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Estimation of Assimilative Capacity of the Airshed in Iron Ore Mining Region of Goa

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Abstract

The assimilative potential of the atmosphere entails the capacity of the atmosphere to accept and dissipate the pollutant discharge without exceeding the standard limits. The evaluation of assimilative potential is important because it is a useful tool for the area-based management of air pollution and to mitigate the pollution level. The assimilative potential of the atmosphere can be represented in two ways: one as the ventilation coefficient and the other as the dispersion potential of emission loads discharged into the region. The ventilation coefficient is directly proportional to the assimilation potential of the atmosphere and can be computed using meteorological parameters. In the second approach, the assimilative capacity can be estimated in terms of permissible emission load that is the difference between the permissible and the existing pollutant concentration levels. The existing concentration levels can either be monitored or predicted using an appropriate dispersion model. For this study the assimilated potential of the atmosphere was estimated in terms of potential pollution load by comparing the predicted concentration of PM_{10} at 14 discrete receptor points using the American Meteorological Society EPA Regulatory Model (AERMOD) dispersion model. The investigation clearly inferred that, the area under consideration has a fair assimilative capacity.

Keywords: AERMOD, Dispersion Model, PM_{10}, Predicted Concentration

1. Introduction

Mining and industrial activities positively contributes to local and national economy as well as metamorphoses the social spectrum. However, these activities also have detrimental effects on all the environmental regimes in the area. The scenario of environmental degradation, especially, air pollution is most severe in open cast mining areas. Particulate matter is the most abundant and most emitted air pollutants in mines[1,2] having a similar chemical composition as that of re-suspended particles around the mines[3]. The major sources of atmospheric emissions from open-cast mining as a dominant industrial activity include land clearing, removal of overburden, vehicular movement on the haul roads, excavation, loading and unloading of the ore materials as well as overburden. Dust emanating from haul roads contributes considerably to the particulate matter content in the atmosphere. These pollutants reduce air quality and affect human health severely. Human exposure to such small airborne particles may be a cause of a number of respiratory and cardiovascular ailments. The communities which are usually found to be developed in close proximity to mining regions are most affected to the particulate matters arising due to mining activities. Apart from these, the most prominent sources of particulate matter exposure to humankind is transportation activities. In transportation routes, the concentration of pollutants generally observed high due to exhaust as well as non exhaust emission. Transportation of materials is the main source of Total Suspended Particulate (TSP) matters generation in the mining area[1,4–6]. Maximal concentrations of TSP and PM_{10} are found in a mining area and the concentrations are gradually diminished with increase in distance due to transportation, deposition and dispersion of particles[7–11]. The dispersion of particulate matter follows the

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annual predominant wind direction of an area[12–14]. The deterioration of air quality in transportation routes is of particular concern due to high pollutant concentration and large exposure time.

The current interest in atmospheric particulate matter is primarily due to its wide spread effect on human health[15–19], reduced visibility; which on a global scale affects the radioactive balance of the earth[20] and also its significant role in climate change[21]. Owing to its pervasive consequences, air pollution has become a subject of grave concern, particularly in mining, industrial and urban areas, where the situation is alarming. This necessitate careful urban as well as industrial planning which is a vital prerequisite to minimize the adverse environmental impacts and becomes especially important when the industries are polluting in nature. Planning includes the selection of appropriate setting of polluting industries, which may be the most crucial step. For the selection of appropriate site and the preparation of adequate plans; careful assessment of the assimilative potential of the region is a prerequisite, so that the receiving environment is least affected.

The focus of this study is to estimate the assimilative potential of the atmosphere in the iron ore mining region of Goa. The State of Goa (India) is well known for its iron and manganese ore production. The iron ore is predominantly mined by opencast mining throughout in the State, which is of poor quality (40-50% Fe) with a stripping ratio of 1:2 to 1:3, resulting in voluminous stacks of overburden dumps. Removal of overburden to access the ore can pose major problems in its storage, handling and reclamation[22].

2. Assimilative Potential

The assimilative potential of the atmosphere entails the capacity of the atmosphere to accept and dissipate the pollutant discharge without exceeding the standard limits[23]. This can be an important tool for suggesting the safe limits of disposal of pollutants for industrial operations as well as for the area-based management of air pollution and to mitigate the pollution levels. The assimilative capacity of the atmosphere may be examined either using ventilation coefficient or by estimating pollution potential using air pollution dispersion models[23].

