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Source Apportionment of Particulate Matter (PM_{10}) In an Integrated Coal Mining Complex of Jharia Coalfield, Eastern India, A Review.

Debananda Roy[1] & Gurdeep Singh[2]
Assistant Professor[1], Professor[2]
[1]Dept. Environmental Science & Engineering, Marwadi Education Foundation & Group of Institutions, Rajkot (GTU), Gujarat, India
[2]Centre of Mining Environment / Department of Environmental Science & Engineering, Indian School of Mines, Dhanbad-826004

Abstract
Coal based thermal power generation accounts for 44.7% of the world's electricity and coal alone provides about 80% of the total energy demand in India. Energy-intensive industries deteriorate the air quality of the residential areas due to release of different pollutants, especially a range of deleterious heavy metals like Hg, Cd, Cu, Pb, and Cr. Near about 53.3 percent of the coal produced every year in India has been used for thermal generation. Jharia Coalfield (JCF) is major contributor of coking coal in India. JCF receives particulate matter from various sources such as, opencast coal mining and its associated activities, thermal power stations, automobiles, generator sets fuel burning, construction activities, domestic coal, cooking gas burning, etc. and even the background contribution of natural dust (crustal origin) can not be ruled out, particularly, in the zones having loose topsoil. Concentration of particulate matter causes harmful impacts to the society. These multiple sources are contributing to particulates pollution in the study area. Apportionment of these sources indicating their contribution to ambient air pollution is vital for planning effective control strategies. Management of particulate pollution from various industrial sources in integrated industrial complexes such as JCF is a major area of concern. It can be assessed by determining emissions from various activities and resulting contribution of those multiple sources at various receptors using dispersion and receptor modeling through source apportionment study with respect to particulate matter (PM10) in JCF.
Key Words: *PM_{10}, Jharia Coalfield, Source Apportionment, Industry, Receptor Modeling, Emission Inventory.*

I. Introduction

The air we breathe is a mixture of gases, solid and liquid substances. Air pollution occurs when the air contains substances in such quantities that could harm the comfort or health of humans and animals, or could damage plants and materials (Alias et al. 2007; Hung 2013). Some substances generate from the natural sources while others are caused by human activities. Emissions from industries and auto exhausts are responsible for rising discomfort, increasing airborne diseases and deterioration of an artistic and cultural heritage in urban and industrial areas (Rao et al. 2003).

Particulate pollution is a big area of concern in the field of air pollution. The Particulate Matter (PM) in the air is the resultant of dispersion of dust from industrial (mining and non- mining) and allied activities, transportation, local vehicular movement and domestic fuel (coal, wood burning etc.) (Singh et al. 1992; Krishnamurthy 2005 and Lee et al. 2006). Vehicular pollution is also becoming an alarming issue due to increasing vehicle growth, distances travelled and high rate of emissions. Pollutants from these sources interact with soil and water and enter into the food chain (Zhang et al. 2007a). The PM has an adverse effect on human health too. Human exposure to high concentrations of PM_{10} can lead to several types of respiratory illness. PM is also responsible for the visibility reduction as it can also absorb and scatter sunlight of certain wavelengths (Dockery 1994). Long-term exposure to current ambient PM concentrations may lead to a marked reduction in life expectancy. The reduction in life expectancy is primarily due to increase of cardio pulmonary and lung cancer (WHO 2013).

Assessment of the air quality can provide useful insight for the development of the air quality management plan. The database developed on air quality also helps regulatory agencies to identify the locations where the natural resources and human health could be at risk (Bart 1993; Costa and Dreher 1997 and Murray et al. 2001).

As per The Engineers Joint Council on Air Pollution and its Control, USA", air pollution means "the presence in the outdoor atmosphere of one or more contaminants such as dust, fumes, gas, mist, odour, smoke or vapour in quantities, of characteristics, and of duration, such as to be injurious to human, plant, or animal life or to property which unreasonably interfere with the comfortable enjoyment of the life and property".

According to the World Health Organisation (1971), air pollution may be defined as "substances put into the air by the activity of mankind into concentrations sufficient to cause harmful effect to the health, vegetation, property or to the enjoyment of his property".

The Air (Prevention and Control of Pollution) Act, 1981 of India describes air pollutant and air pollution as: "Air pollutant means any solid, liquid or gaseous substance (including noise) present in the atmosphere in such concentration as may or tend to be injurious to human beings or other living creatures or plants or property or environment."

Concern about air pollution especially with reference to PM is receiving importance worldwide (Azad and Kitada 1998; Salam et al. 2003 and Cachier et al. 2005). Fine suspended particulate matter pose the most widespread and acute risks. It is very well known that industrial installations producing bricks, iron, fertilisers and glass, coal-fired power stations etc. are the most important sources of particulate pollution (Arnesen 1997 and 1998; Cronin et al. 2000; Haidouti et al. 1993 and Stevens et al. 1997).

Airborne **particulate matter** varies widely in its physical and chemical composition, source and particle size. PM_{10} particles (the fraction of particulates in air of very small size (<10μm) are of major current concern, as they are small enough to penetrate deep into the lungs and so potentially pose significant health risks (Begum et al. 2004). A major source of fine primary particles is combustion processes, in particular diesel combustion, where transport of hot exhaust vapour into a cooler exhaust pipe can lead to spontaneous nucleation of "carbon" particles before emission. The atmospheric lifetime of particulate matter is strongly related to particle size, but may be as long as 10 days for particles of about 1mm in diameter.

