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CASE STUDY

Atmospheric dispersion model to predict the impact of gaseous pollutant in an industrial and mining cluster

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ABSTRACT: Dispersion modeling approach was applied for the determination of SO_2 and NO_2 pollution in the ambient air. The model performance has been evaluated by comparing the measured and predicted concentrations of SO_2 and NO_2. This has been tested to measure the air quality and predicted incremental value of pollutant's concentrations by using the data available from the industrial and mining cluster for a period of one year covering from March' 2015 to February' 2016 where more accuracy and specific result oriented is concerned. The maximum cumulative predicted value of SO_2 is 6.99 µg/m^3 and NO_2 is 15.98 µg/m^3. It has been found that the overall resultant concentrations are far below the prescribed standard in all stations. As revealed from the present research that, there is no such pollution impact to the nearby villages where industrial and mining activities are concerned in the study area. This paper can be used as better reference for further and future research in the area, as there is no such study has been carried out before in the specific area.

KEYWORDS: *Ambient air; Atmospheric dispersion model (AERMOD); Industrial and mining; Nitrogen dioxide (NO_2); Sulfur dioxide (SO_2).*

INTRODUCTION

As per the guidelines and definitions stipulated by Environmental Protection Agency (EPA) particulate matter (PM), sulfur dioxide (SO_2), nitrogen oxides(NO_X), carbon monoxide (CO), ozone (O_3) and lead (Pb) as the primary pollutants which causing air pollution (Xiao *et al.*, 2018, Tian *et al.*, 2013). After the Clean Air Act on 1970, the emissions of those pollutants have reduced significantly, with the exception of NO_X emissions which increased by 10 % in this period (Yang, 2005). There are a number of scientific studies and legislative regulations to reduce the NO_X emissions in these countries (Radojevic, 1998 ; Degraeuwe *et al.* 2016). Besides the pollution generated from the mining and industrial activities, forest fire also is a part of the earth's natural process or renewal, sometimes it also become one of the major source which leads to the production of various gaseous and particulates pollutants to the atmosphere(Bahino *et al.*, 2018). But recent study reveals that most of the fire is human initiated rather than natural such as lightning strike, volcanic etc. (Levine, 1994; Roos *et al.*, 2014; Christian *et al.*, 2003). The status of air quality and its importance always required not only to humans but also to the flora, fauna and nearby environment (Hester, 1998; Schwela, 2000). Due to industrial establishment including all types

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of industries like power plant, refineries leads to air pollution because of trace elements (Al-Saad *et al.*, 2010, Wang *et al.,* 2016) are major emission sources particularly in the industries area and also there is an impact on the plants and nearby ecosystem (Dash, 2018). Chusai *et al.*, 2012 used AERMOD to evaluate dispersion of NO_2 and SO_2 and relative roles of emission sources over this area. To manage the air quality system monitoring and evaluation of pollution status has a vital role now a days (Dash, 2015; Dash, 2015; Dash, 2017). Major studies were performed to explore the formulas related to plume rise in different aspects (Turner, 1964; Arthur 2014; Schulman *et al.*, 2000).The importance of the mixing height was explored and gradually it has a major influence on the magnitude of ground level concentrations (Holzworth, 1967; Dash *et al.,* 2017). The AERMOD system is a certified model through one can predict the impact from different sources because of industrialization which is based on gaussian model (*Silverman et al.*, 2007; Huertas *et al.*, 2012 ; Gulia *et al.,* 2015). AERMOD system based on of three main processors such as AERMAP, AERMET and AERMOD as the main dispersion model processor. SO_2 and NO_2 are the criteria pollutant that has various impacts on human health (Kamarehie, *et al*., 2017; Ghozikali *et al*., 2015). This study is aimed to evaluate Ground Level Concentrations (GLC) of SO_2 and NO_2 emitted from the mining and industrial activities near the study area. The maximum ground level concentrations to be analyzed contributed by all industrial activities. This finding will be useful in prioritization of appropriate mitigation measures in controlling emission amount of each type of factory as well as demonstrate application of air dispersion model. It can then serve as a tool for management of air pollution problem as well as helps other researcher. The study has been carried out near Bileipada, Joda of Keonjhar district of Odisha during the period of 2015 to 2016.

