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RESEARCH ARTICLE

Prediction of SO_2 Concentration Using Air Dispersion Model: A Case Study of Thermal Power Plant

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ABSTRACT

The air pollution has assumed greater and alarming proportion in urban , industrial & pockets where cluster of air polluting industries are in existence .Various air pollutants, namely, Carbon Monoxide (CO), Sulphur Dioxide (SO_2), Oxides of Nitrogen (NO_x), Suspended Particulate Matter, Respirable Suspended Particulate Matter (PM10, PM2.5, PM1.0), Hydrogen Sulphide (H_2S), Methane, Hydrocarbons (HC), Benzene, Aldehydes, 1-3 Butadiene, PAH, Mercaptans, Carbon Disulphide (CS_2) , Fluorine based gases and so on so forth are emitted out from these sources. These pollutants are caused on account of vehicular emissions, industrial, Mining, Commercial and Household fuel burning. These pollutants when released in the atmosphere are subjected to transportation, dispersion, transformation, fall out, wash out and finally reach the ground level at a particular distance. Emissions from stacks are subjected to plume rise which again is dependent on force of buoyancy and momentum. The higher is the plume rise, the lesser will be Ground level Concentration. The relationship between the source of emissions and its magnitude with the ground level concentrations at different receptor points is governed by air dispersion models which takes into account the source strength, plume rise, Atmospheric Stability, mixing height, wind velocity, terrain and other meteorological conditions. Various air dispersion models have been developed world over for different applications under different scenarios. Applications of such models have been made mandatory within the framework of Environmental Impact Assessment (EIA) notification, 1994, as amended from time to time. It has therefore assumed greater importance for the academicians, consultants and regulatory authorities. An attempt has been made in the present paper by the authors to discuss such models with a view to select a particular model that can be used for a particular area or application. An effort has also been made to predict SO_2 concentrations from a coal based thermal power plant at various receptor points using model of Gaussian dispersion.

1. Introduction

While air pollution models constitute a sophisticated tool, which basically reflects the current state of knowledge on turbulent transport in the atmosphere, the results they provide are affected by a considerable margin of error. This may be due to a partial description of atmospheric processes to be considered and to the basic model assumptions (Pelliccionia and Tirabassib, 2006). Air dispersion model is a system tools to predict ground level concentrations over a period of time and space from any point, multiple point, line and area sources. It requires input data in the form of source strength for each pollutant from a given source along with meteorological parameters, topography, terrain features, stack details and so on so forth. A dispersion model is a set of mathematical equations that simulates the release and dispersion of air pollutants in the atmosphere. Atmospheric dispersion model is also a mathematical simulation of the physics and chemistry governing the transport, dispersion and transformation of pollutants in the atmosphere. It also determines as to how air pollutant dispersed in to atmosphere. It is performed with computer programs, called dispersion model, that solve the mathematical equations and algorithms which simulate the pollutant dispersion (Shaw and Munn, 1971; Bhargava and Patel, 2016).

The pollution dispersion is quite comprehensive and used in 1930s or even earlier. Air pollutant plume dispersion equations were derived by Bosanquet and Pearson (1936) but the equation did not assume Gaussian distribution nor did it consider the effect of ground reflection of the pollutant plume. Sir Graham Sutton derived an air pollutant plume dispersion equation in 1947 (Sutton, 1947) which include the concept of Gaussian distribution for the vertical and crosswind dispersion of the plume and also included the effect of ground reflection of the plume.

With the enactment of stringent environmental protection laws and provisions made there under, lot many scientists developed air pollutant plume dispersion equations during late 1960s and even today. Comprehensive computer programs were developed for calculating the dispersion of air pollutant emissions and they were called "air dispersion models (Turner, 1994; Beychok, 2005).

2. Air Dispersion Models

2.1. Application of air dispersion models

The application of air dispersion models is quite wide in as much as that it is effectively used for urban planning, industrial estate planning, industrial zoning, sitting of industrial project and overall special planning from environmental point of view. It can also be used to forecast the critical air pollution levels in certain areas and during certain periods. It also helps in managing the air pollution control strategies.

Models can also be used to predict future pollutant concentrations from multiple sources after the implementation of a new regulatory program, in order to estimate the effectiveness of the program in reducing harmful exposures to humans and the environment. Modeling can be used to analyze actual or potential accidents that release contaminants to the atmosphere. With the help of such models, adequate stack heights, managing existing emissions, designing ambient air monitoring networks, identifying main contributors to existing air pollution problems, estimating the influence of geophysical factors on dispersion, assessing the risks of and planning for the management of rare events such as accidental hazardous substance releases. Other applications are as under (Magill et al., 1956; Perry et al., 1989; Hurley, 2002; Bluett et al., 2004).

- Assessing compliance of emissions with air quality guidelines, criteria and standards
- Planning new facilities
- Determining appropriate stack heights
- Managing existing emissions
- Designing ambient air monitoring networks
- Identifying the main contributors to existing air pollution problems
- Evaluating policy and mitigation
- Forecasting pollution episodes
- Assessing the risks of and planning for the management of rare events such as accidental hazardous substance releases
- Estimating the influence of geophysical factors on dispersion (e.g. terrain elevation, presence of water bodies and land use)
- Running 'numerical laboratories' for scientific research involving experiments that would otherwise be too costly in the real world (e.g. tracking accidental hazardous substance releases)
- Saving cost and time over monitoring – modeling costs are a fraction of monitoring costs and a simulation of annual or multi-year periods may only take a few weeks to assess.

2.2. Types of air dispersion models

Various air dispersion models have been or are being used under different scenarios. Broadly these models can be classified under following categories.

- Gaussian models
- Statistical models
- Numerical models

Gaussian models are used for predicting the dispersion of continuous, buoyant air pollution plumes originating from ground-level or elevated sources. Models may also be used for predicting the dispersion of non-continuous air pollution plumes (called *puff models*).

A statistical model is a formalization of relationships between variables in the form of mathematical equations. A statistical model describes how one or more random variables are related. In mathematical terms, a statistical model is frequently thought of as a pair (Y, P) where Y is the set of possible observations and P the set of possible probability distributions on Y.

