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Depreciation in Ambient Air Quality in Iron Ore Mining Region of Goa

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ABSTRACT

Goa is one of the most famous international tourist destinations of the world. Export of Iron ore extracted from the midland of Goa is a major economic activity. However, there is a serious concern of air pollution due to iron ore mining activities. In order to assess the impact of mining activities on the environmental regime, the air quality depreciation index was adopted for this study due to its realistic and meaningful presentation of deterioration in ambient air quality. The index had been applied to the ambient air quality monitoring results of thirty four locations in the iron ore mining region of Goa. To envisage upon the deterioration in air quality due to various activities, eight stations were selected around mines, twelve in the buffer zone (within 4 Km radius of the core mining activities) and fourteen along the ore transportation routes for monitoring of SPM, PM_{10}, SO_2 and NO_X. The deterioration of air quality in the iron ore mining region of Goa is clearly apparent as the depreciation in air quality was found < -1 from the most desired value of 0 at all the stations. In general, the air quality was found most depreciated along the ore transportation routes, which is also evidenced by a considerable load of particulate matters observed. This infers that ore transportation is the most devastating activity in the iron ore mining region of Goa and accordingly mitigation plan should be adopted.

Key words: National Ambient Air Quality Standards (NAAQS), Value function curve, Air quality depreciation index, Iron ore mining.

INTRODUCTION

Iron ore mining is a major economic activity of Goa and it has evolved the economy of the State. Mining and quarrying contributed about 20.4 % of the GDP (gross domestic product) to the state's economy[1]. Mining activities, whether small or large, are inherently disruptive to the environment. The environmental deterioration caused by mining activities occurs mainly as a result of inappropriate and wasteful working practices. The magnitude of impact on air quality depends upon the types of mineral being mined, methods, scale and concentration of mining activities, and the geological and geomorphological setting. Mining in Goa is now highly mechanized employing the open-cast method [2]. Open-cast mining is more deteriorating to air quality than underground mining. Over the past few years, with the introduction of mechanized mining techniques and heavy earth moving equipment, this problem has been further aggravated [3,4]. Major sources of atmospheric emissions from open-cast mining activity include land clearing, removal of overburden, and vehicular movement on the haul roads, excavation, loading and unloading of ore materials as well as overburden. Dust emanating from the haul roads contributes considerably to the particulate matter content in the atmosphere.

Air pollution related problems have resulted in an increased public awareness of the air quality in both developing and developed countries[5]. Therefore, air quality monitoring and assessment are required to prevent and minimize the deterioration of air quality due to mining and other anthropogenic activities. The existing evaluation and assessment of air quality in India is based entirely on the compliance of measured concentration levels of pollutants with the National Ambient Air Quality Standards (NAAQS)[6]. This approach is useful up to some extent to maintain the desired quality of the ambient atmosphere, but it cannot truly map the deterioration of air quality when the concentration of pollutants remains below the NAAQS, because NAAQS provides an upper threshold concentration in the form of standards, and the air quality is designated accordingly based on the standards. The concentration level of pollutants found below the NAAQS are falsely interpreted as fair and acceptable air quality, but sometimes the concentrations are sufficiently high to pose serious environmental and health problems. Dee *et al*., also observed that in many cases these standards are represented as the upper concentration limits or maximum ranges for selected parameters that will be acceptable to maintain some desired quality[7]. More precisely, the use of standards is important in administrating and enforcing a desired policy, but they are not a complete tool for evaluating the environmental quality[6]. The need to quantify air quality and follow the evolution of pollution has led to a large amount of Air Quality Indices, giving an idea of the state of pollution in a day[8]. Air Quality Indices are also of specific significance because; air pollution monitoring data are generally complex and not understandable to the general public. The large data often do not convey the air quality status to the scientific community, policy makers and the general public in a simple and straightforward manner. This problem can be addressed by determining the Air Quality Index (AQI) of a given area using environmental synthetic indices to summarize complex situations in a single ûgure, allowing for comparisons in time and in space[9]. Plaia and Ruggieri, defined AQIs as a simple and understandable way to measure the air quality with respect to its effects on human health[10]. A number of air quality indices have been formulated[11,12]. Most of the indices take NAAQS as the base for devising the scale. There are other systems, which are independent of the NAAQS and based on the measurement of air quality (with due weightage to the potential of pollutants to affect biophysical, health and aesthetic attributes) on an absolute environmental quality scale and not in relation to NAAQS[13].

