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Particulate Pollution in Coal Mining Area of Jharia Coalfield

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Coal is the main source of energy in India. Among all coal mining area, Jharia Coalfield (JCF) occupies an important place in India's industrial and energy scenario by virtue of being the only storehouse of prime coking coal and important source of coal for the thermal power generation and is also referred as coal capital of India. The present study was conducted during 2008-2009 to assess the sources of particulate matter in coal mining area. This region covers several coal mining/industrial areas, residential, commercial and mixed use areas. In the present study, assessment of particulate pollution in coal mining area was done by trace metal analysis using EPM 2000 filter paper followed by acid digestion, extraction and analysis through Atomic Absorption Spectrophotometer (AAS). The annual average suspended particulate matter (SPM) and respirable particulate matter (PM_{10}) concentrations varied from 425-738 µg /$m^3$and 170-339 µg /m^3 respectively. This was followed by source profile study. The two approaches were adopted including principal factor analysis (Varimax rotated analysis) and Enrichment factor analysis to identify sources. The major sources of particulate matter were mainly from resuspended soil dust and earth crust, emissions from automobile exhaust, coal mining and associated activities, fugitive emissions, industries and oil combustion, etc.

Key words: *Particulate pollution, coal mining, Jharia*

Introduction

Jharia Coalfield is a coal mining, industrial and commercial area in the state of Jharkhand, Eastern India. Among all the developmental activities, coal mining is one of the core industries in India and plays a positive role in the economic development of the country[1]. Most major mining activities contribute directly or indirectly air pollution[2-3].Mining of coal opened new avenues for other related industries like thermal power plants, cement industries, refractories, brick kilns, steel and forging industries, coal briquettes, coke plants etc. Rate of population growth increased with the migration of people into this area in anticipation of employment and economic gains. This influx of population in turn caused various changes in the study area. Moreover, as industrial development and energy use grow, air pollution levels begin to rise rapidly. The particulate matter (PM) is an important criteria air pollutant. It comprises among variety of substances, inorganic and organic carbon (containing polycyclic aromatic hydrocarbons), acidic or neutral sulphates and nitrates, fine soil dust, residues of lead and other toxic trace heavy metals, asbestos and other fibres. PM_{10} ($\leq$10 µm in diameter) particles, however, penetrate deep into the lungs and pose significant health risks[4-6]. Particulates in an air are emitted chiefly by human activities. The principal sources are fuel combustion, motor vehicle movement, industrial processes and open burning operations. Besides, opencast mining operations involving use of heavy earth moving machinery for extracting and transporting coal release substantial quantities of both particulate and gaseous pollutants directly into the atmosphere. Particulate matter (SPM and PM_{10}) have several environmental effects and plays a significant role in modifying or changing climate, hydrological cycles, chemistry of the atmosphere, biogeochemical cycles, visibility reduction, affecting radiation balance,

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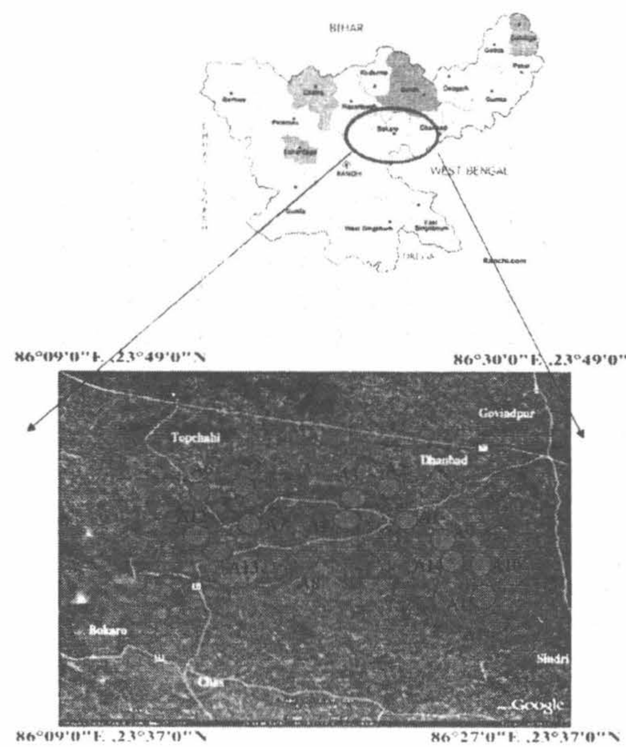
modifying cloud property and causing health related problems[7-9]. Particulate pollution leads to increased cardiovascular mortality, increased health care utilization especially among vulnerable groups including asthmatics, bronchitis and coronary artery disease patients, poorer lung function, impaired exercise capacity, impairment of immune functions, neurological and other cardiovascular problems[10].This induces acute respiratory morbidity[11]. The adverse impact of coal mining on the environment cannot be ignored[12-14] though this is an inevitable activity which plays an important role in the economy of any country[15-16]. In order to meet ever increasing demand of electricity, requirement of various industrial activities, there seems to be more thrust on the coal mining industry to augment the capacity of the existing mines as well as exploring the feasibility of new mines. It leads to more pollution in these areas. So the present study deals with concentration of particulate matter (SPM and PM_{10}), their variation and associated trace metals along with their source profile study by using multivariate technique (Factor analysis and Enrichment factor analysis).