A Numerical model expressed in mathematical formulas and solved approximately on a computer. Numerical models are mathematical models that use some sort of numerical time-stepping procedure to obtain the models behavior over time. The mathematical solution is represented by a generated table and/or graph.

Usually in practice, Gaussian models are being used widely all over the world. However, there are different types of Gaussian models which are being used presently in different parts of the world under different conditions (Pasquill, 1962; Perkins, 1974).

2.3. Common features of Gaussian plume models

Gaussian-plume models are widely used, well understood, easy to apply, and until more recently have received international approval. Even today, from a regulatory point of view ease of application and consistency between applications is important. Also, the assumptions, errors and uncertainties of these models are generally well understood, although they still suffer from misuse (Bluett et al., 2004). General characteristics of steady-state Gaussian models are as under (Stern, 1968; Strauss, 1978; Ross, 2001; Bluett et al., 2004).

- Do not require significant computer resources? – They can be run on almost any desktop PC and can usually process a complete year of meteorological data in a matter of minutes
- Are easy to use? – They come with user-friendly graphical user interfaces (GUIs)
- Are widely used? – Well developed knowledge due to many users and results can easily be compared between different studies
- Have simple meteorological data requirements? – An input data set can be developed from standard meteorological recordings.

3. Case Study

An effort has been made in the present paper to develop air dispersion model by using Gaussian distribution approach. While developing this model, source strength of SO_2 based on composition of fuel has been estimated along with meteorological conditions were analyzed on Annual and seasonal basis to form a part of input data in the model. Similarly, plume rise from 10 model equations were estimated and the average value of the plume rise was considered in the present model. The atmospheric stability was also analyzed for making use in this model. The ground level concentrations of SO_2 were estimated under all stability conditions starting from A to till category F. An isopleth was then prepared using surfer9 software. The predictions were done up to a distance of 120 km from the Gandhinagar thermal power plant.

The vertical and horizontal dispersion coefficients were estimated using following equations.

$$\sigma y = ax\text{^}b \quad (1)$$

$$\sigma z = cx\text{^}d+f \quad (2)$$

Gaussian Equation is as under:

$$X(x, y, 0, h) = Q/\pi\, u\, \sigma y\, \sigma z\, exp(-H^2)/(2\sigma z^2)\, exp(-Y^2)/(2\sigma y^2) \quad (3)$$

By using above equations and assuming constants as referred in above Tables 1 and 2, the values so obtained for σy and σz at various distances are as under (Tables 3 and 4).

Subsequent to estimation of σy and σz under all atmospheric stability conditions, the wind velocity at stack heights of Gandhinagar thermal power plant were estimated using power law, the equation of which is as under.

$$\mu 1 = \mu 2\, (Z1/Z2)\, n \quad (4)$$

where, $\mu 1$ and $\mu 2$ are wind speeds at height $Z1$ and $Z2$ respectively. n is an exponent, is a function of stability class as shown in Table 5.

Gandhinagar thermal power plant has five stacks attach to different units of power production; the details of each stack are as reflected in Table 6 below. The wind velocities at different stack heights indicated in Table 6 above were estimated using power law and values of exponent n referred in Table 4. The Average Estimated wind velocities at different stack heights under different stability conditions and directions for annual and different seasons are given in the following Tables 7-10.

Table 1. Showing the values of constants {when x is <1 km} (Wark and Warner, 1981)

Stability	a	c	d	f
A	213	440.8	1.941	9.27
B	156	106.6	1.14	3.3
C	104	61	0.911	0
D	68	33.2	0.725	-1.7
E	50.5	22.8	0.678	-1.3
F	34	14.35	0.74	-0.35

Table 2. Showing the values of constants {when x is >1 km} (Wark and Warner, 1981)

Stability	a	c	d	f
A	213	459.7	2.094	-9.6
B	156	108.2	1.098	2
C	104	61	0.911	0
D	68	44.5	0.516	-13
E	50.5	55.4	0.305	-34
F	34	62.6	0.18	-48

