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ASSESSMENT OF SPATIO-TEMPORAL VARIATION AND POTENTIAL HUMAN HEALTH RISK OF AMBIENT NITROGEN DIOXIDE AND SULFUR DIOXIDE AROUND INDUSTRIAL AREA OF MUNDRA, GUJARAT USING GIS AND AERMOD MODEL

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ABSTRACT

Coastal area of Mundra in Gujarat is the crucial power generating area in India, which contains coal based mega thermal power plants. In order to assess the pollutant levels the continuous monitoring of the gaseous and particulate pollutants was observed from 2008 to 2015. The trend was initially increasing when the plant construction started due to construction related activities and then decreasing as can be seen from the regression analysis for various parameters. For briefness, the trend has been shown here for SO_2 and NO_2 at stations for 5 locations within the 3km radius of plant area in upwind and downwind direction of the power plants. The study has been conducted for the seasonal and temporal alteration in the ambient SO_2 and NO_2 concentration of in for a period of eight years in the industrial area of coastal Gujrat in India. Geographical information system (GIS) tool has been used to identify the study area land-use pattern of the coastal Mundra region. Pollution dispersion and trend has been observed with AERMOD Model and statistically. Multiple regression model and regression line analysis has been analyzed in this study for metrological parameters and dispersion of SO_2 and NO_2 concentration in this industrial area. Health risk assessment has been performed association Indian National Ambient Air Quality standard. Gaseous pollutant emission and dispersion can be influenced by meteorological variables such as temperature, humidity, wind characteristics and the children are also sensitive receptors for air pollution.

KEY WORD : Ambient Air Quality, Gaseous pollutant, Meteorology, Industrial area

INTRODUCTION

In industrial region Ambient Air quality (AAQ) examine is primary step for prevention and management strategy in India, in which air pollutants such as sulphur dioxide (SO_2) and nitrogen dioxide (NO_2) are crucial concern. G_{AAP} is denigrated atmospheric pollutants, on account of its negative impact on AAQ in terms of local chemistry of atmospheric elements, and largely alteration in climatic conditions globally due to trans-boundary nature (Goel *et al.*, 2018; Jain *et al.*, 2017; Cesari *et al.*, 2016; Pant and Harrison, 2012). In the previous joint studies of Public Health Foundation of India (PHFI), Ministry of Health and Family Welfare and Indian Council of Medical Research (ICMR) in the year 2017 had been found that 26% of premature deaths are cause due to AAQ pollution in India where 12.4 lakh deaths solely accounted for GAAP (Balakrishnan *et al.*, 2019).

World Health Organization Air Quality Guidelines (WHO 1987; 2000a; b; 2006) had been published for PM_{10}, SO_2, NO_2 and ozone. In India, for monitoring and control of various air pollutants, Central Pollution Control Board (CPCB) has developed the national ambient air quality standards (NAAQS) which indicates the exposure level of G_{AAP}, safe for human health over a time period (Table 1).

Dispersion of G_{AAP} depends on the change of land use pattern, topography and climatic conditions which intensify the formation of secondary pollutants. Climate is an important factor that influences air quality (Murari *et al.*, 2020; Behera *et al.*, 2011; Chakraborty and Gupta, 2010; Gupta *et al.*, 2008). Spatio– temporal variation of $G_{AAP}$are dependent factors like emission, transport, dispersion will be controlled by meteorological parameters (temperature, humidity, wind characteristics and vertical mixing).Variability of air pollutant in composition, quantity and characteristics depends on sources and changing meteorological conditions, topography as well as source strength. The extensive growth in traffic and coal-based power plants, trash burning, unregulated diesel generator sets use and other significant anthropogenic activities are major contributers to degrading the ambient air quality of India (Gordon *et al.*, 2018; Mannucci and Franchini 2017). Meteorological conditions have impact in the dispersion of ambient air pollution. It has been studied that the concentration of PM_{10} or $PM_{2.5}$ in AAQ are negatively correlation because the rate of dispersion shows faster in the increase wind speed. However, the wind speed impact in the dispersion of finer particulates is noticeable than coarser particulates (Nihalani et al., 2020). It may show similar pattern in case of gaseous air pollutant.

The dispersion of SO_2 and NO_2 are predicted using Geographical Information System with Gaussian air pollutant dispersion model AERMOD (Cimorelli *et al.*, 2004) which requires hourly meteorological observations of surface and upper air. The meteorological conditions simulate the pollutant dispersion which is not available over this industrial region.

The trend analysis in concentration of G_{AAP} and non-carcinogenic risks are related with Acute and chronic toxicity in an industrial area is a major concern of air pollution health research (Maji et al., 2017). This study represents the trend of SO_2 and NO_2 concentration in AAQ, main emitting sources of air pollutants in the port-industrial area of Mundra. In coastal Mundra, cement plant, large coal-based thermal power plant and the harbor activities, the vehicular pollution and large number of small industrial companies located. The research is also concerned with the dispersion of G_{AAP} and meteorological condition of the region and health impact of the exposed population of different age groups.

MATERIALS AND METHODS

Description of the Study Area: For the present study, the study area selected was Mundra region, located in the east of Kutch District of Gujarat, India. Mundra region is surrounded by Gulf of Kutch in South-East, Mandvi in North-West and Anjar-Bhuj in North-East direction. Mundra region is also having India's largest private port, located on the bank of Northern Gulf of Kutch (Figure 1). In Mundra region there are more than thirty air polluting industries, both large and medium scale. Firstly, coastal area of Mundra in Gujarat is the crucial power generating area in India, which contains coal-based mega thermal power plants. Secondly, because of development of Mundra Port, logistics in terms of Import-Export have become more feasible in Mundra Region. New SEZ i.e., Mundra Port and Special Economic Zone (MPSEZ) this region has become an industrial hub for various industries like steel, cement, coke, plywood, steel pipes, oil refineries, port base storage terminal and power project.

Study area and periods: The variations in gaseous parameters sulfur dioxide (SO_2) and nitrogen dioxide (NO_2) in the coastal Mundra region were

Table 1. Reference G_{AAP} standards for NO_2 and SO_2

S. No.	Pollutant	Time Weighted Average	Industrial, Residential, Rural and Other Area	Ecologically Sensitive area (notified by Central Government)
1	Sulphur dioxide (SO_2), µg/m^3	Annual	50	20
		24 hours	80	80
2	Nitrogen dioxide (NO_2), µg/m^3	Annual	40	30
		24 hours	80	80

24 hourly or 8 hourly or 1 hourly monitored values, as applicable shall be complied with 98% of the time in a year. 2% of the time they may exceed the limits but not on two consecutive days of monitoring

observed over the period of 2008 to 2015 at five sites during different seasons like summer, post monsoon and winter. All the sampling sites have predominant uses as industrial, urban, traffic and residential. The monitoring stations were selected in based on the annual wind direction to enable comparison and observe trend. The monitoring sites were selected considerations such as wind direction, accessibility, and availability of reliable power supply etc. The locations sampling sites are given in Table 2 and Figure 1.

The temporal data will be projected based on the data generated at CPCB, GPCB and compliance reports submitted by the projects located in the Industrial Area. The changes of the ambient concentrations of environmental variables showed temporal and spatial variations at different locations around the study area. This study also showed in trend analysis of gaseous pollutant in the study area in 2008 and changes thereof after operation of projects in 2015, which has been assessed through regression line analysis of the variables.

Sampling and analysis methodology: The monitoring stations were selected with reference to coverage factor according to the annual wind speed and direction as per the guidelines set by CPCB. The samples were collected by Envirotech Make Calibrated Respirable Dust Samplers (RDS-APM 460 BL) along with Gaseous attachment. SO_2 and NO_2 were collected in specific 30ml absorbent in low temperature by drawing ambient air with a flow-rate of 0.5 lpm. The absorbing solutions used 0.04M Potassium Tetrachloride Mercurate (TCM) and sodium hydroxide - sodium arsenite for SO_2 and NO_2 respectively.