Considering the disadvantages of the existing methods of ambient air quality assessment, the present paper attempts to follow an air quality depreciation index that measures deterioration in air quality (with due weightage to the potential of pollutants to affect bio-physical, health and aesthetic attributes) on an 'absolute' environmental quality scale independent of NAAQS[6]. The index is determined on the basis of value function curves to assess the air quality. This approach is conceptually similar to the environmental evaluation system developed by Dee *et al*., for assessing environmental impacts related to water resources[7] Sharma *et al*., Singh and Roy *et al*., have also used this concept for determining the air quality status of Raniganj Coalûelds (India), coal mining areas of Korba Industrial *et al* belt of Chhattisgarh, (India) and a case study from the Coal-fields of eastern India, respectively[14,6,13].

MATERIALS AND METHODS

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 & 74°20'13" E with geographical area of 3,702 km^2 and a coastline of 105 km. The average wind speed recorded during the period of study (January 2011 to December 2012) was 0.64 m/s of which 0.5 – 2.1 m/s were observed in 78.7 % of the recorded data and calm conditions prevailed in 21.03 %. The prevailing wind direction accounting for maximum length of time was west. The maximum temperature recorded during the study period was found 30°C while the minimum temperature was 11°C. The average relative humidity was found to be in the range of 35% to 97%. The study area comprising a geographical area of 1513 km^2 (situated between 15°16' to 15°38'N and 73°50' to 74°17'E) had been selected 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 encompasses mining and associated activities confined to active

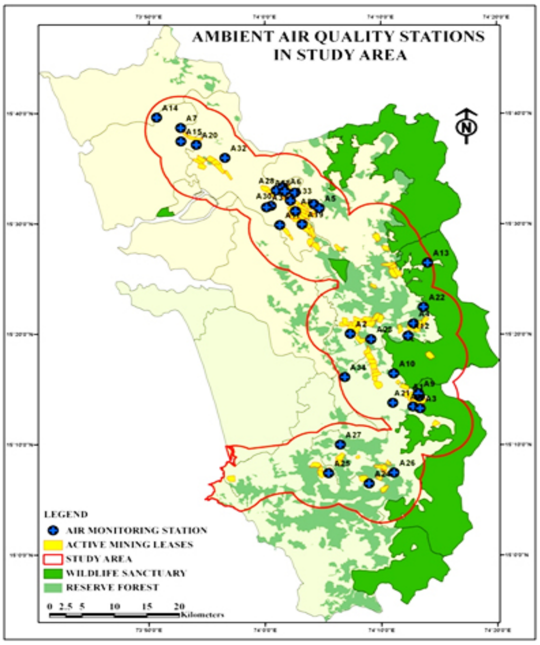

Fig. 1: Ambient air quality monitoring stations in study area

mining leases and additional 5 Km around the core mining activities. Map of the study area along with ambient air quality monitoring locations is depicted in Figure 1.

Sampling and Analysis

Systematic ambient air quality monitoring was carried out to obtain an overall picture about air quality parameters in this region using Fine Particulate Samplers (Envirotech-Model APM 550 MFC) and Respirable Dust Samplers (Envirotech-Model APM 460). 24-hourly ambient air samples were collected during post-monsoon, winter and summer seasons for SPM, PM_{10}, SO_2 and NO_X as the monitoring and analysis criteria provided. For the purpose of ambient air quality monitoring of these criteria pollutants, thirty four (34) representative ambient air quality stations was selected as per selection criteria provided in IS: 5182 Part XIV [15]. Of the 34 stations, 8 stations are selected in mines, 12 in buffer zone around core mining activity and remaining 14 in ore transportation routes in order to