The assimilative potential of the atmosphere can be represented in two ways: one as the ventilation coefficient and the other as the dispersion potential of emission loads discharged into the region. The ventilation coefficient is defined as the rate at which the air is transported within the Convective Boundary Layer (CBL)[24]. It is directly proportional to the assimilation potential of the atmosphere. It is a crucial factor in the dispersion of air pollutants and determines the dispersal potential of pollutants over a region of interest. The ventilation coefficient is the product of two meteorological parameters; mixing height and average wind speed through the mixing layers.

$$\text{Ventilation coefficient} = Z_i * U$$

Where, Z_i is the atmospheric boundary layer height (mixing height), m, U the average wind velocity $\left(U = \sum_{i=1}^{i=Z_i} U_i\right)$ in the mixed layer, ms^{-1}.

In the second approach, the assimilative capacity can be estimated in terms of permissible emission load that is the difference between the permissible and the existing pollutant concentration levels. The existing concentration levels can either be monitored or predicted using an appropriate dispersion model. This approach has some advantages over the previous one, because the ventilation coefficient can only represents the dispersion potential of the region in terms of low, medium or high. This representation does not give any idea about the amount of emission load that can be assimilated in the region without exceeding the standard limits prescribed by various standardizing authorities World Health Organization (WHO), US Environmental Protection Agency (EPA) and Central Pollution Control Board (CPCB). This approach was used by Goyal, and Rao, for air assimilative capacity-based sitting of new industries in Kochi region, India[25].

3. Study Area

Goa is a relatively small state which lies between the latitudes 14°53’54” N & 15°40’00” N and longitudes 73°40’33” E and 74°20’13” E with geographical area of 3,702 km^2 and coastline of 105 km (63 miles). The annual rainfall varies from 2,700 mm to 3,500 mm and the temperature varies between 15°C and 33° C. The State Goa accounts to about 13% of the iron ore production in India. Iron ore mining is the major economic activity in Goa and most of the mines are concentrated within five talukas viz. Bicholim, Sattari, Dharbandora, Sanguem and Quepem. The study area comprising 1513 km^2 is situated between 15°16’ to 15°38’N and 73°50’ to 74°17’E. This covers all the areas wherein mining activities in Goa are encompassed along with a belt of five km from the lease boundary in order to provide more focus on the key theme of regional impacts of mining activities on the pristine environmental setting of the region.

4. Micrometeorological Status

The dispersal of air pollutants released in the environment strongly depends on the meteorological parameters like wind speed and prevailing wind direction, variation in temperature, relative humidity and rainfall pattern. The average wind speed recorded during the 1 year period was observed to be 0.64 m/s of which 0.5 - 2.1 m/s were observed in 78.7% of the recorded data. Calm conditions prevailed for 21.03%. The prevalent wind direction accounting for maximum length of time is west. The maximum temperature recorded during study period was found 30°C while the minimum temperature was 11°C. The average relative humidity was found to be in range of 35% to 97%.

5. Methodology

For this study, the assimilative capacity was estimated as a function of the maximum emission load that would be assimilated without adversely affecting the natural environment or ecological integrity of the region. This is the difference between the maximum permissible and the existing pollutant concentration levels. The assimilative potential of the study area was determined by the difference between the permissible National Ambient Air Quality Standards (NAAQS) and the existing pollutant concentration levels at selected sensitive receptors. For this study 14 sensitive receptors were selected with due consideration of the sensitivity of the region as well as population exposure. The existing concentration level at these receptors can either be monitored or predicted using an appropriate dispersion model for the existing sources that contribute to air pollution[25]. The existing concentration levels were predicted using AMS/EPA Regulatory model (AERMOD View 8.1.0). AERMOD is a steady-state Gaussian dispersion model useful for the assessment of different ambient air pollutants concentration from different emission sources (Area, line and point)[26,27]. This incorporates dispersion of air pollutants based on planetary boundary layer turbulence structure and scaling concepts and applicable for both simple and complex terrain. The model is composed of three domains: AERMOD Meteorological Preprocessor (AERMET), AERMOD Terrain Preprocessor (AERMAP) and AERMOD Gaussian Plume Model with the PBL modules. The AERMET processes the hourly surface and upper meteorological data. For this study hourly surface meteorological data was procured from, IMD, Pune and upper air meteorological data was obtained from AERMOD upper air estimator. These meteorological inputs for AERMET were used to calculate boundary layer parameters, such as the Monin-Obukhov length, convective velocity scale, temperature scale, mixing height, and surface heat flux. The second module, AERMAP, is used for processing the terrain data in conjunction with a layout of receptors and emission sources to be used for the AERMOD input files.