Table 1: Principal component loadings of the airborne trace metals for the study period

Factors	Components		
	PC1	PC2	PC3
PM10	0.458	0.339	0.301
Pb	0.305	**0.809**	-0.397
Ni	-0.082	**0.790**	0.018
Cu	-0.066	0.039	**0.953**
Mn	**0.922**	-0.041	-0.241
Fe	**0.909**	0.099	0.124
Zn	**0.632**	-0.086	0.722
Cd	-0.285	0.670	0.383
Cr	0.346	0.600	0.039
Eigen value	2.85	2.02	1.84
% Variance	31.64%	22.49%	20.46%
% Cumulative variance	31.64%	54.13%	74.60%

2.0 Study area

JCF is located in the Dhanbad and Bokaro districts of Jharkhand State, at a distance of 260 km from Kolkata (Fig. 1). Geographically it is bounded by Latitudes 23°37' to 23°49'N and longitudes 86° 08'to 86°30' E encompassing a total area of about 450 sq km and belongs to Gondwana group of Permian age (Fig 1). This has Talcher, Barakar, Barren Raniganj measures. It is a sickle shaped coalfield occurring in the form of basin truncated with a major boundary fault on the southern flank. Jharia is among the most important coalfields in India because most of the nation's reserve of coking coal is located in this area[17]. Jharia is actively associated with coal mining activities for more than a century. There are many active opencast and underground mines, abandoned coal mines and overburden dumps located in Jharia coalfield. The major coal mining township and important business centers of coalfield have registered tremendous population growth rate in the last two decades. The area is worst affected by dust pollution due to vehicular and mining activities.



A1- Kusunda	A2- E.Bassuriya	A3- Tetulmari	A4-Sijua
A5- Murulidih	A6-Baghmara	A7-Kharkharee	A8- Muraidih
A9-Bastcola	A10-Tisra	A11-Sudamdih	A12-Madhuband
A13-Lodna	A14-Lohapatti	A15-Patherdih	

Fig. 1: The study area with sampling locations

3.0 Methodology

3.1 Ambient monitoring

Ambient monitoring was done at 15 locations From December 2008 to November 2009 for particulate matter and they were collected on EPM 2000 Glass Microfiber filter paper by using Respirable dust sampler