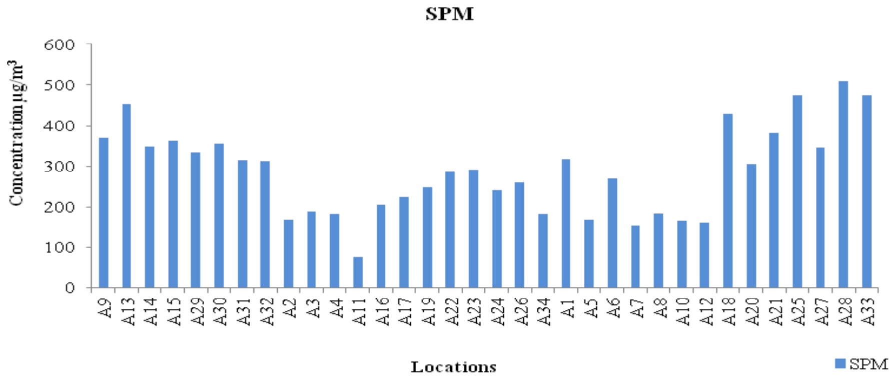

Fig. 2: Average concentration levels of SPM in the study area

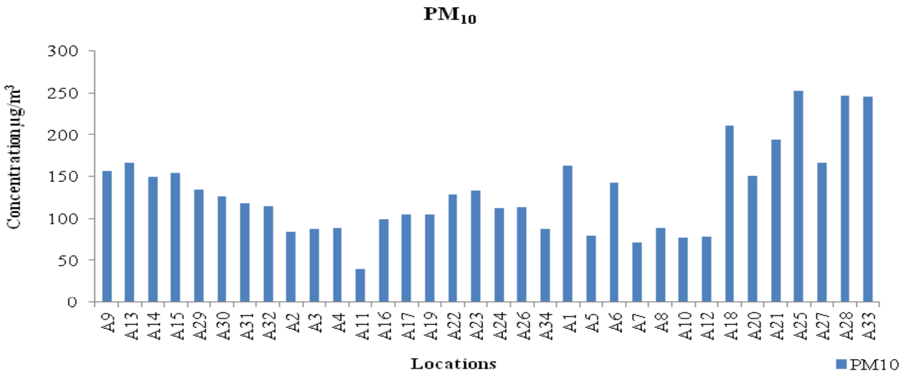

Fig. 3: Average concentration levels of PM_{10} in the study area

emphasize and characterize the sources responsible for criteria pollutants. The details of monitoring locations are represented in Table 1 with their respective coordinates.

RESULTS AND DISCUSSION

To assess the air quality status of the study area, the CPCB guidelines for sampling and

Table 1: Ambient Air Quality (AAQ) Monitoring Stations in the Study Area

Station Code	Location	Location Latitude (North)	Location Longitude (East)
Stations Around Mines			
A9	Tollem Mine	15°14'20.8"	74°13'18.3"
A13	Codli Group of Mines	15°20'36"	74°7'1.7"
A14	Bombod Mine	15°13'16.3"	74°13'20.7"
A15	Bimbol Mine	15°20'57.7"	74°12'47.4"
A29	Pissurlem Mine	15°31'24.8"	74°04'42.1"
A30	Harvalem Mine	15°32'56.1"	74°01'44.3"
A31	Adwalpal Mine	15°38'40.7"	73°52'45.1"
A32	Velguem - Surla Mines	15°31'08.4"	74°2'38.3"
Stations Selected in Buffer Zone			
A2	Dudal Village	15°16'28.4"	74°11'04.0"
A3	Tudou Village	15°13'53"	74°14'31"
A4	Shigao Village	15°19'51"	74°12'18.4"
A11	Tambdi Surla	15°26'33.1"	74°14'03.6"
A16	Revora Village	15°39'35.8"	73°50'41.2"
A17	Tivim Village	15°37'27.7"	73°52'46.3"
A19	Harvelem Village	15°33'18.1"	74°01'33.1"
A22	Surla Village	15°29'53"	74°01'17.4"
A23	Honda Village	15°32'48.6"	74°02'35.7"
A24	Velguem Village	15°29'56.6"	74°03'13.4"
A26	Assanora Village	15°37'09.0"	73°54'06.1"
A34	Darguina Village	15°14'36.8"	74°13'12.5"
Stations along Ore Transportation Routes			
A1	Uguem Village	15°13'49.8"	74°10'58.6"
A5	Mollem Village	15°22'27.5"	74°13'39.4"
A6	Carmonem Village	15°19'32.5"	74°09'08.8"
A7	Sulcorna Village	15°6'28.1"	74°8'57.3"
A8	Maina Village	15°07'25.0"	74°05'29.0"
A10	Curpem Village	15°07'26.8"	74°11'06.0"
A12	Rivona Village	15°09'59.6"	74°06'28.3"
A18	Cudnem Village	15°33'01.0"	74°00'59.6"
A20	Pissurlem Village	15°31'45.4"	74°01'33.1"
A21	Navelim	15°31'37.3"	74°00'33.4"
A25	Amona Village	15°31'29.3"	74°00'08.9"
A27	Bicholim Town	15°35'57.9"	73°56'34.58"
A28	Sonshi Village	15°32'5.4"	74°02'13.2"
A33	Sanvordem	15°16'06.7"	74°06'52.5"

measurement of ambient air quality parameters were followed. For PM_{10}, SO_2 and NO_X, NAAQS, 2009 Standards and for SPM, NAAQS, 1994 Standards were followed. The NAAQS for SPM, PM_{10}, SO_2 and NO_X is depicted in Table 2. The concentration levels of SPM, PM_{10}, SO_2 and NO_X in the iron ore mining region of Goa are presented in Table 3 and Figure 2, 3, 4 and 5, respectively. The spatial distribution of Concentration Levels of SPM, PM_{10}, SO_2 and NO_X in the study area is presented in Figure 6.