1.1 Energy Scenario in World

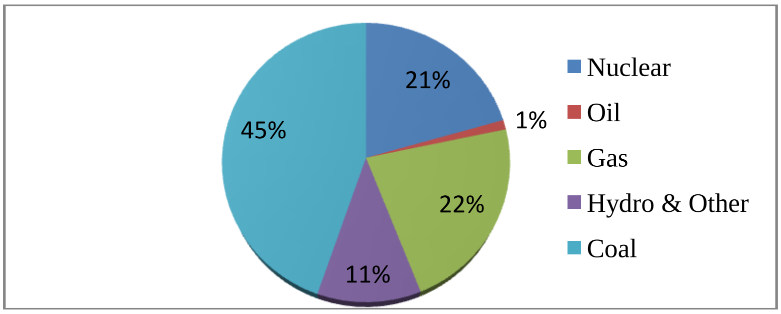
Technologies of energy production and environmental pollution are intimately linked with each other (Nriagu et al. 1996). Energy-intensive industries are the industries that are specifically established for power or electricity production, e.g., thermal power plants and coal mines. Energy-intensive industries deteriorate the air quality of the residential areas due to release of different pollutants, especially a range of deleterious heavy metals like Hg, Cd, Cu, Pb, and Cr (Messey et al. 2013).

Electricity has become an essential part of our daily life. Coal based thermal power is meeting about two third of the total requirement of global power. Coal alone provides about 80% of the total energy demand in India. Total primary energy demand in the world will grow by 54% by the year of 2030; it is projected to grow at an average rate of 1.6% per year. Electricity growth is even stronger and is projected to be almost double from 2004 to 2030 (growing at average 2.6% per year from 17,408 TWh to 33,750 TWh). Demand of electricity is increasing most dramatically in developing countries like China and India. China and India together account for 45% of the increase in energy sector, in the present scenario (World Energy Outlook 2012).

Coal based thermal power generation accounts for 44.7% of the world's electricity. Other resources are providing over 55.3% of world electricity (nuclear 20.6%, oil 1.1%, natural gas 22.3% and hydro & other 11.3%). It is especially suitable for large-scale, base-load electricity demand. The demand of coal power is increasing all over the world (CEA 2013). Global energy scenario is given in Fig 1.

In recent years, India's energy consumption has been increasing at one of the fastest rates in the world due to population growth and economic development. During the 5-year period ended March 31, 2013, the Compound Annual Growth Rate (CAGR) of consumption of petroleum products was approximately 4.6% (Source: PPAC, August 2013), compared to a CAGR for Gross Domestic Product (GDP) of 7.6% (Reserve Bank of India) for the same period. Despite the overall increase in energy demand, per capita energy consumption in India is still very low compared to other developing countries.

Now a days, India has one of the highest potential for the effective use of renewable energy. India is the world's fifth largest producer of wind power after Denmark, Germany, Spain, and the USA. There is a significant potential in India for generation of power from renewable energy sources, like small hydro, biomass, and solar energy. It is estimated that national SHP (small-hydro power) potential is about 15000 MW (World Energy Outlook 2012).



(Source: Consumer Energy Alliance 2013)
Fig. 1: Share of Coal Energy in Global Electricity Generation

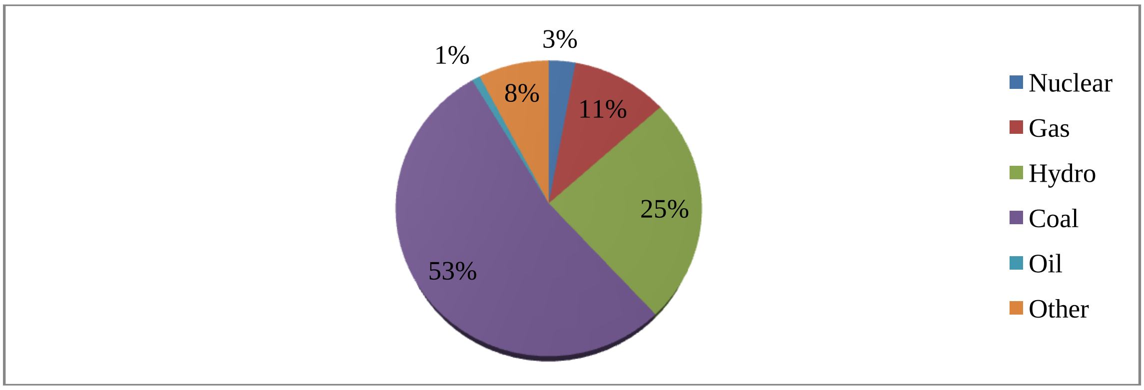
1.2 Energy Scenario in India

Power sector has grown at an exceptional rate during the last four decades in India to meet the rapidly growing demand for electricity as a commercial fuel. Increasing demand of power with a very slow pace of capacity addition requires that the power plants must operate with highest possible power availability and reliability. The enhanced production of power will result in polluting the environment. Thermal power plants and hydro-sectors are the major power producers in India. The foremost portion of power demand in India is met by thermal power plants due to availability of fossil fuels (coal, oil, and gas). Thermal power plants and hydraulic power generators are contributing about 72% and 25% to 30% of total installed capacity, respectively. Among the conventional means of power generation, fossil fuel fired thermal power plants are very significant in the energy scenario of India. However the situation with respect to coal reserves is comparatively better, as it contributes about 84% of thermal power generation while gas and oil contribute about 13% and 3% of thermal power generation, respectively (World Energy Outlook 2012).

Power production is totally dependent on the coal due to better coal reserves in India than other fossil fuels. Coal based thermal power stations are responsible to a large extent in environmental pollution problems. Environmental problems associated with thermal power plants start with transportation of coal from mine, feeding it to boiler, the emission of flue gases, etc. Today the environmental problems of energy use are related with environmental cost, which have been rising, reinforcing the effect of increased monetary costs in creating incentives for increasing the efficiency with which energy is used. The impacts of coal-based thermal plants are particularly important to study in India, as these plants currently provide the largest generating capacity.