Sampling frequency and duration: Sampling of SO_2 and NO_2 followed as per the specification of the Central Pollution Control Board, guidelines on ambient air quality monitoring. The sampling was conducted for four seasons like summer, monsoon, post-monsoon and winter of 2008 to 2015. The frequency of sampling for every season was four weeks period and two consequent days in each week. The duration of the sampling was carried out

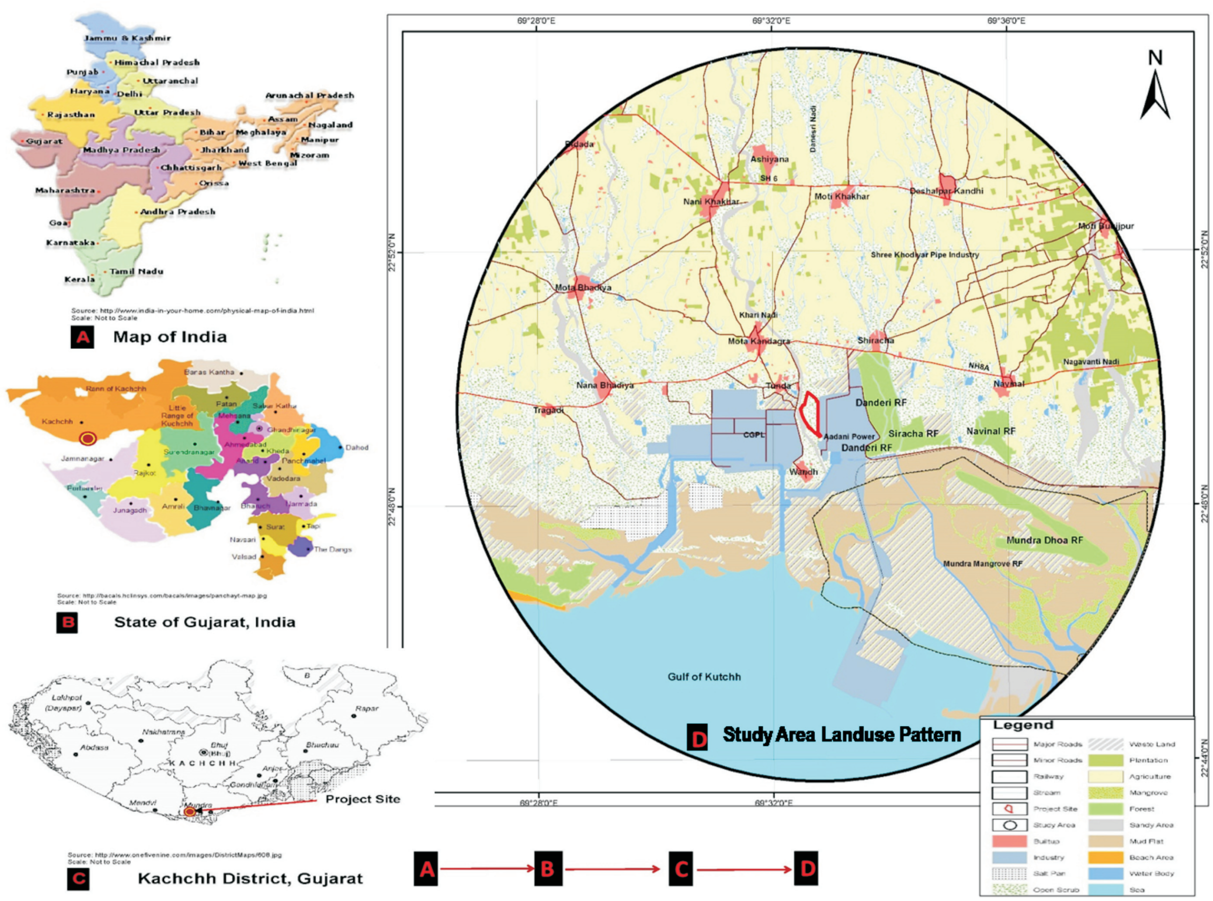


Fig. 1. Ambient Air Quality Locations in the Study Area

24 hours for each day in every location. Air quality monitoring has been performed at all four seasons in the study period for all location, which is representative of the season.

Gaseous pollutant (SO_2 & NO_2): The concentration estimation of SO_2 and NO_2 in the AAQ was done as per IS 5182, Part 2, 2001 (Modified West and Gaeke method) and IS 5182, Part 6, 2006 (Improved Jacobs-Hochheiser method) respectively.

Table 2. Ambient Air Quality Monitoring Locations

S. No.	Location	Code	Height of instrument from GL in m approx.
1	Industrial site	AAQ1	3.5
2	Tunda	AAQ2	4.0
3	Vandh	AAQ3	3.5
4	Mota Khandagra	AAQ4	3.0
5	Sirancha	AAQ5	3.0

Potassium tetrachloromercurate (TCM) solution was used to absorb the Sulphur dioxide from air. SO_2 react with TCM and forms dichlorosulphito mercurate complex which resists oxidation. Dichlorosulphitomercurate is a stable complex which does not react with strong oxidants like ozone and nitrogen oxides. After sampling the absorbent solution was stored in 4°C before analysis. Dichlorosulphitomercurate complex was made to react with pararosaniline and methyl sulphonic acid and develop color as per the concentration of absorbed SO_2. The absorbance of color solution was measured by UV-Visible spectrophotometer. The concentrations of the SO_2 had been estimated in respect to Standard Curve, prepared following the same reactions with of standard SO_2 solution.

Nitrogen dioxide was collected by RDS with gas attachment in a solution of sodium arsenite and sodium hydroxide. After sampling the absorbent was stored in4°C before analysis. The nitrite ion (NO_2) concentration absorbed from ambient air during sampling period was estimated spectrophotometrically at 540nm form a highly colored azo–dye developed by reaction with the nitrite ion of absorbent and phosphoric acid, sulphanilamide, N-(1-naphthyl)-ethylenediamine di-hydrochloride (NEDA).

METEOROLOGY

Two major meteorological parameters related to ambient air pollutant dispersion are wind speed and wind direction. These were analyzed for this study. Meteorological parameters were taken from secondary source of Indian Meteorology Department book. Wind rose of the study area had been plotted using WR Plot software.

Health Risk Assessment: Possible health risks have been estimated to assess the potential threat to habitants of study area by exposure to NO_2 and SO_2. The Human Health Risk Assessment (HHRA) apply to the make the policies to care for public health which source of harmful impacts by the air pollutant (OECD, 2017). The method applied for HHRA with the four components: identification of hazard, dose-response assessment, and assessment of exposure and characterization of risk.

Hazard identification: It reveals the likelihood of impact induced by level pollutant present in an environment on human health (Saliba *et al.,* 2016). The literature review has provided guidelines for identification injurious effect of NO_2 and SO_2 on human health in this study.

Dose-Response assessment: It dependent on two variables (i) exposure level-Concentration and Duration and severity on human health. These values of these variables establish the health impact on living organism (Gratt, 1996). The quantity of NO_2 and SO_2captivation in the body was estimated based on values of the variables mentioned above. The observed concentrations of G_{AAP} are compared with the Indian National Ambient Air Quality Standards (NAAQS) (Table 1).

Exposure assessment: The exposure assessment is based on three parameters (i) Number of People exposed; (2) exposure magnitude and (3) exposure duration to the pollutant. The present study deals with the habitants of Industrial area of Coastal Mundra are to be expected receptors of changeable levels of the pollutants. The population in study area can be classified under various age groups. The study population are classifies into two categories: children (0–6 years) and adults (19"75 years) with a division of male and female population (Table 3).

Risk characterization: The characterization of risk is the quantitative assessment of likelihood of health impact due to the individual exposure in the ambient air pollutant. It also specifies prediction of consequence taking place in the healthy and/or sensitive individuals. The exposure risk to G_{AAP} (SO_2 and NO_2) has been determined by the Hazard Quotient (HQ) as follows Equation (1) and (2)

(Saliba *et al.*, 2016).

$$ADDin\square = \frac{C \times In\square R \times EF \times ED}{BW \times AT} \quad ..(1)$$

$$HQ = \frac{ADDin\square}{RfC} \quad ..(2)$$

Where,

ADD -Average daily dose (NO_2 and SO_2)by inhalation route

C -Concentration of NO_2 and SO_2 in ambient air

InhR-Inhalation rate (m^3 /day)

ED -Exposure duration (days)

BW - Body weight (kg)

AT -Averaging time (days)

EF -Exposure frequency (days/year)

HQ -Hazard quotient

RfC-Reference dose (Table 1)

Table 4 represents the values apply to for the different parameters. HQ >0.5 recommend the likelihood for the individuals sensitive affected in non-cancer health effects for exposure to air pollutant.

Statistical Analysis: Trend analysis has been performed to determine the significant differences between different sites and temporal variation of the different pollutants. Significant correlations among meteorology with air-quality parameters have been established. Average, standard deviation and standard error have also determined using SPSS 15.0 software.