The monitoring results illustrate that particulate materials are the major pollutants to be concerned in mining areas of Goa as the concentration levels of SPM and PM_{10} were found exceeding the NAAQS standards. The concentration levels of SO_2 and NO_X were found below the standard at almost all of the stations. In general, the concentration of particulate matters was found higher in the ore transportation routes followed by mines. This depicts that transportation is the most devastating activity in the iron ore mining region of Goa. The preeminent source of particulate matters in transportation routes are suspensions and resuspension of dust due to aerodynamic pressure, spillage of ore dust from the ore carrying dumpers and wearing of tyres, brake, etc.

Air Quality Depreciation Index

The air quality depreciation index adopted for this study, attempts to measure deterioration in air quality on an arbitrary scale that ranges between 0 and –10. An index value of '0'represents most desirable air quality having no depreciation from the best possible air quality with respect to the pollutants under consideration while an index value of –10 represents maximum depreciation or worst air quality. The reduction in index values ranging from 0 to –10 represents the successive depreciation in air quality from the most desirable. The air quality depreciation index is calculated as follows:

$$AQ_{dep} = \sum_{i=1}^{n}(AQi * CWi) - \sum_{i=1}^{n} CWi \quad ...(1)$$

Where,

AQ_{dep} = Air quality depreciation index

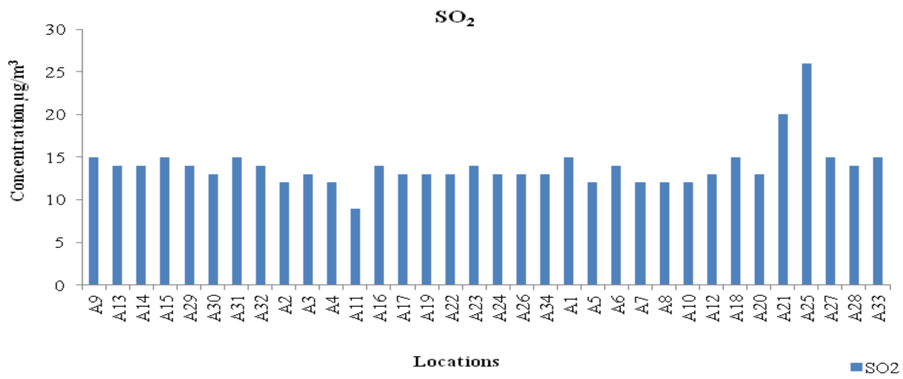

Fig. 4: Average concentration levels of SO_2 in the study area

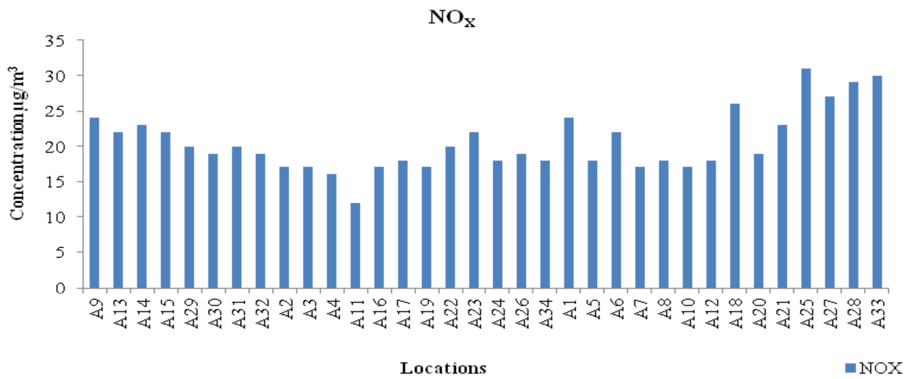

Fig. 5: Average concentration levels of NO_X in the study area

AQ_i = Air quality index value for i^{th} parameter
CW_i = Composite weight for i^{th} parameter
n = Total no. of pollutants considered

The values of the AQi were obtained from the value function curves. In the value function curves the value of 0 signifies worst air quality and value of 1 represents the best air quality for