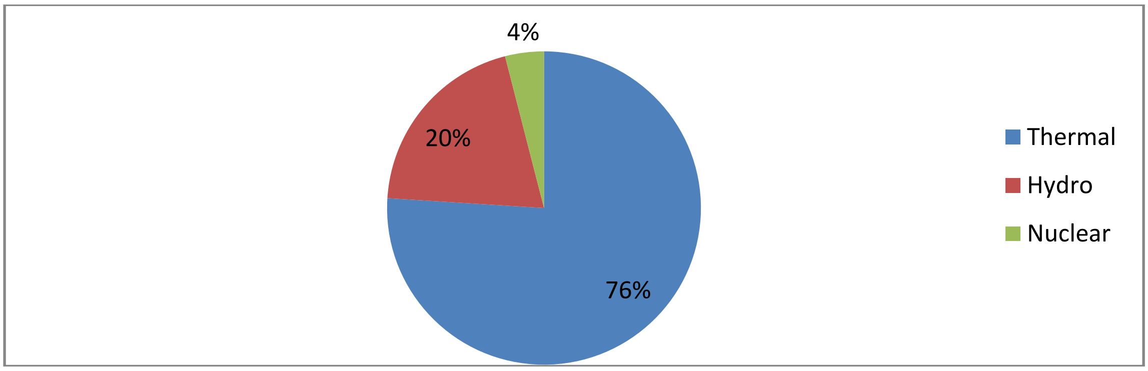
India, though rich in coal and abundantly endowed with renewable energy in the form of solar, wind, hydro and bio-energy has very small hydrocarbon reserves (0.4% of the world's reserve). It is a net importer of energy and more than 25 percent of primary energy needs being met through imports mainly in the form of crude oil and natural gas. Energy demand in India is expected to increase over the next 10-15 years; although new oil and gas plants are planned, coal is expected to remain the dominant fuel for power generation. The pattern of energy production shows that coal and oil account for 54.2% and 45.8% with natural gas, hydro and nuclear contributing the balance (Fig. 2). In the power generation front, nearly 62 percent of power generation is from coal fired thermal power plants and 53.3 percent of the coal produced every year in India has been used for thermal generation (CEA 2013). The share of coal along with other forms of energy in electricity generation in India is given in Fig. 2.

However, feasible Capacity Addition for 11th Plan is 77,070MW as shown in Fig. 3. Despite significant increase in total installed capacity during the last decade, the gap between electricity supply and demand continues to increase. The resulting shortfall has had a negative impact on industrial output and economic growth. However, to meet expected future demand, indigenous coal production will have to be greatly expanded.



(Source: Consumer Energy Alliance 2013)

Fig. 2: Share of Coal and other Forms of Energy in Electricity Generation in India



Thermal- 58,183MW (Coal- 48,609MW, Gas -7,293MW, Lignite- 2,280MW)
Additional capacity expected: New Renewable- 14,000MW, Captive-12,000MW

Fig. 3: Feasible Capacity Addition for 11th Plan 77,070 MW

1.3.1 Emission Inventory

An air pollutant emission inventory is a process to identify the possible sources and their contribution. It provides fundamental information for air quality modeling and air pollution control strategy development (Huang et al. 2011). Mining, non-mining, industrial, vehicular and other sources are contributing in critical coal mining zone like JCF, India (Dubey et al. 2012). According to possible emission sources, sources are divided into three categories like point sources, area sources and line sources. The inventory of these sources is important to make a proper source profile.

- **Inventory of Point Sources**

A point source of pollution is a single identifiable source that is responsible for significant pollution load in the study area, like thermal power stations (Dubey et al. 2012). For obtaining a comprehensive list of different point sources in the region, State Government, State pollution control boards/committees, concerned government institutions, office of the commissioner for Industries, District Industrial Center (DIC) and other organizations in the concerned area should be approached. Specific information on production capacities, raw materials used, manufacturing process, fuel consumption, etc. should be collected from the available secondary records followed by an eventual collection of primary data through surveys and questionnaires for the cross checking & validation of the secondary data (CPCB 2010).

- **Inventory of Area Sources**

Area sources are sources of pollution which emit a substance or radiation from a specified area. Mining activities, domestic/hotel fuel (coal) burning, garbage burning, etc. are the major contributing area sources in the study area (Sahu et al. 2011). In order to assess the fuel consumption in the domestic sector, necessary information should be collected from some representative localities covering all socioeconomic groups with a view to assess variation between urban and sub-urban areas. The information proposed to be collected includes number of houses and family members in each house, type, source, quantity and cost of fuel used. Data on gross fuel consumption will also be collected from fuel supply agencies. Based on the above information, daily per capita consumption of different fuels will be estimated. The questionnaire should include seasonal implication of fuel use particularly wood and coal burning.

Information on refuse burning, commercial hotels and restaurants, bakeries and other commercial activities, etc. should be obtained from the municipal or other concerned departments of the city. The emissions will then be estimated using relevant emission factor for each type of fuel (CPCB 2010).

- **Inventory of Line Sources**

Line source is a source of air that emanates from one dimensional (line) geometry. Vehicular emission is the most common line source in the study area. Various transport related project reports should be examined to determine the profile of vehicular traffic emissions within the study area. The quantity of air pollutants emitted from the different categories of vehicles is directly proportional to the average distance traveled by each types of vehicle, number of vehicles plying on the road, quantity and type of fuel being used, age and technology of vehicle in use, etc. However, several other factors like geographical locations, unplanned developed business areas, inadequate and poorly maintained roads as well as adopted practices of inspection & maintenance of vehicles, unplanned traffic flow, meteorological conditions and non availability of effective emission control technology would also affect emissions (Sahu et al. 2011). In order to arrive at the actual vehicular emission scenario, vehicle counts on the major traffic corridors within the study area would be undertaken. The vehicles will be categorized under various groups' viz. heavy-duty vehicles, light-commercial vehicles, passenger cars, taxis, two/three wheelers, etc.

Hourly variation in the vehicle count will be recorded (manually/videotapes) during periods of both day and night. For line sources, the traffic volume and its characteristics (including vehicle speed) at the major traffic lanes are to be conducted (CPCB 2010).