Table 3. Showing values of σy under all stability conditions

x (km)	Class A	Class B	Class C	Class D	Class E	Class F
	σy	σy	Σy	σy	σy	σy
2	395.82	289.89	193.26	126.36	93.84	63.18
4	735.56	538.72	359.14	234.82	174.39	117.41
6	1056.93	774.09	516.06	337.42	250.58	168.71
8	1366.91	1001.12	667.41	436.38	324.08	218.19
10	1668.70	1222.15	814.76	532.73	395.63	266.36
12	1964.11	1438.50	959.00	627.04	465.67	313.52
14	2254.33	1651.06	1100.70	719.69	534.47	359.84
16	2540.17	1860.40	1240.27	810.94	602.24	405.47
18	2822.23	2066.98	1377.99	900.99	669.12	450.49
20	3100.99	2271.14	1514.09	989.98	735.21	494.99
22	3376.80	2473.15	1648.76	1078.04	800.60	539.01
24	3649.96	2673.21	1782.14	1165.24	865.36	582.62
26	3920.72	2871.51	1914.34	1251.68	929.56	625.84
28	4189.27	3068.20	2045.46	1337.42	993.23	668.71
30	4455.80	3263.40	2175.60	1422.51	1056.42	711.25
32	4720.45	3457.23	2304.82	1506.99	1119.16	753.49
34	4983.35	3649.78	2433.18	1590.93	1181.49	795.46
36	5244.62	3841.13	2560.75	1674.33	1243.44	837.16
38	5504.35	4031.35	2687.57	1757.25	1305.02	878.62
40	5762.63	4220.52	2813.68	1839.71	1366.25	919.85
42	6019.55	4408.68	2939.12	1921.73	1427.17	960.86
44	6275.18	4595.90	3063.93	2003.34	1487.77	1001.67
46	6529.57	4782.22	3188.15	2084.56	1548.09	1042.28
48	6782.80	4967.68	3311.79	2165.40	1608.13	1082.70
50	7034.91	5152.33	3434.88	2245.88	1667.90	1122.94
52	7285.95	5336.19	3557.46	2326.03	1727.42	1163.01
54	7535.97	5519.30	3679.53	2405.85	1786.69	1202.92
56	7785.01	5701.70	3801.13	2485.35	1845.74	1242.67
58	8033.12	5883.41	3922.27	2564.56	1904.56	1282.28
60	8280.31	6064.45	4042.97	2643.48	1963.17	1321.74
62	8526.63	6244.86	4163.24	2722.11	2021.57	1361.05
64	8772.11	6424.65	4283.1	2800.48	2079.77	1400.24
66	9016.78	6603.84	4402.56	2878.59	2137.78	1439.3
68	9260.67	6782.46	4521.64	2956.45	2195.60	1478.23
70	9503.79	6960.52	4640.35	3034.07	2253.24	1517.03
72	9746.19	7138.05	4758.70	3111.46	2310.71	1555.73
74	9987.86	7315.05	4876.70	3188.61	2368.01	1594.30
76	10228.85	7491.55	4994.37	3265.54	2425.151	1632.77
78	10469.17	7667.56	5111.70	3342.27	2482.12	1671.13
80	10708.83	7843.08	5228.72	3418.78	2538.94	1709.39
82	10947.86	8018.15	5345.43	3495.09	2595.61	1747.54
84	11186.27	8192.76	5461.84	3571.20	2652.14	1785.60
86	11424.08	8366.93	5577.95	3647.12	2708.52	1823.56
88	11661.3	8540.67	5693.78	3722.85	2764.76	1861.42
90	11897.96	8713.99	5809.33	3798.40	2820.87	1899.20
92	12134.05	8886.91	5924.60	3873.78	2876.85	1936.89
94	12369.61	9059.43	6039.62	3948.98	2932.7	1974.49
96	12604.63	9231.56	6154.37	4024.01	2988.42	2012.00
98	12839.13	9403.30	6268.87	4098.87	3044.02	2049.43
100	13073.13	9574.68	6383.12	4173.58	3099.49	2086.79
102	13306.63	9745.70	6497.13	4248.12	3154.85	2124.06
104	13539.65	9916.36	6610.90	4322.51	3210.10	2161.25
106	13772.19	10086.68	6724.45	4396.75	3265.23	2198.37
108	14004.27	10256.65	6837.76	4470.84	3320.26	2235.42
110	14235.89	10426.29	6950.85	4544.79	3375.17	2272.39
112	14467.07	10595.6	7063.73	4618.59	3429.98	2309.29
114	14697.81	10764.59	7176.39	4692.25	3484.69	2346.12
116	14928.12	10933.27	7288.84	4765.78	3539.29	2382.89
118	15158.01	11101.64	7401.09	4839.17	3593.8	2419.58
120	15387.48	11269.71	7513.13	4912.43	3648.20	2456.21

Table 4. Showing values of *σz* under all stability conditions

x (km)	Class A	Class B	Class C	Class D	Class E	Class F
	σz	*σz*	*Σz*	*σz*	*σz*	*Σz*
2	1952.99	233.61	114.70	50.63	34.44	22.91
4	8369.32	497.78	215.67	77.99	50.55	32.34
6	19575.38	775.81	312.05	99.17	61.68	38.42
8	35762.54	1063.25	405.55	117.12	70.46	43.01
10	57069.16	1357.89	496.96	133.00	77.81	46.74893
12	83604.6	1658.41	586.76	147.40	84.21	49.90
14	115459.7	1963.89	675.23	160.68	89.90	52.66
16	152712.5	2273.7	762.57	173.07	95.05	55.11
18	195431.2	2587.33	848.95	184.73	99.77	57.32
20	243676.8	2904.40	934.47	195.78	104.14	59.33
22	297504.5	3224.60	1019.24	206.30	108.21	61.19
24	356964.6	3547.67	1103.32	216.37	112.04	62.92
26	422103.4	3873.4	1186.78	226.04	115.65	64.53
28	492963.7	4201.58	1269.67	235.36	119.07	66.04
30	569585.7	4532.08	1352.03	244.36	122.32	67.46
32	652006.9	4864.75	1433.90	253.08	125.43	68.81
34	740262.5	5199.45	1515.33	261.53	128.40	70.09
36	834385.9	5536.10	1596.32	269.75	131.26	71.31
38	934408.7	5874.59	1676.92	277.75	134.01	72.48
40	1040361	6214.82	1757.14	285.55	136.66	73.60
42	1152272	6556.73	1837.00	293.16	139.22	74.67
44	1270168	6900.24	1916.52	300.60	141.69	75.70
46	1394076	7245.28	1995.73	307.88	144.09	76.70
48	1524021	7591.79	2074.63	315.00	146.42	77.66
50	1660027	7939.73	2153.23	321.98	148.68	78.58
52	1802118	8289.03	2231.56	328.83	150.88	79.48
54	1950316	8639.65	2309.62	335.55	153.02	80.35
56	2104642	8991.54	2387.42	342.16	155.10	81.19
58	2265118	9344.67	2464.97	348.65	157.14	82.01
60	2431764	9698.99	2542.29	355.03	159.12	82.81
62	2604600	10054.48	2619.38	361.31	161.06	83.58
64	2783645	10411.09	2696.24	367.49	162.96	84.33
66	2968917	10768.8	2772.90	373.58	164.82	85.07
68	3160435	11127.56	2849.34	379.58	166.64	85.79
70	3358215	11487.37	2925.59	385.50	168.42	86.49
72	3562276	11848.18	3001.64	391.33	170.17	87.17
74	3772634	12209.98	3077.51	397.09	171.88	87.84
76	3989304	12572.73	3153.19	402.77	173.56	88.49
78	4212303	12936.43	3228.70	408.38	175.21	89.13
80	4441647	13301.03	3304.03	413.92	176.83	89.76
82	4677349	13666.54	3379.20	419.40	178.43	90.37
84	4919427	14032.91	3454.20	424.81	180.00	90.97
86	5167892	14400.15	3529.05	430.16	181.54	91.56
88	5422761	14768.22	3603.74	435.44	183.05	92.14
90	5684046	15137.11	3678.28	440.67	184.55	92.71
92	5951761	15506.8	3752.67	445.85	186.02	93.27
94	6225920	15877.29	3826.91	450.97	187.46	93.81
96	6506536	16248.55	3901.02	456.04	188.89	94.35
98	6793621	16620.56	3974.99	461.05	190.30	94.88
100	7087187	16993.33	4048.83	466.02	191.68	95.40
102	7387248	17366.82	4122.53	470.94	193.05	95.92
104	7693816	17741.03	4196.11	475.82	194.40	96.42
106	8006901	18115.95	4269.56	480.64	195.73	96.92
108	8326517	18491.56	4342.89	485.43	197.04	97.40
110	8652673	18867.85	4416.09	490.17	198.34	97.88
112	8985383	19244.82	4489.18	494.87	199.62	98.36
114	9324656	19622.44	4562.15	499.53	200.89	98.83
116	9670504	20000.72	4635.01	504.15	202.13	99.29
118	10022937	20379.63	4707.76	508.73	203.37	99.74
120	10381967	20759.18	4780.39	513.28	204.59	100.19