5.1 Emission Inventory

For obtaining better insight into the impacts of indistinctly scattered mines along the undulating complex terrain, four clusters were formulated, incorporating in each cluster several mines. The source designation was done based on the type of activity, and emission rate was calculated accordingly. These clusters are shown in Figure 1. Emissions from Cluster operations will result from process equipment and mining operations[28]. Emissions from mining were based upon the mining rate and haul truck travel necessary to transport the ore and waste from the pit to the primary crusher and the waste rock storage area[29]. The formulae used for the calculation of emission rate are depicted in Table 1.

Table 1. Formula for calculation of emission rate for various activities

Activity	Formula
Bulldozing	E=0.75 * (8.44) * S1.5/M1.4 Kg/h (US EPA)[30]
Unloading/Loading (loading: OB, Unloading: OB and ore	E=0.00056 * (U/2.2)1.3/ (M/2)1.4 Kg/T (US EPA)[31]
Transportation	E=0.423 (S/12)0.9 * (W/3)0.45 (1-πr) Kg/VK (US EPA; Cowherd)[32,33]
Loading (ore)	E=0.75 * 0.0596/ M0.9 Kg/T (US EPA; Missouri Department of Natural Resources)[30,34]

M:moisture content(%); s:silt content(%); U:wind speed(m/s); E:emission rate (g/s), W = truck average weight(T), p = average daytime evaporation rate (mm/hm = number of days in the period (days), n = number of rainy days in the period with precipitation levels exceeding 0.254 mm (days)

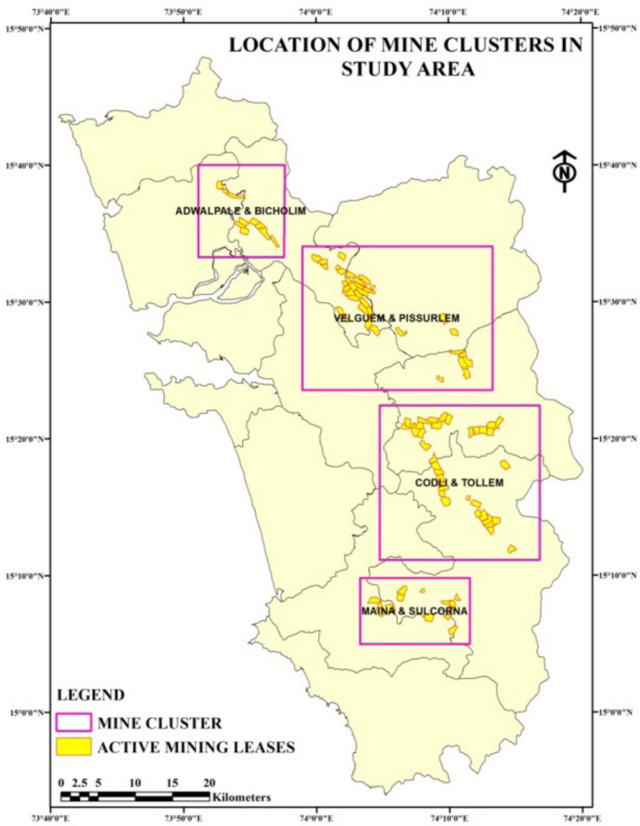

Figure 1. Cluster of mines for the purpose of air quality modeling.

6. Results and Discussion

From the equation the emission rates of PM_{10} were calculated for 62 designated sources in all four clusters. The emission rates were then exported into the model domain as an input. In the model domain the sources were considered as open pit source. The concentration levels of PM_{10} from the model run at different emission loads from all the designated sources were obtained as annual ground level concentration isopleths at different distances from mines, as depicted in Figure 2, Figure 3, Figure 4 and Figure 5. The concentration isopleths represent the contribution of mining activities considering the worst case scenario.