Emission load should be estimated using emission factors, being developed by Automotive Research Association of India (ARAI) for different possible scenarios. The task of estimating emission load will be carried out with due consideration to various parameters viz. type/ technologies of vehicle, age groups, fuel quality, with/without tailpipe treatment, etc.

Jharia is one of the important coal producing area in India. Area source like open coal mining and its associated activities are the major source of particulate pollution at the study area (Ghose 2000).

1.4 Coal Mining in India

Coal has held centre court in India for a very long time. Now it holds India at ransom. The coal reserves of the country are estimated at 285862.21 million tonnes (IBM 2012), coal appears to be the answer to India's burgeoning energy demand.

Seventy percent of total electricity generation in the India is from coal based thermal power plants (Shanmugan and Kulshreshtha 2005). The exploitation of any natural resource, including coal, has the potential for producing adverse environmental effects. It creates a variety of impacts on the environment during and after the mining operations. In India coal is produced by both underground and opencast mining but present thrust is being given to increase opencast mining where gestation period is much shorter (Huertas et al. 2012). India has huge untapped potential for underground mining with extractable reserves upto a depth of 600 metres. Currently mining is done predominantly by opencast methods to exploit the 64 billion tonnes of proven reserves situated within a depth of 300 metres. Coal deposits in India occur mostly in thick seams and at shallow depths. Indian coal has high ash content (15-45%) and low calorific value. The extent and nature of impacts from mining can range from minimal to significant depending on a range of factors associated with ongoing mining processes as well as post mining management of the affected landscapes. The sensitivity of the local environment also determines the magnitude of the problem (IBM 2011).

1.5 Coal Mines and Associated Air Pollution Problems

Coal mining and its associated activities are the major sources of particulate matter in the coal mining areas. High concentration levels of particulate matter give rise to various health problems (particularly Respirable and skin disease), visibility problems associated with various risks/ accidents etc.

1.5.1 Sources of Particulate Pollution

In India, opencast mining today constitutes nearly 70% of the total coal production. Opencast coal mining using large-scale mechanization results in the release of huge quantities of PM, which are changing the environmental impact of coalmines, and adversely affecting human health (Abernathy 2001). The effects of dust clouds are both visible and tangible in communities around industrial activities or construction sites (Hall et al. 1993 and Fuglsang 2002). Dust emission is the foremost problem of opencast coalmines and results from blasting and drilling operations, transportation of coal and overburden on haul roads, from coal handling plant operation, loading of overburden and coal by shovel dumpers, from crushing, conveying and handling of overburden by draglines, running of other vehicular traffic on the unpaved road and from vehicular emission. Numerous researchers have reported on various aspects of dust pollution (Tripathi et al. 1996 and Wanquan et al. 2004). A good example of dust deposition modeling comes from Gao et al. 2003.

Ghose (1997) reported presence of high level of air borne dust in opencast mines and its abatement measures whereas Ghose and Sinha (1990) gave information on an air pollution control plan for opencast coalmines. Ghose and Banerjee (1995) highlighted the air pollution status in opencast coalmines. Energy Environment Monitor discussed the air pollution problem and abatement measures in Indian opencast coalmines. Ghose and Banerjee (1997) conducted a study on the physicochemical properties of air-borne dust in coal washeries of India. Ghose and Majee (2000 a, b) assessed the impact of opencast coal mining on the air environment. Ghose and Majee (2001) suggested abatement measures for air pollution caused by opencast coal mining. Ghose (2000) and Chaulya (2004) discussed the air pollution problems in Indian opencast coalmines. Prabha and Singh (2006) reported that large scale mechanized opencast coal mining generates huge amount of air-borne dust that may cause safety and health hazards and associated negative effects on working efficiency through poor visibility, failure of equipment, increased maintenance cost and lowering of labour productivity. However, still there is a paucity of data regarding seasonal variation of dust fall and its chemical constituents in opencast coalmines.

The basic meteorological parameters determining the horizontal transport and dispersion of air pollutants are the mean wind speed and the wind direction (Ziomas et al. 1995). Exposure to elevated concentrations of air pollutants causes adverse human health effects (Hall 1993). Similarly, as per Moorcraft and Laxen 1990 local inhabitants are living in unhealthy conditions that could result in health problems. The pollution control measures used by the mining authorities are inadequate, and urgent action is required to remediate the pollution problem. The residential areas around coalmines should be shifted farther away in the opposite direction of prevalent winds.

1.5.2 Characterization of Particulate Matter

Airborne particulate matter is a big area of concern today (Dordevic et al. 2004 and Hinz et al. 2005). The characterization of the respirable fractions (PM_{10} and $PM_{2.5}$) represents an interesting field of investigation (Harrison et al. 1997and Aneja et al. 2012). Study of phase analysis of airborne particulate matters is an active field of research. In recent years, more importance is giving on particulate matter of size 2.5μm ($PM_{2.5}$) as reflected by a growing number of studies of this fraction, including not only the measurements of its concentration but also the determination of its chemical content (Yatkin and Bayram 2008 and Huertas et al. 2012). During the characterization of the fugitive dust, Organiscak and Reed (2004) concluded that the unpaved mini haulage roads generate dust particle of all sizes.

The morphology, size, and composition of PM_{10} can also provide clues about process performance (Stone et al. 2011). Characterizing PM_{10} can also help to understand potential health effects of airborne particles (HEI, Health Effects Institute 2002). The behavior of airborne particulate matters can best be understood, if its chemical composition is known through Inductively Coupled Plasma Atomic Emission Spectrometry (ICP OES), Gas Chromatography-Mass Spectrometry (GC-MS), Organic/Elemental Carbone and X-ray diffraction technique (Hussain et al. 1997). The most common methods for the analysis of the quartz found on the filter paper are based on Fourier Transform Infra Red (FTIR) and Powder X-ray Diffraction (XRD) techniques and NIOSH have provided methods that describe accurate sample preparation and quantification of quartz on air filters.

