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Dispersion of particulate matter generated at higher depths in opencast mines

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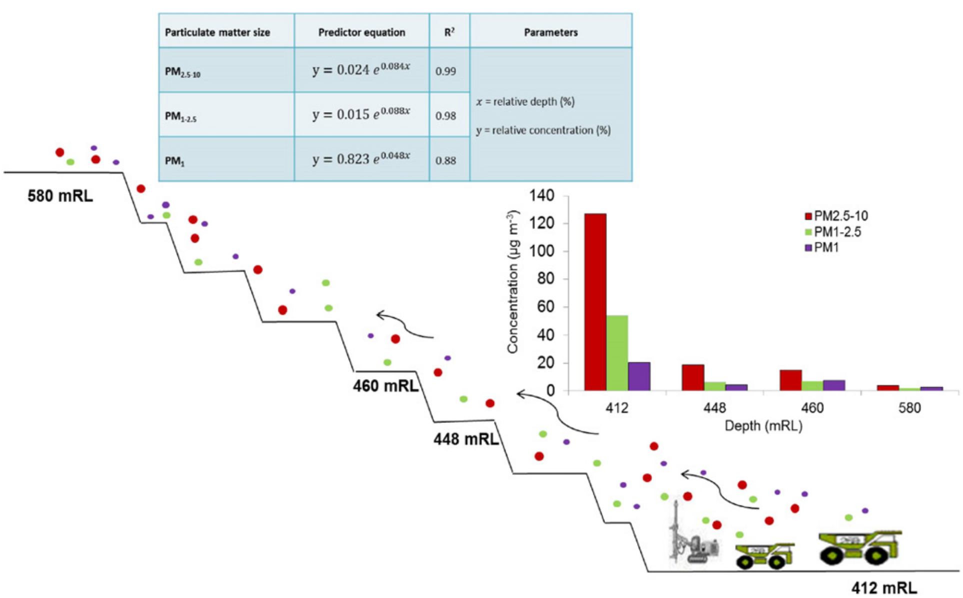
GRAPHICAL ABSTRACT



HIGHLIGHTS

- Vertical concentration profile of particulate matter is measured.
- Size variability of particles in background air and mining emission is estimated.
- Particulate matter dispersion dependency on depth is estimated.
- Predictor equations for the upward movement of particles are developed.
- No significant relationship was found between particle concentration and wind speed.

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ABSTRACT

Dispersion studies of particulate matter generated during opencast mining until now have mostly been confined to estimation of emissions from individual mining activity as well as total emission from an opencast mine. No study is available on particulate matter dispersion inside the mine since its generation

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until it escapes the mine. However, this is important particularly for deep mines where mine workings are confined to bottom benches and emission from it passes across all benches before it reaches surface, thus affecting the exposure level of workers at higher benches. This paper presents the results of a study on the dispersion of particulate matter in Malanjkhand Copper Project, one of the deepest opencast mines in India. The study was conducted for 4–5 h daily for 10 days during the month of October 2013. Mining activities at 168–180 m depth were the source of particulate matter. Particulate matter concentrations were measured by portable aerosol spectrometer. Meteorological data were collected using portable weather station. There was no direct correlation between wind speed and particulate matter concentration. Correlation between wind direction and particulate matter concentration was somewhat better. While coarse particle ($PM_{2.5-10}$) constituted 6%–8% of the background concentration, it increased to 31%–61% during mining, primarily due to generation of more coarse particles during mining. At locations farther from and higher than the source location, continuous decrease of concentration of particles of all sizes was observed due to settling and dispersion of particles. From source locations to the surface, the average mining induced incremental concentration of $PM_{2.5-10}$, $PM_{1-2.5}$ and PM_1 decreased from 127.02 to 3.98 $\mu g\ m^{-3}$, 5.39 to 1.95 $\mu g\ m^{-3}$ and 20.26 to 2.74 $\mu g\ m^{-3}$ respectively. An empirical relationship has been established between particulate matter concentration and depth.

