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Air quality standard exceedance and management in an Indian mining area

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SUMMARY

Detailed studies are essential in India to evaluate air quality and implement measures for effective control of mining in sensitive locations. A study for this purpose was carried out in the Basundhara area of the Ib Valley coalfield in Orissa State, India. The 24-hr average concentrations of suspended particulate matter (SPM), respirable particulate matter (RPM), sulphur dioxide (SO_2) and oxides of nitrogen (NO_x) were determined at regular intervals throughout one year at seven monitoring stations in residential areas and two stations in mining/industrial areas. The 24-hr average SPM and RPM concentrations were 312.7–598.4 $\mu g\,m^{-3}$ and 100.2–199.6 $\mu g\,m^{-3}$ in industrial areas, and were 95.6–275.7 $\mu g\,m^{-3}$ and 28.5–86.8 $\mu g\,m^{-3}$ in residential areas. During the study period, 24-hr and annual average SPM and RPM concentrations exceeded the respective standards set in the Indian national ambient air quality standard (NAAQS) protocol in certain residential and industrial areas. However, 24-hr and annual average concentrations of SO_2 (residential: 20.5–24.3 $\mu g\,m^{-3}$, industrial: 15.3–30.8 $\mu g\,m^{-3}$) and NO_x (residential: 19.7–25.3 $\mu g\,m^{-3}$, industrial: 14.3–33.5 $\mu g\,m^{-3}$) were well within the prescribed limit of the NAAQS in both residential and industrial areas. The temporal variations of SPM and RPM fitted polynomial trends well and on average in the mining area 31.38% of the SPM was RPM. The linear regression correlation coefficients between SPM and RPM and between NO_x and SO_2 were 0.90 and 0.52, respectively. The kriging technique determined that maximal concentrations of SPM and RPM occurred within the mining site. A management strategy is formulated for effective control of air pollution at source, and mitigative measures should include implementation of green belts around the sensitive areas where the concentration of air pollutants exceeds the standard limit.

Keywords: air pollution, green belt, management, monitoring, opencast mines, temporal and spatial variation

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INTRODUCTION

India is ranked eighth in the world in terms of total world coal resources and fourth in identified reserves, coal being the most abundant fossil fuel resource in the country. The challenge of increasing the coal production to meet the ever-growing needs of the country has been admirably met by the phenomenal increase in coal production from opencast mines; India ranks fourth in world coal production and is the third largest producer of coal from opencast mines (Chaulya & Chakraborty 1995). There are 44 major coalfields located in peninsular India and 17 in the north-eastern region. The bulk of the coal reserves are confined to the south-eastern quadrant of the country in West Bengal, Jharkhand, Orissa and Chattisgarh states. The geological reserves were estimated in 1996 to be 24 123 Mt of coking coal and 162 914 Mt of non-coking coal up to a depth of 600 m (Kumar 1996).

Coal mining is one of the core industries in India and plays a positive role in the economic development of the country. Its environmental impact cannot be ignored but, to some extent, is unavoidable (Tichy 1996; Corti & Senatore 2000; Tripathi & Panigrahi 2000; Baldauf *et al*. 2001; Collins *et al*. 2001). Most major mining activities contribute directly or indirectly to air pollution (Kumar *et al*. 1994; CMRI [Central Mining Research Institute] 1998). Sources of air pollution in the coal mining areas generally include drilling, blasting, overburden loading and unloading, coal loading and unloading, road transport and losses from exposed overburden dumps, coal handling plants, exposed pit faces and workshops (CMRI 1998). These air pollutants reduce air quality and this ultimately affects people, flora and fauna in and around mining areas (Chaudhari & Gajghate 2000; Crabbe *et al*. 2000; Wheeler *et al*. 2000; Nanda & Tiwary 2001). The major air pollutants produced by opencast mining are suspended particulate matter and respirable particulate matter (Sinha & Banerjee 1997; CMRI 1998), which is in contrast to vehicular emissions where lead and gaseous pollutants are the major concern (Meenalbal & Akil 2000; Almbauer *et al*. 2001).

