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THE SPATIAL CHARACTERISTICS AND HEALTH IMPACTS OF PARTICULATE MATTERS IN MINING REGION OF NORTH GOA

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ABSTRACT

Iron ore mining is a major economic activity in Goa. However, over the recent past years Goa had faced a hugeclamor against the worsened level of pollution due to rampant mining activities and resulting into a complete halt on mining activities.In order to estimate the impact of particulate pollution on human health, health impact assessment was done using the average concentration of PM_{10} and $PM_{2.5}$ in the iron ore mining region of north Goa. The average concentration levels of PM_{10} and $PM_{2.5}$ in the study area were observed 170μg/m^3 and 82 μg/m^3, respectively, which are beyond the NAAQS as prescribed by CPCB by the factor of 1.7 and 1.4. Transportation routes were found most polluted with the concentrations of PM_{10} and $PM_{2.5}$ as 227 μg/m^3 and 116 μg/m^3, respectively. From the observation of health impact assessment, maximum number of premature mortality cases (1266) were found to be associated with $PM_{2.5}$, while PM_{10} was associated with maximum number of cases of cardiovascular diseases, respiratory diseases and chronic bronchitis. The number of cases of chronic bronchitis were over whelmingly larger than other health endpoints implying that reducing PM_{10} and $PM_{2.5}$ concentration would gain significant benefit from avoiding chronic bronchitis.

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INTRODUCTION

Mining is among the eight core industries in India andhas a significantimpactonthe national economy.In addition, it also facilitates the growth of other core industries, which, in turn, are critical for the overall economic development.However, mining activities also have detrimental impacts on the environment (Singh and Perwez, 2015a).Therefore, it is imperative for any nation to promote mining while ensuring that environmental conditions meet quality standards. Major air pollutants emitted from mining operations are TSP and PM_{10} (Chakraborty *et al.,* 2002). The deterioration in air quality is most severe in open-pit mining regions. The primary sources of atmospheric particulates (PM) from mining activities include removal of overburden, excavation, vehicular movement on the haul roads, loading and unloading of the overburdenas well as ores(Singh and Perwez, 2015b). These atmospheric particulatesdegradethe quality of ambient air and also decrease the visibility to a significant extent (Xue *et al.,* 2015). The effects on the global radiative balance (Watson, 2002) and its role in climate change (IPCC, 2001) are also other important aspects of interest on PM.

Air pollution has emerged as the most critical problem of the century (Kumar *et al.*, 2011). The current interest in atmospheric particulate matters (PM) is mainly due to its effect on human health (Pope *et al.*, 2002). It is closely associated with increases in morbidity and mortality (Maier *et al.,* 2008; Abbas *et al.,* 2009). PMs consist a variety of components such as trace elements, organic compounds, acids, soil and dust (Rai and Panda, 2014). Trace elements are severely toxic to humans because of their tendency of bio accumulation in the biological system (Du *et al.,* 2013) especially, in the fatty tissues. It is found in almost all atmospheric aerosol size fractions and in general, fine PM carries a higher burden of toxic elements than does coarse PM (Fang *et al.,* 2000). Trace elements associated with respirable particles have been observed to increase lung and cardiopulmonary injuries in humans (Shaheen *et al.,* 2005).Several organic components of PM (polycyclic aromatic hydrocarbons (PAHs)) are labelled as carcinogenic (Pedersen *et al.,* 2006).

Adverse health impacts associated with $PM_{10}$is well documented (Zeger *et al.,* 2008; Mitchell *et al.,* 2010).It impairs respiratory system (Hansard *et al.*, 2011), cause inflammation and diminish pulmonary function (Maher *et al.,* 2008). Fine particulates ($PM_{2.5}$) are even more deleterious in terms of health impacts because they can penetrate deeper into the lungs alveoli (Saragnese et al., 2011). Links with lung cancer (Pope *et al.,* 2002) and increased cardiovascular mortality rates (Schwartz, 1996) have also been established.

Goa is one of the smallest states of India and is endowed with a number of mineral resources of economic importance. Itis an important iron and manganese ore producing State in the Country.The rampant mining over the region had exacerbated the level of particulate pollution to a critical level, resulting into a complete halt on mining activities by the order of Honorable Supreme Court of India in October, 2012. The concern about environmental quality in this region is due the high ecological significance of the region, its scenic beauty and an important tourist destination (Singh *et al.,* 2015). In order to develop an abatement plan for the region to control the pollution levels within the desire limits, an assessment of existing scenario is vital. Hence, the present study was emphasized to estimate the concentrations of PM_{10} and $PM_{2.5}$in iron ore mining region of North Goa. It also dealt the health impacts associated with these atmospheric particulates.

