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Spatial and Temporal Variation of Urban Air Quality: A GIS Approach

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ABSTRACT

This study investigated the seasonal variation of ambient air quality status of Burdwan town using GIS approach. Concentration of SO_2 (*sulphur dioxide*), NO_2 (*nitrogen dioxide*) *and RSPM* (*respiratory suspended particulate matter*) *were measured once a week for* 24 *hour in both premonsoon and postmonsoon season.* *The seasonal average concentration of the RSPM*, SO_2 *and* NO_2 *in premonsoon season was observed to be* 188.56 ± 88.63, 5.12 ± 6.27 *and* 92.51 ± 64.78 $\mu g/m^3$ *respectively whereas in postmonsoon it was* 53.03 ± 38.27, 8.51 ± 7.11 *and* 162.85 ± 184.80 $\mu g/m^3$ *respectively. Statistical analysis showed the significant monsoonal effect on mean difference of RSPM*, SO_2 *and* NO_2 *concentration. Postmonsoon concentration of ambient* SO_2 *and* NO_2 *were observed to be higher than premonsoon*, *suggesting longer residence times of these pollutants in the atmosphere due to stagnant conditions and low mixing height. Spatial distribution of pollutants throughout the town in both the season was represented by digital elevation model* (*DEM*). *On the basis of Air Quality Index* (*AQI*) *a GIS based air pollution surface models were generated in both the seasons by means of Inverse Distance Interpolation* (*IDINT*) *technique. From the output surface model it was found that in comparison to premonsoon there was a significant increase of clean and fairly clean area and decrease of moderately polluted area of the town during postmonsoon.*

***Keywords*: *Ambient Air Quality, Seasonal Variation, Air Quality Index* (*AQI*), *Geographic Information System* (*GIS*)**

1. Introduction

Throughout the world, air pollution is a matter of concern at all levels. The worldwide epidemiological study on the effect of air pollution had revealed that gaseous pollutants and particulate matter had enough potential to cause severe health effect like respiratory, cardiovascular diseases and cardio pulmonary mortality [1,2]. Being a serious matter of concern now-a-day, a systematic monitoring programme all over the world especially in urban cities are urgently needed as the level of air pollution is increasing rapidly in many areas of mega cities of the developing world [3]. It was found that the modernization and industrialization of developing countries had led to the increase use of fossil fuels and their derivatives. As such, developing countries were confronted with the great challenge of controlling the atmospheric pollution especially in the rapidly growing mega cities. Concern about air pollution in urban regions is receiving increasing importance world-wide, especially pollution by gaseous and particulate trace metals [4-7]. The urban centers might be viewed as dense sources of enormous anthropogenic emissions of pollutants, which could alter the atmospheric composition, chemistry and life cycles in its down wind regimes, extending over several hundred kilometers [8]. It had been found that world motor vehicle population growth had reached 700 million in the year 2000 [9]. Petrol and diesels engines of motor vehicles were found to emit a wide variety pollutants, principally, oxide of nitrogen (NOx) which had an increasing impact on urban air quality [10]. Various monitoring programme had already been done in developing countries like Bangladesh and Pakistan [11,12].

In India, air pollution had also become a topic of intense debate at all levels mainly because of the enhanced anthropogenic activities [13]. Today India is one of the first ten industrial countries of the world [14]. Urban air pollution in India had increased rapidly with the population growth, numbers of motor vehicles, use of fuels with poor environmental performance, badly mentioned transportation systems, poor land use pattern, and above all, ineffective environmental regulations [8,9]. Among the worst air city the name of the capital of India is enlisted followed by Beijing, China, Xian, Kathmandu, Dhaka in Asia**.** So far various research work had been done on spatial and temporal variation of urban air pollution in various cities of India like Kolkata, Delhi, Lucknow, Haryana, Chennai, Mumbai, Dhanbad-Jharia and on Raniganj-Asansol [8,13,15-20].

GIS is used as a platform for spatio-temporal analysis or for building relationships between the GIS database and stand-alone modeling tools. Air data are generally very complex to model due to the underlying correlation among several pollutants. The significant differences among the results obtained from the techniques, indicated that proper air quality management requires sensitive air quality evaluation [21]. Various research work had also been done on the GIS aspect of spatio-temporal analysis of urban air quality [22-25].