MATERIALS AND METHODS

Study Area

Keonjhar is an important city in the state of Odisha, India which is rich in natural resources, particularly the minerals like iron and manganese ore. In order to meet the requirement of steel in the world scenario, a number of mining activities and other industries like sponge iron, beneficiation, and pelletisation unit were established in this area. Dusts emitting from the haul roads in iron, manganese mines contribute considerably to the particulate matter pollutant content in the ambient air. Details of the study area and sampling stations are shown in Fig. 1 and Table 1.

As per CPCB (Central Pollution Control Board), Government of India guidelines, monitoring station has been selected based on sources and emissions, meteorological information, topographical information and previous air quality report. The predominant wind direction is east and south east during the study period. The monitoring stations are fixed based on meteorological data, predominant wind direction,

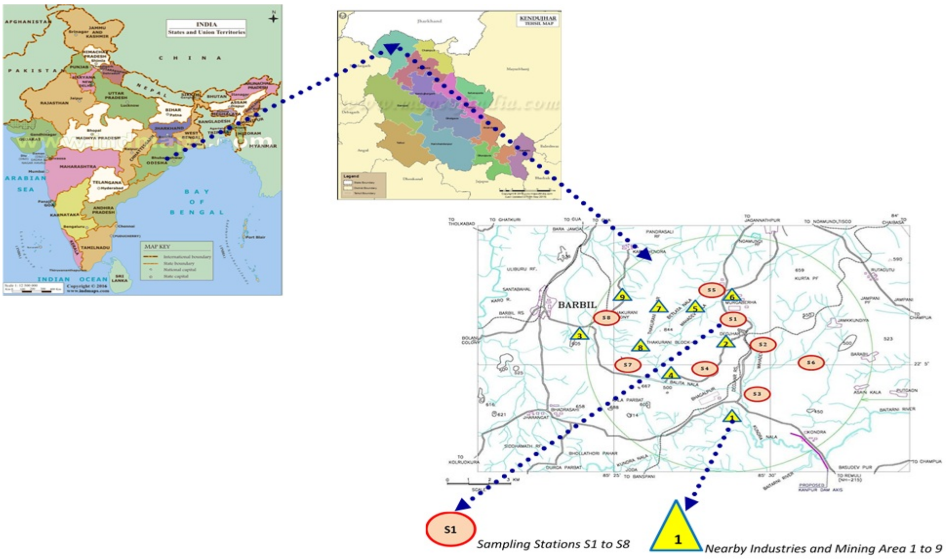

Fig. 1: The study area details

topographical features and terrain of the study area. There are two monitoring stations in upwind direction (east) and two monitoring stations in downwind direction (west). These four monitoring stations were selected in order to assess the impact from transportation path and from nearby mining and industrial activity.

About AERMOD

Air pollution models are valuable tool to predict the quality of air against the National Ambient Air Quality Standards (NAAQS) by CPCB (Central Pollution Control Board), Government of India guidelines which is beneficial in the air pollution control strategies. Efficiency of the model is available in many research projects. AERMOD View is a complete and powerful air dispersion modeling package that seamlessly carries the popular U.S. EPA models, ISCST3, ISC-PRIME and AERMOD, into one interface without any changes to the models. In order to examine pollution concentration and deposition from verity of sources, such models are widely used. AMS/EPA Regulatory Model (AERMOD) was designed in order to support the EPA's regulatory modeling programs in air pollution studies (USEPA, 2004). The AERMOD is a regulatory steady-state plume modeling system with three separate components: such as AERMOD (AERMIC Dispersion Model), AERMAP (AERMOD Terrain Preprocessor), and AERMET (AERMOD Meteorological Preprocessor). For modeling air quality impacts of pollution sources, and making it a popular choice among the modeling community for a variety of applications, AERMOD model includes a wide range of options. Basically there are same options both in AERMOD and ISCST3 model.

Air quality monitoring

Ambient air quality parameters such as SO_2 and NO_2 were carried out for a period of one year starting from March' 2015 to February' 2016 covering all three seasons i.e. summer, monsoon and winter at eight locations. As per CPCB guidelines standard method were followed for both collection and analysis of different parameters. APM 433, Gaseous Pollutant sampler based on absorption (wet chemical method) method for measurement of SO_2 and NO_2.