The FTIR analysis is based on the bonding parameters of pure quartz, where quantitative analysis has been reported on particles as low as 10μg. However, interferences are possible due to overlapping spectral peaks at 798 cm^{-1} from the other phases of silica. Thus it is difficult to distinguish between different silica forms with FTIR at the particular analytical peak. Also the variation in particle size can result in significant error by reporting a comparatively lower value for the same mass samples that had larger particles. The technique of XRD relies on the well-defined diffraction pattern of crystalline quartz and has been shown to give detection levels on particles as small as 20μm. But again, errors can arise due to particle size variation and especially sample preparation. Literature has reported that the variation in particle size of a sample was shown to give comparatively larger X- ray intensity values for the same sample mass, when the particles are comparatively larger. Single particle studies are essential in environmental atmospheric chemistry, which allow identifying the various processes involved in the formation and evolution of atmospheric aerosols (Raes et al. 2000).

1.6 Air Pollution in Thermal Power Plants

The major portion of power demand in India is met by thermal power plants due to availability of fossil fuels (coal, oil, and gas). Power sector in India has grown at a phenomenal rate during the last four decades to meet the rapidly growing demand for electricity as a commercial fuel. Among the conventional means of power generation, fossil fuel fired thermal power plants are very significant in the energy scenario of India (Chandra et al. 2003 and Agarwal et al. 2004).

Thermal power plants are major sources of PM (SPM, PM_{10}, and $PM_{2.5}$) emissions in the atmosphere. Depending upon the types of fuel used emission of one or more of these pollutants may be of environmental significance. A large amount of PM as fly ash is emitted from coal fired plants, particularly if the ash content of coal is high and a fly ash removal unit, such as an electrostatic precipitation (ESP) is not used (Rao and Dubey 1990 and Agrawal et al. 1993).

Fly ash contributes major proportion of particulate emission from thermal power plants (Agrawal and Singh 2000). Coal combustion in power stations gives rise to emissions made up of flue gases and particulate matter. The emissions depend on ash quality and combustion technology. In addition to the primary fly ash emission, the gases to particle conversion processes also give rise to considerable volumes of secondary pollutants (Shamshad et al. 2012).

It has been established by many scientists that industrial activities are the main contributors for heavy metals in the urban atmosphere (Azimi H. Zhang et al. 2005). Many studies have indicated that this pollution trend has been increasing as reviewed by Fang et al. (2004). It is also observed that ash particles emitted from thermal power plants show enrichment in several toxic elements (Roy et al. 2012). Coal combustion can mobilize trace elements by introducing them to terrestrial, aquatic and atmospheric environment. Thus, environmental problems associated with thermal power plants start with transportation of coal from mine, feeding it to boiler, and the emission of flue gases (Singh 1998).

1.7 Standard Monitoring Procedure

Under the Air act 1981 and EPA 1986 it is necessary to assess the present and projected air pollution through continual monitoring. This programme instigate during 1984-85 at the national level under the surveillance of CPCB and National Air Quality Monitoring Programme (NAMP)

1.7.1 National Air Quality Monitoring Programme

The objectives of NAMP are:

- To determine the status and trend in ambient air quality and effects of pollution on air quality in urban environment.
- To estimate the future changes in air quality and to obtain the knowledge and understanding necessary for developing preventive and corrective measures;
- To understand the natural cleansing process undergoing in the environment through dilution, dispersion, wind based movement, dry deposition, precipitation and chemical transformation of pollutants generated;
- To ascertain whether the prescribed ambient air quality standards are violated;
- To assess the likely health and damage to materials etc. and
- To control and regulate from the various sources.

Bureau of Indian Standards (2004), Air Quality Sectional Committee CDC 53, prepared series of Indian Standards relating to air pollution. The standard procedures for the measurement of pollution are given in Table 1.

Table 1: Standard Procedures for the Measurement of Particulate Pollution

Number	Title
IS : 4167 – 1980	Glossary of terms relating to air pollution
IS : 5182 – (Part 1) 1969/83/2001	Method for measurement of air pollution.
IS : 5182 – (Part IV) 1973/88/99	Method for measurement of air pollution (Part IV) Suspended matter.
IS : 5182 – (Part XIV) 1985/2000	Method for measurement of air pollution (Part 14) Guideline for planning the sampling monitoring station.
IS : 9620 – 1980	Guide for units used in air quality measurement.

(Source: Bureau of Indian Standard 2004)

1.7.2 Selection of Area and Number of Monitoring Stations

Inquisition based on public complaints received from the locality related to air pollution and associated significant health problems are the prior concern area for air quality assessment. It is always convenient to collect some background information of the study area before setting up the monitoring station. This includes pollutants and sources of pollution, meteorological condition, topography, demography and existing health status of the area under survey. The number of sampling stations depends on:

- Objectives of the monitoring
- Total area to be covered
- Variability of pollutant concentrations over the study area.
- Population density per unit area and health status.

Common pollutants and their distribution based on population size as per IS: 5182 – (Part XIV) 1985/2000 is depicted in Table 2.

Table 2: Common Pollutants and their Distribution Based on Population Size

Pollutant	Population of Evaluation Area	Minimum No. of AAQ Monitoring Station
SPM(High Volume)	<1,00,000	4
	1,00,000-10,00,000	4+0.6 per 1,00,000 population
	1000000-5000000	7.5+0.25 per 1,00,000 population
	>5000000	12+0.16 per 100000 population

There are several other modifying factors to accomplish other monitoring objectives, particularly in relation to epidemiological studies.

- In highly industrial zone the number of stations for PM must be increased.
- In regions with irregular terrain there should be more number of stations.

1.7.3 Selection of Monitoring Stations

Selection of different strategic air monitoring stations was done as per standard siting criteria (IS: 5182, Part XIV) with special considerations on:

- Security, physical access and availability of electricity
- Area of population exposure
- Existing meteorological parameters
- Particular method and instrument used for sampling, etc.