Burdwan being a city of West Bengal state in eastern India and headquarters of Burdwan district now a day draws attention with respect to ambient air quality status. Not only being a busy town (populated by 2,85,871 people as per 2001 census) but also being nearest to Durgapur, this place was given importance keeping in mind that Durgapur is the 7th polluted city in India and air pollutants had the capacity to travel a long distance. Apart from several residential projects a major public private project "the largest heath city of Asia" was also proposed here. Medical report (**Table 1**), collected from the Govt. Hospital of this town, reflected that health problem due to air pollution is increasing day by day. So far no systematic air quality-monitoring programme with GIS approach was reported from this town. Hence the quality of ambient air deserved a systematic as well as scientific investigations so that proper strategies could be taken to mitigate in case of any pollution was found. The objective of this study was to evaluate the premonsoon and postmonsoon distribution of selected gaseous pollutants *i.e.* sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and respiratory suspended particulate matter (RSPM) and its interaction with meteorological parameters. This study also performed to develop a GIS based air pollution surface model on the basis of air quality index (AQI) by using continuous surface generation technique.

2. Methodology

2.1. Study Area

Burdwan town is located at 23.25° N latitude and 87.85° E longitude. It has an average elevation of 40 meters (131 feet). The city is situated a little less than 100 km northwest of Kolkata on the Grand Trunk Road (NH-2) and eastern railway (**Figure 1**). It is a city with an increasing number people opting for better residential spaces and higher living standards. The number of registered motor vehicle in the town (according to 2007 statistics) was 3, 97,5509. On basis of land use/land cover classification map (**Figure 2**) the respective locations of sampling encompassing sensitive, residential and industrial areas were selected. Altogether 25 locations encompassing all the three areas were selected randomly for air quality monitoring (**Figure 2**). Details of the sampling locations are represented in **Table 2**. Mainly the schools, colleges, university and children parks are enlisted as sensitive zones whereas the places beside road and others residential areas are considered as residential zones and others as per Central Pollution Control Board (CPCB). The place where the industries (mainly rice mills in the study area) are aggregated is considered here as industrial zone.

Table 1. Medical record (2008) of respiratory disease in Burdwan municipality.

Sl. No	Month	Case	Death
1.	January	17	03
2.	February	12	01
3.	March	34	00
4.	April	09	01
5.	May	22	00
6.	June	19	05
7.	July	18	01
8.	August	04	01
9.	September	09	00
10.	October	16	01
11.	November	39	03
12.	December	30	00

*Data Obtained from Medical Record Department Burdwan Medical College & Hospital Burdwan, West Bengal.

2.2. Sampling (6:00 A.M. to 6:00 A.M.) and Analysis of Gaseous Pollutants and Particulate Matter

In both the seasons the sampling was done for twenty-four (24) hours at each site. The seasonal classification was followed as per specification laid by Indian meteorological department [26]. March, April and May months were considered as premonsoon season and June, July, August, and September were considered as postmonsoon season. Air quality parameter such as repairable suspended