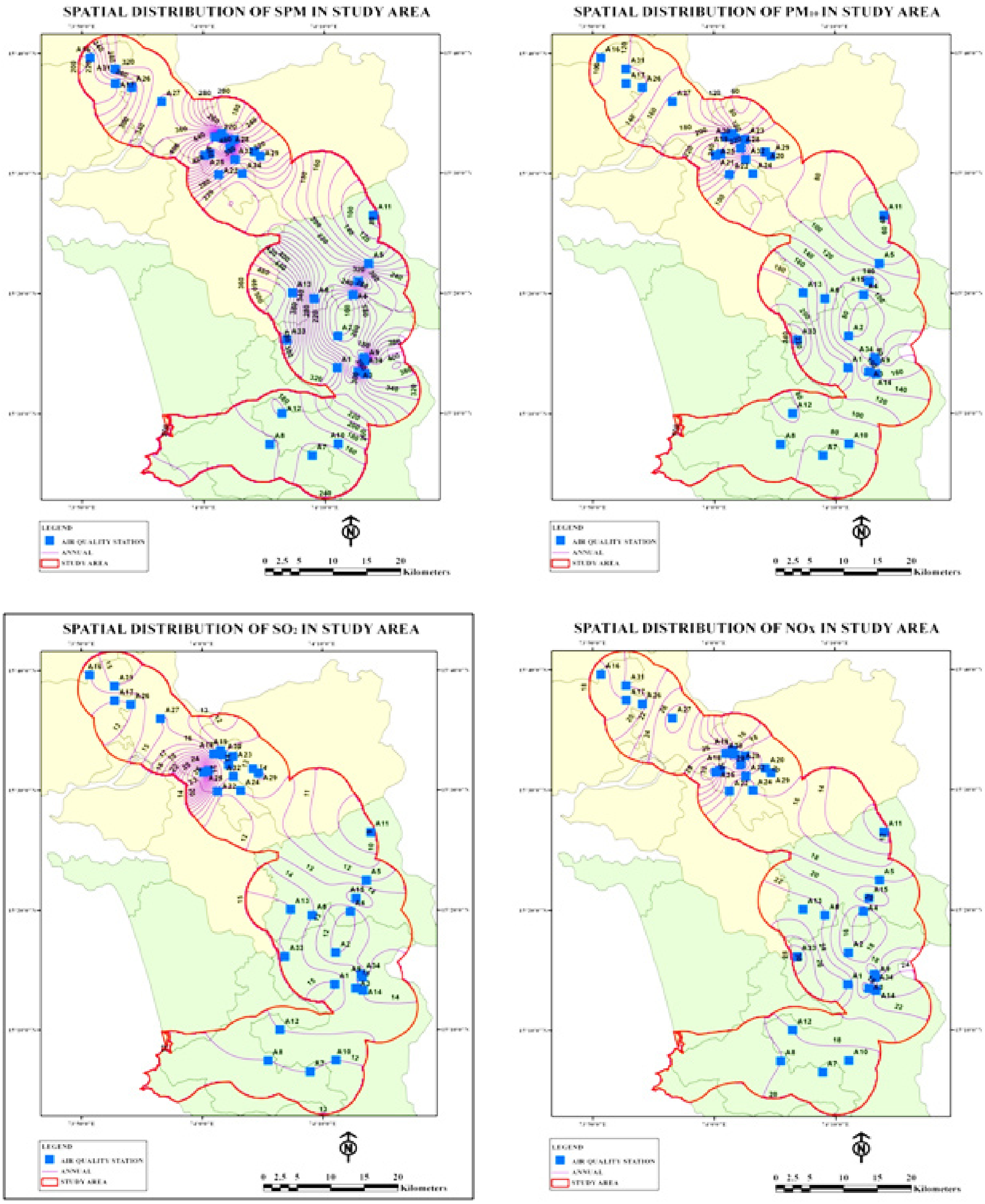

Fig. 6: Spatial distribution of annual average (a) SPM, (b) PM_{10}, (c) SO_2 and (d) NO_X concentration levels in the study area

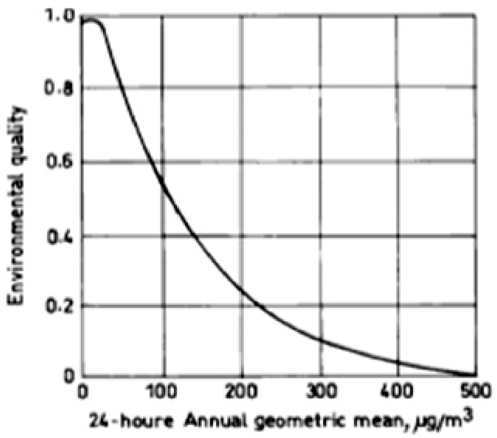

Fig. 7: Value function curve for suspended particulate matter (Jain *et al.*)[17]

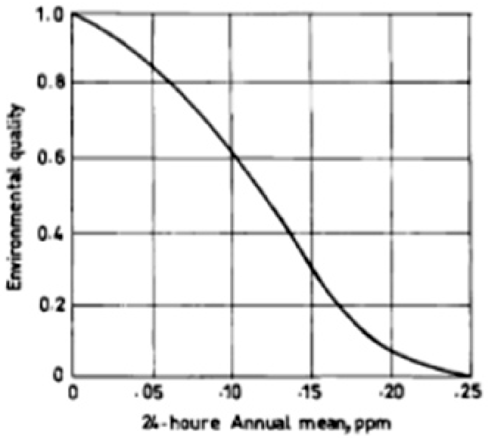

Fig. 8: Value function curve for Sulphur dioxide (Jain *et al.*)[17]