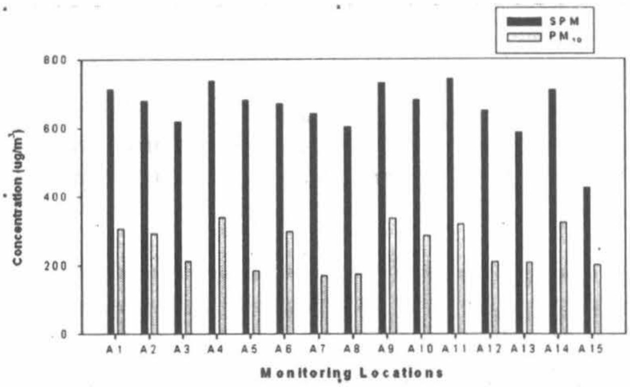


Fig. 2: Annual average pollutant concentrations at various locations

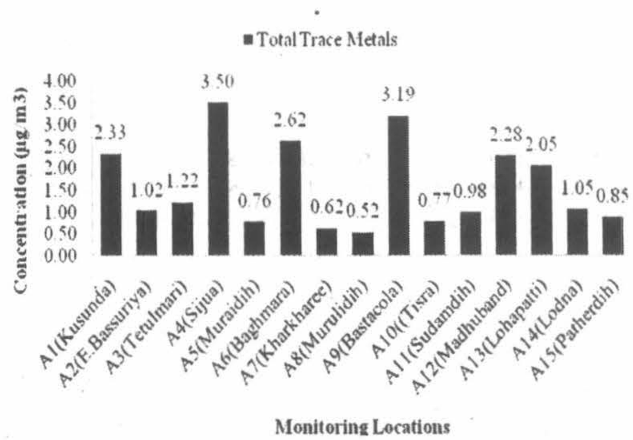


Fig. 3: Total metal concentrations at various locations of the study area

460 NL(1.1-1.3m³/min) Envirotech make, India. Dust laden ambient air enters the Respirable Dust Sampler through inlet pipe. The sampling locations have been selected as per criteria of IS 5182 Part-XIV[18].

3.2 Sample analysis

Airborne fraction masses of particulate matter samples were measured by the use of a Mettler AE163 microbalance followed by the determination of trace metal concentrations. The filter paper was weighed under controlled conditions of humidity and temperature before and after collection of particulate matter. Prior to weighing, all filter paper (EPM 2000) were left to equilibrate their humidity (around 50%) and temperature conditions (20±1 °C) for at least 24 hours. The collected particle mass was calculated by subtracting pre-weight from post-weight of the filter. Acid digestion, required for the metals determination by GBC-Avanta, Atomic absorption spectrophotometer(AAS), was carried out according to a standard procedure[19].

4.0 Results and discussion

4.1 Particulate matter concentration

The mean annual average suspended particulate matter (SPM) and respirable particulate matter (PM_{10}) concentration varied from 425-738 µg /m³ and 170- 339 µg /m³ respectively, at all the monitoring locations (Fig. 2). The maximum SPM concentration was reported at station A4 (Sijua), 794 µg/m³ during winter while A11(Sudamdih) recorded higher concentrations during winter and post monsoon 779 µg/m³ and 768 µg/m³ respectively. The values were exceeding the 24 hour average permissible limits of 700 µg/m³ for Jharia coalfield[20]. The overall SPM concentrations varied from 376 to 653 during monsoon, 459-794 µg/m³ (winter), 437-779 µg/m³ (summer) and 427-768 µg/m³ (post –monsoon). The lowest concentration was reported at A15(Patherdih) in all the seasons i.e., 459 µg/m³ in winter, 437 µg/m³ in summer, 376 µg/m³ in monsoon and 427 µg/m³ in post- monsoon. Similarly, the annual average respirable particulate matter (PM_{10}) concentration varied from 170 µg/m³ -339 µg/m³. During winter higher concentration reported at station A4 (Sijua) 378 µg/m³ while minimum was recorded at A7(Kharkhare) 185µg/m³ .All the locations were crossing the standard limit set by the statutory norms[21]. As far as deterioration of air quality is concerned, surface mining (open cast) plays a very important role, especially the increase in concentration of suspended particulate matter (SPM) within and around mining areas. In coal mining areas vehicular traffic on haul roads has been identified as copious source of fugitive dust[22]. Chadwick et al., (1987) studied about 50% of the total coal dust released during the journey time of a dumper on unpaved road haul road[23]., while loading and unloading of dumper creates 25% of dust. An estimation done by Cowherd shows that about 0.02% of coal is lost as fugitive dust during loading and similar percentage during unloading. Nair and Singh (1990) estimated that the road dust contains 3-4% of or more of the respirable dust particles[24]. Wind erosion also plays an important role for dispersion of pollutants[25].

