., 2007; Wang and Xiao, 2004).This is achieved by diagnolising the correlation matrix of the variables through the computation of eigen values and eigen vectors. Each factor explains the maximum total variability of the data set and this set is completely uncorrelated with the rest of the data. The factor loadings obtained after the Varimax rotation gives the correlation between the variables and factor as shown in Tables 1 and 2. Thus the chemical elements with higher loading in each factor are interpreted as fingerprints of emission source that it represents.

The Factor Analysis (FA) model used in this study is expressed as a bilinear model:

$$\mathbf{C}_{it} = \sum \mathbf{L}_{ij} \mathbf{x} \mathbf{S}_{jt} + \mathbf{E}_{it}$$

Where, $\mathbf{C}_{it}$ is the normalized value of concentration of i^{th} species for t^{th} samples, N is the total number of sources, $\mathbf{S}_{jt}$ is the factor score of the jth common factor for the t th sample, $\mathbf{L}_{ij}$ is the factor loading of the ith species of the jth source and $\mathbf{E}_{it}$ is the residual of ith species in the jth sample not accounted by the j sources or factors (Negi et al., 1998, Kumar et al., 2001).]

3. Results and Discussion

To assist in the interpretation of the results a Varimax rotation technique (Sharma, 1996) was used. The Varimax rotational technique is a useful method to find simply underlying components and identify attributed contributions for highly correlated variables on environmental problems (Rachdawong, 1998; Carlon, 2001; Jaung et al., 1996; Baek et al., 1997; Yu and Chang, 1999). PCA with Varimax normalized rotation on the dataset of selected metals and particulate matter is performed for the source identification. Table 2 presents the PC loadings with Eigen values >1, embodying and explaining more than 70.36% of total variance.

The first factor of PCA results of PM_{10} showed higher loadings for Mn and Cu at 22.12% of variance. The industry factor was characterized by high concentrations of Mn and Cu. Non-ferrous and steel-processing factors have source profiles including the trace metals Cu and Mn (Lee et al., 2006). It represents the contribution of these metal particulates emitted from different industries and other anthropogenic sources.

Factor 2 explained 39.91% of the variance with high loadings of RPM, Fe and Al. The main source of this factor is road dust because both high factor loadings in the PCA results and high composition were found for crustal elements, e.g., Respirable particulate matter (RPM), Al and Fe (Watson and Chow, 2001; Almeida et al., 2005). It is important to note that the metals generated from various sources also become part of crustal dust over time (Khemani et al., 1985; Balachandran et al., 2000; Anju and Banerjee, 2003; Monkkonen et al., 2004; Khillare et al., 2004). The condition is reversed in the case of fine particulate source apportionment. The negative loading of Zinc represents the different source than that of RPM, Al and Fe. Zn is emitted from lubricant oil, brake linings, and tires (Zhou et al., 2004, Lough et al., 2005; Lee and Hopke, 2006; Chellam et al., 2005, Polissar et al., 1998). Zn originates from the interaction of road-tyre (Ho et al. 2006) too. So, Zn has been used as the fingerprint of mobile vehicle emission sources (Li et al., 2004).In two-stroke engines, because fuel and lubricant are mixed and burnt together in the piston chambers, Zn is emitted in higher quantities from two-stroke engines (Begum et al., 2005).

The third factor with high loadings of fluoride particulate (FP) and fluoride gaseous (FG) and Zn explains 56.59 % of the variance. Zn is used in the non-ferrous industries like Smelter (Ho et al., 2006) and fluoride particulate and fluoride gaseous is released from the smelter. It is used in the form of Gallium in non-ferrous metallurgical units of smelter processing plants.

Factor 4 containing high values for Pb and Ni can be labeled as vehicular emission (Handt et al., 2008).The source identification of this study is in agreement with the majority of the reported data on this subject (Ragosta et al., 2001;Khillare et al., 2004; Manoli et al., 2002; Statheropoulos et al., 1998) and shows that the major anthropogenic contribution of toxic metals in the airborne particulate matter comes from traffic emissions/oil combustion along with industrial emissions as recently proposed by different workers in various parts of world (Manoli et al., 2002; Statheropoulos et al., 1998; Biblos et al., 2001; Sharma et al., 1992).