The environmental impact of coal mining areas must be assessed by detailed studies of air quality (Jones 1993; Canter 1996; CMRI 1998; Chaulya *et al*. 1998, 2000; Ferreira *et al*. 2000). Analysis of temporal and spatial variation of air pollutant concentration is also essential (Sehaug *et al*. 1993; Tayanc 2000) and, where necessary, effective mitigative measures including green belts can be devised for sensitive areas (Kapoor & Gupta 1984; NEERI [National Environmental Engineering Research Institute] 1993; Shannigrahi & Agarwal 1996; Sharma & Roy 1997).

The air quality in the Basundhara area of the Ib Valley coalfield, a new coal mining region located in a pollution-free area surrounded by villages, was studied. The conditions are similar to those of all the new and proposed Indian opencast coalmines. The study sought to determine the severity of the level of air pollutants in the mining area relative to the Indian National Ambient Air Quality Standard (NAAQS) protocol (CPCB [Central Pollution Control Board] 1998) and the extent of temporal and spatial variation of particulate matter over a one-year period. A specific objective was to assess the spatial distribution of particulate matter over the Basundhara area by the use of the kriging spatial prediction technique (Sehaug *et al*. 1993; Tayanc 2000). Respirable particulate matter (RPM) being the main focus of concern for human health, this study aimed to help in predicting the RPM concentration by determining the concentration of suspended particulate matter (SPM) for a similar mining site.

STUDY SITE AND METHODS

Study site

Basundhara is located in the Ib Valley Coalfield situated in parts of Jharsuguda, Sambalpur and Sundergarh districts of Orissa state and is operationally under the control of Mahanadi Coalfields Limited, Sambalpur, India (Fig. 1). The Ib River is a tributary of the Mahanadi River. The coal-field has large reserves of coal suitable for power generation and extends over an area of 1375 km^2, the strike line swinging from north-south to east-west in the southern and northern extremes. The geology of the area is mainly in the Lower Gondwana system (Coal India Limited 1993).

The Basundhara area lies in the northern part of the Ib Valley Coalfields in the district of Sundergarh, Orissa. The area consists of two opencast projects, namely Basundhara (East) and Basundhara (West), which produced 0.682 Mt yr^{-1} during 1998–1999. The Basundhara and Chaturdhara Nallahs (streams) and their feeder streams control the drainage of the area.

The climate of the area is dry tropical, and there are four seasons, namely summer (March–May), rainy (June–September), autumn (October–November) and winter (December–February). Meteorological data were from the Jharsuguda Meteorological Station of the Indian Meteorological Department (IMD). During the summer months the temperature can reach 47°C and in winter months can fall to 10°C. Annual mean maximum and minimum temperatures are 33.2 and 20.5°C, respectively. Wind speed in the area varies from 8.2–16.0 km h^{-1} with an average of 11.8 km h^{-1}. The annual calm period (wind speed < 2.1 km h^{-1}) for the area is 50% and 40% of total duration at 08:30 and 17:30 hours, respectively. The predominant wind direction for the area is towards the south-west. The south-west monsoon is the principal source of rainfall in the area, the average rainfall at the Jharsuguda IMD station being 1400 mm yr^{-1} and there being on average 81 rainy days per year.

Figure 1 Location of the study site and sampling stations.

Methods

Sampling and analysis were twice monthly for residential areas (buffer zone) and six times monthly for industrial areas (core zone/mining area) during the year from September 1998 to August 1999. The siting of nine air-sampling stations (two in the core zone and seven in the buffer zone, Fig. 1) was based on prevailing micro-meteorological conditions and availability of infrastructure. Details of sampling stations along with the respective sources of air pollution are given in Table 1. Concentrations of carbon monoxide (CO) and lead (Pb) were below detectable limits or negligible (CMRI 1998). Suspended particulate matter (SPM) including PM10 (particulate matter $<10\mu m$ aerodynamic diameter) or respirable particulate matter (RPM), sulphur dioxide (SO_2) and oxides of nitrogen (NO_x) were sampled by high volume samplers with an average flow rate >1.1 m^3 min^{-1} and having gaseous sample collection attachments. The 24-hr average samples were obtained following the NAAQS protocol of the Central Pollution Control Board, New Delhi (CPCB 1998). SPM and RPM were measured by difference in weight, SO_2 by the improved West and Gaeke method with ultraviolet fluorescence, and NO_x by the Jacob-Hochheiser modified method (Na-arsenic) with gas phase chemiluminescence (Stern 1968). The 24-hr average data measured for all the monitoring stations during one year were statistically

Table 1 Sampling locations and probable sources of air pollution.