Correlation analysis: Generalized formula use to calculate pearson correlation coefficients among SO_2, NO_2 concentration in AAQ and different meteorological parameters as Equations (3).

$$r = \frac{\sum_{i=1}^{n}(Xi-\bar{X})(Yi-\bar{Y})}{(n-1)SxSy} \quad ..(3)$$

Where, X and Y - variables, $\bar{X}$and $\bar{Y}$- mean values and S_x and S_y- standard deviations

Regression analysis: Multiple linear regression or MLR model has been studied to establish the interrelationship among two or more independent and one dependent or response variable with a linear equation to the observations. MLR technique is useful for exploring observed variables selected for G_{AAP} dispersion. The equation general use for MLR is as Equations (4).

$$y = b0 + \sum_{k=1}^{p} biXi + \varepsilon \quad ..(4)$$

Where,

bi - regression coefficient, xi - independent variable, and î - stochastic error associated with the regressions.

RESULTS AND DISCUSSION

Land Use Pattern: The land use/land cover pattern of the Study Area have been framed from the Satellite Imagery and Topo-sheet and authenticated by field visit. The land use/land cover pattern can be divided into following 15 categories: (i) Built-up (ii) Water Bodies (iii) Industrial Area (iv) Marshy Land (v) Mud Land (vi) Open Scrub Area (vii) Forest Land (viii)Mangrove Area (ix) Plantation Area (x) Sandy Area Sand (xi)Salt Pane (xii)Sea Beach (xiii)Waste Land (xiv)Sea Water (xv) Agriculture Land

Database Used: To study and map the land use

Table 3. Child and adult population of the Study Area

Age Group	No. of Villages	Total Population			Male			Female		
		2001	2011	2016	2001	2011	2016	2001	2011	2016
Child (0-6 yrs)	20	4966	9229	11349	2581	4803	5905	2385	4426	5444
Adults (19-75 yrs)	20	27757	57948	72965	14162	32952	41962	13595	24996	31003

Table 4. Recommended values in equations of the daily exposure dose of NO_2 and SO_2

Parameters	Definition	Value for Age Categories		Reference
		Child (2-6 Yr)	Adult (19-75 Yr)	
EF	Exposure frequency (days/year)	350	350	Morakinyo *et al.*, 2017USEPA, 2015
ED	Exposure duration(year)	6	30	USEPA, 2015; Matooane *et al.*, 2015
AT	Averaging time (days); AT = ED X365 days	2190	10950	USEPA, 2015; Matooane *et al.*, 2015
BW	Body weight (kg)	22.6	71.8	USEPA, 2015; Matooane *et al.*, 2015
InhR	Inhalation rate (m^3/day)	16.74	21.4	USEPA, 2015

pattern of the area, IRS-P6 LISS IV MX Multispectral imagery with extension from 22º55′16.9 to 22º43′02.3" North and from longitude 69º25′04.3" to 69º38′23.2" East has been used as input data of 18th March, 2013 and 11th February, 2014. The spatial Resolution of the satellite data is 23 m. The bands used as input data for the current study have these following features:

Band 2: 0.52 - 0.59 µm (green): It corresponds to green reflectance for vegetation cover and is spanning the region between the blue and red chlorophyll absorption bands.

Band 3: 0.62 - 0.68 µm (red): It denotes green cover of healthy vegetation by detecting red chlorophyll absorption band, most significant bands to vegetation discrimination. This band is also functional to determine soil boundary as well as geological boundary identification. It is a higher contrast band than 1 and 2 due to reduction of atmospheric effects. Crossover of the vegetation reflectance at spectral region from 0.69 to 0.75 ìm can reduce the accuracy.

Band 4: 0.77 - 0.86 µm (near infrared): Vegetation biomass, landwater contrasts, soilcrop, vegetation types are identified in this band

The forest land, barren land, open scrub, river, mangrove area, sandy area, mud land, marshy land, sea beach, waste land, sea water, and water bodies are the lands cover in the study area whereas the agricultural land, Industries, plantation and built-up are the land use in the study area. The given categories of land use and land cover pattern covers an area of about 40976.30 Ha. The percentage of land area covered in figures is mentioned in the Table 5 and has been illustrated in the pie diagram in Figure 1 & 2.

Meteorology as per IMD: Meteorology parameters like speed and direction of wind, air temperature, relative humidity and rail fall are the driving factors to understand the air pollution dispersion. The essential relationship between meteorological condition and atmospheric dispersion involves the wind in the broadest sense. Wind direction alteration over a very wide range of time, associated with dispersion and primarily influence further processes.

Wind pattern: Generally light breeze prevails throughout the year. The dominant wind direction throughout the whole year is South-west, followed by West and North-east. The wind-speed was found to be highest during the monsoon months with the average wind speed varying between 17.2 kmph in June to 5.6k mph in the month of November(Figure 3a-e). The predominant wind direction in the study area observed to be from North West (NW) to South East (SE), therefore the variations in particulate and gaseous pollutants at two stations AAQ1 and AAQ3 are located in downwind direction are studied and three stations AAQ2, AAQ4 and AAQ5 in upwind directions and near the settlements and forest areas are also studied (Figure 1).

Table 5. Land-use Pattern of Study Area

Land Type	Area (in Ha)	Area (in %)
Water Bodies	403.8	1.0
Built-up Area	651.6	1.6
Industrial Area	1556.7	3.8
Marshy Land	23.6	0.1
Mud Land	2853.7	7.0
Open Scrub Area	8341.1	20.4
Forest Land	1251.9	3.1
Mangrove Area	543.5	1.3
Plantation Area	1322.2	3.2
River Sand	563.6	1.4
Salt Pane	445.9	1.1
Beach Area	171.9	0.4
Waste Land	3026.3	7.4
Sea Water Area	9067.3	22.1
Agriculture Land	10753.2	26.1
Total	**40976.3**	**100.0**

Source: (i) LISS III Satellite Imagery of Study Area, 2014; (ii) Open Series Map Sheet No. F42J5, F42J9 &F42J10, First Edition, 2011, Published under direction of Swarna Subba Rao, B.E., Surveyor General of India, Printed at the Southern Printing Group of Survey of India, Government of India;

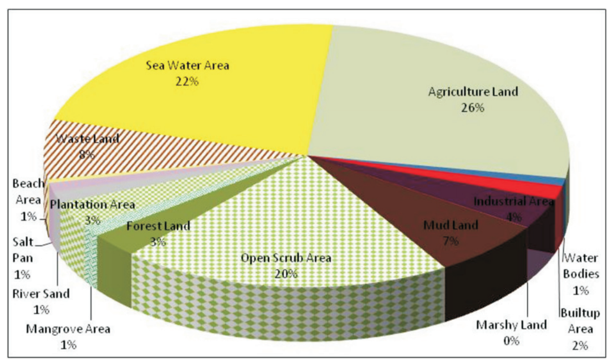


Fig. 2. Land-use/Land cover Pattern within Study Area

Relative Humidity, Temperature, and Rainfall: The region has reasonably dry climate except during monsoon season when moisture levels are high in the surrounding air. The summer season is the driest part of the year when humidity levels go below 30%

especially during March and April. July to September, being the rainiest months, experience humidity level of 73% to 82% respectively in the daytime (Table 6, Figure 4a). The region has reasonably dry climate except during monsoon season when moisture levels are high in the surrounding air. The summer season is the driest part of the year when humidity levels go below 30% especially during March and April. July to September, being the rainiest months, experience humidity level of 73% to 82% respectively in the daytime.

The area has quite high temperatures during summer and is moderately cold in winter. The highest monthly maximum temperature recorded is 43.8°C in May while the lowest monthly average temperature recorded is 8.4°C in January (**Figure 4b**).

The Kutch area experiences very low rainfall with the total average annual rainfall of about 276.4mm (as per IMD 30 year's average data 1970-2000) with 13.9 numbers of rainy days. The heaviest rainfall in 24 hours experienced was 467.9 mm on the 15th July 1959. Maximum rainfall is experienced in the month of July and August (Figure 4c).