Representative site, Comparability, Topographical & Meteorological Factors and Physical requirement of the monitoring site are the major requirements that should be satisfied during the selection. Emphasize should also given to the NAAQS measurement technique for various pollutants, sampling frequency and duration, laboratory requirement, data handling and presentation along with quality control and quality assurance. It is pertinent to mention here that all the guidelines are prescribed for carrying out ambient air quality monitoring under NAMP but while dealing with the field condition we might compromise little bit with guidelines. This study has been carried out.

1.8 Source Apportionment Study of Particulate Matter

Source apportionment (SA) is a big area of concern in the field of atmospheric sciences today. This study aims to re-construct the impacts of emissions from different sources of atmospheric pollutants, e.g., particulate matter (PM), based on ambient data collected at monitoring sites (Watson et al., 2002). Among all the critiria air pollutants, particulate matters (SPM & RSPM) have emerged as the most critical one in almost all urban and industrial areas of India. High concentration values of SPM concentrations are primarily irritants but don't have much relevance for direct health consequences as compared to the effects of its respirable fractions (PM_{10} and $PM_{2.5}$). Due to this reason, the worldwide focus of monitoring is now increasingly being shifted to measurement of fine particulates ($PM_{2.5}$ and even PM_1), which can penetrate the human respiratory system and causes severe illness. Since 2000 the focus on suspended particulate monitoring has shifted to PM_{10} in India. Being a critical pollutant, PM_{10} has also been included in National Ambient Air Quality Standards, 2009. In view of this, the main focus of this study is the characterization and apportionment of PM_{10}. Source apportionment study has been carried out in six cities in India (Delhi, Mumbai, Chennai, Bangalore, Pune and Kanpur) by CPCB.

1.8.1 Methodology for Source Apportionment Study

A source apportionment study was carried out in six mega cities of India by Central Pollution Control Board (CPCB) at 2010. The methodology which CPCB followed is given in Fig. 4.

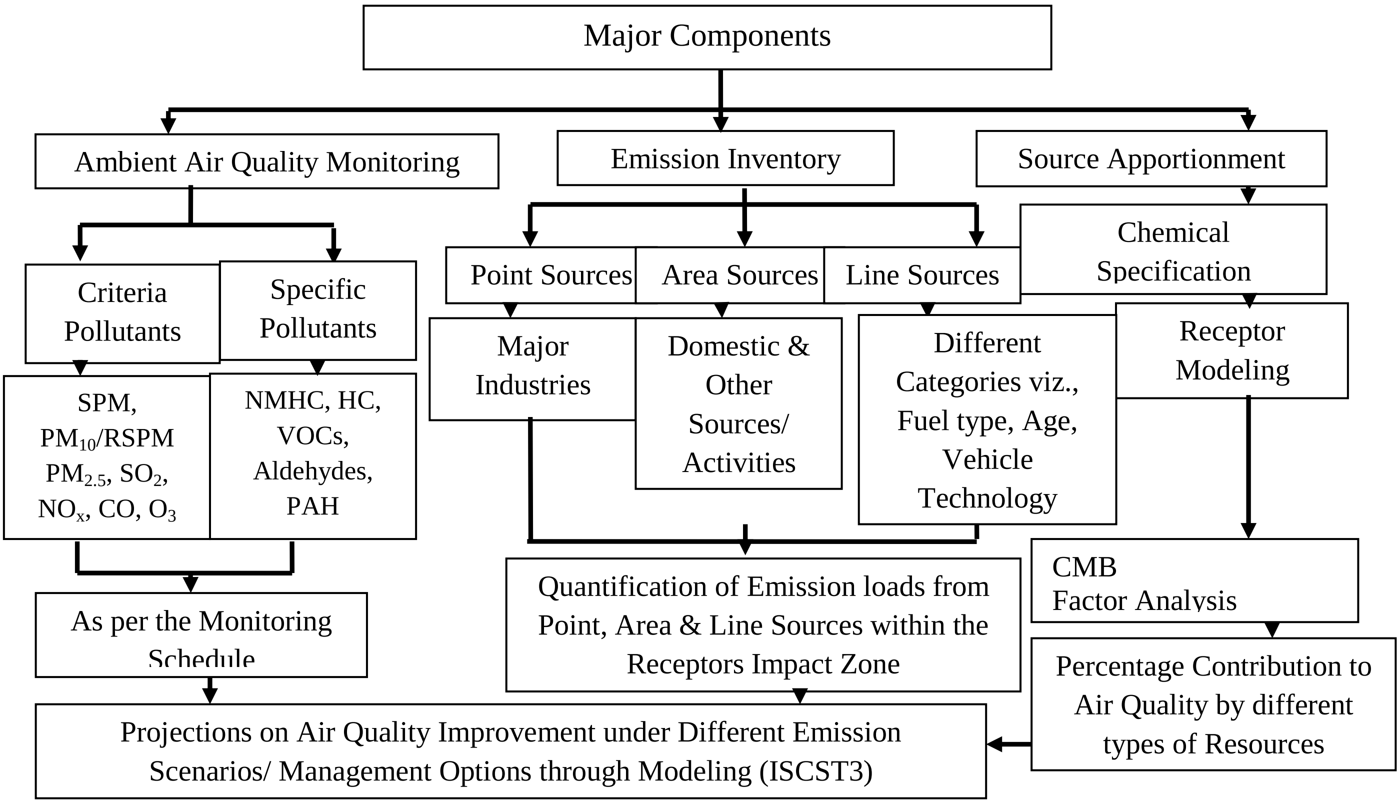


Fig. 4: Methodology of Source Apportionment Study followed by CPCB (CPCB 2010)

The CMB receptor model consists of a solution to linear equations that expresses each receptor chemical concentration as a linear sum of products of source profile abundances and source contributions (Hidy and Venkataraman 1996). The source profile abundances (i.e., the mass fraction of a chemical or other property in the emissions from each source type) and the receptor concentrations, with appropriate uncertainty estimates, serve as input data to CMB. The output consists of the amount contributed by each source type represented by a profile to the total mass, as well as to each chemical species. CMB calculates values for the contributions from each source and the uncertainties of those values. CMB is applicable to multi-species data sets, the most common of which are chemically-characterized as PM_{10}, $PM_{2.5}$, and Volatile Organic Compounds (VOCs).