Station code	*Location*	*Direction and distance from the centre of the mine (km)*	*Sources of air pollution*
Industrial area (core zone/mining area):			
A1	Mine office	East, 0.43	Overall mine and transportation
A2	Coal handling plant	East, 1.21	Loading, unloading and crushing of coal, transportation, etc.
Residential area (buffer zone):			
A3	Kullapara village	North-east, 1.86	Traffic and domestic
A4	Balbaspur village	West, 5.14	Traffic and domestic
A5	Karlikachar village	South-east, 4.71	Traffic and domestic
A6	Sardega village	North-west, 0.86	Mining and domestic
A7	Tikilipara village	North-east, 1.28	Mining, domestic and transportation
A8	Tollipara village	North-east, 3.00	Mining, domestic and transportation
A9	Bankibahal village	South-east, 2.56	Mining, domestic and transportation

analysed following Ott (1995) and annual averages of the air pollutants were calculated for each station. The 24-hr and annual average concentrations of air pollutants were compared with the NAAQS protocol to determine air quality status. The monitoring stations were grouped into six categories by comparing the percentage of SPM or RPM concentration with the respective standard limit for each particular area. The categories of SPM or RPM concentration with respect to the relevant standard limit were: very good (0–50%), good (>50–75%), fair (>75–100%), poor (>100–125%), very poor (>125–150%) and dangerous (>150 %). The temporal and spatial variation in particulate matter was analysed to establish the seasonal trend by using polynomial regression analysis to obtain the best fit (Tayanc 2000). Kriging, the optimum interpolation technique (Delfiner & Delhomme 1975; Journel & Hujibregts 1978; Cressie 1991), was used to obtain the spatial distribution of particulate matter over the one-year period, the idea behind kriging being to make inferences from unobserved values of a random process from data observed at known spatial locations (Tayanc 2000). Linear regression analysis was carried out to derive the best fit equation between measured SPM and RPM concentrations and the correlation coefficient.

RESULTS

SPM concentration

Annual average SPM concentrations in the industrial/mining area were 455.2 and 502.0 $\mu g\,m^{-3}$ at the A1 and A2 monitoring stations, respectively (Table 2), and these were both higher than the threshold limit of 360 $\mu g\,m^{-3}$ of the NAAQS protocol (Table 3). The 24-hr average SPM

Table 2 Annual (± standard error) and 24-hr mean SPM and RPM concentrations in the industrial area.

Variable	*Station code*	*Annual mean ($\mu g\,m^{-3}$)*	*24-hr mean ($\mu g\,m^{-3}$)*			*Category*
			Maximum	*Minimum*	*95th percentile*	
SPM	A1	455.70 (± 63.08)	565.7	312.7	559.2	Very poor
	A2	502.07 (± 46.74)	598.4	402.6	593.7	Very poor
RPM	A1	145.47 (± 20.57)	186.9	100.2	182.6	Poor
	A2	164.47 (± 14.11)	199.6	130.8	194.6	Very poor

Table 3 National ambient air quality standards (1994) for sulphur dioxide, oxides of nitrogen, and respirable and suspended particulate matter (CPCB 1998). * Annual arithmetic mean of 104 measurements in a year, twice a week, 24 hourly at uniform interval; and ** 24 hourly or 8 hourly values should be met 98% of the time in a year. However, 2% of the time values may be exceeded, but not on two consecutive days.