Emission factor

Emissions factor helpful to find out the impact of pollutants to the nearby areas by using some empirical equations. Table 2 expresses the different empirical formula to find out the emission factor of SO_2 and NO_2 (Chaulya *et al.* 2002).Wind speed has been measured at an altitude of 3-10 m.

RESULTS AND DISCUSSION

In the study area the minimum temperature recorded as 31.5^{0}C during December 2015 (Winter Season) and the maximum temperature recorded as 41.3^{0}C during May-2015 (Summer Season). The annual average temperature is 35.8^{0}C for the years 2015-16. The highest mean humidity in the morning (8.30 h.) is recorded in

Table 1. The sampling station details

Sl. No.	Station Name	Direction	Latitude	Longitude
1	S-1	NNE	22^{0}05'37.7"	85^{0}28'43.4"
2	S-2	E	22^{0}05'08.6"	85^{0}28'50.3"
3	S-3	SE	22^{0}04'46.3"	85^{0}28'42.9"
4	S-4	S	22^{0}05'05.8"	85^{0}28'11.8"
5	S-5	N	22^{0}06'59.6"	85^{0}28'7.0"
6	S-6	E	22^{0}04'41.1"	85^{0}29'50.7"
7	S-7	SW	22^{0}04'22.8"	85^{0}27'20.3"
8	S-8	WNW	22° 05' 13"	85° 28' 24"

Table 2: Empirical formula for different mining activities

Mining activity	Empirical equation
Overall mine (SO_2)	$E = a0.14\{u/(1.83+0.93u)\}[\{p/(0.48+0.57p)\}+\{b/(14.37+1.15b)\}]$
Overall mine (NO_2)	$E = a0.25\{u/(4.3+32.5u)\}[1.5p+\{b/(0.06+0.08b)\}]$

u = Wind speed (m/s)
a = area (km^2)
b = OB handling (mm^3/yr.)
p = coal/mineral production (Mt/yr.)

August 2015 i.e. 91.9 % and in the evening (17.30 h.) is recorded in August-2015 i.e. 88.4%. Similarly the lowest mean humidity in the morning (8.30 h.) is recorded in March-2015 i.e. 61.1 % and in the evening (17.30 h.) is recorded in January-2016 i.e. 28.7 %. The annual average humidity is 73.2% in the morning and 48.9 % in the evening. From the observation the highest rainfall is during the month of July-2015 i.e. 257.5 mm followed by 232.0 mm in June-2015. Lowest rainfall recorded as 8.5 mm during the month March-2015 and the average rainfall is 81.9 mm for the year 2015-16. The total rainfall during the year 2015-16 is 983.0 mm (Table 3). All the meteorological data were obtained from nearby industries' meteorological monitoring station fixed under the supervision of Odisha State Pollution Control Board (OSPCB), Government of Odisha, India. All the meteorological data are being converted to Samson format from AERMET and basing upon this detail respective wind rose has been made as per the standard of model.

There are total 9 industrial complexes including some mining activities in the area. Based on the production capacity we have calculated the pollution load and then emission factors. Seasons has been defined as per guideline of Indian Meteorological Department. In Indian subcontinent March April and May is considered as summer season, monsoon season covering June, July, August, September, October and winter covering November, December, January, February. The impacts of pollution from point and non-point sources on air quality predictions were carried out for the SO_2 and NO_2. The point source of pollution is a single identifiable source of air with limited extent, differentiating it from other pollution geometries sources. This is a single unchanging point, from where air pollutants are emitted into the atmosphere continuously. The non-point source i.e., a line source refers to emissions from the sources such as transport along with a line of the road, railway-track etc. The sources of pollution which emit the substances or radiation from a specified area is known as area sources, e.g., air pollution sources which operate within a certain region. During the study period we have taken 4 numbers of industries as point sources, 5 numbers of mining industries as non-point sources and mineral transportation road as line source to carry out the research. Weekly 2 samples had been collected for each parameter (SO_2 and NO_2) in a month from each station during the study period as per CPCB (Central Pollution Control Board), Government of India guidelines. The corresponding isopleth for respective gaseous pollutants such as SO_2 and NO_2 are presented in Figs. 2, and 3 which showing the impact due to annual (overall) impact. The maximum cumulative predicted value for SO_2 and NO_2 are 6.99µg/m^3 and 15.98µg/m^3 respectively.