The CMB modeling procedure requires:

1) identification of the contributing source types;
2) selection of chemical species or other properties to be included in the calculation;
3) knowledge of the fraction of each of the chemical species which is contained in each source type (source profiles);
4) estimation of the uncertainty in both ambient concentrations and source profiles;
5) solution of the chemical mass balance equations.

The CMB approach is implicit in all factor analysis and multiple linear regression models that intend to quantitatively estimate source contributions (Watson 1994). These models attempt to derive source profiles from the cooperation in space and/or time of many different samples of atmospheric constituents that originate in different sources. These profiles are then used in a CMB solution to quantify source contributions to each ambient sample.

CMB model assumptions are:

1) compositions of source emissions are constant over the period of ambient and source sampling;
2) chemical species do not react with each other;
3) all sources with a potential for contributing to the receptor have been identified and have had their emissions characterized;
4) the number of sources or source categories is less than or equal to the number of species;
5) the source profiles are linearly independent of each other;
6) measurement uncertainties are random, uncorrelated, and normally distributed.

The degree to which these assumptions are met in applications depends to a large extent on the particle and gas properties measured at the source and receptor. CMB performance is examined generically by applying analytical and randomized testing methods and specifically for each application by following an application and validation protocol.

The six assumptions are fairly restrictive and they will never be totally complied with in actual practice. Fortunately, CMB can tolerate reasonable deviations from these assumptions, though these deviations increase the stated uncertainties of the source contribution estimates (Balachandram et al 2012).

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). 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 PM levels is only possible when the emission sources have been uniquely identified and characterized (Viana et al. 2006).

There are several types of multivariate receptor models used in the source apportionment studies (Henry et al. 1984). Factor Analysis (FA) and Principal Component Analysis (PCA) are commonly used receptor techniques, that can lead to the identification of the sources and they cannot directly provide the quantitative estimation of the sources. Multivariate factor analysis was adopted to help identification of dominant source categories (Wang et al. 2008) and the results obtained by Varimax rotated factor analysis for coarse and fine particles. Principal Component Analysis (PCA) allows a better interpretation and assessment of the inter-relations of the set of data under study (Zunckel et al. 2003 and Wahid et al. 2013). The correlation coefficient matrix, factor loading and scores obtained from factor analysis are utilized to draw inferences about artificial and natural occurrence of the various trace elements (Shi et al. 2011).

Metallic elements originate from different anthropogenic sources and are associated with different particles fractions. Those emitted during the burning of fossil fuels (V, Co, Mo, Pb Ni and Cr) (Lin et al. 2005) were mostly associated with particles smaller than $PM_{2.5}$. As, Cr, Cu, Mn and Zn are released into the atmosphere by metallurgical industries (Alastuey et al. 2006), and traffic pollution involves a wide range of trace element emissions that include Fe, Ba, Pb,Cu, Zn, and Cd (Birmili et al. 2006), which may be associated with the fine and coarse particles.

However, the evidence about particle sources leading to the observed adverse effects is still limited. Many studies so far have been done in India and abroad on the trace element concentration of urban aerosols and attempts were made to identify the source of trace elements through factor analysis (Fergusson and Kim 1991) but very little work has been carried out on the elemental compositions of aerosol in the mining areas. Several studies on the stack emissions, dispersion, and the source apportionment of particulate matter have been conducted (Costillo 2013). Only few studies have investigated the health effects of source-specific PM (Mar et al. 2006).

Singh and Sharma (1992) observed that in an urban atmosphere 80-90% of the mass of aerosol was inorganic and 10-20% was organic. In the inorganic fraction elements remained in the form of ions such as sulphate, nitrate and ammonium. Elements like Aluminium (Al), Silica (Si), Potassium (K), Calcium (Ca), Iron (Fe), Magnesium (Mg), Sodium (Na), Chlorine (Cl), Bromine (Br), Lead (Pb), Zinc (Zn), Copper (Cu), and Manganese (Mn) are found in abundance and many of them are in the form of oxides. The elements like Nickel (Ni), Cadmium (Cd), Chromium (Cr), Mercury (Hg), Arsenic (As), Cobalt (Co), and Vanadium (V) are released into atmosphere during high temperature process. A prominent origin for trace elements is the weathering of rocks.

Similarly, as per Fernandez-Camachoa et al. (2012) main source of Pb emissions were burning of lead containing products like batteries and plastics in incineration. It was also produced by combustion of leaded petroleum. Sources for Hg were electrical apparatus Industries (mercury battery cells; fluorescent bulbs, switches etc.), chlor alkali industry, pulp and paper, mining and smelting industry (where vapour of Hg loss take place), refining of other metallic ores, fuel (coal, oil) burning, etc. Major sources of Cd in the atmosphere were primary non ferrous metals production (e.g., zinc operation, copper smelting, lead smelting, and cadmium extraction), secondary non ferrous metals, iron and steel production, industrial applications (electroplating, pigment, plastic, alloys and batteries) and inadvertent sources (coal combustion, oil combustion, wood combustion, waste incineration, rubber tyre wear, phosphate fertilizers, etc.).

Dubey (2010-2011) based on his investigation in Jharia Coalfield using factor analysis observed that three factors account for 100% of the variance. In the first factor which was 40% of the total variance a high loading from Pb, Cu and Ni were observed.

Similarly, Sharma (1991) observed that in Raniganj Coalfield the sources were wind borne soil/coal (Fe, Mn, Zn) coal burning activities (Cr, Mn, Fe, Pb) iron and steel works (Cr), refuse incinerator (Zn) and vehicular exhausts (Pb).