Pollutant	*Time weighted average*	*Concentration in ambient air ($\mu g\,m^{-3}$)*		
		Industrial area	*Residential, rural and other areas*	*Sensitive area*
SO_2	Annual average*	80	60	15
	24 hours**	120	80	30
NO_x	Annual average*	80	60	15
	24 hours**	120	80	30
SPM	Annual average*	360	140	70
	24 hours**	500	200	100
RPM	Annual average*	120	60	50
	24 hours**	150	100	75

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Table 4 Summary of 24-hr average SPM and RPM concentrations exceeding the standard limit.

Station code	*Location*	*Measurements exceeding the NAAQS of 1994 (CPCB 1998)* SPM *Number*	SPM *% of total*	RPM *Number*	RPM *% of total*
Industrial area (core zone)					
A1	Mine office	21	29	29	40
A2	Coal handling plant	38	53	54	75
Residential area (buffer zone)					
A3	Kullapara village	0	0	0	0
A4	Balbuspur village	0	0	0	0
A5	Karlikachar village	0	0	0	0
A6	Sardega village	14	58	0	0
A7	Tikilipara village	14	58	0	0
A8	Tollipara village	10	42	0	0
A9	Bankibahal village	8	33	0	0

concentration ranged from 312.7 μg m^{-3} (A1) to 598.4 μg m^{-3} (A2). The percentage of measurements of the 24-hr average SPM concentration that exceeded the standard limit was 29% (A1) and 53 % (A2) (Table 4).

The annual average SPM concentrations were much higher than the standard limit of 140 μg m^{-3} at monitoring stations A6–A9 in the residential area (categorized ‘poor’), whereas they were below the permissible limit at monitoring stations A3–A5 (categorized ‘fair’) (Fig. 2). The range of annual average SPM concentrations was between 131.2 μg m^{-3} (A5) and 221.2 μg m^{-3} (A7). The 24-hr average SPM concentrations were found to vary between 95.6 μg m^{-3} (A4) and 275.7 μg m^{-3} (A7) in the residential area. The 24-hr average readings never exceeded the standard limit at the A3, A4 and A5 monitoring stations during the study period; however, they did elsewhere, 33% (A9) to 58 % (A6 and A7) of the total measurements exceeding the standard limit (Table 4).

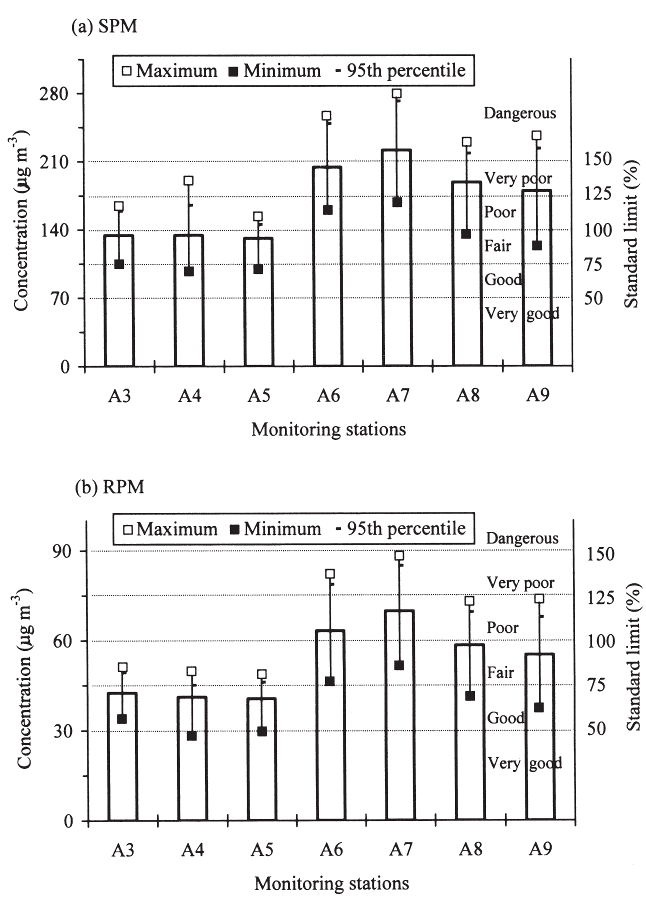

Figure 2 Mean concentrations in the residential area with annual mean, 24-hr mean maximum, minimum and 95th percentile values, and comparison with threshold value for (*a*) SPM and (*b*) RPM.