The maximum incremental GLCs from various sources of study area for SO_2 and NO_2 are superimposed on the maximum baseline concentrations recorded during the period in the downwind direction to arrive at the likely resultant concentrations. Around 3 – 10 m height has been taken from the ground level for monitoring of SO_2 and NO_2 as per CPCB (Central Pollution Control Board), government of India guidelines. It has been observed that the maximum predicted incremental value of SO_2 concentrations are recorded as 10.47716µg/m^3, 4.5987 µg/m^3 and 10.67686 µg/m^3 in summer, monsoon and winter season respectively. During the summer season it has been observed that in one station i.e. S-5 has the predicted highest resultant concentration i.e. 26.23 µg/m^3. In all other stations the observed results are within the prescribed standard. In monsoon and winter season there is no such result observed during the study where the SO_2 concentrations exceeding the prescribes standard. Similarly the maximum predicted value of NO_2 concentrations are recorded as 15.70448 µg/m^3, 15.86559 µg/m^3 and 13.09298 µg/m^3 in summer, monsoon and winter season respectively. Where the resultant concentration of NO_2 is concerned all the observed and experimented results are within the prescribed standard which reveals that there is no such impact of NO_2 in and around the study area. Whereas only in summer season we found SO_2 in higher concentrations in a single station. Besides this in all station there is no such impact

Table 3: Details of Meteorological parameters during the study period Mar' 2015 to Feb' 2016

Study period (Season wise)	Temperature (^{0}C)		Relative humidity (%)		Rainfall (mm)	Predominant wind direction		Avg. wind speed (m/s)	Calm (%)
	Max.	Min.	8.30 h.	17.30 h.		First	Second		
Summer	41.3	12.0	65.3	30.7	137	ESE to WNW	E to W	1.44	34.25
Monsoon	39.3	18.0	91.9	44.1	727	E to W	ENE to WSW	1.03	55.74
Winter	36.5	9.0	74.8	28.7	119	E to W	ESE to WNW	0.53	67.31
Over All	41.3	31.5	88.4	28.7	983	E to W	ESE to WNW	1.17	31.52

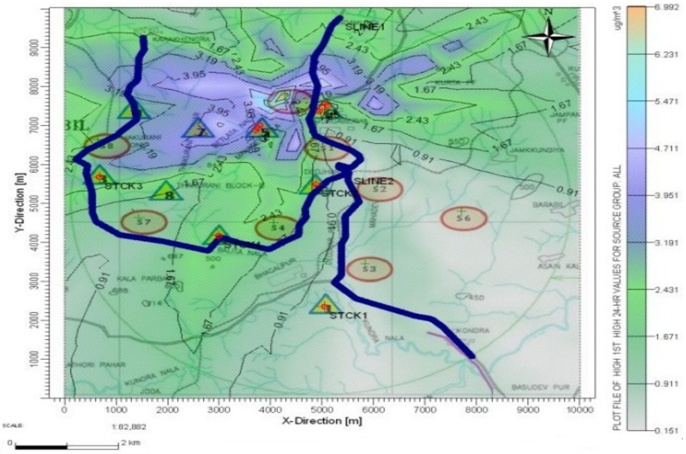

Fig. 2: Isopleths of overall impact – SO_2 (Max. Conc. = 6.99 µg/m^3)