G_{AAP} Distribution: The seasonal data were analyzed at 5 locations in downwind & upwind direction as mentioned in Table-7 and 8. The variation in

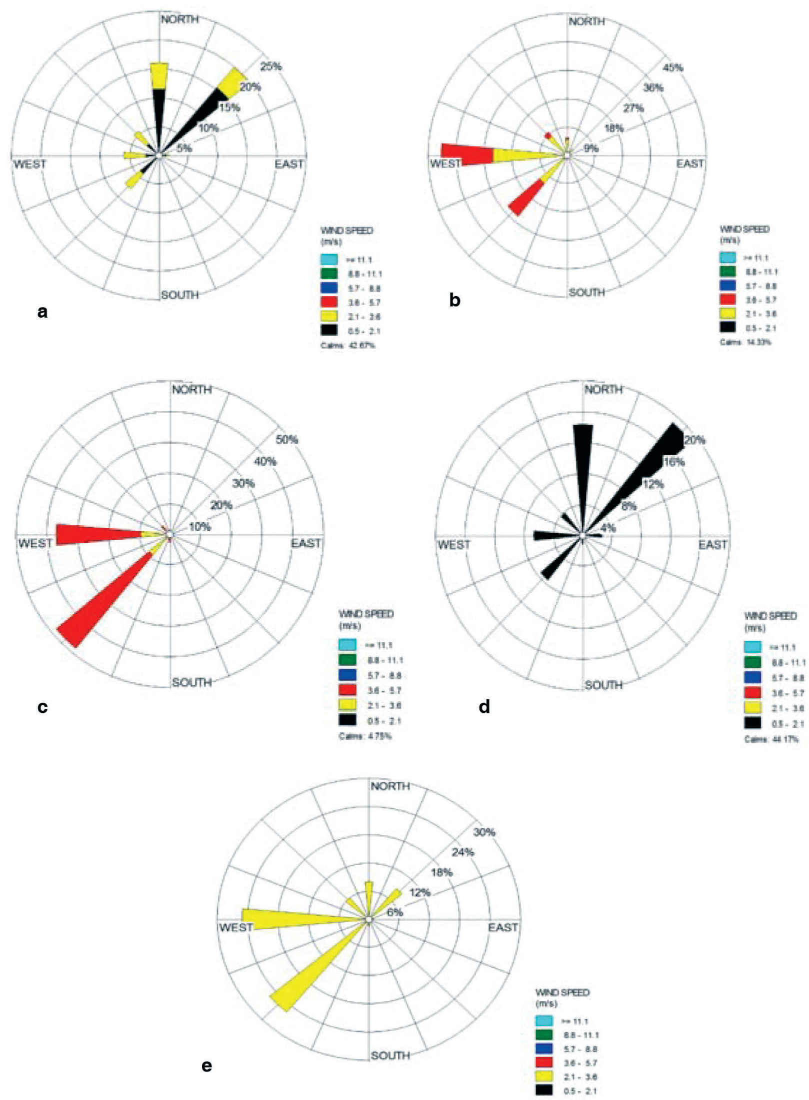


Fig. 3. Seasonal & Annual Wind Directional Pattern-as per IMD, Bhuj-1971-2000; 3**a -**Winter (December to February); 3**b -** Summer (March to May); 3**c -** Monsoon (June to September); 3**d -** Post-monsoon (October to December) and 3**e -** Annual

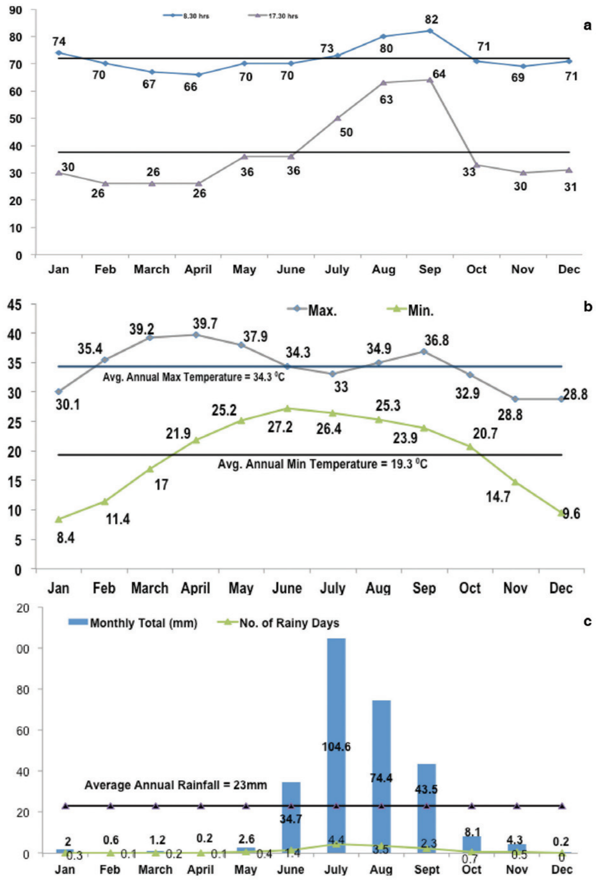


Fig. 4. Monthly Relative Humidity during Day and Evening (3a), Maximum and Minimum Temperature (3b) and Average Rainfall in mm and No. of Rainy Days (3c) as per IMD

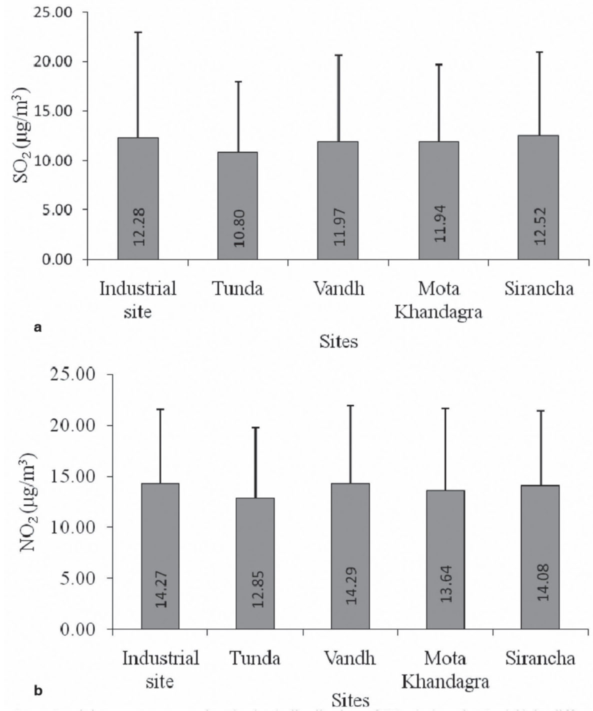


Fig. 5. Spatial mean concentration (µg/m^3) distribution of SO_2 (5a) and NO_2 (5b) in different sites. Figures show mean concentrations and standard deviation

concentration values in various seasons from 2008-15 across all the 5 locations shows similar characteristics and nature of variation. The location wise seasonal variations observed are discussed below.

Mean concentrations of NO_2 and SO_2: Annual average concentrations from 2008 to 2015, of SO_2 (Table 7) and NO_2 (Table 8) followed a variable pattern in different sites. The inter-annual mean variation of SO_2concentrationswas 12.2 ± 10.7 µg/m^3 and 12.5 ± 8.5 µg/m^3 at industrial area and Sirancha village from 2008 to 2015(Figure 5a). These results justify the annual wind direction and pollutant distribution towards the downwind direction. The lowest inter-annual mean of SO_2 was found at Vandh village (12.0 ± 8.6 µg/m^3). Vandh village is situated adjoining to the industrial zone. Tunda (10.8 ± 7.2 µg/m^3) and Mota Khandagra (11.9 ± 7.7 µg/m^3) villages are in the same direction as per annual upwind direction which shows similar pattern of inter-annual mean of SO_2. 98 Percentile values of SO_2 concentrations was at industrial area (38.2 µg/m^3) followed by Vandh (35.0 µg/m^3), Sirancha (34.0 µg/m^3), Mota Khandagra (31.8 µg/m^3) and Tunda (28.6 µg/m^3).

Nitrogen dioxide concentration shows a slight different pattern of spatial distribution (Figure 5b). The inter-annual mean of NO_2 concentrations was found more or less similar at industrial (14.3 ± 7.3 µg/m^3) and Sirancha village (14.1 ± 7.4 µg/m^3) along with Vandh village (14.3 ± 7.7 µg/m^3). Lowest mean of NO_2concentrations was found at Tunda village (12.9 ± 6.9 µg/m^3).

The NO_2 concentration level in AAQ at residential Kolkata observed 32.5±14.2 µg/m^3 whileit was in industrial area 49.9±9.8 µg/m^3 (Gupta *et al.*, 2008). In the winter season the average NO_2 level was approx 20.12 ± 6.11 µg/m^3 and the range was 1.47–72.93 µg/m^3 in the of Delhi urban region (Sharma *et al.*, 2010). In Haryana, India NO_2 level is higher than National Ambient Air quality Standards in sensitive area (10.6 µg/m^3 – 83.6 µg/m^3) and industrial region (17.7–117.1 µg/m^3) (Kaushik *et al.*, 2006). Studies reveal that in Lucknow the NO_2 level in AAQ was 38.240 µg/m^3 (Verma *et* *al.,* 2003). It was observed that NO_2 concentrations were fluctuate seasonally like, in pre monsoon (97.6 ± 79.0 µg/m^3), post monsoon (97.6 ± 79.0 µg/m^3) and winter seasons (95.1 ± 52.4 µg/m$_3$) in the industrial areas at Burdwan, India (Chattopadhyay, 2012).

