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Kriging Interpolation Approach for Monitoring of Ambient Air Quality in Opencast Iron Ore Mining Region of Keonjhar District, Odisha, India

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Abstract

Joda- Barbil region of the Keonjhar District, Odisha is blessed with vast natural resources especially, high-grade iron and manganese ore deposits, due to which it has occupied a vital position in the mineral map of India. Mining of minerals resources is an important commercial activity indispensable for the economic development of a nation. Opencast iron ore mining and other ancillary activities influence the adjoining ecology and environment. Numbers of environmental issues are arising due to unscientific widespread opencast mining activities and have a direct impact on other natural resources like land, water, soil, air, flora and fauna. Ambient air gets severely affected due to the addition of fugitive dust and other pollutants directly or indirectly at every stage of mining activity starting from exploration, exploitation and mineral beneficiation. All forms of pollutants reduce the ambient air quality and enhance the health risk of the people living nearby villages. Increasing air pollution levels in the mining region can have immediate effects on the health of indigenous community and also on flora. A Kriging interpolation method has been applied to monitor the ambient air quality in opencast iron ore mining region of Keonjhar district. This practice is very useful for sustainable and eco-friendly mining as it is cost-effective and time-saving techniques and can interpret the spatial dispersion of pollution levels in un-sampled regions. Kriging interpolation analysis revealed that the ambient air quality level during the year 2005 to 2008 were high around Barbil, Thakurani and Noamundi.

Keywords: Ambient Air Pollutants, Opencast Mining, Kriging Interpolation, Keonjhar District

Introduction

Keonjhar district of Odisha is blessed with vast natural resources especially, high-grade iron and manganese ore deposits, due to which it has occupied a significant position in the mineral map of India. The ample deposits of iron and manganese ores of the district are mainly confined in the Jamda-Koira valley, as a part of Banded Iron Ore Formation of famous horseshoe synclinorium belt of north Odisha and adjoining areas of south Jharkhand (Jones, 1934). Owing to its specific nature of high-grade iron and manganese ore, favourable geologic condition, cheap availability of skilled labour and easy accessibility of water along with other natural resources, this region became the mining hub of the district. By virtue of the above-described conducive environment, many Indian and overseas iron and steel manufacturers company have been given priority to this piece of land for setting up their beneficiation plants. Number of large-scale intensive mining activities is in process in this region to maintain the balance between demand and supply of raw materials needed for steel production.

Mining of minerals is an important commercial activity, as it is essential for the economic development of the region, state and nation (Behera, 2017; Chaulya *et al*., 2019). Simultaneously, it generates numerous environmental problems by adding fugitive dust to the ambient air at every stage of its activities starting from exploration, exploitation and mineral beneficiation (Chaturvedi and Patra, 2016; Chaulya *et al*., 2019). Mining and its allied activities are the sources of air pollution in the mining areas (ELAW, 2010; Singh *et al*., 2010; Chaulya *et al*., 2019). As a result, mining of minerals and ores turns into a contentious issue over the past few decades. The local environment and ecology get deteriorated due to rampant and unscientific mining which directly influence the nearby natural resources like land, water, soil, air, flora and fauna (Nanda and Tiwary, 2001; Ahmad *et al*., 2014; Singh *et al*., 2017; Chaulya *et al*., 2019). Usually, mining is site-specific activity and, in particular, the opencast mining is a composite system of operation where exploration, excavation and mineral processing are carried out simultaneously (CPCB, 2007; Behera, 2017). The status of air pollution of a regain due to mining and its ancillary activities also depends on various meteorological parameters such as precipitation, temperature, wind speed and direction and state of atmospheric condition (Gowda, 2016; Chaulya *et al.*, 2019). In the mining region, suspended particulate matter is only the dominant pollutants over the vehicular emission where, gaseous contaminants are involved (Almbauer *et al.*, 2001).

