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Dust fall and elemental flux in a coal mining area

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ABSTRACT

Air is a very essential part for the existence of humans and other living organisms. To know the quantum of atmospheric dust fall and their mineral and morphological characteristics, dust samples were collected at monthly intervals from three different sites (commercial, residential, and control) of the Jharia coal mining area, India. Samples were analysed for heavy metals, minerals, and morphological features by ICP-AES, XRD, and SEM respectively. The yearly average dust fall was higher for the commercial site (15.5 t/km^2/month) than the residential site (10.7 t/km^2/month) of Jharia coal mining area. The dust deposition rate was highest during summer (March–June), followed by winter (October–February) and lowest in the monsoon season (July–September). The elemental fall was higher for Zn followed by Pb > Sr > Cu > V > Cr > Ni > Co. The major minerals in dusts from Jharia mining area were quartz, kaolinite, pyrite, albite, and magnesiohornblende. The SEM-EDS analysis showed the dust in commercial sites has contributions from coal, and soil. In the residential site, soot particles from domestic coal burning; and in control site, soot particles from biomass burning were observed in SEM. Overall the intensity of dust pollution is more in the commercial sites of the coal mining area.

1. Introduction

Air is a very essential part for the existence of human and other living organisms. Major air pollution sources can be broadly categorized into natural as well as anthropogenic emissions. Natural emissions are still not in the control of humans wherein air pollution control technologies can be incorporated to curb human emissions. The major anthropogenic sources of air pollution are industries (thermal power plants, refineries, steel plants, open cast mines, various coking and briquetting units, etc.), vehicular and domestic emissions. Among various sources of air pollution, mining is a major source of dust pollution (Ghose and Majee, 2000).

Opencast coal mines use large-scale mechanization and release huge quantities of dust and gases, which adversely affect human health (Dhar, 1994). Various processes of mining which releases huge quantities of dust especially in open cast mining are topsoil removal, overburden removal, blasting and drilling operations, coal extraction, size reduction, transportation of coal on haul roads, coal handling plant operation, loading of coal by shovel dumpers, etc. Dust fall rate and its chemical constituents are required in quantitative as well as qualitative terms to study the dust pollution of a particular region (Harrison and Perry, 1986). Managing dust from coal mines is important as it can impact local and regional air quality, adversely affect local amenity and pose a risk to public health. Pandey et al. (2008) reported a mean annual dust fall of 96.2 ± 3.6 ton/km^2/month in a sub-tropical opencast coal mine, Bina, India. The maximum dust deposition occurred in summer (32.8 ± 1 to 278.9 ± 2.9 ton/km^2/month), and the lowest, in the rainy season (16.2 ± 1.2 to 111.3 ± 3.2 ton/km^2 per month).

Dust has a complex mineral and chemical composition as it comes from various sources and processes (Abed et al., 2009; Chen and Xu, 2003) and provides reaction sites for various atmospheric reacting chemical species. These reacting species could cause modifications in the properties of dust, therefore, it is necessary to study the source, composition, and content of falling dust as it can cause risk to human health, ecology and atmospheric environment. Elements present in the dust can influence terrestrial biogeochemistry through several processes. On short time-scales (days to weeks), dust directly affects vegetation, (Farmer, 1993) alters the rate and timing of snowmelt, (Painter et al., 2007) and provides essential elements (nutrients) for plant and microbial productivity (Chadwick et al., 1999). In the long run, dust can be an important factor in the formation and development of soils (Lawrence and Neff, 2009).

Jharia coalfield is the only coking coal production region in India located at 5 km south of the Dhanbad town of Jharkhand state. The presence of active and abandoned coal mines, overburden dumps, coking coal plants and other coal based industries including refractories, pose serious threats to the air quality of the area. According to Ghose and

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Majee (2000), a total of 9.4 t dust per day was generated due to mining operations in an open cast mine of Jharia coalfield, of which 7.8 t was generated due to various activities like topsoil removal, overburden removal, extraction of coal, size reduction of coal, etc. and 1.6 t per day was contributed by wind erosion. It is reported that 80.2% of total dust emission is from the transport road of mines (CMRI, 1998), screening plant is the next larger source of dust emission (8.1%) followed by overburden removal (2.8%), top soil handling (2.6%), coal extraction (2.2%), drilling and blasting (1.3%), coal handling or stockpile (1.1%). Mandal et al. (2012) studied the dust emission from four different opencast coal mines and found that dust emission was maximum in the haul road (78.4–124.5 t/km) followed by transport road (48.0–98.2 t/km), and communication road (38.7–50.3 t/km).

Due to various mining activities, Jharia is worst polluted by particulate matter and dust. The aesthetic view of this area is being exploited due to over exploration of coal, increase of overburden dumps, subsidence of land due to underground mine fire, etc. To improve the living conditions of the local people, there is an urgent requirement of data on dust pollution and its general characteristics based on scientific disclosures to make possible policy guidelines and implementing of the same. The present study was aimed to (i) measure the monthly and seasonal dust fall rate; (ii) assess the fluxes of the potentially toxic elements through dust fall; and (iii) characterise dust mineralogy and morphology.