Table 1. Correlation Matrix of particulates and trace elements with five factor components

	RPM	Pb	Cu	Fe	Zn	Ni	Mn	Al	F(P)[1]	F(G)[2]
RPM	1.00									
Pb	-0.26	1.00								
Cu	-0.08	-0.10	1.00							
Fe	**0.40**	-0.18	-0.04	1.00						
Zn	-0.09	-0.03	0.07	-0.24	1.00					
Ni	-0.12	**0.43**	0.31	0.04	0.03	1.00				
Mn	0.25	-0.05	**0.57**	0.34	-0.01	0.04	1.00			
Al	**0.41**	-0.32	-0.08	0.02	-0.19	-0.29	-0.31	1.00		
F(P)	-0.25	0.30	-0.35	0.21	**0.46**	-0.25	-0.23	0.21	1.00	
F(G)	-0.24	0.27	-0.36	0.24	**0.49**	-0.25	-0.22	0.24	**0.98**	1.00

Bold values are significant at 0.01% significant level

[1] F (P) - Fluoride Particulate

[2] F (G) - Fluoride Gaseous

Table 2. Loadings rotated by Varimax

	PC 1	PC 2	PC 3	PC 4
RPM	0.109	**0.675**	0.034	-0.084
Pb	-0.175	0.060	0.084	**0.922**
Cu	**0.545**	0.099	0.097	-0.008
Fe	0.331	**0.602**	-0.127	-0.177
Zn	-0.062	**-0.804**	**0.892**	-0.055
Ni	-0.128	-0.105	-0.435	**0.646**
Mn	**0.953**	0.053	0.0009	-0.019
Al	-0.028	**0.587**	0.161	-0.252
F(P)	-0.248	0.386	**0.580**	0.273
F(G)	-0.256	-0.064	**0.595**	0.248
Eigen value	2.434	1.847	1.834	1.516
%Variance	22.123	17.795	16.674	13.777
%Cumulative variance	22.123	39.918	56.592	70.369

High loadings are shown in bold

Extraction method: principal component analysis. Rotation method: Varimax with Kaiser Normalization.

4. Conclusions

Thus, the present study brings out the clear difference between the levels of trace metals in local atmosphere. The most dominant metals in local atmosphere are Mn, Cu, Zn Al, Fl and Fe. Of the remaining fractions Pb and Ni emerges as minor contributors. The relatively higher levels of selected trace metals in Angul-Talcher area are indicative of the fact that the local atmosphere is undergoing some remarkable anthropogenic translocations. Source apportionment study through PCA and CA enabled to identify five sources of trace metals and particulate fractions in the local atmosphere, industrial activities, automobile emission, metallurgical operations and soil derived dust. PM_{10} derived from power generation is the main contributor. The comparison study presents an alarming situation of airborne trace metals and it is high time to evolve an air pollution abatement strategy to ward off people against the hazardous effects arising from elevated trace metal levels.

Acknowledgements:

Authors are thankful to State Pollution Control Board, Orissa for sponsoring this study. One of the authors (Suman) is grateful to ISM /MHRD/Govt. of India, for providing research facility.

Corresponding Author:
Ms. Suman
Department of Environmental Science and Engineering, Indian School Mines
Dhanbad, Jharkhand-826004, India
E-mail: sumanismd@gmail.com