At present around 118 mines are in operation in the Bonai-Keonjar belt of North Orissa and adjoining areas of Jharkhand in the southern part of the Singhbhum Craton. Out of which only 48

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working mines are present in the study area. Incidentally, most of the mines are located within the thick forest and hilly terrain. Minerals of the region are being exploited by the opencast mining method because at many places ores are exposed to surface or found at shallow depth and act as a blanket deposit. Since 1927 opencast mining activities started in the Joda-Barbil area and gradually cumulated year by year causing various types of environmental problems. Therefore, mining-related activities in the region affect the local inhabitants due to air water and soil pollution. All forms of pollutants reduce the quality of air and enhance the health risk of the people in the surrounding village. Rising of air pollution level in mining sectors can have immediate effects on the health of local people as air contains free silica and respirable particulate matter which causes lung diseases, allergy and asthma (Kumar and Kumar, 2015; Dadhich *et al.*, 2018). Exposure to airborne particulate in the atmosphere leads to the increasing premature mortality and range of inflammatory illnesses and morbidity through the respiratory disease (Hopke, 2009; Sneha *et al.*, 2012; Patra *et al.*, 2021). Air pollution also influences the flora and fauna by reducing the photosynthesis processes which lower down the reproduction capabilities and productivity (Nanda and Tiwary, 2001). Therefore, it is high time to control the air pollution in the mining region as air loaded with free silica and respirable particulate matter for which flora and fauna suffer from several health problems (Kumar and Kumar, 2015; Chaulya *et al.*, 2019). So, this paper has attempted to address the mining-related air pollution due to dispersion of airborne particulate matter in and around the habitats located in the mining sector of the Keonjhar district.

Study Area

Joda-Barbil region is a part of Champua sub-division in Keonjhar district of Odisha which features in the Survey of India Toposheet No. 73F/8. The study area is bounded by latitude $22^{\circ}\,00^{\prime}$N to $20^{\circ}\,10^{\prime}$N and longitude $85^{\circ}\,15^{\prime}$E to $85^{\circ}\,30^{\prime}$E (Fig.1). This region is represented by rugged topography which exhibits the scenic beauty of hills, hillock, thick greenery. Joda-Barbil region is an important mining hub of Odisha and around 118 numbers of opencast mines are in operation under the jurisdiction of Joda mining circle. Around 48 mines are working within the study area which directly influences the other environmental parameters.

Joda is about 75 km and Barbil is about 80 km on road from Keonjhar town. The NH 215 connects these areas with Keonjhar town. The nearest railway station is at Barbil that linked with Tatanagar under SE railway. Thus, the area is well connected with other important cities of Odisha as well as India. Because of mining and industrial activities, network of roads has been laid down in the area.

Materials and Methodology

Data Collection

Air samples were collected from a selective location by the help of High-Volume Air Samplers (HVAS) during the study period. At the time of sampling, CPCB guideline has been followed and measured the SPM, RPM and other gaseous pollutants like SO_2 and NO_2. Pre-weighted rubber cup and glass fiber filter of Whatman were used for the collection of SPM and RPM concentrations respectively after running the HVAS for 24 hrs as per the NAAQS guideline of the CPCB (2003). SO_2 and NO_2 were collected by bubbling the samples in a specific absorbing solution (sodium tetra chloromercurate for SO_2 and sodium hydroxide for NO_2. The recovered samples were placed inside the iceboxes soon after sampling and shifted to a refrigerator and preserved until analyzed.