RPM concentration

The annual average RPM concentrations were more than the prescribed limit of 120 μg m^{-3} at both monitoring stations in the industrial area (Table 2), the A1 monitoring station being in the ‘poor’ category and the A2 station in the ‘very poor’ category. The 24-hr average RPM concentrations ranged from 100.2 μg m^{-3} (A1) to 199.6 μg m^{-3} (A2). The percentages of readings exceeding the 24-hr average threshold limit of 150 μg m^{-3} ranged from 40% (A1) to 75 % (A2) of the total measurements (Table 4).

Annual average RPM concentrations above the threshold limit of 60 μg m^{-3} were found only at monitoring stations A6 and A7 in the residential areas, which were categorized as ‘poor’ (Fig. 2). The A3 to A5 stations were categorized as ‘good’, and the A8 and A9 stations as ‘fair’. Annual average RPM concentrations varied between 40.6 μg m^{-3} (A5) and 69.8 μg m^{-3} (A7). The 24-hr average SPM concentrations ranged from 28.5 μg m^{-3} (A4) to 86.8 μg m^{-3} (A7). The 24-hr average RPM concentrations never exceeded the prescribed limit at the monitoring stations.

Spatio-temporal variation of SPM and RPM

The temporal variations of SPM and RPM fitted a polynomial trend (average correlation coefficient R^2 of 0.67 ± 0.10 for SPM and 0.70 ± 0.11 for RPM; Fig. 3). The correlation coefficient between SPM and RPM was 0.90 (± 0.09). On average, the RPM in the ambient air of the mining area constituted 31.38 (± 0.69)% of the SPM, the best fit equation being $y = 0.3303x - 3.3246$ (correlation coefficient of

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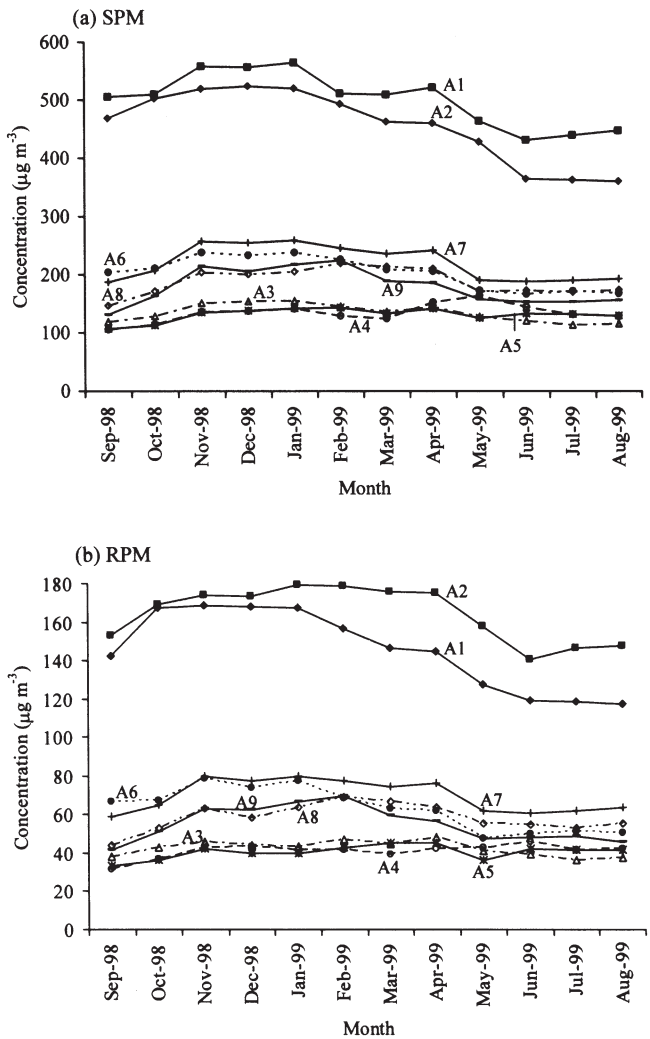

Figure 3 Polynomial regression analysis of monthly average of concentrations for the nine monitoring stations during September 1998 to August 1999 of (*a*) SPM and (*b*) RPM.