Temporal variations and trend analysis: It is observed that SO_2 concentration ranged from 6.24-66.04 µg/m^3 in the study period during of 2008 to 2015 which was always remain lower than the NAAQS except sudden high value during winter 2011-12, which appears to be a sampling error. In general, it is observed that the 98 percentile values of both pollutants SO_2 and NO_2 had distinct temporal variations among preconstruction, construction and operation stages. There was an increase in SO_2 values in operational stage over preconstruction and construction stages. During operation, the values reveal increasing trend. Regression line of the SO_2 concentration signifies this observation (Figure 6a-e). Regression lines of the NO_2 (Figure 7a-e) concentration signify the similar type of increasing trained in this observation (Table 9).

Meteorology and G_{AAP} distribution: Linear regression model analysis was applied for the consideration the relation between meteorological conditions and the distribution of SO_2 and NO_2 by mean annual the concentration in AAQ of G_{AAP} as on three major stack emitted pollutants viz., SO_2, NO_2, and PM.

The hourly Triple Joint Frequency data had been used in the present case model as simulations (Figure 9a and 9b). Variation of SO_2 and NO_2 levels at the different receptor had been estimated to find the optimum description in the 10km radius of the study area in 16 directions. The incremental concentrations of SO_2 and NO_2 are estimated for the monitoring period. The maximum incremental GLCs (ground level concentrations) for the industrial activities had been predicted. According to the model output GLC are 77.0, 88.5, 72.2, 54.3 and 77.8 µg/m^3 for SO_2 at industrial site, Tunda, Sriancha, Vandh and MotaKandagra villages respectively. Incremental concentrations of NO_2 are 27.1, 32.1, 37.0, 23.0 and 30.6 at industrial site, Tunda, Sriancha, Vandh and Mota Kandagra villages respectively. Uses of different ambient air quality controlling measures in industries reduce the concentrations of SO2andNO_2in ambient air which leads to improve the air quality.

G_{AAP} impact to non-carcinogenic health risks : The non-carcinogenic risks for the exposure via the inhalation route for ambient air SO_2 and NO_2study results are presented in Figure 10a and 10b. The major pathway of entry of the ambient air pollutants to the human system is inhalation route. In terms of health risk, the study shows a parallel model of

Table 6. Meteorology Condition in Study Area of Bhuj Observatory

Season	Months	Temperature (^{0}C)		Rainfall in mm			Relative Humidity in %	
		Maximum	Minimum	Total	Heaviest fall in 24 hr	Heaviest fall in 24 hr	0830 hrs	1730 hrs
Winter	December	28.8	9.6	0.2	36.8	0	71	31
	January	30.1	8.4	2.0	14.5	0.3	74	30
	February	35.4	11.4	0.6	61.5	0.1	70	26
	Average	31.4	9.8	2.8	-	0.4	71.7	29
Summer	March	39.2	17.0	1.2	42.2	0.2	67	26
	April	39.7	21.9	0.2	67.1	0.1	66	26
	May	37.9	25.2	2.6	186.9	0.4	70	36
	Average	38.9	21.4	4.0	-	0.7	67.7	29.3
Monsoon	June	34.3	27.2	34.7	178.5	1.4	70	36
	July	33.0	26.4	104.6	467.9	4.4	73	50
	August	34.9	25.3	74.4	241.4	3.5	80	63
	September	36.8	23.9	43.5	176.1	2.3	82	64
	Average	34.8	25.7	257.2	-	11.6	76.3	53.3
Post Monsoon	October	32.9	20.7	8.1	118.6	0.7	71	33
	November	28.8	14.7	4.3	102.4	0.5	69	30
	December	28.8	9.6	0.2	36.8	0	71	31
	Average	30.2	15.0	12.6	-	1.2	70.3	31.3

Source: Climatological Table1951-80, Indian Meteorological Department, Govt. of India, New Delhi variable function of relative humidity (RH), temperature (T), and rain fall (RF) (**Figure 8a &b**). This model proposes the concentration of SO_2 and NO_2 is mostly impacted by meteorological condition temperature negatively (Tolerance: p>0.01) followed by relative humidity (RH) and rain fall (RF). Due to high level of temperature near the earth surface the air boundary layer height increase. It increases the dispersion rate of the pollutant at the surface of earth. Step wise MRM or Multiple Regression Model study was performed for G_{AAP} data set. MRM shows the concentration of SO_2 and NO_2 (C_{SO2} and C_{NO2}) are considered dependent variable and ambient T, RH and RF are assumed independent variables. The constructed equation is as follows:

$$C_{SO2} \text{ or } C_{NO2} = 54.4 - 0.964*T - 1.0132E\text{-}03*RF - 0.125*RH$$

Futuristic emission scenario and model output: Gaussian plume dispersion model had been carried out at multiple point sources of short term impact prediction on air environment. It is a mathematical model based for the steady state condition. In this study, based on steady state condition Gaussian plume dispersion principal AERMOD dispersion modeling, considered for multiple point sources. It has been introduced by USEPA (United States Environmental Protection Agency) for simulations from point sources. The model simulations depend

Table 7. Mean seasonal concentrations of SO_2 ($\mu g/m^3$)

Year	Seasons	Industrial site	Tunda	Vandh	Mota Khandagra	Sirancha
2008	Winter 07 -08	11.17	7.60	10.30	10.15	13.00
	Summer	8.15	5.90	5.70	6.45	6.65
	Monsoon	8.11	5.73	6.19	6.50	6.52
	Postmonsoon	11.03	5.73	10.30	10.12	12.96
2009	Winter 08 - 09	7.45	8.45	8.20	7.77	7.76
	Summer	7.95	6.95	9.50	8.35	8.00
	Monsoon	9.92	6.83	9.44	10.22	11.75
	Postmonsoon	7.00	6.83	7.49	7.50	13.10
2010	Winter 09 -10	12.02	7.85	11.04	9.71	9.56
	Summer	10.50	7.40	9.10	14.45	9.70
	Monsoon	11.10	8.20	12.46	12.25	9.89
	Postmonsoon	12.40	8.20	12.70	10.35	10.01
2011	Winter 10 -11	9.55	7.26	7.42	8.31	10.81
	Summer	8.80	7.20	7.80	9.60	7.80
	Monsoon	8.42	6.59	6.90	9.62	9.41
	Postmonsoon	6.85	6.59	6.30	6.45	5.75
2012	Winter 11 -12	66.04	38.20	47.06	41.06	42.86
	Summer	6.24	5.65	6.25	6.30	7.60
	Monsoon	7.05	6.30	6.47	6.47	7.05
	Postmonsoon	8.90	6.30	8.51	7.30	5.50
2013	Winter 12 -13	8.67	7.90	9.20	7.80	7.57
	Summer	8.52	8.15	8.40	7.85	8.80
	Monsoon	7.30	7.60	6.40	8.34	8.90
	Postmonsoon	8.26	7.60	8.90	7.45	7.37
2014	Winter 13 -14	16.06	18.05	14.86	7.74	19.67
	Summer	8.82	7.90	9.25	7.50	9.74
	Monsoon	12.32	13.25	14.40	9.54	13.57
	Postmonsoon	16.05	13.25	16.18	14.33	19.70
2015	Winter 14 -15	19.60	23.20	27.00	26.60	28.10
	Summer	17.10	19.30	22.20	21.20	21.40
	Postmonsoon	19.20	21.10	25.20	24.50	27.70
	Minimum	6.236	5.650	5.700	6.300	5.500
	Maximum	66.040	38.200	47.058	41.060	42.864
	Average	12.277	10.796	11.972	11.936	12.522
	Standard Deviation	10.699	7.228	8.682	7.747	8.452
	98 Percentile	38.176	28.600	35.023	31.806	34.006