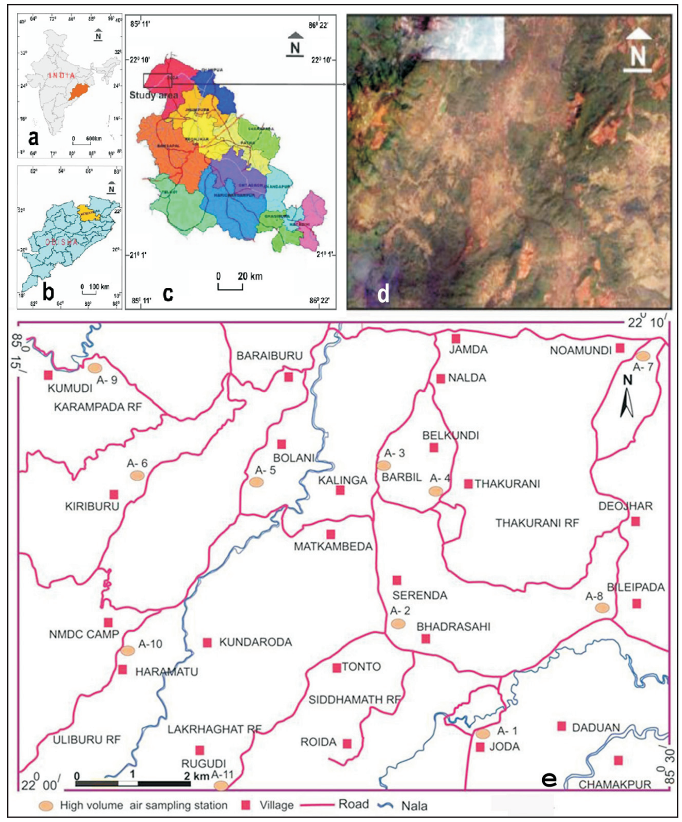

Fig. 1 a-d. Map showing location of the study area (*after* Behera, 2017). e. Location map of air sampling points

Selection of Air Sampling Points

The selection of air sampling points is very important (Chaulya, 2005) as the concentrations of pollutants are influenced by factors like distribution of emitters, pathway and the receptors of dust. As the mining activities are enclosed all parts of the study area including the dense forests, it was decided to collect air samples from various locations *viz.* active mining area, blasting site, drilling site, loading points, transporting site, haul roads, crushing and screening points, residential areas and dense forest areas to note the variations if any. A total of eleven numbers of sampling points were selected within the study area on the basis of prevailing meteorological conditions, available infrastructure facilities, terrain condition, pathway and the receptors of dust and distribution of emitters. Air sample was collected once in a month in the residential area and twice in a month in the mining/industrial area during the period 2005 to 2008. During the sampling period the HVAS were kept on the rooftop of single storied house approximately at a height of 3 m above the ground, at all the monitoring stations. A constant height was maintained for a particular monitoring station throughout the study period.

The detail information of the locations is provided as the air sampling points (Fig. 1e; Table 1). At the time of sampling extensive mining activities were going on and there was heavy traffic density.

Table 1: Details about air quality monitoring stations of Joda-Barbil region

Name of the Location	Index	Latitude/ Longitude	Source of Pollution
Joda	A-1	22°1'11"N; 85°25'31"E	Industry and Transportation
Bhadrasahi	A-2	22°3'25"N; 85°23'36"E	Transportation
Barbil	A-3	22°6'57"N; 85°23'22"E	Transportation (buffer zone)
Thakurani	A-4	22°6'18"N; 85°25'00"E	Mining and transportation
Bolani	A-5	22°6'45"N; 85°20'17"E	Mining and transportation
Kiriburu	A- 6	22°6'55"N; 85°17'56"E	Mining and transportation
Noamundi	A-7	22°9'14"N; 85°29'23"E	Mining and transportation
Bileipada	A- 8	22°3'46"N; 85°28'38"E	Transportation (buffer zone)
Kumundi	A- 9	22°9'07"N; 85°16'35"E	Transportation (buffer zone)
Harmatu	A- 10	22°3'53"N; 85°17'19"E	Transportation (buffer zone)
Rugudi	A- 11	22°0'16"N; 85°19'26"E	Transportation (buffer zone)

Thousands of trucks/ dumpers were transported the lumpy/fine iron and manganese ores on various haul roads without covering the loads/materials. Almost all the sampling stations were close to the transport roads. The road condition was very miserable and the metal cover was virtually removed. There were numerous potholes of various sizes all along the roads. No water sprinkling system or other precautionary measure was being taken neither by the transporters nor the mining companies to suppress the emitted dust. Salient points about the sampling stations *viz.* distance from mines, probable sources of air pollution and activities during the sampling are mentioned in Table 1.

The collected data from various locations during 2005 to 2008 represents the ambient air quality of the study area (Table 2).