MATERIALS AND METHODS

Study area

North Goa is one of the two districts that make up the State of Goa. The district has an area of 1736 km². North Goa is bounded by Sindhudurg and Kolhapur districts of Maharashtra state to the north and east respectively, by South Goa District to the south, and by the Arabian Sea to the west. The study area comprising 570.63 Km² (latitude of 15°24′ to 15°41′N and longitude of 73°49′E to 74°13′E). In order to provide more focus on the key theme of regional impacts of mining and ancillary infrastructures on the pristine environmental setting, the study area has been broadly divided into; Core Zone (wherein all the core mining activities in North Goa are located along with adjoining 1 km belt), Buffer Zone (encompassing additional 4 km around the core zone) and ore transportation routes. Seventeen (17) representative ambient air quality monitoring stations were selected as per selection criteria provided in IS: 5182 Part XIV (BIS, 2000) for systematic ambient air quality monitoring. In order to emphasize the sources responsible for pollution, four stations were selected around mines, seven in the buffer zone and remaining six along ore transportation routes as depicted in Table 1 and Fig. 1.

The study was carried out during the summer season (represented by April, May and June) in 2013. 24 hourly ambient air samples were collected on twice a week basis. PM_{10} samples were collected, using respirable dust sampler (Envirotech APM 460 NL) (flow rate of 1.1 m^3min^{-1}) on Whatman glass fiber filters (20.4 cm x 25.5 cm) (IS 5182 Part 23, 2006) and $PM_{2.5}$ samples were collected, using fine particulate sampler (Envirotech APM 550 MFC) (flow rate 16.7 LPM) on PTEF filter paper (47 mm diameters) (CARB, 2002). Filter papers were properly inspected for damage using a light table before use. After inspection, the filter papers were conditioned in the desiccator, 24 hours before sampling and kept 24 hours after sampling. The differences in the weight of the filters before and after sampling (using an electronic microbalance (AND HR-200)were used to calculate PM_{10} and $PM_{2.5}$ concentrations.

Health Impact Assessment

The health impact assessment is widely used tool to quantify the hazards associated with air pollution (Huang and Zhang, 2013; Dias *et al.,* 2012; Matus *et al.,* 2012). For this study, health impact of airborne PM_{10} and $PM_{2.5}$ was assessed by using exposure response functions, as described by Cheng *et al.*(2013), Song *et al.* (2016) and the World Bank (2007). The primary assumption of this method is that, if the concentration of pollutant exceeds beyond the threshold, the risk by 1 $\mu g/m^3$ increment can be calculated based on an epidemiological coefficient for one person. If we know the population of an area, we can estimate the health impact for the whole area.

In this study four health endpoints associated with PM_{10} and $PM_{2.5}$ exposure (mortality, respiratory diseases, cardiovascular diseases and chronic bronchitis) were examined. The relative risk (RR) for the health outcomes were calculated using Equation (1):

$$RR = \exp[\beta * (C - Co)] \quad (1)$$

Where,

C is the average PM_{10} and $PM_{2.5}$ concentration, and C_0 is the reference. Here, C_0 values for PM_{10} and $PM_{2.5}$ were considered as 20 $\mu g/m^3$ and 10 $\mu g/m^3$ (WHO, 2005). âis the empirical coefficient (percentage increase in health effect per 1 $\mu g/m^3$ increment in concentrations. The values of âfor the four endpoints are listed in Table 2.

The number of cases for each endpoint (E) attributed to PM_{10} and $PM_{2.5}$ was calculated by multiplying the population (P) by the difference in the current incident rate (f_p) and the incidence rate in a clean environment (f_0) using Equation (2).

$$E = P * (f_p - f_o) \quad (2)$$

The current incident rate (f_p) was calculated by multiplying the incidence rate in a clean environment (f_0) by the relative risk (RR), using Equation(3). For this study the values of f_0 for each endpoint were taken from Song et al. (2016).

$$F_p = f_o * RR \quad (3)$$

By substituting Equation (3) into Equation (2), we obtained the value of E ((Equation (4)).

$$E = (RR - 1) / RR) * f_p * p \quad (4)$$

RESULTS AND DISCUSSION

Spatial distribution of PM

The average concentrations of PM_{10} and $PM_{2.5}$ (Table 3) during the period of observationin the study area were observed 170 $\mu g/m^3$ and 82 $\mu g/m^3$, respectively, which is 1.7 and 1.4 times the National Ambient Air Quality Standards (NAAQS) prescribed by Central Pollution Control Board (CPCB, 2009). Careful observation of the results reveals an apparent spatial