The values of average wind velocities at stack heights under different directions were used in the model as an input for predicting; annual average, winter average, summer average and monsoon average ground level concentrations of SO_2 at different receptor points.

Similarly, as an input to air dispersion model, the source strength of SO_2 were also estimated for different stacks as shown in the Table 11 given below. Similarly, plume rise was estimated using different model equations, the details of which are shown in Table 12.

Table 5. Showing the values of exponent "n"

Stability class	Urban conditions	Rural and other conditions
A	0.1	0.07
B	0.15	0.07
C	0.2	0.1
D	0.25	0.15
E	0.4	0.35
F	0.6	0.55

Table 6. Showing stack details of Gandhinagar Thermal Power Plant

Stack No	Attached to unit	Capacity of plant (Mw)	Height of stack (m)	Dia (m)	Temperature of Flue gases (°C)	Exit velocity (m/s)	Heat emission rate KJ/S
S1	1	120	94.5	4.33	150	4.76	8084.26
S2	2	120	94.5	4.33	150	4.76	8084.26
S3	3	210	120	5.2	155	11.78	29558
S4	4	210	120	5.2	160	11.78	30245.5
S5	5	210	220	5.02	160	12.63	30245.6

Table 7. Showing annual average wind velocity at different stack height

Stack No	H	Direction	WS at 10MT	A	B	C	D	E	F
S1	94.5	NNE	0.72	0.90	1.00	1.12	1.26	1.77	2.77
	94.5	SSE	0.68	0.85	0.96	1.07	1.20	1.68	2.64
	94.5	SSW	0.80	1.01	1.13	1.26	1.41	1.98	3.11
	94.5	ESE	0.55	0.69	0.77	0.87	0.97	1.36	2.13
	94.5	NNW	0.84	1.06	1.18	1.33	1.48	2.08	3.26
	94.5	ENE	0.97	1.21	1.36	1.52	1.70	2.38	3.74
S2	94.5	NNE	0.72	0.90	1.00	1.12	1.26	1.77	2.77
	94.5	SSE	0.68	0.85	0.96	1.07	1.20	1.68	2.64
	94.5	SSW	0.80	1.01	1.13	1.26	1.41	1.98	3.11
	94.5	ESE	0.55	0.69	0.77	0.87	0.97	1.36	2.13
	94.5	NNW	0.84	1.06	1.18	1.33	1.48	2.08	3.26
	94.5	ENE	0.97	1.21	1.36	1.52	1.70	2.38	3.74
S3	120	NNE	0.72	0.92	1.04	1.18	1.34	1.94	3.20
	120	SSE	0.68	0.88	0.99	1.12	1.27	1.85	3.04
	120	SSW	0.80	1.03	1.17	1.33	1.50	2.18	3.59
	120	ESE	0.55	0.71	0.80	0.91	1.03	1.50	2.46
	120	NNW	0.84	1.08	1.23	1.39	1.58	2.29	3.77
	120	ENE	0.97	1.24	1.41	1.59	1.81	2.62	4.31
S4	120	NNE	0.72	0.92	1.04	1.18	1.34	1.94	3.20
	120	SSE	0.68	0.88	0.996	1.128	1.277	1.854	3.048
	120	SSW	0.80	1.038	1.175	1.33	1.506	2.187	3.594
	120	ESE	0.55	0.712	0.807	0.913	1.034	1.501	2.467
	120	NNW	0.84	1.089	1.233	1.396	1.58	2.294	3.771
	120	ENE	0.97	1.246	1.411	1.598	1.81	2.627	4.318
S5	120	NNE	0.72	0.924	1.046	1.185	1.341	1.947	3.201
	120	SSE	0.68	0.88	0.996	1.128	1.277	1.854	3.048
	120	SSW	0.80	1.038	1.175	1.33	1.506	2.187	3.594
	120	ESE	0.55	0.712	0.807	0.913	1.034	1.501	2.467
	120	NNW	0.84	1.089	1.233	1.396	1.58	2.294	3.771
	120	ENE	0.97	1.246	1.411	1.598	1.81	2.627	4.318