Kriging

Kriging is geostatistics based famous spatial assessment method (Krige, 1951). It has multidisciplinary and extensive applications in the field of mining engineering, geology, mathematics and statistics, environmental assessment of sites and geographical mapping, *etc* (Deutsch and Journel 1998). Krige (1951) first applied this technique in the Rand gold deposit, in southern Africa. Subsequently, Matheron (1963) developed this Kriging technique in France (Guo *et al.*, 2007). This is very effective in predicting the possibility of unobserved spatially distributed variable such as a mine grade (Krige, 1951), a soil characteristic (Webster, 1985), rainfall (Bacchi and Kottegota, 1995), gene frequency (Piazza, *et al.*, 1981), or image sequence

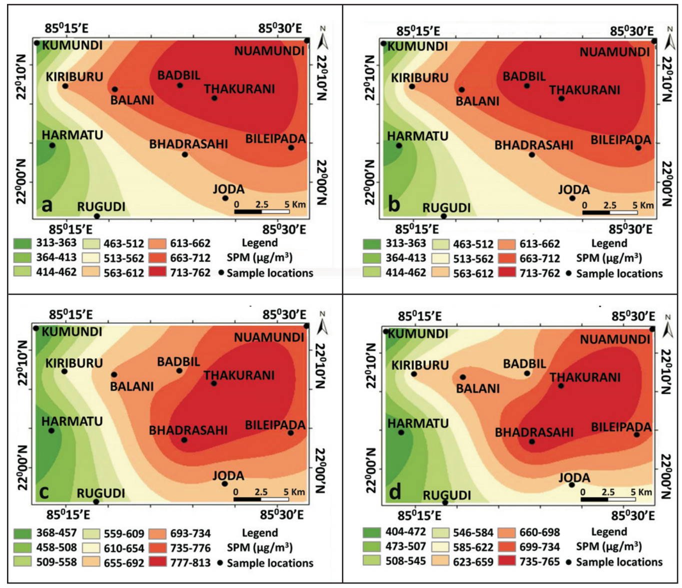

Fig. 2. a. Dispersion pattern of SPM during the year 2005, b. during the year 2006, c. during the year 2007, d. during the year 2008

coding (Decenciere *et al.*, 1998). This method provides an impartial estimation of unknown locations by reducing the estimation variance (Sukkuea and Heednacram, 2022; Mallik *et al.*, 2022). However, geostatistics based Kriging technique offers an interpolation method to estimate the random sampling data at unobserved stations from the observation of values at known locations (Sharma *et al.*, 2018; Jain *et al.,* 2021). The objective is to consider the observations as an understanding of a random spatial process (Bayraktar and Turalioglu, 2005). In the present study, Interpolation Kriging has been applied to develop spatio-temporal variation contour maps of ambient air pollutants in the opencast iron mining area of Joda-Barbil region (Fig. 2-5 a-d).

Results and Discussion

The spatial distribution of particulate matter (SPM and RPM) in the iron ore mining region exceeds the permissible limit at most of the monitoring stations. This condition was persisted round the year except rainy season during the study period from 2005 to 2008.

Table 2: Ambient air quality data (in μg/m^3) for the period from 2005-2008

Year of Sampling	Pollutants	Locations										
		A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8	A-9	A-10	A- 11
2005	SPM	580.3	605.3	752.3	758.8	677.0	619.3	686.5	698.3	311.8	346.8	488.5
	RPM	265	333	275	306	307	257	280	284	159	209	299
	SO_2	29.3	35.3	31.0	33.8	31.5	33.3	33.0	31.5	20.8	31.3	32.3
	NO_2	31.0	39.5	33.3	31.8	30.3	32.0	34.8	32.3	20.8	31.3	34.5
2006	SPM	614	812	648	783	694	645	726	730	344	387	530
	RPM	292	388	285	310	319	278	305	308	179	237	336
	SO_2	31.8	42.3	33.8	35.0	33.3	36	36.5	34.5	21	32.3	36.5
	NO_2	31.3	42	33.8	35.3	32	36.3	36.8	34.8	19.8	32.3	36.3
2007	SPM	637	817	669	809	711	677	755	758	362	402	544
	RPM	316	414	303	321	328	297	322	323	179	237	336
	SO_2	32.3	46.5	36.3	37.3	34.8	35.8	37.8	37.3	21.5	34.8	37.3
	NO_2	33.0	44.8	35.8	37.8	34.0	34.0	40.3	36.8	18.8	33.3	37.5
2008	SPM	682	847	685	834	730	702	789	816	381	432	554
	RPM	239	432	318	326	332	307	342	343	187	253	340
	SO_2	33.8	48.8	39.5	38.8	36	38.3	40	38.8	20	33.5	38.8
	NO_2	34.8	45	37.5	41	36	36	41.8	38.5	20.3	34	38.5