References

1. Abdul-Wahab SA, Bakheit CS, Al-Alawi SM. Principal component and multiple regression analysis in modelling of ground-level ozone and factors affecting its concentrations. Environmental Modelling & Software.2005; 20 (10): 1263-1271.
2. Almeida SM, Pio CA, Freitas MC, Reis MA, Trancoso MA). Source apportionment of fine and coarse particulate matter in a sub-urban area at the Western European Coast. Atmospheric Environment. 2005; 39: 3127–38.
3. Anju and Banerjee, DK. Heavy metal levels and solid phase speciation in street dusts of Delhi, India. Environmental pollution. 2003; 123: 95–105.
4. Baek SO, Choj JS, Hwang, SM. A quantitative estimation of source contributions to the concentrations of atmospheric suspended particulate matter in urban, suburban and industrial areas in Korea. Environment International. 1997; 23: 615-639.
5. Balachandran S, Meena BR, and Khillare PS. Particle size distribution and its elemental composition in the ambient air of Delhi. Environment International, 2000; 26: 49–54.
6. Begum BA, Biswas SK, Kim E, Hopke PK, and Khaliquzzaman M .Investigation of sources of atmospheric aerosol at a hot spot area in Dhaka, Bangladesh, JAPCA. Journal of Air Waste Management. 2005; 55(2): 227–240.
7. Biblos C, Colombo JC, Skorupka CN, Rodrguex MJ, Presa. Sources, distribution and variability of airborne trace metals in La Plata City area, Argentina, Environmental pollution.2001 ; 111: 149–158.
8. Carlon C, Critto, A, Marcomini A, Nathanail P. Risk based characterization of contaminated industrial site using multivariate and geostatistical tools. Environmental pollution. 2001; 111: 417-427.
9. Chellam S, Kulkarni P, and Fraser MP. Emission of organic compounds and trace metals in fine particulate matter from motor vehicles: a tunnel study in Houston, Texas, JAPCA, Journal of Air and Waste Management Association. 2005; 55(1): 60–72.
10. Chow JC, Watson JG, Green MC, Lowenthal DH, DuBois DW, Kohl SD, Egami RT, Gillies J, Rogers CF, Frazier CA, and Cates WMiddle, and Neighbourhood. Scale variations of PM_{10} source contributions in Las Vegas, Nevada. Journal of Air and Waste Management Association. 1999; 49: 641-654.
11. Dockery DW, Pope CA III, Xu X, Spengler JD, Ware JH, Louis TA, Spiro A III. An association between air pollution and mortality in six U.S. cities. New England. Journal of Medicine.1993; 329: 1753- 1759.
12. Gupta AK, Karar K, Srivastava A. Chemical mass balance source apportionment of PM_{10} and TSP in residential and industrial sites of an urban region of Kolkata, India. Journal of Hazardous Materials.2007; 142: 279-287.
13. Handt H, Fernanadez R. Operational Speciation of Cd, Cr, Cu, Mn, Ni, Pb, V and Zn in dust samples from schools in Caracas, Venezuela. Atmosfera. 2008; 21(4): 335-345.
14. Henry RC, Lewis CH, Hopke PK, and Williamson HJ. Review of receptor model fundamentals. Atmospheric Environment.1984; 18: 1507-1515.
15. Ho KF, Cao JJ, Lee SC, Chak Chan K. Source apportionment of $PM_{2.5}$ in urban area of Hong Kong. Journal of Hazardous Materials. 2006; B138:73–85.
16. Hopke PK. Receptor modelling in environmental chemistry. John Wiley & Sons, New York. 1985.
17. Horvath H, Kasahara M, Pesava P. The size distribution and composition of atmospheric aerosol at a rural and nearby urban location. Journal of Aerosol Science.1996; 27:417–435.
18. Juang BJ, Liaw CM, Sheu FC. (). A study on the delineation of air basins at Taiwan. Proceedings of 13th Air Pollution Control Technologies Conference, Taipei, Taiwan. 1996; 967-974.
19. Karar K and Gupta AK. (. Source apportionment of PM_{10} at residential and industrial sites of an urban region of Kolkata, India. Atmospheric Environment.2007; 84:30-41.
20. Khemani LT, Naik MS, Momin GA, Kumar R, Chatterjee RN, Singh and Ramana Murty BV. Trace elements in the atmospheric aerosols at Delhi, North India. Journal of Atmospheric Chemistry.1985; 273–285.