Table 8. Showing winter average wind velocity at different stack height

Stack No	H	Direction	WS at 10MT	A	B	C	D	E	F
S1	94.5	NNE	0.62	0.78	0.88	0.98	1.10	1.54	2.41
	94.5	SSE	0.64	0.81	0.90	1.01	1.13	1.58	2.48
	94.5	SSW	0.55	0.69	0.77	0.87	0.97	1.36	2.13
	94.5	ESE	0.13	0.17	0.19	0.21	0.24	0.34	0.53
	94.5	NNW	0.61	0.76	0.85	0.95	1.07	1.50	2.35
S2	94.5	NNE	0.62	0.78	0.88	0.98	1.10	1.54	2.41
	94.5	SSE	0.64	0.81	0.90	1.01	1.13	1.58	2.48
	94.5	SSW	0.55	0.69	0.77	0.87	0.97	1.36	2.13
	94.5	ESE	0.13	0.17	0.19	0.21	0.24	0.34	0.53
	94.5	NNW	0.61	0.76	0.85	0.95	1.07	1.50	2.35
S3	120	NNE	0.62	0.80	0.91	1.03	1.16	1.69	2.79
	120	SSE	0.64	0.82	0.93	1.06	1.20	1.74	2.87
	120	SSW	0.55	0.71	0.80	0.91	1.03	1.50	2.46
	120	ESE	0.13	0.17	0.20	0.22	0.25	0.37	0.61
	120	NNW	0.61	0.78	0.88	1.00	1.13	1.65	2.71
S4	120	NNE	0.62	0.80	0.91	1.03	1.16	1.69	2.79
	120	SSE	0.64	0.82	0.93	1.06	1.20	1.74	2.87
	120	SSW	0.55	0.71	0.80	0.91	1.03	1.50	2.46
	120	ESE	0.13	0.17	0.20	0.22	0.25	0.37	0.61
	120	NNW	0.61	0.78	0.88	1.00	1.13	1.65	2.71
S5	120	NNE	0.62	0.80	0.91	1.03	1.16	1.69	2.79
	120	SSE	0.64	0.82	0.93	1.06	1.20	1.74	2.87
	120	SSW	0.55	0.71	0.80	0.91	1.03	1.50	2.46
	120	ESE	0.13	0.17	0.20	0.22	0.25	0.37	0.61
	120	NNW	0.61	0.78	0.88	1.00	1.13	1.65	2.71

Table 9. Showing summer average wind velocity at different stack height

Stack No	H	Direction	WS at 10MT	A	B	C	D	E	F
S1	94.5	NNE	0.91	1.14	1.28	1.43	1.60	2.24	3.51
	94.5	SSE	0.77	0.97	1.09	1.22	1.36	1.914	2.999
	94.5	SSW	1.22	1.53	1.71	1.91	2.14	3.00	4.70
	94.5	NNW	1.11	1.39	1.55	1.74	1.95	2.73	4.28
	94.5	ENE	0.97	1.21	1.36	1.52	1.70	2.38	3.74
S2	94.5	NNE	0.91	1.14	1.28	1.43	1.60	2.24	3.51
	94.5	SSE	0.77	0.97	1.09	1.22	1.36	1.91	2.99
	94.5	SSW	1.22	1.53	1.71	1.91	2.14	3.00	4.70
	94.5	NNW	1.11	1.39	1.55	1.74	1.95	2.73	4.28
	94.5	ENE	0.97	1.21	1.36	1.52	1.70	2.38	3.74
S3	120	NNE	0.91	1.17	1.32	1.50	1.70	2.46	4.05
	120	SSE	0.77	0.99	1.13	1.28	1.45	2.10	3.46
	120	SSW	1.22	1.56	1.77	2.00	2.27	3.30	5.42
	120	NNW	1.11	1.42	1.61	1.83	2.07	3.00	4.94
	120	ENE	0.97	1.24	1.41	1.59	1.81	2.62	4.31
S4	120	NNE	0.91	1.17	1.32	1.50	1.70	2.46	4.05
	120	SSE	0.77	0.99	1.13	1.28	1.45	2.10	3.46
	120	SSW	1.22	1.56	1.77	2.00	2.27	3.30	5.42
	120	NNW	1.11	1.42	1.61	1.83	2.07	3.00	4.94
	120	ENE	0.97	1.24	1.41	1.59	1.81	2.62	4.31
S5	120	NNE	0.91	1.17	1.32	1.50	1.70	2.46	4.05
	120	SSE	0.77	0.99	1.13	1.28	1.45	2.10	3.46
	120	SSW	1.22	1.56	1.77	2.00	2.27	3.30	5.42
	120	NNW	1.11	1.42	1.61	1.83	2.07	3.00	4.94
	120	ENE	0.97	1.24	1.41	1.59	1.81	2.62	4.31

Table 10. Showing monsoon average wind velocity at different stack height

Stack No	H	Direction	WS at 10MT	A	B	C	D	E	F
S1	94.5	NNE	0.62	0.77	0.86	0.97	1.08	1.52	2.38
	94.5	SSE	0.65	0.82	0.91	1.02	1.15	1.61	2.52
	94.5	SSW	0.65	0.81	0.91	1.01	1.13	1.59	2.50
	94.5	NNW	0.76	0.95	1.06	1.19	1.33	1.87	2.93
S2	94.5	NNE	0.62	0.77	0.86	0.97	1.08	1.52	2.38
	94.5	SSE	0.65	0.82	0.91	1.02	1.15	1.61	2.52
	94.5	SSW	0.65	0.81	0.91	1.01	1.13	1.59	2.50
	94.5	NNW	0.76	0.95	1.06	1.19	1.33	1.87	2.93
S3	120	NNE	0.62	0.79	0.9	1.01	1.15	1.67	2.75
	120	SSE	0.65	0.84	0.95	1.07	1.22	1.77	2.91
	120	SSW	0.65	0.83	0.94	1.06	1.20	1.75	2.88
	120	NNW	0.76	0.97	1.10	1.25	1.42	2.06	3.39
S4	120	NNE	0.62	0.79	0.9	1.01	1.15	1.67	2.75
	120	SSE	0.65	0.84	0.95	1.07	1.22	1.77	2.91
	120	SSW	0.65	0.83	0.94	1.06	1.20	1.75	2.88
	120	NNW	0.76	0.97	1.10	1.25	1.42	2.06	3.39
S5	120	NNE	0.62	0.79	0.9	1.01	1.15	1.67	2.75
	120	SSE	0.65	0.84	0.95	1.07	1.22	1.77	2.91
	120	SSW	0.65	0.83	0.94	1.06	1.20	1.75	2.88
	120	NNW	0.76	0.97	1.10	1.25	1.42	2.06	3.39

Table 11. Showing source strength of SO_2 from different stacks

Stack No	Source strength (SO_2 in g/s)
S_1	128.8
S_2	128.8
S_3	225.4
S_4	225.4
S_5	225.4

Table 12. Showing plume rise from different stacks under different stability conditions

Stability	Stack No				
	S1	S2	S3	S4	S5
A	86.68	86.67	160.66	156.91	207.54
B	415.5	415.53	719.95	730.75	862.39
C	328.8	328.85	559.29	573.84	654.84
D	330.6	327.03	549.52	533.88	605.63
E	242.2	240.35	388.86	376.97	398.08
F	155.5	155.49	237.98	260.02	239.76

After estimating all the above parameters as an input to air dispersion model, the predicted concentration of SO_2 were estimated on annual and seasonal basis. The isopleths were also drawn in respect of SO_2 for different seasons and on annual basis under all the stability conditions. On the basis of predicted values, the isopleths for annual SO_2 concentration have been drawn for all the stability conditions and some of them are being shown in the Figs. 1-7.