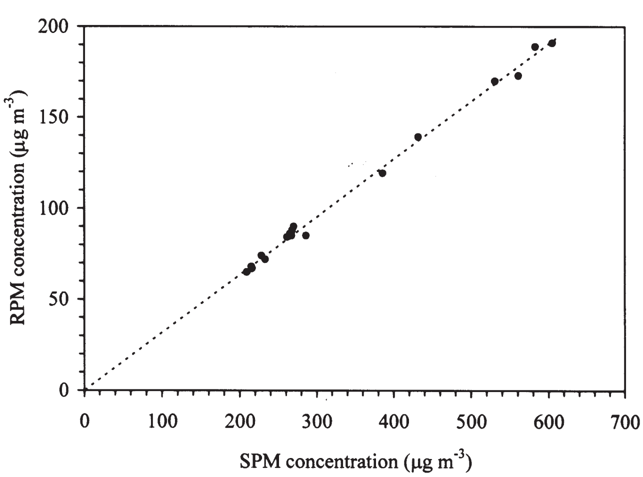

Figure 4 Linear regression analysis of annual average of SPM and RPM concentrations for the nine monitoring stations.

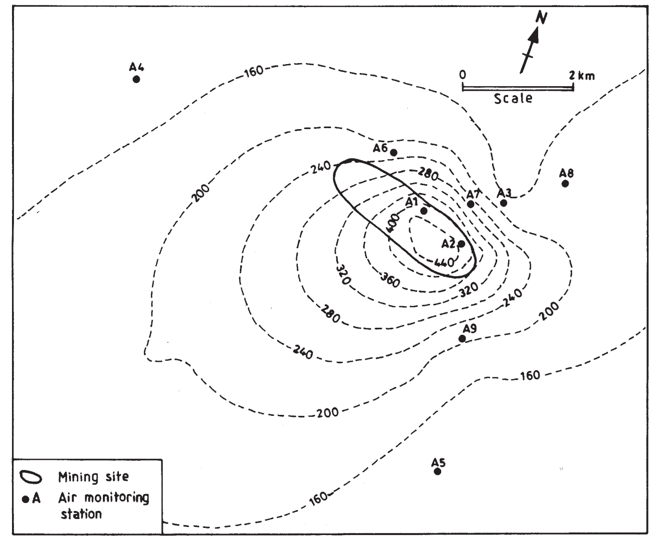

Figure 5 Spatial distribution of annual SPM concentration ($\mu g\,m^{-3}$) over the study area.

0.99; Fig. 4). Linear regression analysis was also performed between concentrations of NO_x and SO_2, and the correlation coefficient of NO_x with SO_2 was 0.52 ($\pm$ 0.31). Transportation of coal was the main source of SPM generation and other sources of air pollutants are given in Table 1. The kriging technique determined that maximum concentrations of SPM (Fig. 5) and RPM occurred within the mining site. The concentrations gradually diminished with increasing distance from the mining site.

SO_2 and NO_x concentrations

The mean annual average SO_2 concentrations among all the monitoring stations ranged between 20 $\mu g\,m^{-3}$ (A3) and 24.3 $\mu g\,m^{-3}$ (A9), being well below the threshold limits of 60 $\mu g\,m^{-3}$ (residential) and 80 $\mu g\,m^{-3}$ (industrial). The 24-hr average SO_2 concentrations were between 15.3 $\mu g\,m^{-3}$ (A8) and 30.8 $\mu g\,m^{-3}$ (A9), well within the standard limits of 80 $\mu g\,m^{-3}$ (residential) and 120 $\mu g\,m^{-3}$ (industrial). The SO_2 in the residential areas derived from open burning of raw coal and other domestic and commercial activities. The annual and 24-hr average NO_x concentrations were found to be well within the prescribed limit at all the monitoring stations, the range of annual average NO_x concentrations lying between 19.7 $\mu g\,m^{-3}$ (A5) and 25.3 $\mu g\,m^{-3}$ (A4). The 24-hr average NO_x concentrations varied from 14.3 $\mu g\,m^{-3}$ (A5) to 33.5 $\mu g\,m^{-3}$ (A7).