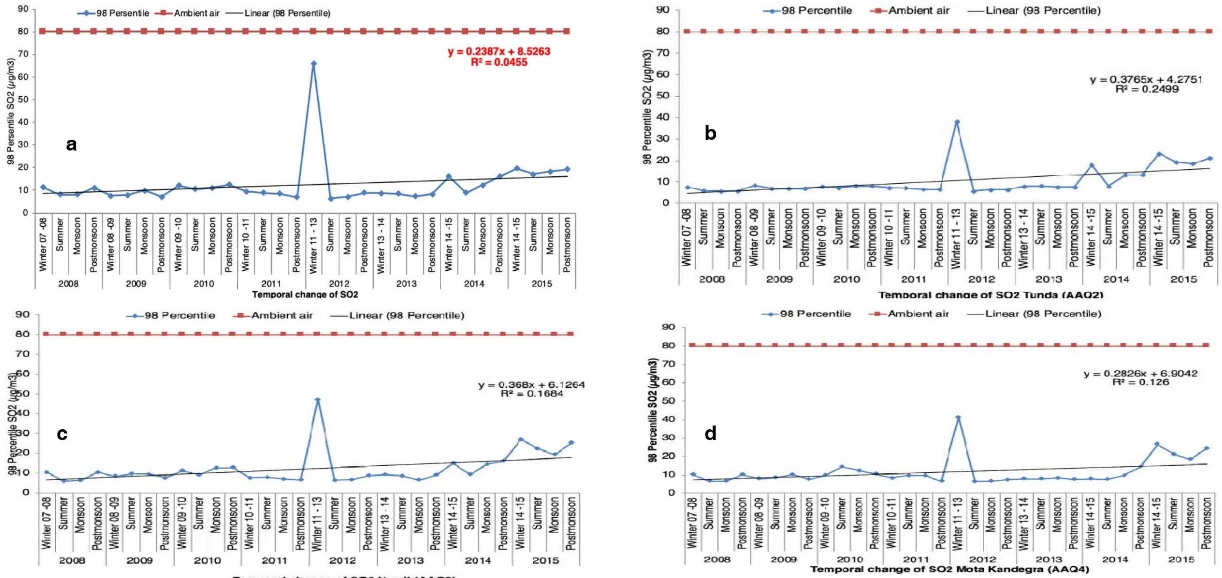
NA- not available

impact for the exposure to studied G_{AAP} for SO_2 and NO_2. The calculated Hazard Quotient (HQ) for the pollutants in different age groups of Mundra Industrial area and other villages of the study are exposed is less than 0.5 (HQ <0.5) except children in all study sites. This observation indicates that levels of SO_2 and NO_2 recorded during the study period are implausible impact to public health. The HQ of exposure to NO_2 (0.68) at industrial site for the children is higher than other site. In Vandh (0.62) and Sirancha (0.60) villages are also in health risk for the children. In case of adult, HQ for the both pollutants is less than 0.50. The highest non-carcinogenic risks on adults for SO_2has found at industrial areas (0.27) followed by Vandh (0.25), Sirancha (0.24), MotaKhandagra (0.23) and Tunda (0.20). HQ_{SO2} of children is highest at industrial site (0.54). HQ_{SO2} for adults are range between 0.16 at Vandh to 0.22 at industrial site. These results imply, children (2–6 years) are the primary sensitive and potential receptors in the industrial area of coastal Mundra region. The health impact of exposure to both pollutants SO_2 and NO_2 on children are more than adults. In previous study, it has been observed that exposure in the low ambient nitrogen dioxide may cause respiratory infections in lung with an acute and obstructive diseases (Santus *et al.,* 2012; Chen *et al.,* 2012). The event of acute ichaemic stroke is also significantly associated with low concentration of NO_2 exposure.

Table 8. Mean seasonal concentrations of NO_2 (μg/m^3)

Year	Seasons	Industrial site	Tunda	Vandh	Mota Khandagra	Sirancha
2008	Winter 07 -08	13.216	11.65	22.3	13.45	15.7
	Summer	15.25	8.2	8.2	7.7	9
	Monsoon	13.54	8.15	8.33	7.42	8.95
	Postmonsoon	13.184	8.15	21.996	13.432	15.408
2009	Winter 08 - 09	13.748	12.35	12.3	10.462	11.324
	Summer	10.808	8.4	13.2	9.8	9.5
	Monsoon	12.228	8.468	11.324	13.54	14.81
	Postmonsoon	10.78	8.468	9.988	9.25	16.25
2010	Winter 09 -10	14.652	10.564	15.848	11.512	14.004
	Summer	13.9	12.65	17.1	17.4	17.95
	Monsoon	16.25	11.36	18.68	14.796	14.35
	Postmonsoon	20.25	11.36	20.256	16.2	15.46
2011	Winter 10 -11	10.512	9.348	8.8	10.88	14.664
	Summer	11.95	9.7	10	13.75	10.15
	Monsoon	NA	9.98	9.96	12.2	10.92
	Postmonsoon	NA	9.98	8.9	9	8.2
2012	Winter 11 -12	10.4	7.356	10.2	8.654	7.5
	Summer	8.698	8.602	8.534	8.104	8.452
	Monsoon	8.698	8.602	8.534	8.104	8.452
	Postmonsoon	10.532	8.602	10.212	9.1	7.6
2013	Winter 12 -13	10.734	9.908	10.5	9.45	9.612
	Summer	10.544	10.35	9.95	10.3	11.25
	Monsoon	8.2	8.102	7.572	10.1	10.934
	Postmonsoon	7.196	8.102	7.8	6.3	6.68
2014	Winter 13 -14	18.888	23.104	16.57	6.468	21.572
	Summer	6.7	6.15	7.45	5.65	7.7
	Monsoon	18.298	15.904	16.452	7.7	17.756
	Postmonsoon	20.424	15.904	19.84	17.324	21.64
2015	Winter 14 -15	29.2	31.1	33.6	36.5	32.3
	Summer	26.5	26.1	28.3	29.3	29.2
	Postmonsoon	28.5	26.4	30.2	32	29.2
	Minimum	6.700	6.150	7.450	5.650	6.680
	Maximum	29.200	31.100	33.600	36.500	32.300
	Average	14.268	12.853	14.287	13.644	14.080
	Standard Deviation	7.330	6.899	7.713	8.010	7.370
	98 Percentile	28.808	29.628	31.560	33.620	30.440

NA- not available



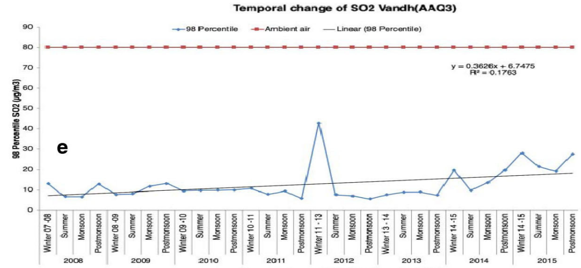
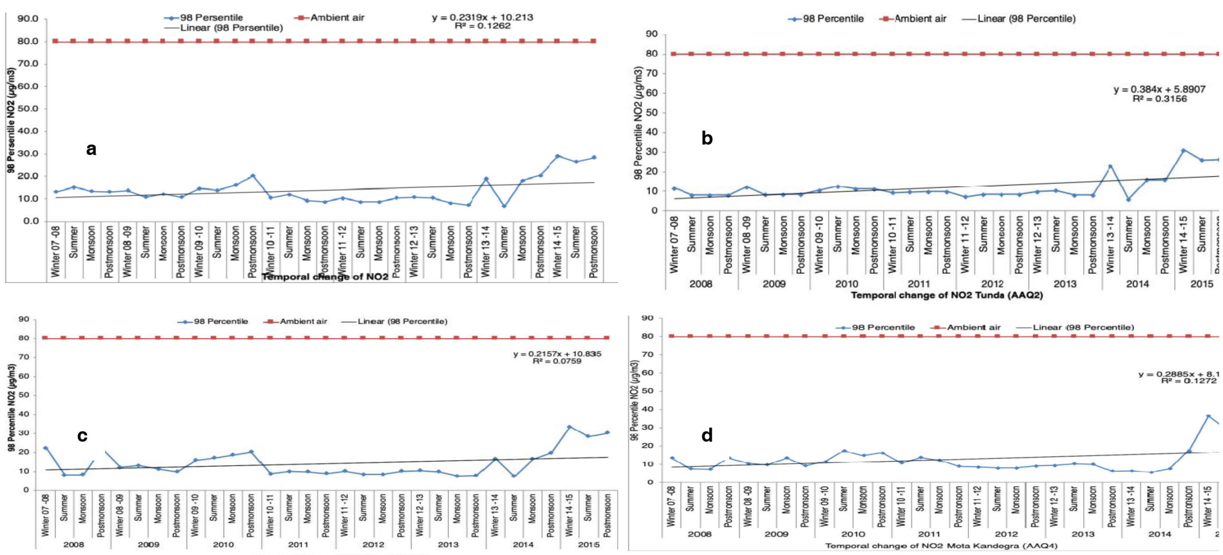


Fig 6: Temporal Variations and trained analysis of SO_2 ($\mu g/m^3$) distribution in Industrial area (6a), Tunda (6b), Vandh (6c), Mota Khandegra 6(d) and Sirancha (6e). Figures show seasonal changes, National Ambient Air Quality Standards as Ambient air, regression line and equations concentrations.