1. Introduction

Open pit mining operations have been identified as a major source of particulate pollution (Csavina et al., 2012; Cowherd, 1979; Gautam et al., 2012; Ghose and Majee, 2001; Li et al., 2014; Pless-Mulloli et al., 2001; Reddy and Ruj, 2003). Inhalation of particulate matter in respirable sizes (PM_{10}) generated during mining results in several diseases like black lung, asthma, cardiovascular diseases and lung cancer (Banks et al., 1998; Boyd et al., 1970; Chau et al., 1993; Chen et al., 1990; Dockery and Pope, 1994; Fernandez-Navarro et al., 2012; Ghose and Majee, 2001; Hendryx and Ahern, 2008; Kinlen and Willows, 1998; Turner and Grace, 1938; Wild et al., 2009). Some studies have suggested that fine particles from mining activities contribute to significant adverse effect on health (Boyd et al., 1970; Fernandez-Navarro et al., 2012; Finkelman et al., 2002; Goix et al., 2011; Li et al., 2014; Pless-Mulloli et al., 2001; Seaton et al., 1995).

As impacts of particulate matter from mining on human health got widely reported, studies on generation and dispersion of particulate matter during mining were carried out. While some studies focused on estimation of particulate matter generated by a mining activity (Chaulya, 2004; Zhang et al., 2013), several other studies measured the contribution of a surface mine to the particulate matter level in atmosphere near the mine (Chakraborty et al., 2002; Trivedi et al., 2009). Most of the studies reported that mining operations generate more inhalable coarse particulate matter ($PM_{2.5-10}$) than fines ($PM_{2.5}$) (Aneja et al., 2012; Onder and Yigit, 2009; Tecer et al., 2008). Empirical formulae have been developed to estimate the emissions from different mining operations (Chakraborty et al., 2002; Chaulya et al., 2002). A few studies were aimed to estimate the change of concentration of particulate matter with increasing distance from the mine boundary (Trivedi et al., 2009, 2011).

While quantification of particulate matter generated from mining activities is important, understanding its dispersion inside the mine is equally important because the nature of dispersion will determine the level and duration to which a miner is exposed to mining induced particulate matter. Particulate matter generated at the lower benches of a mine travels across all the higher benches before it escapes the mine. Therefore an activity at deeper parts of the mine contributes to the enhanced concentration at higher benches. Time taken by the particulate matter generated at a certain depth to escape the mine is therefore important. If the time taken for the particulate matter to escape the mine is very long, it indicates that workers inside the mine are exposed to elevated concentration for a longer duration. On the other hand, if the particulate matter escapes the mine in a short time, its adverse effect on health will be less due to less exposure duration. Further, as the particulate matter travel from lower part of the mine to upper horizons, not all particles travel at same speed and proportion. A coarser particle with higher settling velocity settles on mine floor faster than fine particles and therefore may get depleted form the particulate matter plume as it travels higher. No study has been conducted to estimate this dispersion pattern of particulate matter inside the mine as they travel from source to the mine boundary. With opencast mines going deeper day by day, the study of dust dispersion inside the mine needs attention.

The dispersion of particles inside the mine primarily depends on local meteorology and mine geometry. Wind flow is the prime mover of the particulate pollution from one place to another. Wind flow depends on pit geometry. Further, as the opencast mines go deeper, dispersion of particulate matter from mine becomes more complex due to improper ventilation in deeper parts of the mine. One of the earliest studies on particulate matter movement inside the mine was carried out using tracer (Richardson, 1926). Peng and Lu (1995) used smoke to simulate the dispersion of particulate matter inside the mines. They released smoke from one point in pit bottom and measured the pollution concentration at different places inside the mine by photoelectric sensor. Simulation of particulate matter inside the mines has also been studied by using computational fluid dynamics model (CFD) (Hargreaves and Wright, 2007; Kakosimos et al., 2011; Loomans and Lemaire, 2002). Larcheveque et al. (2003) and Chowdhary (1977) have discussed the variation of wind profile on the basis of aspect ratio (ratio of length to depth of the mine). Chowdhary (1977) has reported that wind velocity will be more in shallow mines than in deep mines and deeper parts of the mine will experience poor ventilation than shallow parts. All the above studies tried to simulate the wind flow pattern with the assumption that the particulate matter dispersion will follow it. However, no field study has been conducted to verify these. Further, these simulation studies will not be able to predict the differential movement of particles depending on their size.

The paper presents the findings of a comprehensive dust dispersion study in Malanjkhand copper project in India. It is one of the deepest mine of India with present working being carried out at a depth of 180 m from the surface. The main objectives of the study included estimation of contribution of mining to the particulate matter level inside the mine and understanding particulate matter dispersion as they travel from source to the surface. Influence of wind direction and wind speed on particulate matter concentration at different locations