DISCUSSION

The concentration of particulate matter (Fig. 3) at most of the monitoring stations reached a maximum during winter and was at its minimum in the rainy season; this is similar to the reports by Soni and Agarwal (1997), CMRI (1999), Ghose and Majee (2000) and Nanda and Tiwary (2001) for

Indian coal mining areas, and Karaca *et al.* (1995) and Tayanc (2000) for Istanbul in Turkey. However, for certain urban areas maximal concentrations of particulate matters are observed in winter (Crabbe 2000; Ferreira *et al.* 2000; Meenalbal & Akil 2000; Almbauer *et al.* 2001). The concentrations of particulate matter at monitoring stations A4 and A5 were inversely related to the temporal trend of other monitoring stations during April–August 1999 as a result of a change in the domestic activities near these monitoring stations at the time. The strong correlation between SPM and RPM indicates that the concentration of RPM, which is the main concern for human health effects (Wheeler *et al.* 2000; Baldauf *et al.* 2001), would be well estimated for any opencast coal mining area with similar conditions, by knowing the SPM concentration. Coal transportation was the main source of SPM generation (as reported by Sinha & Banerjee 1994; Sinha 1995; Soni & Agarwal 1997; Ghose & Majee 2000).

The annual and 24-hr average SPM and RPM concentrations were compared with the national ambient air quality standards (health related) of the USA (USEPA [US Environmental Protection Agency] 1992). The annual average SPM concentrations were higher at all the monitoring stations than the USEPA prescribed limit of 75 $\mu g\,m^{-3}$, whereas only at monitoring stations A1 and A2 did the 24-hr average concentrations exceed their standard limit of 260 $\mu g\,m^{-3}$. Annual average RPM concentrations were within the threshold limit of 50 $\mu g\,m^{-3}$ at A3, A4 and A5 stations. The 24-hr average RPM concentrations were higher than the USEPA standard limit of 150 $\mu g\,m^{-3}$ at A2 throughout the monitoring period and at A1 only during October 1998–February 1999. Annual and 24-hr average concentrations of SO_2 and NO_x were well within the USEPA standard limit at all monitoring stations.

Maximal concentrations of SPM and RPM found in the mining area, and levels gradually diminished with increasing distance due to transportation, deposition and dispersion of particles (Ermak 1977; Horst 1977; California Department of Transportation 1979; Hanna *et al.* 1982; Chaulya *et al.* 2001). The dispersion of particulate matter tended to be towards the south-west, which followed the annual predominant wind direction of the area (Chaulya *et al.* 1998; Corti & Senatore 2000; Baldauf *et al.* 2001). Concentrations of SO_2 and NO_x were far below the NAAQS at all the monitoring stations. Therefore, there is a need to control and manage air pollution in the residential areas surrounding the mines, where the people are directly exposed to a high SPM concentration throughout the year. The findings of this study may also be applied to other similar mining areas located in India and abroad.

Management strategy

The air quality of the Basundhara area has deteriorated and implementation of effective control measures is needed. Apart from the regular environmental control measures adopted by the mining company, a few additional measures might aid the control of air pollution at vulnerable sites (Table 5). CMRI (1999) provide details of control measures and the technical reasons for the recommendation of a particular measure for a specific site. Truck loading restrictions and regular road cleaning are essential in order to control dust pollution from transportation, together with regular water spraying on roads. At almost all locations, the sprinkling system was observed to be faulty. Regular maintenance/repair of the sprinkling system and construction of a more effective sprinkling system, along with application of a binding agent on the unpaved roads, are essential. In addition, unpaved roads should be converted to black-topped roads, with regular maintenance/repair of roads and the imposition of speed limits on trucks and other vehicles. Biological reclamation of overburden dumps and wastelands is also essential. Effective control measures at the coal handling plant, excavation area and overburden dumps should also be implemented to mitigate the SPM emissions at source.