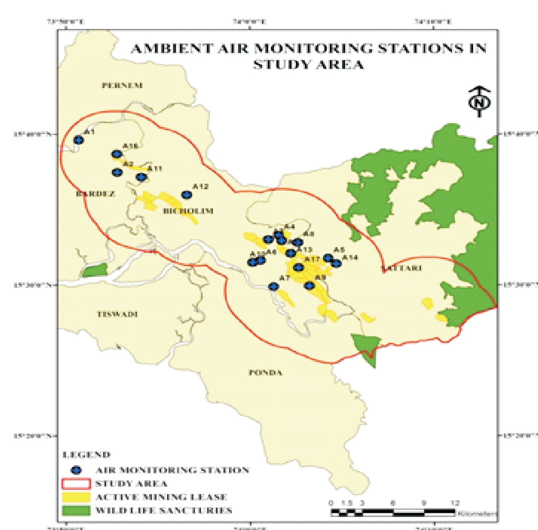

Figure 1: Ambient air quality monitoring stations in the study area

Table 1: Ambient air quality (AAQ) monitoring stations in the study area

Monitoring Stations	Code	Name	Location Latitude (N)	Longitude (E)
Mines	A14	Pissurlem Mine	15°31′24.8"	74°04′42.1"
	A15	Harvalem Mine	15°32′56.1"	74°01′44.3"
	A16	Adwalpal Mine	15°38′40.7"	73°52′45.1"
	A17	Velguem - Surla Mines	15°31′08.4"	74°2′38.3"
Buffer Zone	A1	Revora Village	15°39′35.8"	73°50′41.2"
	A2	Tivim Village	15°37′27.7"	73°52′46.3"
	A4	Harvelem Village	15°33′18.1"	74°01′33.1"
	A7	Surla Village	15°29′53"	74°01′17.4"
	A8	Honda Village	15°32′48.6"	74°02′35.7"
	A9	Velguem Village	15°29′56.6"	74°03′13.4"
	A11	Assanora Village	15°37′09.0"	73°54′06.1"
Ore Transportation Routes	A3	Cudnem Village	15°33′01.0"	74°00′59.6"
	A5	Pissurlem Village	15°31′45.4"	74°01′33.1"
	A10	Navelim	15°31′37.3"	74°00′33.4"
	A6	Amona Village	15°31′29.3"	74°00′08.9"
	A12	Bicholim Town	15°35′57.9"	73°56′34.58"
	A13	Sonshi Village	15°32′5.4"	74°02′13.2"

Table 2: Concentration-response empirical coefficients for the four health endpoints

Health endpoints	Empirical coefficient â (95% confidence interval) PM_{10}*	$PM_{2.5}$**
Mortality	0.00038 (0.00035, 0.00042)	0.00336 (0.00076, 0.00504)
Cardiovascular Disease	0.00066 (0.00036, 0.00095)	0.00068 (0.00043, 0.00093)
Respiratory Disease	0.00124 (0.00084, 0.00162)	0.00109 (0, 0.00221)
Chronic Bronchitis	0.00656 (0.00238, 0.01013)	0.01009 (0.00366, 0.01559)

*Peng et al. (2009); Guo et al. (2009); Huang and Zhang (2013); Xu et al. (2014)**Aunan and Pan (2004); Song et al. (2016)

Table 3: Spatial variation in concentrations of PM_{10} and $PM_{2.5}$($\mu g/m^3$)in the study area

Monitoring Stations		Average ± Std. Dev.	Standard (NAAQS, 2009)	Exceedance Factor (EF)	Average ± Std. Dev.	Standard (NAAQS, 2009)	Exceedance Factor (EF)	$PM_{2.5}/PM_{10}$ ratio
Mines	A14	159±27	100	1.6	72±19	60	1.2	0.45
	A15	157±13	100	1.6	67±9	60	1.1	0.43
	A16	136±22	100	1.4	56±10	60	0.9	0.41
	A17	116±5	100	1.2	52±3	60	0.9	0.45
Buffer Zone	A1	113±6	100	1.1	52±5	60	0.9	0.46
	A2	129±17	100	1.3	62±6	60	1.0	0.48
	A4	120±15	100	1.2	59±8	60	1.0	0.49
	A7	165±29	100	1.6	80±20	60	1.3	0.48
	A8	162±17	100	1.6	75±15	60	1.3	0.46
	A9	137±16	100	1.4	59±7	60	1.0	0.43
	A11	135±22	100	1.3	66±11	60	1.1	0.49
Ore Transportation Routes	A3	232±18	100	2.3	114±13	60	1.9	0.49
	A5	172±20	100	1.7	92±10	60	1.5	0.53
	A10	220±21	100	2.2	112±21	60	1.9	0.51
	A6	263±48	100	2.6	130±23	60	2.2	0.49
	A12	197±12	100	2.0	103±7	60	1.7	0.52
	A13	276±36	100	2.8	147±20	60	2.4	0.53