The ground level concentration isopleths depict the spatial pattern of PM_{10} dispersion which is the product of meteorological conditions, topography and emission characteristics. The pattern of spatial distribution of PM_{10} clearly indicates that PM_{10} is present in highest concentration in mines and adjoining areas, and with the increasing distance from the mines the concentration gradually decreases. The sharp decrease in concentration

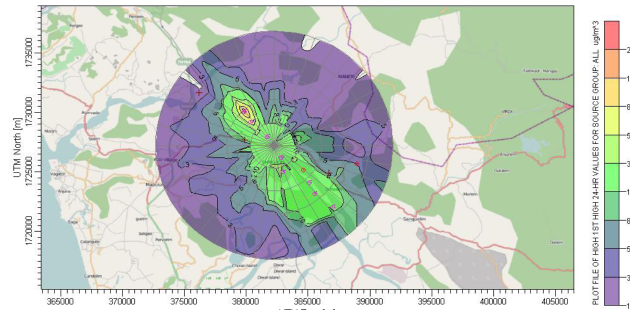

Figure 2. Concentration Isopleths of PM_{10} for Cluster 1.

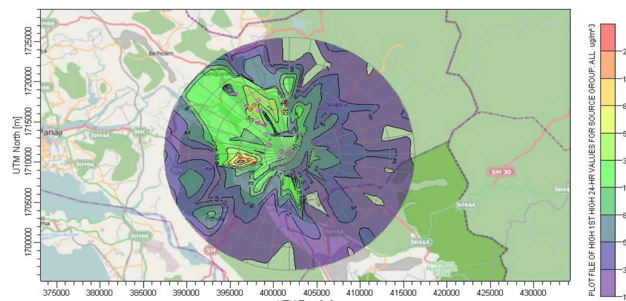

Figure 3. Concentration Isopleths of PM_{10} for Cluster 2.

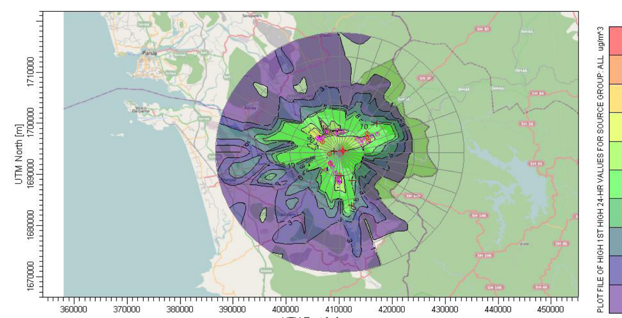

Figure 4. Concentration Isopleths of PM_{10} for Cluster 3.

level substantiates a fair dispersion capacity of the atmosphere. However, it may also be acclaimed to high specific gravity of the particulates arising from iron ore mines, meteorological condition and the undulating terrain of the area, that confine the dispersion of particulates away from mines. The highest predicted concentration might be spatially located at activity point (excavation, loading, unloading, stock piling and hauling). The predicted concentration levels varied from 100-200μg/m^3 in and around the mining clusters but decreased to below standard limit (NAAQS 2009)[35] at about 100s of meters from mines depending upon emission strength, terrain and meteorology. The same result was also conserved by Hanna et al.; Chaulya et al.; Jones et al. and Chaulya[9–11,36]. They concluded that, maximum concentration of TSPM

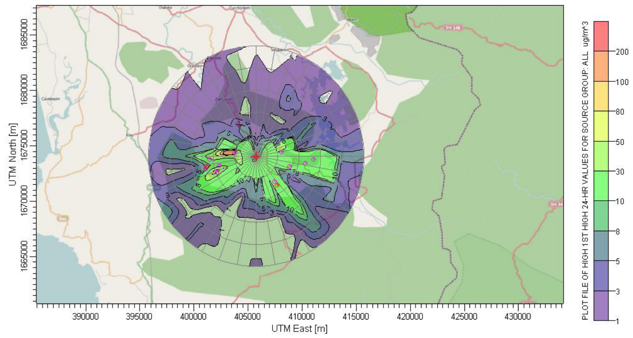

Figure 5. Concentration Isopleths of PM_{10} for Cluster 4.

and PM_{10} were found in mining area and diminishes gradually with increasing distance due to transportation, dispersion and deposition.