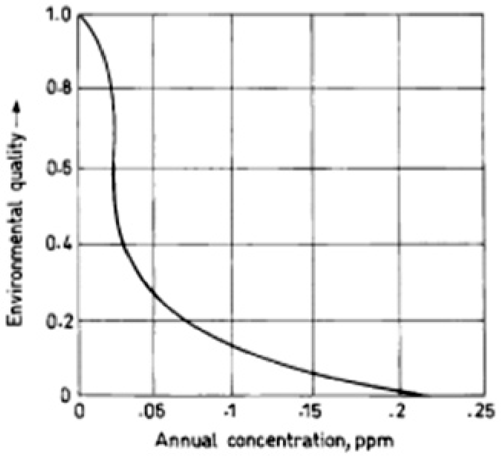

Fig. 9: Value function curve for Nitrogen oxides (Jain *et al.*)[17]

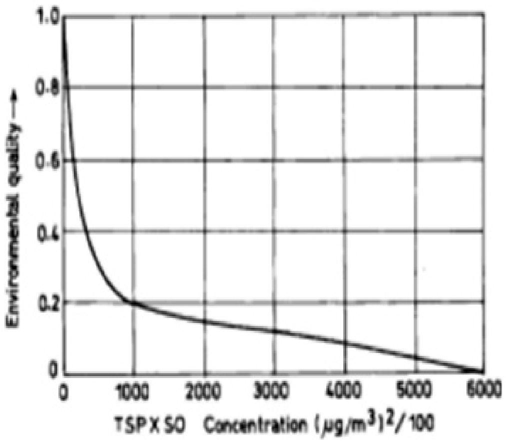

Fig. 10: Value function curve for TSP × SO_2 (Luhar and Khanna)[18]

Table 2: National Ambient Air Quality Standards (NAAQS, 2009)[16]

Pollutants	Time Weighted Average	Concentration in Ambient Air: Industrial, Residential, Rural and other Areas.		Concentration in Ambient Air: Ecologically Sensitive Area
Sulphur Dioxide	Annual *	50		20
(SO_2), μg/m³	24 Hours **	80		80
Nitrogen Oxides	Annual *	40		30
(NO_x), μg/m³	24 Hours **	80		80
Particulate Matter,	Annual *	60		60
(PM_{10}), μg/m³	24 Hours **	100		100
Suspended Particulate Matter*(SPM), μg/m³		**Industrial Area**	**Residential, Rural and other Area**	
	Annual*	360	140	70
	24 hours**	500	200	100

corresponding pollutant concentration. Typical value function curves for SPM, SO_2, NO_X and (TSP x SO_2) are given in Figures 7, 8, 9 and 10, respectively.

The value of CW_i in equation (1) is computed using the following expression:

$$CW_i = \frac{TWi}{\sum_{i=1}^{n} TWi} * 10 \qquad ...(2)$$

Where,

TW_i = Total weight of i^{th} parameter

$$TW_i = A_iW_i + BPIW_i + HW_i \qquad ...(3)$$

Table 3: Ambient Air Quality Monitoring Results in Iron Ore Mining region Of Goa

Station Code	SPM[1]	PM_{10}	TSP[2]	SO_2	NO_X	SPM[3]	$TSP*SO_2/100$
A9	369	156	525	15	24	370	78.75
A13	452	167	619	14	22	454	86.66
A14	347	149	496	14	23	348	69.44
A15	362	154	516	15	22	361	77.4
A29	334	134	468	14	20	335	65.52
A30	354	126	480	13	19	351	62.4
A31	314	118	432	15	20	316	64.8
A32	313	115	428	14	19	310	59.92
A2	167	84	251	12	17	168	30.12
A3	188	88	276	13	17	190	35.88
A4	182	89	271	12	16	183	32.52
A11	75	39	114	9	12	76	10.26
A16	205	99	304	14	17	205	42.56
A17	225	105	330	13	18	226	42.9
A19	247	105	352	13	17	249	45.76
A22	285	129	414	13	20	282	53.82
A23	290	133	423	14	22	290	59.22
A24	240	113	353	13	18	240	45.89
A26	259	114	373	13	19	256	48.49
A34	182	87	269	13	18	184	34.97
A1	316	163	479	15	24	317	71.85
A5	167	80	247	12	18	167	29.64
A6	269	142	411	14	22	270	57.54
A7	152	72	224	12	17	153	26.88
A8	185	89	274	12	18	185	32.88
A10	165	77	242	12	17	165	29.04
A12	159	78	237	13	18	160	30.81
A18	429	211	640	15	26	432	96
A20	304	150	454	13	19	307	59.02
A21	382	194	576	20	23	379	115.2
A25	474	252	726	26	31	479	188.76
A27	345	166	511	15	27	343	76.65
A28	509	247	756	14	29	512	105.84
A33	474	245	719	15	30	481	107.85