4.2 Trace metal concentration

Trace metal concentrations for Pb varied from 0.05 µg/m³ to 0.31, Ni 0.004 to 0.027 µg/m³ , Cu 0.06 to 6.3 µg/m³ , Mn 0.07 to 1.7 µg/m³ , Fe 1.43 to 28.0 µg/m³ , Zn 0.18 to 1.66 , Cd 0.03 to 0.07 µg/m³ and for Cr varied from 0.11 to 0.43 µg/m^3. Higher average annual concentrations for Mn, Fe and Zn were recorded at A9 (Bastacola), while for Pb and Ni A1 (Kusunda) had maximum average concentration. Total trace metal concentration for the study area is shown in Fig. 3, indicating higher trace metal concentration at station A4 (Sijua) followed by A9 (Bastacola) and lowest at A8(Muraidih).

4.3 Source profile analysis

To understand the sources of pollution in the study area, two methods were used viz. principal component analysis (varimax rotated analysis) and Enrichment factor analysis.

4.3.1 Principle component analysis or Factor analysis:

PCA was performed by the Varimax Rotated Factor Matrix method, based on the orthogonal rotation criterion which maximizes the variance of the squared elements in the column of a factor matrix, using a statistical package SPSS (Version 16.0). This method focuses on cleaning up the factors. It produces factors that have high correlations with one smaller set of variables and little or no correlation with another set of variables[26].

Table 4.3 presents the Principal Component (PC) loadings for the metal data of the study period with corresponding eigen values and variances. Three PCs with eigen values greater than 1.0 were extracted with 74.60% cumulative variance. An examination of the Table 1.0 showed maximum variance of 31.64% was contributed by PC 1 which had higher loadings for Fe and Mn. This revealed close association of Fe and Mn in PM_{10} in the atmosphere, mainly contributed by earth crust[27-28] and significant association of Zn .

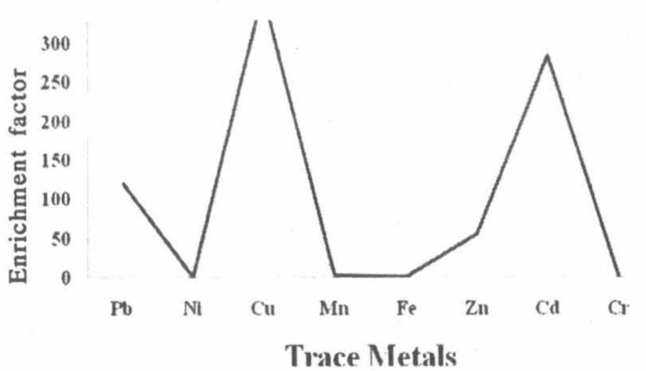


Fig.4: Enrichment factor of different metals in PM_{10}

The PC 2 showed higher loadings for Pb, Ni[29-32], Cd and Cr with significant contributions from crude oil combustion and metallurgical units housed in the industrial area and vehicular emissions. One of the most important sources of cadmium, chromium and lead in the urban environment is road traffic as suggested by various researchers[33-36]. Other contributors include waste incinerators, coal fired power plants, geogenic dust, and construction debris[35]. Third has high loadings of Cu and Zn hence may be attributed to industrial emission[27, 37].

4.3.2 Enrichment Factor Analysis

The concept of enrichment factor was introduced by Rahn (1971) as a useful way of determining whether particular element was found in greater abundance than that which might be expected from crustal sources[38]. Enrichment factor compares that ratio of the concentration of the element in air in a sample with that of a selected reference element such as iron[39].The enrichment factor was calculated through the equation given in equation 1.

$$EF(x) = \frac{(X/Fe)_{Sample}}{(X/Fe)_{Crust}} \quad .....(1)$$

Where EF(x)=the ratio of element to reference material, [X/Fe]Sample and [X/Fe] Crust refers to the mean concentrations of the target element and Fe in atmospheric particulate matter and continental crust, respectively. Fig. 4 depicts that Fe and Ni are showing EF equal to unity which indicate the association of sources of these elements to the earth's crust. On the other hand, the EF values for Cr and Mn were found to be a little higher than unity, whereas Cu, Cd, Pb and Zn were found to be highly enriched indicating that these might have been contributed by anthropogenic sources. The very high EF for these metals indicates vehicular exhausts and industrial activities as major sources of pollution.