Another study in Jharia coalfield, carried out by Sinha and Banerjee (1997) indicated five major sources that appeared to have contributed trace elements of the total particulate load. These were wind borne soil/coal (SPM, Fe, Co, Mg), vehicle exhaust (Pb), metallic corrosion (Cu, Ni), tire wear (Mn and Cr) and galvanized material, tyre wear, and zinc compound in rubber material (Zn). Sadasivan and Negi (1990) concluded in their study that Pb, Zn, As and Mn have linkage to combustion sources whereas Al, Si, K and Co have linkage with soil origin.

In order to establish the combined effect of the heavy metals on air pollution, principal component analysis (PCA) as a multivariate analysis was used (Statheropoulos et al. 1998). PCA, oldest among the multivariate analysis is widely used for source apportionment studies (Fang et al. 2004). Basically it is an exploratory tool to identify the major sources of aerosol emissions and to statistically select independent source tracers.

1.9 Effect of Air Borne Particles

The health effects of particulates are strongly linked to particle size. Small particles, such as those from fossil fuel combustion, are likely to be most dangerous, because they can be inhaled deeply into the lungs, settling in areas where the body's natural clearance mechanisms can't remove them. The constituents in small particulates also tend to be more chemically active and may be acidic as well and therefore more damaging (Lin et al. 2005).

It is well known that the health effects associated with the airborne particles are dependent on their toxicity. The extent to which air borne particles penetrate into the human respiratory system is mainly determined by the size of the penetrating particles (Balachandran et al. 2000). There are several epidemiological studies present in the literature (Dockery 1993; Harrison and Yin 2000), which have demonstrated a direct association between atmospheric inhalable particulate matter and respiratory diseases, pulmonary damage, and mortality especially in the urban areas. Exposure to elevated levels of PM increases the rate of respiratory problems, hospitalizations due to lung or heart disease, and premature death (Asgharian et al. 2001 and Dominici et al. 2006). Fuel combustion, industries, and power plants are the main sources of particles in urban and industrialized areas. Depending upon the atmospheric conditions, the health risks can be aggravated (Zhang et al. 2007).

In several studies it was found that the existence of fine particles in the air is associated with cardio vascular diseases and mortality (Sunyer et al. 2006). In particular, fine particles ($PM_{2.5}$ and $PM_{1.0}$ fractions with aerodynamic diameter less than 2.5 μm and 1.0 μm, respectively) have a strong correlation with morbidity and/or mortality due to pulmonary and cardiac disease (Samet et al. 2000 and Pope et al. 2002). Fine particles can penetrate the human respiratory tract and lungs, and several epidemiological studies have reported a link between elevated particle concentration and increased mortality and morbidity (Wilson and Suh 1997). Hospital admissions indicating the number of patients admitted into hospitals are a marker for an adverse health event (Delfino et al. 2004). Moreover, these particles may have wide-ranging potential effects on agricultural and natural ecosystems, and they may reduce visibility affecting transportation safety and aesthetics (Yuan et al. 2007).

Numerous studies associate particulate pollution with acute changes in lung function and respiratory illness (U.S. Environmental Protection Agency (USEPA) 1998) resulting in increased hospital admissions for respiratory disease and heart disease, school and job absences from respiratory infections, or aggravation of chronic conditions such as asthma and bronchitis. But the more demonstrative and sometimes controversial evidence comes from a number of recent epidemiological studies. Many of these studies have linked short-term increase in particulate levels, such as the ones that occur during pollution episodes, with immediate (within 24 hours) increases in mortality. This pollution-induced spike in the death rate ranges from 2 to 8 percent for every 50-$\mu g/m^3$ increase in particulate levels.

A focus on the occupational hazards and overall condition prevailing in Indian coalmines are felt to be important. Simple Coal Workers' Pneumoconiosis (SCWP) and Progressive Massive Fibrosis (PMF) are the major occupational respiratory diseases of coal miners caused due to exposure to respirable dust generated during various mining operations. The concentration of respirable coal dust, the period of exposure and free silica content are important factors associated with pneumoconiosis risks. Assessment of respirable dust in coalmines and its control are of primary importance to undertake preventive measures.

Several epidemiological studies conducted in different countries reported a reducing trend of pneumoconiosis mortality since last two decades due to gradual reduction in dust levels at work faces through stringent control measures (Ostro 1993 and Health Effects Institute (HEI) 1995). There are number of scattered studies reported in Indian coalmines by different agencies and the prevalence of the disease varied widely from one another to draw any definite conclusion on the prevalence, distribution and determinants of the disease (Bertollini et al. 1996). Roy (1956) first reported pneumoconiosis cases in bituminous coal mines of Madhya Pradesh prior to that it were presumed occupational diseases like silicosis, pneumoconiosis were not properly diagnosed in India.

During major pollution events, such as those involving a 200-μg increase in particulate levels, an expert panel at the World Health Organization (WHO) estimated that daily mortality rates could increase as much as 20 percent (Op. cit. 4, pp. v-18). In the aggregate, pollution-related effects like these can have a significant impact on community health. WHO estimated that short-term pollution episodes accounted for 7 to 10 percent of all lower respiratory illnesses in children, with the number rising to 21 percent in the most polluted cities. Furthermore, 0.6 to 1.6 percent of deaths were attributable to short-term pollution events, climbing to 3.4 percent in the cities with the dirtiest air (Bertollini et al. 1996).

Health effects are not only restricted to occasional episodes when pollutant levels are particularly high. Numerous studies suggest that health effects can occur at particulate levels that are at or below the levels permitted under national and international air quality standards. In fact, according to WHO and other organizations, no evidence so far shows that there is a threshold below which particle pollution does not induce some adverse health effects, especially for the more susceptible populations (Op. cit. 5, p. 14., Op. cit. 1, p. 11). Therefore, the estimation of the levels of respirable particulate and its major toxic constituent present in the urban atmosphere is a prime requirement of epidemiological investigation, air quality management, and air pollution abatement (Chow et al. 1992 and Querol et al. 2002). This situation still has prompted a vigorous debate about whether current air quality standards are sufficient to protect public health.

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