2. Materials and methods

2.1. Study area

Jharia town is located in the eastern part of Jharkhand state of India, between latitudes 23°44′53″ N and 23°44′02″ N; and longitudes 86° 25′ 13″ E and 86° 24′54″ E, with an average elevation of 202 m above the mean sea level (Fig. 1). The area experiences tropical climate and is characterised by very hot pre-monsoon and cold winters. The month of May and half June is the peak of pre-monsoon season with an average maximum temperature of 44 °C, while December and January are the coldest months. Jharia has been actively associated with coal mining activities for more than a century. There are many active opencast and underground mines, abandoned coal mines, natural coal fires, and overburden dumps. The area is also affected by pollutions from vehicular activities. A control site, Chandankyari, 18 km away from the Jharia town was also selected to compare the variations in dust fall. Control site comprises barren and some agricultural lands.

2.1.1. Geological setting

Jharia Coalfield is a member of the Damodar Valley coal belt, occurring as an "outlier" in the Archaean basement area. The sedimentary succession, unconformably overlying the Archean gneissic basement, starts with the glaciogenic sediments of the Talchir Formation followed upward by fluvial and fluvio-lacustrine sediments successively of the Barakar, Barren Measures and Raniganj Formations deposited within an intracratonic extensional setting (Dasgupta, 2005). The soil is grey brown to very pale brown sandy loam, and clay loam, the whole having a sub-angular blocky structure. Ferromanganese concretions and clay content are present in the subsoil (Chaulya et al., 2011).

2.2. Sample collection

2.2.1. Dust fall measurement

The study area was categorized into three different zones as commercial site, residential site, and control site. Sampling points were free from any obstacle, open to atmosphere and easily accessible. In each site, 5 separate sampling jars were placed on five different random spots in a tripod stand. The sampling period was from October 2010 to September 2011. Free dust fall samples were collected from these sampling jars (cylindrical shape glass jar having 15 cm diameter and 45 cm height). Distilled water was placed in each of the collectors to prevent sample loss by blowing air. A glass funnel was kept at the mouth of the jar to prevent evaporation loss of water, loss of dust by wind and to prevent interference of birds and other animals. The collectors were then placed in position in guard frame on roof tops of approximately 5 m height. The jars were inspected periodically for water loss, and replenished. Samples were collected at monthly intervals. At the end of sampling period, the residual water in the container was filtered and the residue was dried (105 °C) in a hot air oven and weighed. The month wise dust fall rate was calculated for each sampling sites. The seasonal dust fall measurement was done by averaging the dust fall value of the concerned months (summer: March, April, May, and June; monsoon: July, August, September, and; winter: October, November, December, January, and February). The dust fall results were expressed as t/km^2 per month.

2.2.2. Sample collection for elemental and mineralogical study

Wooden trays covered with stainless steel plates (0.6 × 0.4 m, height 0.1 m) were placed at 15 different sampling spots for mineralogical study The wooden trays were kept at roof tops of selected buildings (5 m height). There were 05 different sampling spots in commercial, residential, and control sites. After the sampling period, dust particles were wiped off from the plates with a camel hair brush, and were collected in polyethylene containers. Dust samples were collected for a period of 15 days for all the three seasons. Samples were collected from 1st January 2011 to 15 January 2011 for winter season, 12th May 2011 to 26th May 2011 for summer season, and from 20 June 2011 to 05 July 2011 for monsoon season.

2.3. Sample analysis

The heavy metal content in the dust samples were analysed in triplicate. Heavy metals from the dusts were extracted using USEPA method 3051A (USEPA, 2007) in a microwave system (Milestone, Italy) and analysed through ICP-OES (ICAP 6300 Duo, Thermo Fisher Scientific). A portion (0.25 g) of each of oven dried dust sample was weighed and transferred into the Teflon vessel containing HNO_3 and HCl acid mixture (3:1), and digested at approximately 200 °C for about 20 min in a microwave digestion system (Milestone, Italy). After digestion, 10 ml of MilliQ water was added, the resulting mixture was filtered through Whatman no. 42 filter paper and the solution was transferred to a 25-ml volumetric flask and diluted to the mark. Determination of As was carried out using ICP-OES with an online hydride accessories. All the other elements were measured using the normal cyclonic spray chamber and concentric nebulizer connected by tygon tubings. Commercially available ICP multi-element standard solutions (Merck) were used for development of calibration curves. All the glassware and plastic vessels were treated by dilute (1:1) nitric acid for 24 h and then rinsed with MilliQ water before use. Quality control measures included use of laboratory reagent blanks, and the analysis of the loamy sand soil reference materials CRM024-05 (RTC, Laramie, WY). After every tenth sample during analysis, the calibration standards were analyzed to check the analysis accuracy. The recovery percentage of metal concentrations from the reference material was between 93.2% and 113.5%. The reagent blank was also spiked with all the standards and the recovery percentage was between 97.3% and 105.2%.

XRD patterns were recorded at room temperature on a D8 ADVANCE (BRUKER AXS, Germany) diffractometer using CuKα radiation with parallel beam (Gobel Mirror). The samples were ground to fine powder prior to measurement. The scans are recorded in the 2θ range between 10 and 75° using step size of 0.02° and scan speed of 2 s/step. Peaks were identified by search match technique using DIFFRAC^{plus} software (BRUKER AXS, Germany) with reference to the JCPDS database. For SEM analysis the powdered samples were fixed on an adhesive tape and coated with gold. The morphological properties of the dust were determined by scanning electron microscopy (JSM-6390LV), at the Sophisticated Test and Instrumentation Centre, Cochin University, India.