4.4 Health impact

In coal mining area, generation of fugitive dust and gaseous pollutants have several health impacts. Apart from this running of vehicles on haul roads after combustion of diesel generates small particulate matter, nitrogen oxides (NO_X), sulphur dioxide (SO_2) and polycyclic aromatic hydrocarbons (PAH). Dieselization of vehicles is accelerating due to relatively low prices of diesel, this is promoting its use further. Use of diesel based vehicles worsens the air quality in coal mining area, bringing in its wake a number of related health problems. It has been reported that high levels of pollution affect mental and emotional health too. Amongst the symptoms, feeling of Fatigue, exhaustion, low mood, nervousness, irritation of eyes and stomach aches have shown a significant association with air quality. The estimates of disease burden due to air pollution are based on the impact of air pollution on mortality. The impact of air pollution on morbidity could not be included in the calculations due to lack of reliable epidemiological data. This study is an effort to identify the adverse health impacts due to air pollution on communities residing in areas of high and low ambient pollution levels. The particulate matter in coal mining area is more dangerous as it contains several other minerals with them in which silica is one. In this connection, by using XRD method the content of silica in respirable particulate samples (PM_{10}) was assessed. After examining the samples by XRD it is suggested that samples which were collected from proximity of coal mining area were containing Si as dominant mineral (Fig. 5). As explained in general, opencast mines have got main complaints on arthritis, followed by general weakness. Several researchers attributed arthritis to repeated silica exposure[40] and Steenland (2001) correlated silica exposure to lung cancer [41].

5.0 Conclusions

It was observed that particulate matter concentration in coal mining area is higher and crossing the standard norms. It is supported by the source profile study (by Principle Component Analysis and Enrichment Factor Analysis) and chemical characterization (through XRD) which revealed that the major contributions of pollution source in the study area are coal mining and allied activities, air borne soil dust due to unpaved road (mud road), when vehicles are moving to the road, most of the time they turn towards the unpaved portion of the road and raise soil to become airborne, fugitive emissions and earth crust, automobile exhaust, industrial emissions, crude oil combustion, metallurgical emissions, etc. Particulate matter enriched with Pb, Ni, Fe, Mn, Cd, Cu, Zn and Cr. Out of eight trace metals, Pb and Ni are mainly coming out gasoline fuelled vehicular exhaust, Fe and Mn are mainly originated by the soil dust (earth crust) and Cu, Cr, Cd and Zn are contributed by the small scale industrial activities. Silica were found in all airborne dust samples which were close to coal mining area and the samples were highly enriched with Pd, Cd and Cu. Combustion of fossil fuels is the principal anthropogenic source of Cu, Ni and Zn in the urban air particulate matter. Higher concentrations of Pb, Cu and Cd in study area are a cause of concern as they have associated disorders as lung and skin cancer, cerebrovascular disease, neurodevelopment, behavioral and hematological disorders, chronic nephritis etc. and the effects are increased manifold as they show synergistic effects.

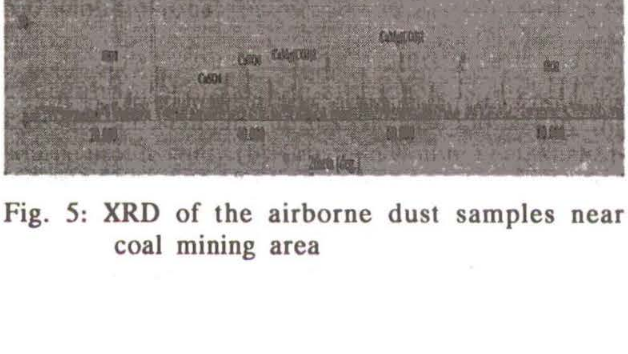


Fig. 5: XRD of the airborne dust samples near coal mining area

So, the overall assessment of the air quality provides useful insights for the development of the air quality management plan based on generated database. The database also helps regulatory agencies to identify locations where the natural resources and human health could be at risk. As such, it is quite necessary to incorporate necessary mitigative/ preventive measures to curb the pollution level within statutory norms.