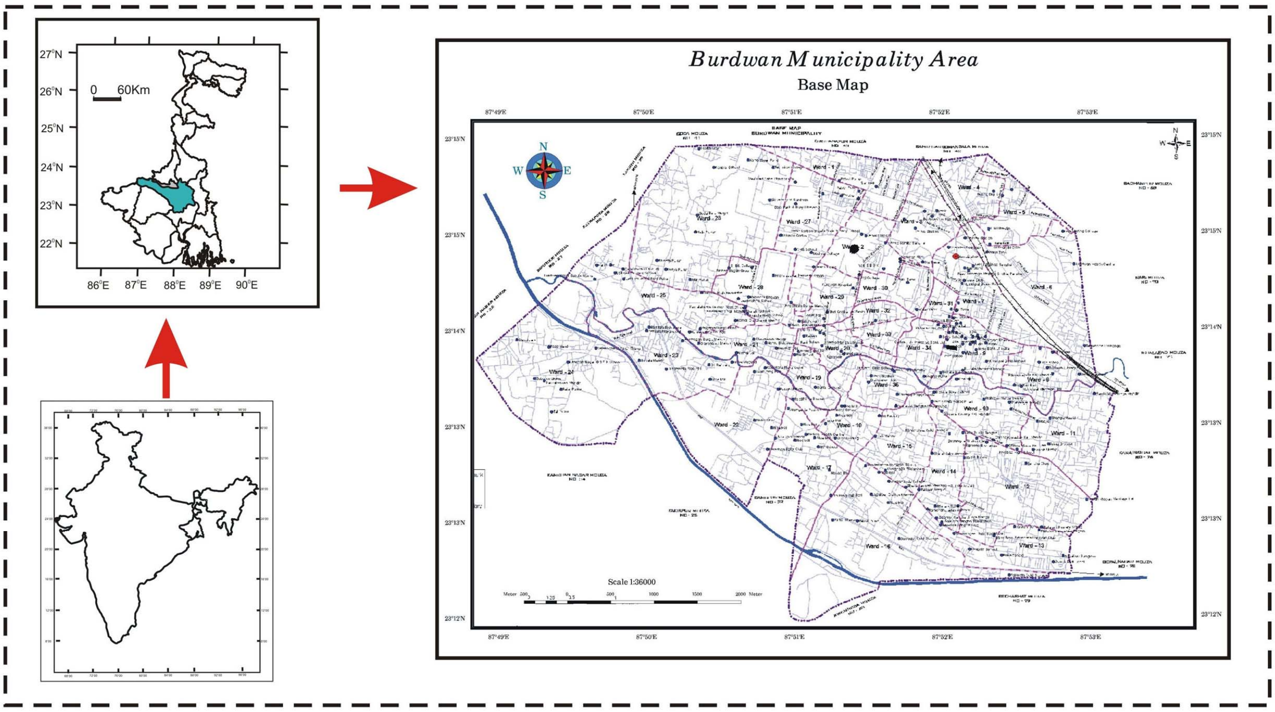


Figure 1. Study area location.

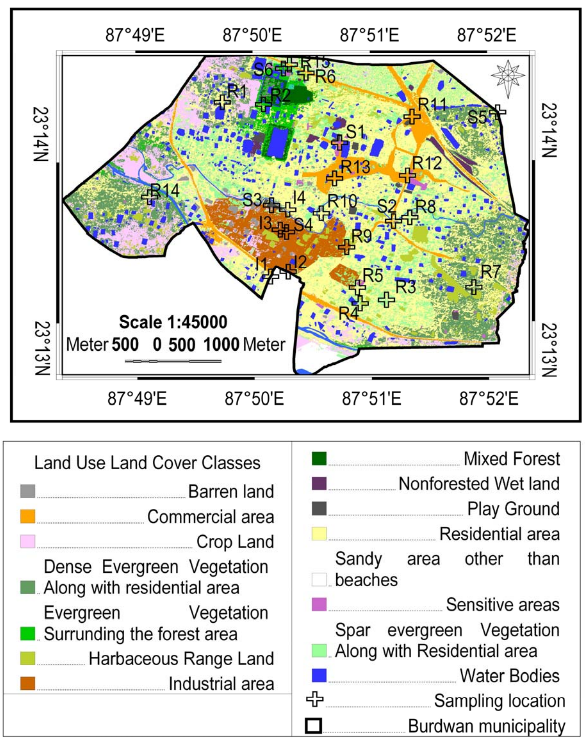


Figure 2. Land use/land cover map showing various sampling locations.

particulate matter (RSPM) which was also known as PM_{10} was monitored by using High Volume Sampler (MODEL NPM HVS) following standard procedure by IS: 5182 (Part iv). Glass fiber filter paper, popularly known as GF/A filter paper was used and the flow rate was kept at 1-1.5 m^3/min. The model NPM HVS had a cyclone separator, which separated the coarser particulate matter larger than 10 μm from air stream (drawn into the HVS)

Table 2. Details of sampling sites.