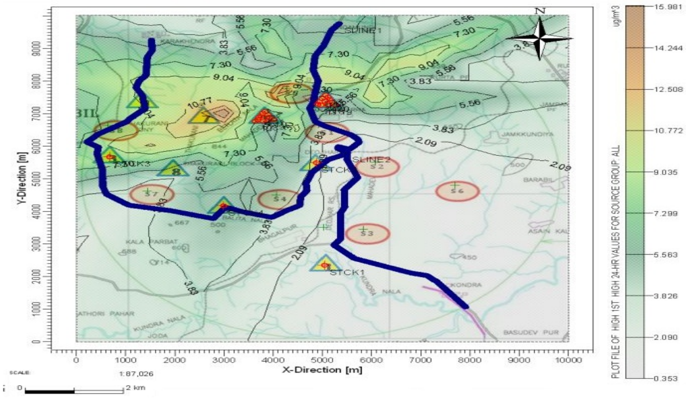

Fig. 3: Isopleths of overall impact – NO_2 (Max. Conc. = 15.98µg/m^3)

of SO_2 and NO_2 in the study area. The total cumulative concentrations, mixing of background maximum value and incremental value of the study area on seasonal wise are tabulated below in Tables 4 and 5 where background concentration was the monitored value through respective monitoring stations, incremental concentration was derived from the model and resultant concentration was the combination of background concentration and incremental concentration. In both the table the resultant concentration was based on respective season i.e. summer, monsoon and winter.

Resultant concentrations in all stations are well within the standard for both SO_2 and NO_2 (Table 6). Here the resultant concentration was calculated based on the overall impact. The study is tried to find out a variation between impacts of resultant concentration different seasons.

Model performance evaluation

In order to predict GLC, an improved version of dispersion Model (AERMOD) has been developed by American Meteorological Society/Environment Protection Agency Regulatory Model Improvement Committee. USEPA has adopted AERMOD as its regulatory model since 2005. The present research examines the suitability of AERMOD for Indian conditions especially for a rural area near to the study area. AERMOD model validity is examined considering a point source of emission from an industry which uses fuel like furnace oil. The predicted value using AERMOD and the actual value of GLC by field observations in order to study the performance evaluation of the model has been compared. Local meteorological data have been used to a greater accuracy to validate the models for the point and non-point source of emission of both the

Table 4: Resultant concentrations respective to station and season wise for SO_2

Sl. No.	Stations	Resultant concentrations (SO_2) season wise in µg/m^3									
		Summer			Monsoon			Winter			
		Back ground conc.	Incr. conc.	Resultant conc.	Back ground conc.	Incr. conc.	Resultant conc.	Back ground conc.	Incr. conc.	Resultant conc.	Stand. (NAAQS), CPCB, India in µg/m^3
1	S-1	17.8	0.97953	18.78	13.5	0.54218	14.04	18.8	1.28638	20.09	80
2	S-2	22.7	0.99914	23.70	13.4	0.32421	13.72	22.3	0.32421	22.62	80
3	S-3	21.3	0.78529	22.09	14.2	0.25546	14.46	21.1	0.24281	21.34	80
4	S-4	16.1	3.86832	19.97	10.8	1.19193	11.99	17.6	1.70893	19.31	80
5	S-5	17.9	8.32599	26.23	11.8	4.5987	16.40	20.3	10.67686	30.98	80
6	S-6	15.8	0.76261	16.56	11.1	0.23401	11.33	17.7	0.22903	17.93	80
7	S-7	9.9	2.08921	11.99	9.5	0.83811	10.34	11.6	1.09351	12.69	80
8	S-8	10.8	4.97991	15.78	8.8	1.58649	10.39	12.4	1.91331	14.31	80

Table 5: Resultant concentrations respective to station and season wise for NO_2

Sl. No.	Stations	Resultant concentrations (NO_2) season wise in µg/m^3									
		Summer			Monsoon			Winter			
		Back ground conc.	Incr. conc.	Resultant conc.	Back ground conc.	Incr. conc.	Resultant conc.	Back ground conc.	Incr. conc.	Resultant conc.	Stand. (NAAQS), CPCB, India in µg/m^3
1	S-1	21.1	1.05663	22.16	15.9	1.93502	17.84	17.6	1.68345	19.28	80
2	S-2	25.5	1.01774	26.52	15.8	1.05197	16.85	21.7	0.32421	22.02	80
3	S-3	23.7	1.07012	24.77	16.5	1.19164	17.69	20.3	0.24281	20.54	80
4	S-4	18.3	4.62489	22.92	12.9	4.99305	17.89	15.9	2.29368	18.19	80
5	S-5	20.2	10.09342	30.29	14.2	14.84534	29.05	19.5	13.09298	32.59	80
6	S-6	19.1	0.92594	20.03	13.3	1.00562	14.31	16.4	0.2798	16.68	80
7	S-7	11.8	2.77031	14.57	12.2	2.94819	15.15	10.8	2.51979	13.32	80
8	S-8	12.8	7.33009	20.13	10.8	7.55861	18.36	11.7	3.77859	15.48	80