The assimilative potential of the air shed in the study area was determined as a function of emission load of PM_{10} that can be dissipated safely without exceeding the permissible standards. The difference between the permissible standard and the predicted concentration level was referred as assimilative potential of the area. For the determination of emission potential, the concentration levels of PM_{10} as a result of mining activities at 14 sensitive receptors were predicted using AMS/EPA dispersion model (AERMOD View 8.1.0).

Available assimilation potential = Permissible standard - Pollutant concentration.

The concentration levels of PM_{10} at all the selected receptors were observed far below the permissible limit (60µg/m^3) as depicted in Table 2. Carmonem was observed with highest concentration of PM_{10}, while Revora Village was observed with lowest. The concentration levels predicted at various receptors are the attribution of distance from mines, production and strength of emission load, local meteorology as well as topographical features. These functions also determine the assimilate capacity.

The highest assimilative capacity was observed as 53µg/m^3 and lowest as 23µg/m^3. From the above estimation, it is evident that the area under consideration has a fair and acceptable assimilative capacity and can further dissipate sufficient pollution load. The fair assimilative capacity of this region might be attributed to good dispersive capacity of the atmosphere. This might also be accredited to the higher specific gravity of the particles and undulating terrain feature of the area, which restricts the mobility of the particles at larger distance from the sources.

However, there are certain limitations of this modeling and simulation procedure. The most significant one is the exclusion of background sources of pollution and emissions due to vehicular traffic, which contributes

Table 2. Assimilative potential of the atmosphere at selected sensitive receptors

Sensitive Receptors	Location		Predicted Concentration (µg/m^3)	NAAQS Standard (Annual) (µg/m^3)	Assimilative Potential (µg/m^3)
	Latitude (East)	Longitude (North)			
Bicholim Town	15°35'57.9"	73°56'34.6"	27	60	33
Revora Village	15°39'35.8"	73°50'41.2"	7	60	53
Tivim Village	15°37'27.7"	73°52'46.3"	24	60	36
Surla Village	15°29'53.0"	74°01'17.4"	16	60	44
Velguem	15°29'56.6"	74°03'13.4"	36	60	24
Amona	15°31'29.3"	74°00'08.9"	29	60	31
Pissurlem Village	15°31'45.4"	74°01'33.1"	13	60	47
Dudal	15°16'28.4"	74°11'04.0"	15	60	45
Ugem	15°13'49.8"	74°10'58.6"	16	60	44
Carmonem	15°19'32.5"	74°09'08.8"	37	60	23
Mollem	15°22'27.5"	74°13'39.4"	18	60	42
Shigao	15°19'51.0"	74°12'18.4"	16	60	44
Curpem	15°07'26.8"	74°11'06.0"	13	60	47
Rivona	15°09'59.6"	74°06'28.3"	35	60	25

significantly to the particulate emissions. Despite of the limitations, it can be inferred that, the region has an endurable dispersive as well as assimilative capacity.

7. Conclusions

The determination of assimilative potential in terms of emission load is a distinctive and valuable tool to depict the maximum concentration of pollutant that can be dissipated in an air shed without much impairment of the air quality. This also entails the potential for industrial development with sufficient mitigation strategies and management plans, as far as air pollution is considered. From the above discussions it can be concluded that, the area has a fair and acceptable, as evidenced by the predicted concentration far below the standards. The highest assimilative capacity of PM_{10} was observed as 53μg/m^3 and lowest as 23μg/m^3 against the annual permissible standard of 60μg/m^3 (NAAQS). The limitations of the study are exclusion of background sources of pollution as well as emissions due to vehicular traffic, which contributes significantly to the particulate emissions. These limitations underestimate the concentration levels up to some extents. Overall, the assimilative potential of atmosphere in the iron ore mining region of Goa was observed endurable. Based on the observations the study strongly recommends the consideration of background sources of pollution as well as emission from vehicular transport into the modeling domain for future studies.

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