Table 5 Suggested mitigative measures at different locations of Basundhara area. R1: check/stop overloading of trucks/dumpers; R2: use covered transportation; R3: regular cleaning of roads; R4: remote control sprinkler system on haul road and transport road; R5: effective use and maintenance of sprinkler system; R6: arrangement for additional sprinkler system; R7: regular maintenance of all heavy earth moving machinery and other machinery; R8: vehicular emission norms to be strictly enforced; R9: all major roads to be metalled and properly maintained; R10: application of chemical binder in the haul road; R11: regular watering on haul road, transport road and other roads; R12: mechanical dust aerators/collectors to be installed wherever possible; R13: crushers of coal handling plants to be enclosed and dust control equipment should be deployed; R14: old inactive overburden dumps to be properly reclaimed and revegetated biologically using both grass and plant species; R15: active overburden dumps to be properly wetted to avoid wind erosion; and R16: implementation of greenbelt around different mining activities.

Station code	*Location*	*Additional recommended control measures*
A1	Mine office	R1–R11, R16
A2	Coal handling plant	R1–R13, R16
A3	Kullapara village	R3, R8, R9, R11
A4	Balbaspur village	R3, R8, R9, R11
A5	Karlikachar village	R3, R8, R9, R11
A6	Sardega village	R1–R3, R8–R11, R14, R15
A7	Tikilipara village	R1–R13, R16
A8	Tollipara village	R3, R7–R11, R16
A9	Bankibahal village	R3, R8, R9, R11

A new approach in recent years has involved the growth of green plants in and around the source of pollution. A green belt is the mass plantation of pollutant-tolerant trees (evergreen and deciduous) for the purpose of mitigating the air pollution in an effective manner by filtering, intercepting and absorbing pollutants (Sharma & Roy 1997). The capacity of plants to reduce air pollution is well known (NEERI 1993; Sharma & Roy 1997; Shannigrahi & Sharma 2000). Optimum green belt development, including factors such as distance of green belt from source, width of green belt and height of green belt, may be achieved using an existing green belt attenuation model (Kapoor & Gupta 1984; Chaulya *et al.* 2001). The likely effectiveness of a green belt in attenuating the pollution is given by the attenuation factor, which is defined as the ratio of mass flux reaching a particular distance in the absence of the green belt, to the mass flux reaching the same distance in the presence of the green belt (Kapoor & Gupta 1984). However, the selection of tree species that can be grown around a mining site is very important. Plants differ considerably in their responses towards pollutants, some being highly sensitive and others hardy and tolerant (Singh & Rao 1983; Shannigrahi & Agarwal 1996; Chaulya *et al.* 2001).

Few plant species can be grown around highly polluting sources in areas where dust (SPM) is the main pollutant; it not only reduces air pollution, but also retards water and soil contamination. The green belt can help to control and check the dust on the surface, the leaves and bark, and can also tolerate SO_2 and NO_x (gaseous pollutants) effectively (Sikarwar *et al.* 1998). India has a host of varieties of plant species that, if planted, would probably serve locally to lower atmospheric SPM, SO_2 and NO_x. Dust attenuating plant species should be used to develop green belt (Chaulya *et al.* 2001).

CONCLUSIONS

SPM and RPM were the major sources of emission from various opencast mining activities, whereas emissions of SO_2 and NO_x were negligible. The annual average concentrations of SPM and RPM were higher than the NAAQS both at monitoring stations in the mining area and a few places in the residential area. In opencast coal mining areas with similar conditions, the linear regression of SPM with RPM may be used to predict the concentration of one type of particulate matter by knowing the level of the other. With the implementation of additional control measures at appropriate sites, the air quality in the study area could be brought within the national ambient air quality protocol threshold limit. This would lead to more eco-friendly mining and a better habitat for all those living in the area.

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