Table 6: Overall resultant concentrations respective to stations for both SO_2 and NO_2 in µg/m^3

Sl. No.	Stations	Overall resultant concentrations (SO_2)			Overall resultant concentrations (NO_2)			
		Back ground conc.	Incr. conc.	Resultant conc.	Back ground conc.	Incr. conc.	Resultant conc.	Stand. (NAAQS), CPCB, India in µg/m^3
1	S-1	16.3	0.91014	17.21	17.8	1.85323	19.65	80
2	S-2	18.7	0.44276	19.14	20.2	1.03961	21.24	80
3	S-3	18.3	0.55348	18.85	19.6	1.11982	20.72	80
4	S-4	14.4	2.20386	16.60	15.3	4.78787	20.09	80
5	S-5	16.1	6.99158	23.09	17.5	14.3732	31.87	80
6	S-6	14.5	0.44621	14.95	15.8	0.96001	16.76	80
7	S-7	10.3	1.23873	11.54	11.6	2.8983	14.50	80
8	S-8	10.5	2.61561	13.12	11.6	7.51744	19.12	80

gaseous pollutants. The present research encompasses that weather data plays a vital role in validation of model and to predict the air pollution concentration in a particular station.

CONCLUSION

From the study it has been revealed that this model can be useful and an appropriate tool to assess and predict the SO_2 and NO_2 concentrations in the study area. Wind speeds and directions were found to be the most important factors in the dispersion of the emissions. Overall it has been concluded that, there is no such impact of gaseous pollutants in and around the study area. The novelty of the present research lies with the fact that, it may be applied to similar environmentally complex areas having mixed sources of pollutions like line source, point source and area source. This will help the regulatory authorities and town planners for better environmental management which may have direct positive societal impacts. This paper can be used as better reference for researcher, statutory bodies and government organizations to take necessary mitigated measures to control over on air pollution. Also give an idea for plan and development of green belt around the mining activities and industrial complex. The output of the study will also help to formulate environmental management plan of the study area.

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CONFLICT OF INTEREST

The author declares that there is no conflict of interests regarding the publication of this manuscript.

ABBREVIATIONS

%	Percentage
$\mu g/m^3$	Microgram per meter cube
AERMAP	Terrain preprocessor
AERMET	Meteorological data preprocessor
AERMOD	American Meteorological Society/ Environmental Protection Agency(AMS EPA) Regulatory Model
AMS	American Meteorological Society
APM	Air pollution monitor
Avg.	Average
CO	Carbon monoxide
Conc.	Concentration
CPCB	Central Pollution Control Board
E	East
ENE	East north east
EPA	Environmental Protection Agency
ESE	East south east
Fig.	Figure
GLC	Ground level concentrations
h.	Hour
Incr.	Incremental
ISCST3	Industrial Source complex model
km	Kilometer
m	Meter
m/s	Meter per second
Max.	Maximum
Min.	Minimum
mm	Millimeter
$mm^3/yr.$	Cubic millimeter per year
Mt./yr.	Metric ton per year
N	North
NAAQS	National Ambient Air Quality Standards
NNE	North north east
NO_2	Nitrogen dioxide
NOx	Oxides of nitrogen
O_3	Ozone
OB	Over burden
^oC	Degree celsius
OSPCB	Odisha state pollution control board
PAREA	Area source
Pb	Lead
PM	Particulate matter
S	South
S-1 to S-8	Station 1to Station 8
SE	South east
Sl. No.	Serial number
SLINE	Source line (in isopleth)
SO_2	Sulphur dioxide
STACK	Point source (in isopleth)
SW	South West
USEPA	United states environmental protection agency
VOC	Volatile organic compounds
W	West
WNW	West north west
WSW	West south west
yr.	Year

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