Sampling Sites	Description
R11, R12, R13, R15, R6, R7	Residential area with high traffic density
R3, R4, R5, R8, R14	Residential area with moderate traffic density
R1, R2, R10	Residential area with low traffic density
R9	Residential area influenced by industrial emission
I1 and I2	Industrial area with high traffic density
I4	Industrial area with moderate traffic density
I3	Industrial area with low traffic density
S2, S5, S6	Sensitive area with high traffic density
S1	Sensitive area with moderate traffic density
S3	Sensitive area with moderate traffic density and highly influenced by industrial emission
S4	Sensitive area with high traffic and highly influenced by industrial emission

before filtering on GF/A filter paper. Air was also allowed to pass through two impingers having specific absorbing reagent for SO_2 and NO_2. SO_2 and NO_2 were collected by bubbling the sample in specific absorbing reagents of 25 ml put in two impingers. The average flow rate through the impingers was 0.5 l/min. After the sampling the impinger samples were kept in iceboxes and transferred to a freeze until the analysis was done. Sodium tetrachloromercurate and Sodium hydroxide were used as absorbing reagents for SO_2 and NO_2 respectively to arrest SO_2 in the form of dichlorosulfitomercurate complex measured spectrophotometrically at 560 nm and NO_2 as sodium nitrite measured at 540 nm. For analysis of SO_2 and NO_2 by spectrophotometeric method, described in IS: 5182 (Part ii) and IS: 5182 (Part vi) were followed [27,28]. National ambient air quality standard (NAAQS) is represented in **Table 3**.

2.3. Meteorology

In each sampling location meteorological parameters such as humidity, temperature, wind speed, wind direction and rainfall were recorded both in premonsoon and postmonsoon seasons. Humidity and temperature were measured by a portable hygrometer (Model-HTC-1), rainfall is measured by a digital rain gauge (Model-RGR 126; Make-Oregon) meter whereas wind speed and direction is measured by a digital anemometer along with wind vane (Model-Lutron-AM-4201). For both the seasons two windrose diagrams (**Figures 3(a)** and **(b)**) were prepared by using windrose pro software. Apart from wind velocity and direction other meteorological data of the study area during monitoring period is represented in **Table 4**.

2.4. Air Quality Index (AQI)

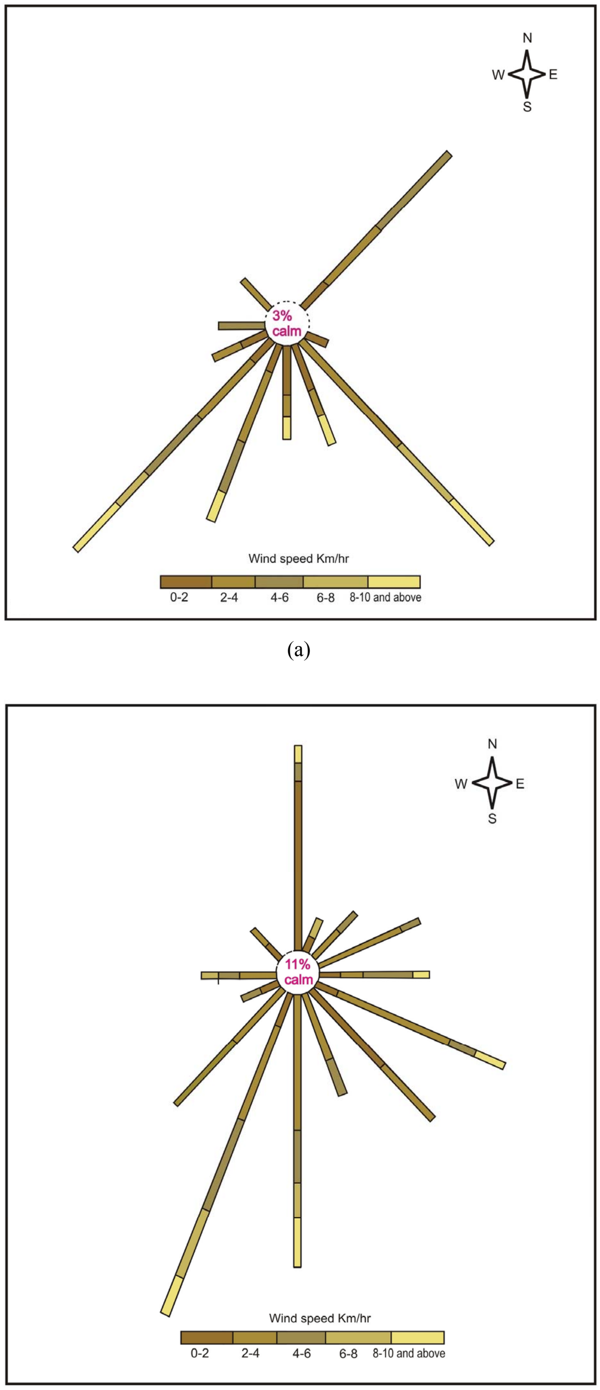
An AQI could be defined as a scheme that transforms the (weighted) values of individual air pollution related parameters into single number. Air quality index [29] was also measured here for each place in each zone. At first air quality rating of each parameter used for monitoring is calculated in each zone by the formula as;

1) q = 100xV/Vs; where q = quality rating; V = observed value of parameter; Vs = value recommended for that parameter.