21. Khillare PS, Balachandran S, and Meena BR. Spatial and temporal variation of heavy metals in atmospheric aerosol of Delhi. Environmental Monitoring and Assessment. 2004; 90: 1–21.
22. Kumar AV, Patil RS, and Nambi DSV. Source apportionment of suspended particulate matter at two traffic junctions in Mumbai, India. Atmospheric Environment.2001; 35: 4245-4251.
23. Laden F, Neas LM, Dockery DW, Schwartz J. Association of fine particulate matter from different sources with daily mortality in six US cities. Environmental Health Perspectives.2000; 108(10): 941-947.
24. Lee JH and Hopke PK. Apportioning sources of $PM_{2.5}$ in St. Louis, MO using speciation trends network data, Atmospheric Environment.2006; 40: SUP2, S360–S377.
25. Lee JH, Hopke PK, and Turner JR (). Source identification of airborne PM2.5 at the St. Louis-Midwest Supersite. Geophysical Research. 2006; 111: D10S10, doi: 10.1029/2005JD006329.
26. Li Z, Hopke PK, Husain L, Qureshi S, Dutkiewicz VA, Schwab JJ, Drewnick F, Demerjian KL. Sources of fine particle composition in New York City. Atmospheric Environment.2004; 38(38): 6521–6529.
27. Lough GC, Schauer JJ, Park JS, Shafer MM, Deminter JT, and Weinstein JP. Emissions of metals associated with motor vehicle roadways. Environmental Science and Technology.2005; 39(3): 826–836.
28. Manchester-Neesvig JB, Schauer JJ, Cass GR. The distribution of particle-phase organic compounds in the atmosphere and their use for source apportionment during the southern California children's health study. Journal of Air and Waste Management Association.2003; 53(9): 1065-1079.
29. Manoli E, Voutsa D, Samara C. Chemical characterization and source identification/apportionment of fine and coarse air particles in Thessaloniki, Greece, Atmospheric Environment. 2002;36: 949–961.
30. Mar TF, Norris GA, Koenig JQ, Larson TV. Associations between air pollution and mortality in Phoenix, 1995-1997. Environmental Health Perspectives.2000; 108(4): 347-353.
31. Marcazzan GM, Ceriani M, Valli, G, and Veechi, R. (). Source apportionment of PM_{10} and PM $_{2.5}$ in Milan Italy using receptor model. Science of the Total Environment2003, 317, 137-147.
32. Monkkonen P, Uma R. Srinivasan D, Koponen IK, Lehtinen KEJ, Hameri K, Suresh R, Sharma VP, and Kulmala M. Relationship and variations of aerosol number and PM_{10} mass concentrations in a highly polluted urban environment - New Delhi, India. Atmospheric Environment. 2004; 38; 425–433.
33. NIOSH Method 7300, NIOSH Manual of Analytical Methods. National Institute of Occupational Safety and Health, Cincinnati. 1984.
34. Polissar AV, Hopke, PK, Paatero P, Malm WC, and Sisler JF. Atmospheric aerosol over Alaska 2. Elemental composition and sources, Journal of Geophysical Research.1998, 103(D15): 19045–19057.
35. Pope CA III. Epidemiology of fine particulate air pollution and human health, biological mechanisms and who's at risk? Environmental Health Perspectives.2000; 108(Sup 4): 713-723.
36. Pope CA III, Burnett RT, Thun MJ, Calle EE, Krewski D, Ito K, Thurston GD. Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. Journal of. American Medical Association.2002; 287:1132-1141.
37. Rachdawong P, Christensen ER, Chi S. (). Source identification of PCBs in sediments from Milwaukee Harbor Estaury, USA. Water Science and Technology. 1998; 37:199-206.
38. Ragosta M, Caggiano R, D'Emilio M, Macchiato M.().Multivariate analysis for investigating profile sources of atmospheric heavy metals emissions, Journal of Applied Statistical Science. 2001; 10: 210–221.
39. Ragosta M, Caggiano R, Macchiato M, Sabia S, and Trippetta S. (). Trace elements in daily collected aerosol, level characterization and source identification in a four-year study. Atmospheric Research.2008; 10.1016/j.atmosres.01.009.
40. Salvador P, Artinano B, Diana GA, Xavier Q, and Andres A ().Identification and characterization of sources of PM_{10} in Madrid (Spain) by statistical methods. Atmospheric Environment.2003; 38: 435-447.
41. Schwartz, J, Dockery DW, Neas LM (). Is daily mortality associated specifically with fine particles? Journal of Air and Waste Management Association.1996; 46: 927-939.
42. Sharma Praveen Kumar and Singh Gurdeep (). Distribution of suspended particulate matter with trace element composition and apportionment of possible sources in the Raniganj Coalfield, India. Environmental Monitoring and Assessment. 1992; 22: 237-244.