1- Arithmetic Mean Value of annual air quality monitoring results

2- Total Suspended Particulate (Sum of SPM and PM_{10})

3- Geometric Mean Value of annual air quality monitoring results

Where,
AW_i = Aesthetic weight for i^{th} parameter
$BPIW_i$ = Bio- Physical Impact Weight for i^{th} parameter
HW_i = Health Weight for i^{th} parameter

For computing TW_i, an importance weight between 1 to 5 is subjectively assigned to AW_i, $BPIW_i$ and HW_i (i.e. for the i^{th} pollutant) by a team of assessors or experts. Least important assignment is 1 and most important marking is 5. The weights are then aggregated in accordance with equations (2) and (3). The assignment and computation of composite weight for different pollutants are illustrated in Table 4. The values of AQ_i and AQ_{dep} are calculated as per the equation (1) and depicted in Table 5 and Figure 11.

Air quality depreciation index had been applied to the ambient air monitoring data of the iron ore mining region of Goa as an index that measures depreciation in air quality in more realistic terms. The deterioration of air quality in the iron ore mining region of Goa can be easily assessed from the AQ_{dep} values. Depreciation in air quality from the most desired value of 0 is clearly apparent, as AQ_{dep} values at all the stations were < -1. Based on the observations of computed $AQ_{dep,}$ the air quality of the Amona Village (A25) was found most depreciated followed by (A28) Sonshi Village with the depreciation values of 4.35 and 4.099, respectively. The depreciation in the air quality of Tambdi Surla (A11) was found least with an AQ_{dep} value of 1.443. The reason of the lowest depreciation of air quality at this site is attributed to its large distance from mines and associated activities, such as ore transportation as well as due to luxurious vegetation in the area. In general, along the ore transportation routes the air quality is found most depreciated followed by mines. The depreciation of air quality in buffer zone was also found considerable, but lower than ore transportation routes and mines. This infers that ore transportation is the most devastating activity in the iron ore mining region of Goa and effective mitigation measure is required with regulatory enforcement to control the deterioration of air quality. Effective mitigation measures are also needed within the mines.

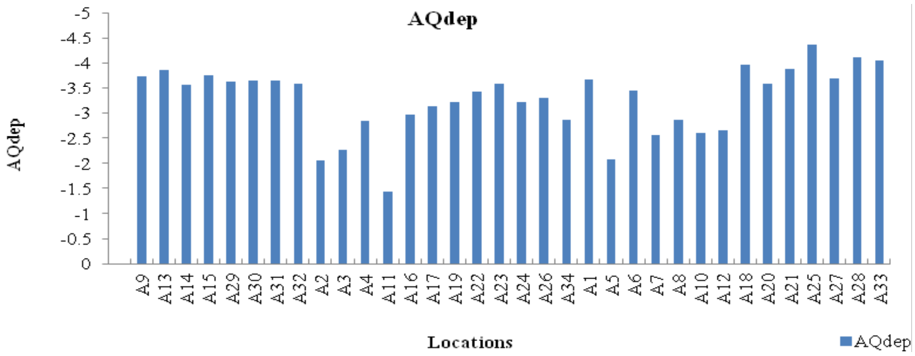

Fig. 11: Depreciation in air quality at different monitoring stations

Table 4: Assignments and Computation of Composite Weight for different Pollutants

Pollutants	Aw_i (Range 1-5)	$BPIW_i$ (Range 1-5)	Hw_i (Range 1-5)	TW_i	CW_i
SPM	4	4	3	11	3.1
SO_2	1	4	4	9	2.5
NO_x	2	3	3	8	2.2
SPM $*SO_2$	1	2	5	8	2.2

$$\sum_{i=1}^{n} TWi = 36$$

This method detects the degree of deterioration in air quality even due to the marginal changes, but the existing approach of ambient air quality assessment, i.e. comparison of measured concentration of pollutants with NAAQS cannot persuasively categorized as unacceptable or objectionable unless the measured concentration exceeded the NAAQS. Till standards are exceeded, there is no indication of deterioration in air quality from what can be considered truly acceptable. It is clearly evident from the measured concentration of pollutants in the study area that, the concentration level of SPM exceeded the NAAQS annual standard at many of the stations and that of PM_{10} at most of the stations, while the concentration level of SO_2 and NO_X were found far below the NAAQS at almost all sampling stations. This figure does not provide a meaningful picture about the air quality of the

Table 5: Value Functions and Aq_{dep} Values for different Sampling Locations in Iron Ore Mining region of Goa