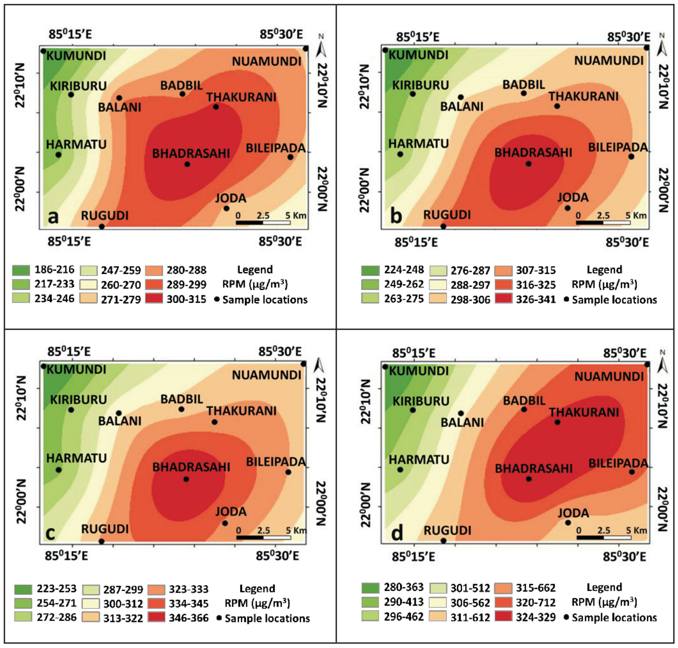

Fig. 3a. Dispersion pattern of RPM during the year 2005, b. during the year 2006, c. During the year 2007, d. during the year 2008

Similar situation has also been found in most of the Indian coal mines as reported by the various workers (Chaulya, 2004; Nanda and Tiwary, 2001; Ghose and Majee, 2000). The average monthly production of iron ore during the study period was roughly uniform. Thus, the temporal or seasonal variations of ambient air quality in the study region may be related to meteorological parameters (Chaulya, 2004). Iron ore transportation was the major source of generation of particulate matter as recorded by different researchers (Chaulya *et al.*, 2019; Kumar and Kumar, 2015; Chaulya, 2006; ELAW, 2010; Singh *et al.*, 2010; Trivedi *et al.*, 2010). The highest concentration of particulate matter was noticed in the active mining region and slowly reduced towards periphery due to dispersion, deposition and transportation of particles as reported by various workers (Khazini *et al.*, 2022; Chaulya, 2004; Chaulya *et al.*, 2002; Ermak, 1977).

Kriging interpolation maps revealed that the ambient air quality level during the year 2005 to 2008 was high around Barbil, Thakurani and Noamundi and below the permissible limit around Harmatu and Kumundi (Fig. 2a-d). This is because of extensive mining activities were concentrated around around Barbil, Thakurani and Noamundi as compare to Harmatu and Kumundi. It was also found that the increasing level of pollution was within a NNE and SSW trending zone in the eastern part of the study area. This trend roughly corresponds to the geomorphologic trend of the valley where there were large number of active mechanized, semi-mechanized and manual mines were in operation. The road network present in these valley regions was occupied with heavy traffic and used for ore transportation. It was observed in all the Kriging interpolation maps (Fig. 2-5a-d) that the level of air pollution gradually decreases towards Harmatu and Kumundi as these villages are away from active mines region. The reasons of the low level of air pollution in the western part of the study area may be due to the fact that only a few small mines were being operated and the roads are rarely used for transportation of iron ores.