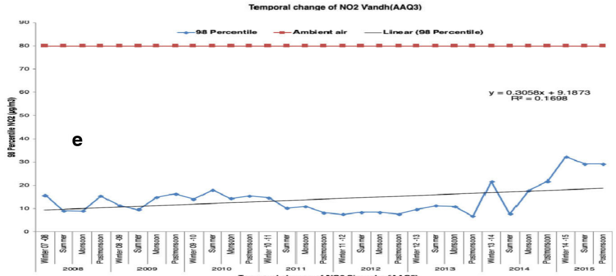


Fig 7: Temporal Variations and trained analysis of NO_2 ($\mu g/m^3$) distribution in Industrial area (7a), Tunda (7b), Vandh (7c), Mota Khandegra (7d) and Sirancha (7e). Figures show seasonal changes, National Ambient Air Quality Standards as Ambient air, regression line and equations concentrations.

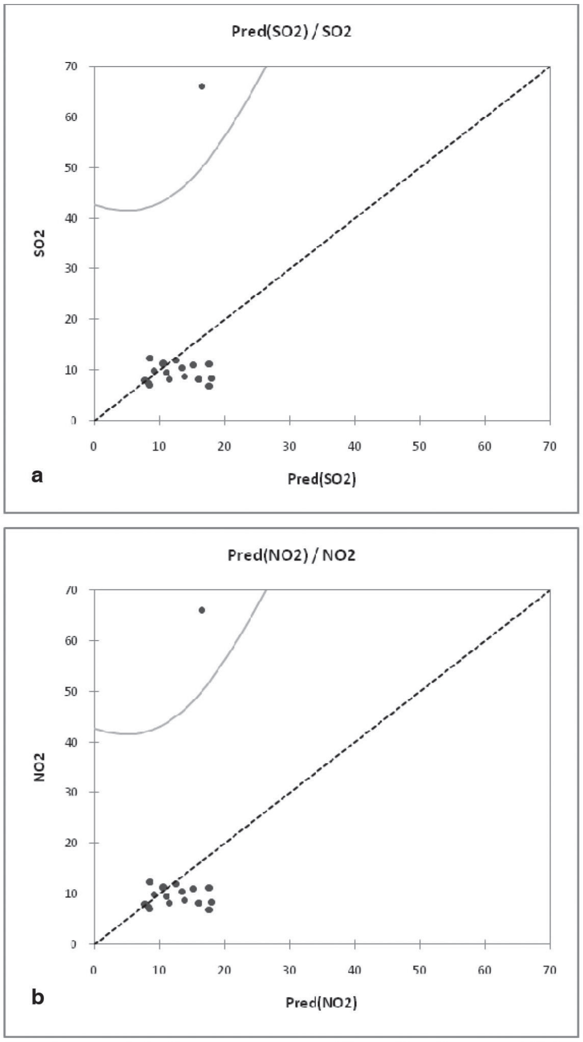


Fig. 8. Multiple regression model of meteorology vs G_{AAP} distribution of SO_2 (8a) and NO_2 (8b)

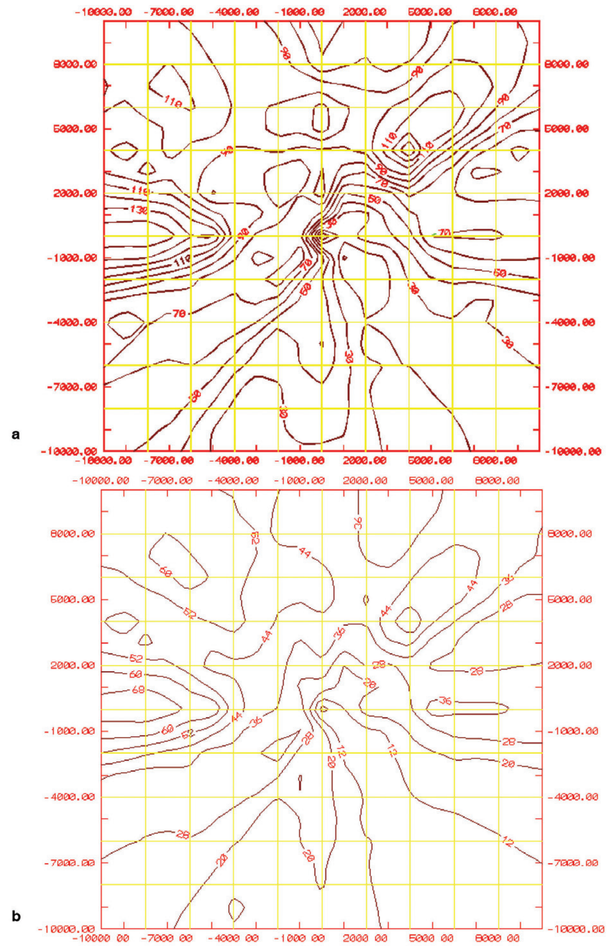


Fig 9. Short Term 24 hourly GLCs of SO_2 (10a) and NO_2 (10b)

CONCLUSION

The study provides information and highlights trend of the concentration of G_{AAP} in the ambient air quality of Mundra over a period of time. This study also revel the seasonal and spatial distribution pattern of SO_2 and NO_2concentration of the coastal industrial area of Mundra. It has been revealed that, in regression analysis G_{AAP} concentrations are in a

Table 9. Regression equation and trained analysis of G_{AAP}

Sl. No	Site	Regression Equation	r^2 value
Equations for SO_2			
1	AAQ1	Y = 0.2387X + 8.5263	0.0455
2	AAQ2	Y = 0.3765X + 4.2751	0.2499
3	AAQ3	Y = 0.3680X + 6.1264	0.1684
4	AAQ4	Y = 0.2826X + 6.9042	0.1260
5	AAQ5	Y = 0.3626X + 6.7475	0.1763
Equations for NO_2			
6	AAQ1	Y = 0.2319X + 10.213	0.1262
7	AAQ2	Y = 0.3840X + 5.8907	0.3156
8	AAQ3	Y = 0.2157X + 10.835	0.0759
9	AAQ4	Y = 0.2885X + 8.0000	0.1272
10	AAQ5	Y = 0.3058X + 9.1873	0.1698

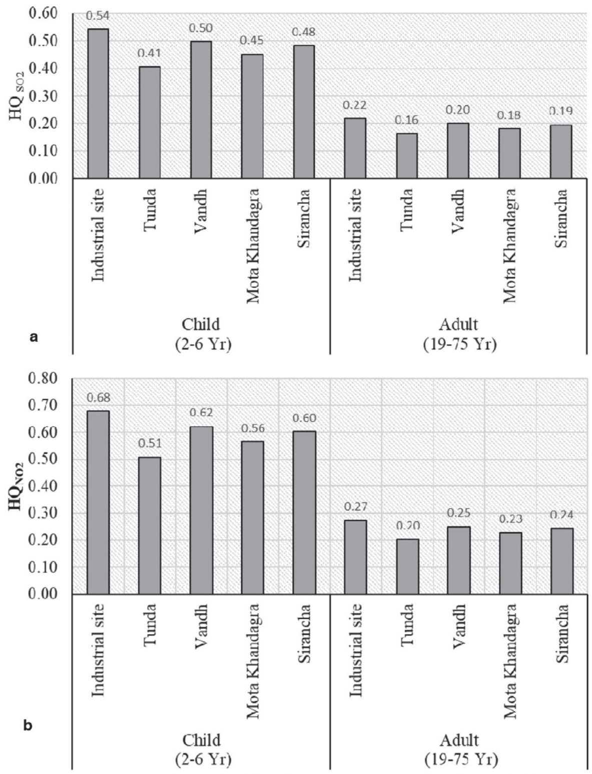


Fig. 10. Non-carcinogenic risks of G_{AAP} like SO_2 (10a) and NO_2 (10b)

increasing trained. In MRM analysis, the meteorological condition and the concentration of G_{AAP} shows a positive relation. The pollutants do not exceed the annual mean concentrations according to the Indian recommended standards for ambient air quality. But it shows that seasonal alteration in concentration level of the pollutants. However, the pollutants mean annual concentrations remain within the National Ambient Air Quality Standard, the observed concentration may cause some degree of chronic and acute non-cancer risk to children. This study suggest that the research on cumulative emission inventory by considering all point and nonpoint ambient air polluting sources in Mundra urban and Industrial zone will depict a more reasonable and real time scenario, which will facilitate in policy making as well as human health condition.