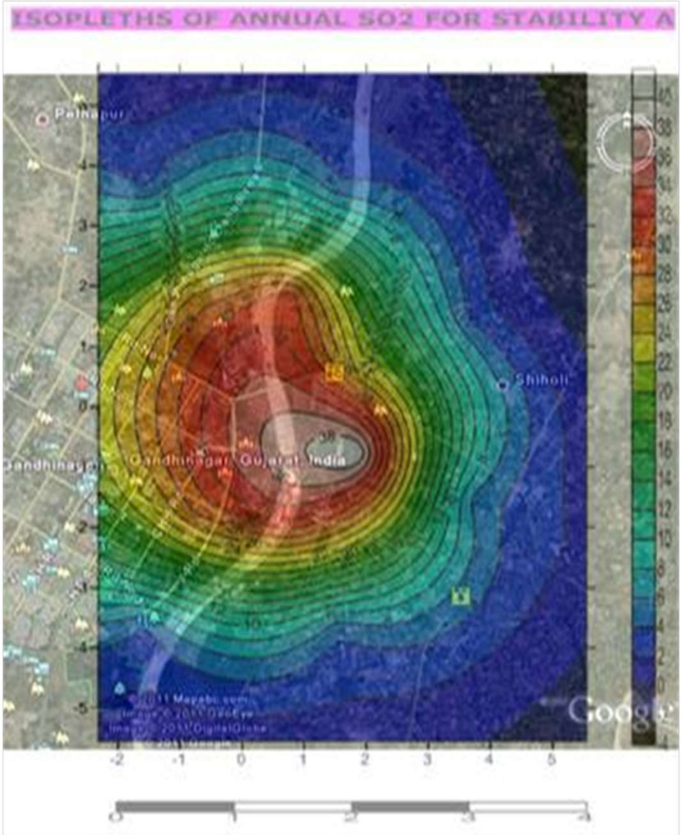

Fig. 1. Showing isopleths of annual average predicted concentration of SO_2 under atmospheric stability A at different distances in km

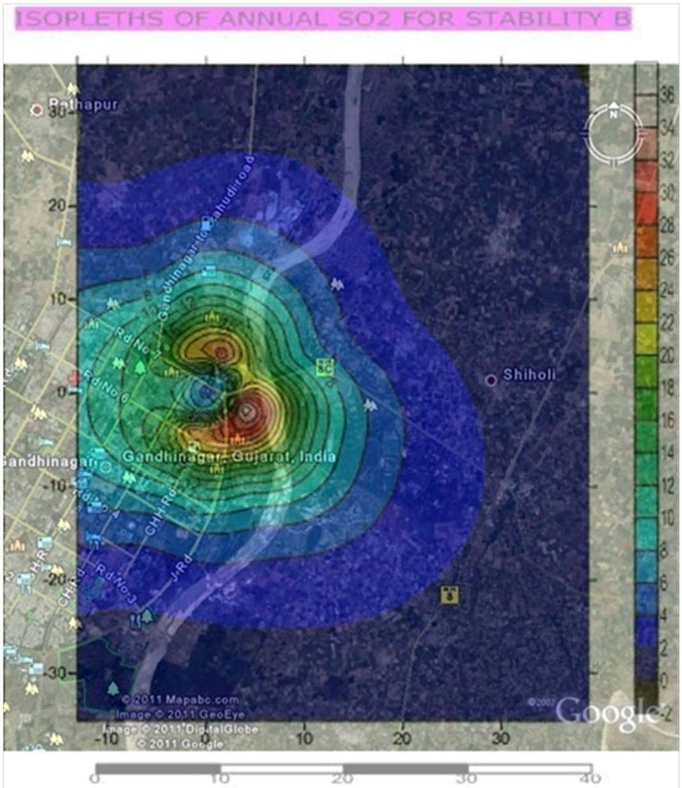

Fig. 2. Showing isopleths of annual average predicted concentration of SO_2 under atmospheric stability B at different distances in km

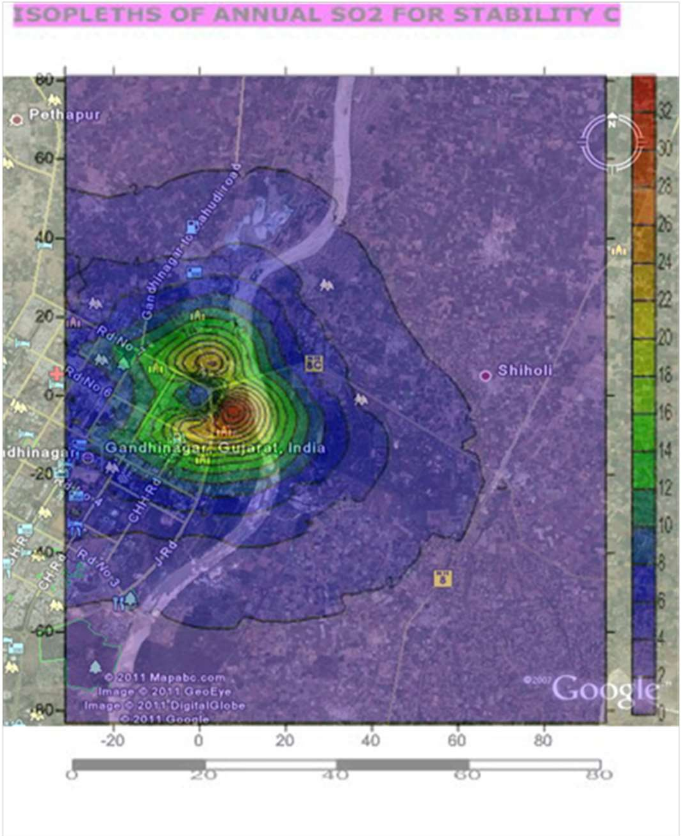

Fig. 3. Showing isopleths of annual average predicted concentration of SO_2 under atmospheric stability C at different distances in km