43. Sharma S. Applied multivariate techniques. John Wiley & Sons, New York, NY, USA.1996; pp 144–181.
44. Sharma VK, and Patil RS (). Chemical mass balance for source apportionment of aerosols in Bombay. Environmental Monitoring and Assessment. 1994; 29 (1): 75-88.
45. Sharma VK, Patil RS. Chemical composition and source identification of Bombay aerosol, Environmental Technology.1992; 13: 1043–1052.
46. Sousa SIV, Martins FG, Alvim-Ferraz MCM, Pereira MC. Multiple linear regression and artificial neural networks based on principal components to predict ozone concentrations. Environmental Modelling and Software.2007; 22: 97e103.
47. Srivastava A, Gupta AS, Jain VK (). Source apportionment of total suspended particulate matter in coarse and fine size ranges over Delhi. Aerosol Air Quality Research.2008; 8: 188-200.
48. Statheropoulos M, Vassiliadis N, Pappa A. Principal component and conanical correlation analysis for examining air pollution and meteorological data. Atmospheric Environment. 1998; 32: 1087–1095.
49. Tsai FC, Apte MG, Daisey JM). An exploratory analysis of the relationship between mortality and the chemical composition of airborne particulate matter. Inhalation Toxicology.2000; 12: 121-135.
50. United States Environmental Protection Agency. Air quality criteria for particulate matter, environmental protection agency, research Triangle Park. 2002; NC, EPA/600/P-99/002aC.
51. Viana M, Querol X, Alastuey A, Gil I, and Menendez M (). Identification of PM sources by principal component analysis (PCA) coupled with wind direction data. Chemosphere.2006; 65: 2411-2418.
52. Wang S, Xiao F. (). AHU sensor fault diagnosis using principal component analysis method. Energy and Buildings. 2004; 36 (2): 147e160.
53. Watson J G, Chow JC, Lu Z, Fujita EM, Lowenthal DH, Lawson DR, and Ashbaugh LL. Chemical mass balance source apportionment of PM_{10} during the Southern California air quality study. Aerosol Science Technology.1994; 21: 1-36.
54. Watson JG, Chow JC. Source characterization of major emission sources in the Imperial and Mexicali valleys along the US/Mexico border. Science of the Total Environment.2001; 276: 33–47.
55. Yu TY, Chang LFW.Division of air basins utilizing principal component analysis. Journal of the Chinese Institute of Environmental Engineering. 1999; 9: 209-218.
56. Zhou L, Hopke PK, Paatero P, Ondov JM, Pancras JP, Pekney NJ, Davidson, CI . Advanced factor analysis for multiple time resolution aerosol composition data. Atmospheric Environment. 2004; 38: 4909–4920.
57. Mehrotra P. Adaptive significance of leaf in relation to other parts in oak forest herbs of Kumaun Himalaya, Ph. D. Thesis, Kumaun University, Nainital, India, 1988.
58. Moustafa AA. Environmental Gradient and Species Distribution on Sinai Mountains. Ph. D. Thesis, Botany Department, Faculty of Science, Suez Canal University, Egypt, 1990;115.
59. Tewari JC. Vegetational analysis along altitudinal gradients around Nainital, Ph. D. Thesis, Kumaun University, Nainital, 1982; 570.
60. Pielou EC. Ecological Diversity. Wiley, New York, 1975; 165.
61. Magurran AE. Ecological Diversity and Its Measurement. Princeton University Press, Princeton, New Jersey, 1988; 179.

6/12/2014