variation in concentration levels. Highest concentration of PM_{10} was observed along the ore transportation routes (227 $\mu g/m^3$), followed by mines (142 $\mu g/m^3$) and buffer zone (137 $\mu g/m^3$). However, $PM_{2.5}$ concentration was found highest along the ore transportation routes (116 $\mu g/m^3$), followed by buffer zone (65 $\mu g/m^3$) and mines (62 $\mu g/m^3$).The exceedance factor (EF) calculated by dividing the average concentration by the desired limit (NAAQS) also evidenced the exaggeration of PM concentrations along the ore transportation routes, especially, of PM_{10}. The EF of PM_{10} along the ore transportation routes was observed highest (2.3) followed by buffer zone and mines (1.4 each). Among the stations situated along the ore transportation routes, A13 (Sonshi Village) and A6 (Amona Village) were observed with highest EF (2.8 and 2.6, respectively), which is due to very intense traffic of ore carrying dumpers in addition to the public traffic. The EF of $PM_{2.5}$ was also observed highest along the ore transportation routes (1.9),

Table 4: The number of cases for each health endpoint attributed toPM_{10} and $PM_{2.5}$in North Goa

Health Endpoints	PM_{10}	$PM_{2.5}$
Mortality	326 (301-360)	1266 (314-1792)
Cardiovascular Disease	424 (236-597)	215 (137-291)
Respiratory Disease	1434 (1000-1823)	638 (0-1243)
Chronic Bronchitis	3927 (1883-4899)	3238 (1453-4230)

followed by buffer zone (1.1) and mines (1), which are slight lower than the exceedance factors of PM_{10}. However, the dominance of $PM_{2.5}$ along the ore transportation routes is apparent from the $PM_{2.5}/PM_{10}$ratios, which were greater than at 66.6% stations (four out of six) with an average of 0.51. This indicates that the contributions of $PM_{2.5}$ to the total PM_{10} is high (Tiwari *et al.,* 2015) along the ore transportation routes. High contribution of $PM_{2.5}$ to the total PM_{10} is the indication of dominance of tail pipe emission and secondary particulate formation to the total emission in comparison to the resuspension of road dusts.The ratios of $PM_{2.5}/PM_{10}$ in mines and buffer zone were observed as 0.43 and 0.47, respectively.Thisshows the dominance of coarser particles. Tecer *et al*. (2008) also reported the dominance of coarse PM fraction in opencast mines in all climatic conditions.

Health impacts due to PM_{10} and$PM_{2.5}$ levels

Similar kind of study was performed by Song *et al*. (2016) in China to estimate the health impacts of ambient fine particulates ($PM_{2.5}$) considering health endpoints.The four health endpoints associated with PM_{10} and$PM_{2.5}$exposures are presented in Table 4.It can be seen that about 326 (301-360) premature mortality, 424 (236-597) cases of cardiovascular diseases, 1434 (1000-1823) cases of respiratory diseases and 3,927 (1883-4899) cases of chronic bronchitis, can be attributed to PM_{10} pollution.The number of cases of premature mortality, cardiovascular diseases, respiratory diseases and chronic bronchitis attributed to $PM_{2.5}$ pollution can be 1266 (314-1792), 215 (137-291), 638 (0-1243) and 3238 (1453-4230), respectivelyin North Goa district. It is clearly apparent that, the number of cases of premature mortality is about four times higher for $PM_{2.5}$ than that of PM_{10}, which can be attributed to the ability of fine particles to get deposited deeper into the alveoli. But, the number of cases related to other health endpoints are larger for PM_{10},which can be attributed to the higher concentration of ambient PM_{10}. It is also observed that the number of cases of chronic bronchitis are overwhelmingly larger than other health endpoints implying that any reduction in $PM_{10}$and $PM_{2.5}$ concentration would gain significant benefit from avoiding chronic bronchitisand respiratory diseases in the North Goa district.

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