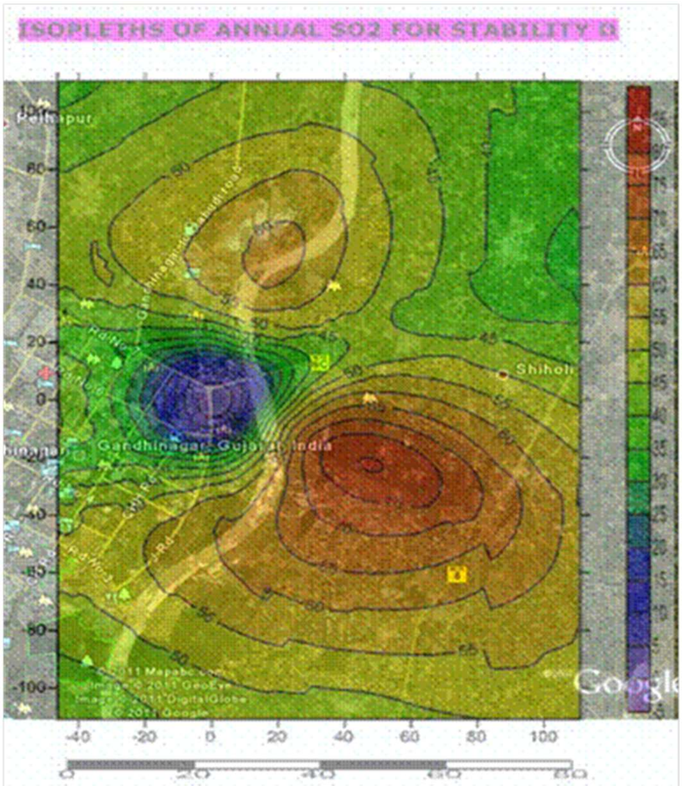

Fig. 4. Showing isopleths of annual average predicted concentration of SO_2 under atmospheric stability D at different distances in km

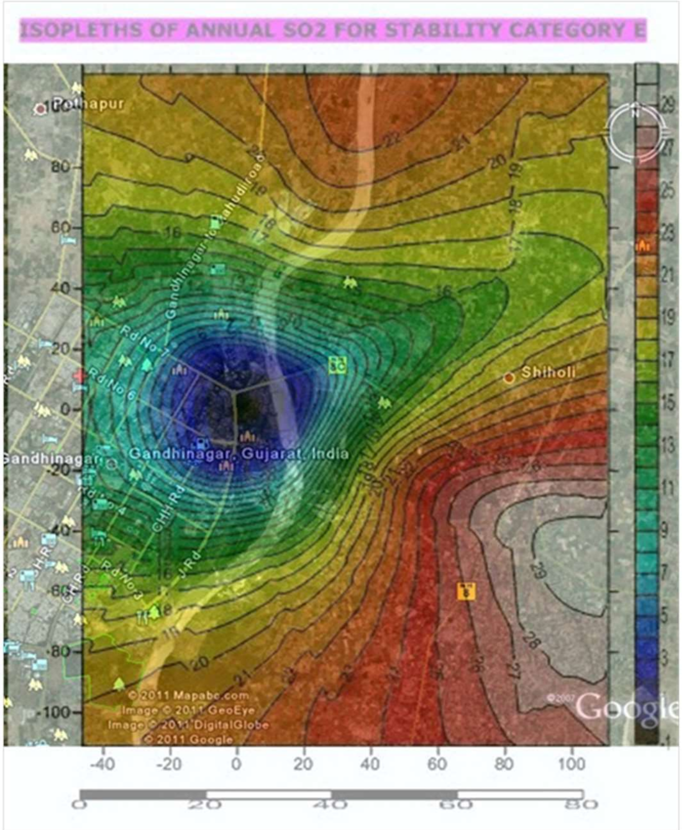

Fig. 5. Showing isopleths of annual average predicted concentration of SO_2 under atmospheric stability E at different distances in km

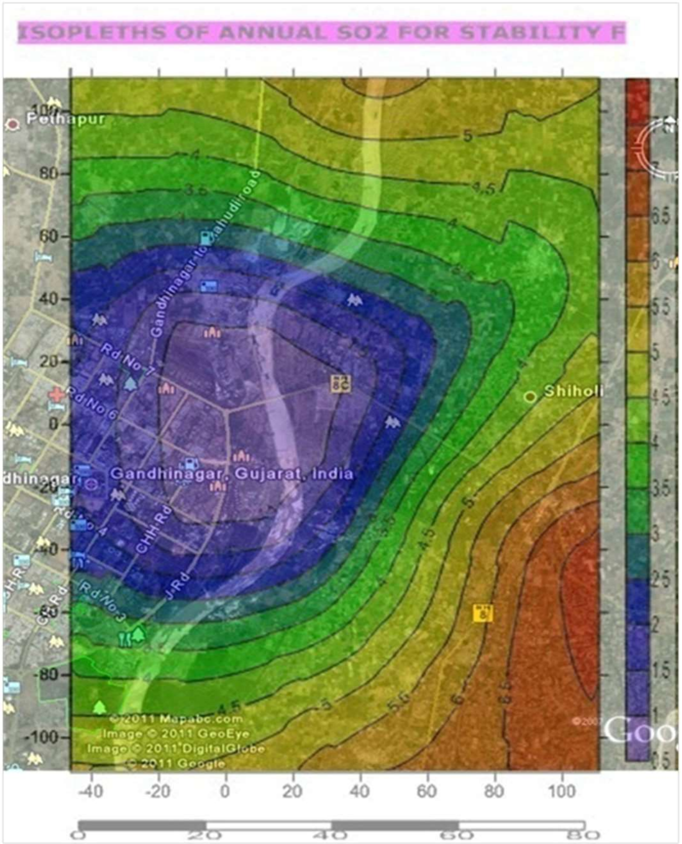

Fig. 6. Showing isopleths of annual average predicted concentration of SO_2 under atmospheric stability F at different distances in km

4. Findings

An effort has also been made to analyse the maximum concentration of predicted Annual SO_2 values in each direction under different stability condition at a particular distance. The findings are such estimations are shown in Table 13.