If total 'n' no of parameters were considered for air monitoring, then geometric mean of these 'n' number of quality ratings was calculated in the following way:

2) g = anti log {(log a + log b + ……………. log x)/n}; where g = geometric mean; a, b, c, d, x = different values of air quality rating; and n = number of values of air quality rating, log = logarithm.

Air quality status [30] on the basis of AQI is represented in **Table 5**.



(a) (b)

Figure 3. Windrose diagram. (a) Premonsoon; (b) Postmonsoon.

2.5. Statistical Analysis

2.5.1. Pearson Correlation Coefficient

The Pearson correlation among SO_2, NO_2 and RSPM was calculated by using the following formula

Table 3. National ambient air quality standards.

Pollutants (μg/m^3)	Time weighted	Concentration in ambient air in average		
		Sensitive	Industrial	Residential and others
Respirable Suspended Particulate Matter (RSPM)	24h	75	150	100
Sulphur dioxide (SO_2)	24h	30	120	80
Oxides of nitrogen (NO_2)	24h	30	120	80

Source: Central pollution control board, Delhi, 1994

Table 4. Meteorological condition during premonsoon and postmonsoon season.

Meteorological parameters	Premonsoon			Postmonsoon		
	Maximum	Minimum	Average	Maximum	Minimum	Average
Rainfall (mm)	118.7	42.7	78.8	433.6	228.2	324.2
Humidity (%)	75	42.5	58.22	85	53	66.13
Temperature (℃)	35.5	16.43	24.54	33.5	16.2	23.81

Table 5. Air quality index table (Mudri, 1999).

Category	AQI of ambient air	Description of ambient air quality
I	Below 10	Very clean
II	Between 10-25	Clean
III	Between 25-50	Fairly clean
IV	Between 50-75	Moderately Polluted
V	Between 75-100	Polluted
VI	Between 100-125	Heavily polluted
VII	Above 125	Severely polluted

$$r = \frac{\sum_{i-1}^{x}\left(X_i - \bar{X}\right)\left(Y_i - \bar{Y}\right)}{\left(n-1\right) S_x S_y}$$

where X and Y are two variables, with means $\bar{X}$ and $\bar{Y}$ respectively with standard deviations S_X and S_Y. Statistical significance of r value is calculated by t-test.

2.5.2 Student's t-Test for Difference of Means

A student's (t) test [31] was carried out for testing significant difference between means of factors for pre- and postmonsoon periods against left sided alternative hypothesis, *i.e.*, the mean of premonsoon is less than that of the other. The test statistic, which follows t-distribution with ($n_1 + n_2 – 2$) degrees of freedom, is given by $t = (X_1 – X_2)/\sqrt{\left(S_P^2 / n_1 - 1\right) + \left(S_P^2 / n_2 - 1\right)}$; where $S_P^2 = (n_1S_1^2 + n_2S_2^2)/(n_1 + n_2)$.

X_1 is the mean variable of premonsoon, X_2 is the mean variable of post-monsoon, S_P^2 is the variance of combined sample (Standard Error of difference between means of pre- and postmonsoon parameters), n_1 is the number of observations on variable of premonsoon and n_2 is the number of observations on variable of postmonsoon. If computed value is greater than critical value there is significant difference between means.

2.6. RS and GIS Methodology

The following RS and GIS methodologies were adopted for carrying out the research work.

2.6.1. Supervised Classification of Study Area

Supervised classification of the Burdwan town was performed with the help of Resourcesat-1 satellite image and Geomatica V.10.2 software. Map collected from Burdwan municipality was considered as base map (**Figure 1**). Base map was georeferenced at latitude/longitude projection system with a datum level of India-Nepal (D076) with an output pixel spacing of 0d00'00.1900". For georeferencing ground control points (GCPs) were collected from study area by using Germin 12 GPS receiver. Burdwan municipality area was clipped from the satellite imagery and image to image georeferencing was done by using already georeferenced base map. Then supervised classification was run by using maximum likelihood classifier with null class. Thereafter both landuse/landcover and base maps were reprojected to Universal Transverse Marcater Projection (UTM) system. Twenty five (25) air sampling locations were then downloaded to the classified image from GPS through Mapsource software. Locational details along with different air quality parameters and their concentrations were attached to this 25 spatial data as an attribute data.