Conclusions

The exploitation of mineral resources is indispensable for the economic development of a nation. However, mining and its allied activities affect the local ecology and environment and generate different environmental issues. Rampant and unscientific mining activities have a direct impact on natural resources like land, water, soil, air, flora and fauna. Ambient air gets severely affected due to the addition of fugitive dust and other pollutants directly or indirectly at every stage of its activities starting from exploration, exploitation and mineral beneficiation. All forms of pollutants reduce the ambient air quality and enhance the health risk of the people in surrounding village. Rising of air pollution level in mining

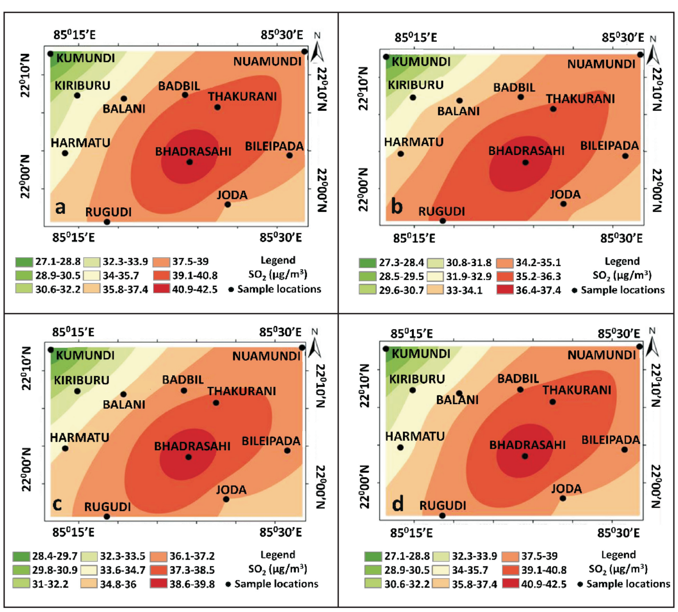

Fig. 4a. Dispersion pattern of SO_2 during the year 2005, b. during the year 2006, c. during the year 2007, d. during the year 2008

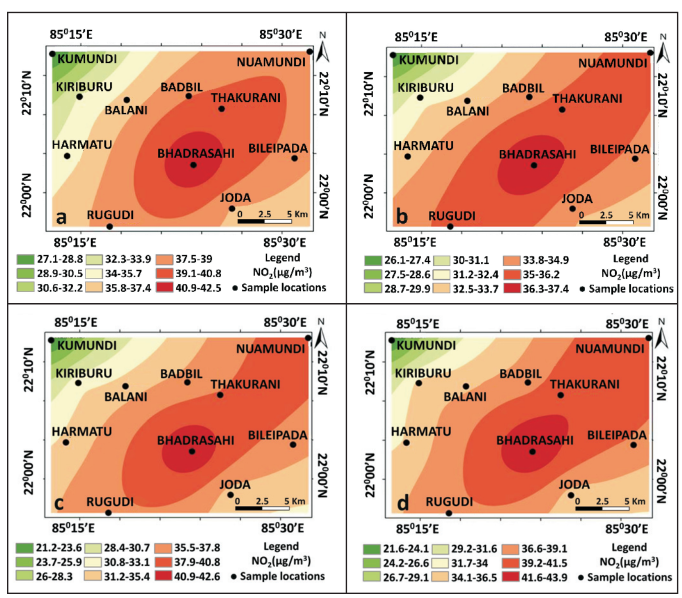

Fig. 5a. Dispersion pattern of NOx during the year 2005, b. during the year 2006, c. during the year 2007, d. during the year 2008

sectors can have immediate effects on the health of local people and also on flora. For sustainable and eco-friendly mining, it is essential to monitor the ambient air pollution at different locations very regularly. Frequent and regular assessment of air quality in various location is time consuming and expensive. The integrated approach of geo-statistics and Kriging Interpolation not only minimize the cost and time of sampling and analysis but also helps in deciphering the spatial spread of pollution levels in un-sampled regions. Therefore, Kriging Interpolation technique can be effectively used in the study of spatial-spread of air pollution in the study region. However, the intensity of mining activities and other meteorological parameters which influence the air pollution are being dynamic in nature. Hence, the periodic air sampling is necessary to keep the data update. For comprehensive and precise result multi point monitoring of air pollution is essential in varying conditions.

Conflict of Interest

Authors declare no conflict of interest.

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