Station Code	AQ_i SPM	SO_2	NO_X	$TSP*SO_2$	Weighted AQI	AQ_{dep}
A9	0.078	0.998	0.939	0.667	6.270	-3.730
A13	0.0369	0.998	0.945	0.662	6.14479	-3.85521
A14	0.088	0.998	0.9942	0.671	6.43124	-3.56876
A15	0.061	0.998	0.945	0.669	6.2349	-3.7651
A29	0.093	0.998	0.954	0.673	6.3627	-3.6373
A30	0.082	0.999	0.96	0.678	6.3553	-3.6447
A31	0.097	0.998	0.945	0.674	6.3575	-3.6425
A32	0.097	0.998	0.96	0.682	6.4081	-3.5919
A2	0.53	0.999	0.972	0.752	7.9333	-2.0667
A3	0.469	0.999	0.972	0.745	7.7288	-2.2712
A4	0.284	0.999	0.974	0.746	7.1619	-2.8381
A11	0.631	0.999	0.983	0.882	8.5566	-1.4434
A16	0.244	0.999	0.972	0.742	7.0247	-2.9753
A17	0.2	0.999	0.963	0.742	6.8685	-3.1315
A19	0.168	0.999	0.972	0.74	6.7847	-3.2153
A22	0.118	0.999	0.954	0.735	6.5791	-3.4209
A23	0.11	0.998	0.945	0.683	6.4176	-3.5824
A24	0.176	0.999	0.963	0.74	6.7897	-3.2103
A26	0.15	0.999	0.96	0.738	6.6981	-3.3019
A34	0.284	0.999	0.963	0.745	7.1355	-2.8645
A1	0.095	0.998	0.939	0.671	6.3315	-3.6685
A5	0.53	0.999	0.963	0.753	7.9157	-2.0843
A6	0.154	0.998	0.945	0.683	6.554	-3.446
A7	0.37	0.999	0.972	0.756	7.4461	-2.5539
A8	0.28	0.999	0.963	0.748	7.1297	-2.8703
A10	0.36	0.999	0.972	0.754	7.4107	-2.5893
A12	0.35	0.999	0.963	0.75	7.3511	-2.6489
A18	0.039	0.998	0.934	0.622	6.0391	-3.9609
A20	0.099	0.999	0.96	0.683	6.419	-3.581
A21	0.044	0.994	0.9942	0.598	6.12424	-3.87576
A25	0.022	0.991	0.918	0.493	5.6499	-4.3501
A27	0.089	0.998	0.935	0.668	6.2975	-3.7025
A28	0	0.998	0.932	0.616	5.9006	-4.0994
A33	0.022	0.998	0.928	0.617	5.9622	-4.0378

region. This would be significant only when all of the pollutants exceed the NAAQS standard, but this situation is not prevailing in the study area. Hence, simple comparison of the measured concentration value of pollutants with NAAQS may not be a true representation of the overall scenario. Singh (2006) calculated the AQ_{dep} index using NAAQS value for each pollutant and observed a considerably degraded scenario (AQ_{dep} = - 6.0320). This gives more credence to the fact that the existing evaluation system may not be the best approach to assess the air quality. The air quality depreciation index is a more articulate approach even to obtain the marginal changes in air quality. The application of depreciation index meaningfully depicts the status of ambient air quality. It provides overall deterioration in air quality from the desired value of 0.

The index adopted for this evaluation has superiority over the interpretive evaluations that use a simple comparison of measured concentration of pollutants with National Ambient Air Quality Standards, because the calculation of AQ_{dep} index using NAAQS value for each pollutant gives a sufficiently high value indicating a considerably degraded air quality scenario. Hence, the approach of simple comparison of measured concentration of pollutants with NAAQS does not truly serve the purpose of assessment of air quality. In this context, the air quality, depreciation index can be an invaluable tool to map, periodic deterioration in air quality with respect to its potential for environmental damages. The adoption of such an index to monitor air quality in and around the mining clusters will help in assessment and comparison of air quality of different mining areas in India in a much more realistic and meaningful manner. Since the air quality depreciation index is not constrained for the type or number of pollutants and is not geographically specific, it can be easily used for different situations, locations and applications.

CONCLUSIONS

Air quality depreciation index was adopted for this study to assess the ambient air quality of the iron ore mining region of Goa. The deterioration in air quality in this region is clearly apparent, as the AQ_{dep} values at all the monitoring locations were observed < -1. In general, along ore transportation routes, the air quality is found most depreciated followed by mines. High depreciation along the transportation routes illustrates that transportation is the most devastating activity to the air environment. Based on the observations, the study portrays the need for effective management plans to mitigate the pollution load along the transportation routes as well as within and around the mines. Strict enforcement of the limit on load as well as vehicle speed might be a pertinent solution to reduce the particulate emission along the transportation routes. During the busy hours the transportation of ores should be prohibited.

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