It would be seen from table 14 that the maximum annual average SO_2 concentration is 40.20 µg/m3 at a distance of 2 km under atmospheric stability A in ESE direction, followed by 32.54, 30.98, 27.59, 26.30 & 22.97 µg/m3 in SSE ,NNE, SSW, NNW and ENE directions respectively but all at a distance of 2 km.

Similarly, under atmospheric stability B, maximum concentration of SO_2 is of the order of 36.43 $\mu g/m^3$ at a distance of 4 km, followed by 29.49, 28.08, 25.00, 23.83 and 20.81 µg/m3 in SSE, NNE, SSW, NNW and ENE directions respectively but all at a distance of 4 km.

Moreover, under atmospheric stability C, maximum concentration of SO_2 is of the order of 32.27 $\mu g/m^3$ at a distance of 8 km, followed by 26.13, 24.88, 22.15, 21.11 and 18.44 $\mu g/m^3$ in SSE, NNE, SSW, NNW, ENE directions respectively but all at a distance of 8 km. Similarly, under atmospheric stability D, maximum concentration of SO_2 is of the order of 6.66 $\mu g/m^3$ at a distance of 52 km, followed by 5.39, 5.14, 4.57, 4.36 and 3.81 $\mu g/m^3$ in SSE, NNE, and SSW, NNW, ENE directions respectively but all at a distance of 52 km.

However, under atmospheric stability E, maximum concentration of SO_2 is of the order of 2.48 $\mu g/m^3$ at a distance of 120 km, followed by 2.01, 1.91, 1.70, 1.62 and 1.41 $\mu g/m^3$ in SSE, NNE, and SSW, NNW, ENE directions respectively but all at a distance of 120 km. Similarly, under atmospheric stability F, maximum concentration of SO_2 is of the order of 0.61 $\mu g/m^3$ at a distance of 120 km, followed by 0.50, 0.47, 0.42, 0.40 and 0.35 $\mu g/m^3$ in SSE, NNE, SSW and NNW, ENE directions respectively but all at a distance of 120 km.

From the above, it tends to indicate that under stability A, the maximum concentration occurs at a distance of 2 km whereas, this distance Increased to 4 km under stability B, 8 km under stability C, 52 km under stability D and 120 km under stability E and F. This analysis tends to show that the distance increases with shifting of stability from A to F. i.e. from highly unstable to highly stable conditions.

Similarly, an attempt was also made to predict the ground level concentrations of SO_2 under all stability conditions for the season winter, summer, and monsoon. The Isopleths were also prepared but not being shown in the present paper due to huge volume. However, the findings of maximum predicted concentration of SO_2 under all stability conditions for all the seasons are shown in Table 14.

Table 13. Showing maximum concentration of annual SO_2 at a distance under each stability category under different directions

Direction	Distance	Stability	Maximum Concentration	Followed by
ESE	2	A	40.2	
SSE	2	A		32.54
NNE	2	A		30.98
SSW	2	A		27.59
NNW	2	A		26.3
ENE	2	A		22.97
ESE	4	B	36.43	
SSE	4	B		29.49
NNE	4	B		28.08
SSW	4	B		25
NNW	4	B		23.83
ENE	4	B		20.81
ESE	8	C	32.27	
SSE	8	C		26.13
NNE	8	C		24.88
SSW	8	C		22.15
NNW	8	C		21.11
ENE	8	C		18.44
ESE	52	D	6.66	
SSE	52	D		5.39
NNE	52	D		5.14
SSW	52	D		4.57
NNW	52	D		4.36
ENE	52	D		3.81
ESE	120	E	2.48	
SSE	120	E		2.01
NNE	120	E		1.91
SSW	120	E		1.7
NNW	120	E		1.62
ENE	120	E		1.41
ESE	120	F	0.61	
SSE	120	F		0.5
NNE	120	F		0.47
SSW	120	F		0.42
NNW	120	F		0.4
ENE	120	F		0.35

Table 14. Showing maximum predicted concentrations of SO_2 under all seasons and atmospheric stabilities

No	Season	Distance	Maximum concentration in µg/m^3 of SO_2					
			A	B	C	D	E	F
1	Annual		40.20	36.43	32.27	6.66	2.48	0.61
		Distance	2	4	8	52	120	120
2	Winter		160.81	145.72	129.11	26.67	70.76	2.98
		Distance	2	4	8	52	120	120
3	Summer		28.65	25.96	47.15	4.75	1.771	0.44
		Distance	2	4	10	52	120	120
4	Monsoon		36.03	32.64	24.93	5.97	2.22	0.55
		Distance	2	4	10	52	120	120

6. Conclusions

Air pollution is growing on a rapid pace, not only in India but globally. It is becoming an emerging issue threating the health of human beings and environment as a whole. Air dispersion modeling is an important decision-making tool to predict air quality from air pollution sources on a scale of time and space. Such models are mandatory in the process of Environmental Impact Assessment and Management Plans required for environmental clearances. However, lot of research needs to be done for developing a scientifically compatible air dispersion models having regard to prevailing local conditions, reliable source strength, meteorological factors etc. Such studies need to be done on scale of time and space. Data base should be developed to keep all such research at one place for the benefit of other researchers.

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