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References

1. Chaulya S. K., Air quality status of an open pit mining area in India. *Environmental Monitoring and Assessment*, 105, 369–389(2005).

2. Kumar, C. S. S., Kumar, P., Deshpande, V. P. and Badrinath, S. D., Fugitive Dust Emission Estimation and Validation of Air Quality Model in Bauxite Mines, in G.S. Khuntia (ed.), *Proceedings of International Conference on Environmental Issues in Minerals and Energy Industry*, New Delhi, India, 77–81(1994).

3. Central Mining Research Institute (CMRI):, Determination of Emission Factor for Various Open Pit Mining Activities, GAP/9/EMG/MOEF/97, Environmental Management Group, Dhanbad, India (1998).

4. Folinsbee L J, Human health effects of air pollution. *Environ. Health Perspect,* **100**, 45-56 (1992).

5. Haritash A. K. and Kaushik C. P, Assessment of Seasonal Enrichment of Heavy Metals in Respirable Suspended Particulate Matter of a Sub-Urban Indian City. *Environ Monit Assess,* **128**,411-420 (2007).

6. Atar Singh Pipal, Aditi Kulshrestha and Ajay Taneja, Characterization and morphological analysis of airborne PM2.5 and PM10 in Agra located in north central India. *Atmospheric Environment,* **45**, 3621-3630 (2011)

7. Carbo P, Krom Homoky WB, Benning LG and Herut B, Impact of atmospheric deposition on N and P geochemistry in the south Eastern Levantine basin. *Deep-Sea Research,* **52**, 2041–3053 (2005)

8. Griffin D W, Kubilay N, Koçak M, Gray MA, Borden TC and Shinn EA, Airborne desert dust and aeromicrobiology over the Turkish Mediterranean coastline. *Atmospheric Environment* 41, 4050–4062 (2007)

9. Ramanathan, V., Crutzen, P.J., Kiehl, T.T. and Rosenfeld, D. Aerosols, climate and the hydrological cycle. *Science,* **294**, 2119-2124(2001)

10. Chabra, S.K. Air pollution and health. *Chest dis Allied Science,***44**,9-11(2002).

11. Pope C A, Dockery D W, Spengler J D and Raizenne M E, Respiratory health and PM10 Pollution: a daily time series analysis. *Am. Rev. Respir. Dis.,* **144**, 668-674(1991)

12. Bauldauf RW, Lane D D and Marote G A, Ambient air quality monitoring network design for assessing human health impacts from exposures to airborne contaminants. *Environmental Monitoring and Assessment,* **66**, 63-76 (2001)

13. Collins M J, Williams P L Macintosh D L. Ambient air quality at the site of a former manufactured gas plant. *Environment Monitoring and Assessment,* **68**,137-152 (2001)

14. Tichy J, Impact of atmospheric deposition on the status of planned Norway space stands: a comparative study between sites and Southern Sweden and the North Eastern Czech republic. *Environment Pollution,* **93**, 303-312(1996).

15. Chaulya S K and Singh M K 1995. Perspective of new national mineral policy and environmental control; for mining sector. *Proceedings of National Seminar on Status of Mineral Exploitation in India Institute of Engineers.* New Delhi, India, 114-123.

16. Kumar, U. *Proceedings of International Conference on Business and Investment Opportunities in Mining Industries,* Oxford and IBH , New Delhi, 183-194 (2001).

17. CMRS: 1961. Dust problem due to washery. Central Mining Research Station, Dhanbad

18. IS 5182 Part XIV, 2000. *Guidelines for Ambient Air Monitoring.* Central Pollution Control Board.

19. Katz, M.: 1977, *Standard methods for air sampling and analysis,* 2nd ed., APHA, Press Inc Spring Field, VA.

20. Air quality standard for coal mining prescribed by MOFE,25 september,2000.

21. National ambient air quality standard (NAAQS), India, prescribed by Central Pollution Control Board on 18 November, 2009

22. Cowherd, C. Jr.: 1979. Measurements of fugutive dust emission from haul roads. Report No. EPA600/7–79–181, *Research Triangle Park,* NC; USEPA, Industrial Environmental Research Lab.