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REFERENCES

Balakrishnan, K., Dey, S., Gupta, T., Dhaliwal, R.S., Brauer, M., Cohen, A.J., Stanaway, J.D., Beig, G., Joshi, T.K., Aggarwal, A.N. and Sabde, Y. 2019. The impact of air pollution on deaths, disease burden, and life expectancy across the states of India: the Global Burden of Disease Study. *Lancet Planet. Health.* 3 (1): 26-39.

Behera, S.N., Sharma, M., Dikshit, O. and Shukla, S.P. 2011. GIS-based emission inventory, dispersion 496 modeling, and assessment for source contributions of particulate matter in an urban environment. *Water Air Soil Pollut.* 218 : 423-436.

Cesari, D., De Benedetto, G.E., Bonasoni, P., Busetto, M., Dinoi, A., Merico, E., Chirizzi, D., Cristofanelli, P., Donateo, A., Grasso, F.M. and Marinoni, A. 2018. Sea- sonal variability of $PM_{2.5}$ and PM_{10} composition and sources in an urban background site in Southern Italy. Sci. *Total Environ.* 612 : 202-213.

Cesari, D., Amato, F., Pandol, M., Alastuey, A., Querol, X., and Contini, D. 2016. An inter- comparison of PM10 source apportionment using PCA and PMF receptor models in three European sites. Environ. *Sci. Pollut. Res.* 23 (15) : 15133-15148.

Chen, S.Y., Chan, C.C., and Su, T.C. 2017. Particulate and gaseous pollutants on inflammation, thrombosis, and autonomic imbalance in subjects at risk for cardiovascular disease. *Environ. Pollut.* 223: 403-408.

Chen, R., Samoli, E., Wong, C.M., Huang, W., Wang, Z., Chen, B. and Kan, H. 2012. Associations between short-term exposure to nitrogen dioxide and mortality in 17 Chinese cities: The China Air Pollution and Health Effects Study (CAPES). *Environ. Intl.* 45 : 32-38.

Chattopadhyay, S. 2012. *Spatial and temporal variations of ambient air quality in Burdwan town, West Bengal, India.* Ph. D. Thesis, The University of Burdwan, West Bengal, India. shodhganga. inflibnet.ac.in/bitstream/10603/21860/2/thesis.pdf

Chakraborty, A. and Gupta, T. 2010. Chemical characterization and source apportionment of submicron (PM1) aerosol in Kanpur Region India. *Aerosol Air Qual. Res.* 10 : 433-445.

Cimorelli A.J., Perry S.G., Venkatram A., Weil J.C., Paine R.J., Wilson R.B., Lee R.F., Peters W.D., Brode R.W. and Paumier, J.O. 2004. AERMOD: Description of model formulation. US Environmental Protection Agency. *EPA Report* No. 454/R-03-002d

Goel, V., Mishra, S.K., Ahlawat, A., Sharma, C., Vijayan, N., Radhakrishnan, S.R., Dimri, A.P. and Kotnala, R.K. 2018. Effect of reduced trafc density on characteristics of particulate matter over Delhi. *Curr. Sci.* 115 (2) : 315.

Gordon T., Balakrishnan K., Dey S., Rajagopalan S., Thornburg J., Thurston G. and Salvi S. 2018. Air pollution health research priorities for India: perspectives of the Indo-US Communities of Researchers. *Environ Int.* 119 : 100-108. doi: 10.1016/j.envint.2018.06.013.

Gratt, L.B. 1996. Air Toxic Risk Assessment and Management: Public Health Risks for Normal Operations; Van Nostrand Reinhold: New York, NY, USA.

Gupta, A.K., Karar, K., Ayoob, S. and John, K. 2008. Spatio-temporal characteristics of gaseous and particulate pollutants in an urban region of Kolkata, India. *Atmospheric Research.* 87 : 103-115.

Happo, M.S., Salonen, R.O., Hälinen, A.I., Jalava, P.I., Pennanen, A.S., Dormans, J.A., Gerlofs-Nijland, M.E., Cassee, F.R., Kosma, V.M. and Sillanpää, M. 2010. Inflammation and tissue damage in mouse lung by single and repeated dosing of urban air coarse and fine particles collected from six European cities. *Inhal. Toxicol.* 22 : 402-416.

Kaushik, C.P., Ravindra, K., Yadav, K., Mehta, S. and Haritash, A.K. 2006. Assessment of ambient air quality in urban centres of Haryana (India) in relation to different anthropogenic activities and health risks. *Environmental Monitoring and Assessment.* 122 : 27-40. doi: 10.1007/s10661-005-9161-x PMID: 16897524

Li, Z., Wang, Y., Xu, Z. and Cao, Y. 2021. Characteristics and sources of atmospheric pollutants in typical inland cities in arid regions of central Asia: A case study of Urumqi city. *PLoS ONE.* 16(4) : e0249563. https://doi.org/10.1371/ journal.pone.0249563

Li, X., Wang, S., Duan, L., Hao, J. and Nie, Y. 2009. Carbonaceous aerosol emissions from household biofuel combustion in China. Environ. *Sci. Technol.* 43 (15) : 6076-6081.

Maji, S., Ahmed, S., Siddiqui, W.A. and Ghosh, S. 2017. Short term effects of criteria air pollutants on daily mortality in Delhi, India. *Atmos. Environ.* 150 : 210-219.

Mannucci P. and Franchini, M. 2017. Health effects of ambient air pollution in developing countries. *Int J Environ Res Public Health.* 14(9) : 1048.

Murari, V., Singh, N., Ranjan, R., Singh, R.S. and Banerjee, T. 2020. Source apportionment and health risk assessment of airborne particulates over central Indo-Gangetic Plain. *Chemosphere*. 127-145.

Nihalani, Seema A., Anjali K. Khambete, and Namrata D. Jhariwal 2020. Source Apportionment of Particulate Matter–A Critical Review for Indian Scenario. https://doi.org/10.1007/978-3-030-38152-3_14

Pant, P. and Harrison, R.M. 2012. Critical review of receptor modelling for particulate matter: a case study of India. *Atmos. Environ.* 49 : 1-12.

Organisation for Economic Cooperation and Development (OECD). 2017. OECD Environmental Outlook to 2030; OECD: Paris, France, 2008; Available online: www.sourceoecd.or (accessed on 8 March 2017).

Saliba, N.A., Nassar, J., Hussein, F., El Kfoury, D.E.L., Nicolas, D.J., El Tal, T. and Baalbaki, R. 2016. Airborne toxic pollutants: Levels, health effects, and suggested policy implementation framework in developing countries. *Adv. Mol. Toxicol.* 10 : 187-233.

Santus, P., Russo, A., Madonini, E., Allegra, L., Blasi, F., Centanni, S., Miadonna, A., Schiraldi, G., & Amaducci, S. 2012. How air pollution influences clinical management of respiratory diseases. A case-crossover study in Milan. *Resp. Res.* 13 : 95.

Sharma, S.K., Datta, A., Saud, T., Mandal, T.K., Ahammed, Y.N. and Arya, B.C. 2010. Study on concentration of ambient NH_3 and interactions with some other ambient trace gases. *Environmental Monitoring and Assessment.* 16 : 225-235.

United States Environmental Protection Agency (US EPA). (2015). Risk Assessment Guidance for Superfund, Vol 1: Human Health Evaluation Manual (Part A); Office of Emergency and Remedial Response, US Environmental Protection Agency: Washington, DC, USA, 1989. Available online: http://www.epa.gov/superfund/programs/risk/ragsa (accessed on 20 June 2015)

United States Environmental Protection Agency (US EPA). (2015). Exposure Factors Handbook; National Center for Environmental Assessment, Office of Research and Development, U.S. Environmental Protection Agency: Washington, DC, USA, 1997. Available online: http://www.epa.gov/ncea/expofac.htm (accessed on 20 June 2015).

Verma, A., Singh, S.N. and Shukla, M.K. 2003. Air quality of the Trans-Gomti area of Lucknow city, India. *Bulletin of Environmental Contamination and Toxicology.* 70 : 166-173. doi: 10.1007/s00128-002-0171-x PMID: 12478440

WHO. 1987. *Air Quality Guidelines for Europe.* European series no. 23. WHO Regional Publications, Copenhagen

WHO. 2000a. *Air Quality Guidelines for Europe:* 2nd ed, in European series, No. 91. WHO Regional Publications, Copenhagen

WHO. 2000b. *Guidelines for Air Quality.* World Health Organization, Geneva

WHO. 2006. *Air Quality Guidelines: Global Update 2005.* WHO Regional Office for Europe, Copenhagen