23. Chadwick M.G. Highton N.H.,Lindman N. *Environmental impacts of coal mining and utilization,* England Pergamon Press, 1987, 295.

24. Nair, P. K. and Sing I., Haul Road Dust Consolidation in Opencast Mines- A New Approach, *Indian Journal of Environmental Protection,* 10(1), 620-65 (1990).

25. Mathur S.K. The energy perspective, *Drilling and Exploration World.* ,6(1),186-190 (1996).

26. Stevens, J. *Applied Multivariate Statistics for the Behavioral Sciences* (3rd ed.). Mahwah, Erlbaum, NJ; 1996.

27. Ragosta M, Caggiano R, D'Emilio M and Macchiato M, Source, origin and parameters influencing levels

of heavy metals in TSP in an industrial background area of Southern Italy. *Atmospheric Environment,* **36**, 3071–3087(2002).

28. Chakraborty A and Gupta T, Chemical Characterization of Submicron Aerosol in Kanpur Region: a Source Apportionment Study, *International Journal of Civil and Environmental Engineering,* 1, 87-90 (2009).

29. Kim K H, Lee H S, Youn Y H, Yun S T, Ro C U and Oh, JM, Studies of spatial variabilities of airborne metals across four different land-use types. *Water, Air and Soil Pollution,* **138** (104), 7–24(2002).

30. Shah MH, Shaheen N, Jaffar M, Khalique A, Tariq SR and Manzoor S, Spatial variations in selected heavy metal contents and particle size distribution in an urban and rural atmosphere. *J. Environ. Manag,* **78**, 128–137(2006).

31. Hafner H R, Wheeler N J and Roberts P T, 2004.Analysis of air toxics monitoring data. *Work plan prepared for Lake Michigan Air Directors Consortium*, Des Plaines, IL, by Sonoma Technology, Inc., Petaluma, CA, STI-903555-2442-WP2, January.

32. Pacyna JM In: Nriagujn.O. Davisonc.I. eds. *Tox-ic Metals in the Atmosphere.* Wiley: New York, 1986.

33. Ayras M, Kashulina G, Regional patterns of element contents in the organic horizon of podzols in the central part of the Barents region (Finland, Norway and Russia) with special reference to heavy metals (Co, Cr, Cu, Fe, Ni, Pb, V and Zn) and sulphur as indicators of airborne pollution. *Journal of Geochemical Exploration,* **68**, 127-144 (2000).

34. Sweet CW, Weiss A and Vermette S J Atmospheric deposition of trace metals at three sites near the Great lakes. *Water, Air, & Soi pollution,* 103, 423-439(1998).

35. Chandler A J, 1996. Characterizing Cadmium i Municipal Solid Waste, Sources of Cadmium i the Environment, *Inter-Organisation Programm for the Sound Management of Chemicals (IOMC)* Organization for Economic Co-operation an Development (OECD), Paris, France.

36. Dianne L, Baker J E, Atmospheric deposition o organic contaminants to the Chesapeake Bay *Atmospheric Environment,* **28**, 1499-1520 (1994)

37. Manoli E, Vousta D, Samara C, Chemica characterization and source identification apportionment of fine and coarse air particles i Thessaloniki, Greece. *Atmospheric Environmen* **36**, 949–961(2002).

38. Rahn, K. A. (1971). *Sources of trace elements i aerosols – an approach to clean air,* PhD Thesi University of Michigan, Ann Arbor.

39. Al-Momani I F, Daradkeh A S, Haj-Hussein T, Yousef Y A, Jaradat Q M and Momani K A Trace elements in daily collected aerosols i Al-Hashimya, Central Jordan. *Atmospher Research,* 73, 87–100 (2005).

40. Holman T, Historical relationship of minin silicosis and rock removal. *BrJ Ind Me* 4,129(1947).

41. Steenland K, Mannetje A and Boffeta P, Poole exposure response analysis and risk assessme for lung cancer in 10 cohorts of silica-expose workers: an IARC multicentre study. *Canc Causes Control,* 12,773-784(2001).