2.6.2. Digital Elevation Model (DEM)

DEM is generated on the basis of sampling points, stored as a point layer along with attributes such as RSPM, SO_2 and NO_2 etc. DEM is generated by using VEDIMINT algorithm in the Geomatica V.10.1 software. The output DEM is represented as a zonation map of the said parameters (**Figures 5**, **6** and **7**). The algorithm consists of three major steps plus an optional step for processing 2D features. In the first step, input vector points (RSPM, SO_2 and NO_2 concentration with respect to different locations) are reprojected to the raster coordinates and burned into the raster buffer, with the elevations generated due to different concentration of the said parameters interpolated linearly between vector nodes. 2D layers are ignored in this stage. If multiple elevation values are scanned into a single pixel, the maximum value is assigned the pixel, and the pixel is marked as a cliff. In the second step, the elevation at each DEM pixel is interpolated from the source elevation data. The interpolation process is based on an algorithm called Distance Transform. Interpolation is made between the source elevations and elevations at equal-distance points from source locations. If 2D vector layers are present, they are scan converted into a flag buffer during the optional step. The 2D features are also initialized to prepare for use in the smoothing stage. In step 3, a finite difference method is used to iteratively smooth the DEM grid. The algorithm uses over relaxation technique to accelerate the convergence. During the iterations, the source elevation values are never changed, while the interpolated values are updated based on the neighborhood values.

2.6.3. Inverse Distance Interpolation (IDINT)

Inverse distance interpolation is used to read the gray level values for an arbitrary number of pixel locations in order to generate a raster image based upon interpolation between the specified gray levels. This method of interpolation combines the idea of Thiessen polygon with the gradual change of trend surface. It considers weighted moving average. Weights are computed from a linear function of distance between sets of points and the points to be predicted. In this method the size of the starting radius is specified, which defines the starting search area for interpolation points around grid point.

3. Results and Discussion

Results of premonsoon and postmonsoon ambient air quality status of different monitoring sites of study area encompassing industrial, residential and sensitive areas are represented in **Tables 6**, **7** and **8** respectively whereas the average seasonal values of RSPM, SO_2 and NO_2 are represented in **Table 9**.

3.1. RSPM Scenario

During premonsoon all the industrial sites had high level of RSPM than the standard prescribed by NAAQS. This might be due to resuspension of road dust, soil dust, and vehicular traffic and nearby industrial emission [8]. But during postmonsoon RSPM level in these sites lied well below the prescribed limit. This implied that the monsoon in these sites had a major role in washing out of RSPM [20].

In residential sites RSPM level exceeded its standard in every monitoring site except R7, R13, and R15 where the level of RSPM lied very near to the standard. But in postmonsoon opposite phenomenon was observed. Only 12% of residential sites *i.e.* R11, R12, and R15 have higher level of RSPM than the permissible standard. In general it is found that most of the postmonsoon RSPM concentration was significantly less than the premonsoon concentration except site R15. This phenomenon might be corroborated to monsoonal wash out of the particles [8]. The site R15 was situated just beside National Highway. So, at that particular time of monitoring high density of traffic, road dust etc might cause it to be more negating the effect of rain which was supported by similar observation of a research work [32].

Regarding sensitive sites except site S5 and S6 most of the RSPM value lied above the limit of NAAQS standard in premonsoon while in postmonsoon the level exceeds

Table 6. Premonsoon and postmonsoon ambient air quality status in various industrial locations of Burdwan municipality (Except AQI, all values are expressed in μg/m^3).

Sites	RSPM		SO_2		NO_2		AQI		Status	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
I1	173.9	74	1.59	20.34	26.62	125.78	15.05	44.33	Clean	Fairly clean
I2	326.2	53.7	26.69	23.11	66.06	60.29	64.33	32.59	Moderately polluted	Fairly clean
I3	154.6	55.2	8.6	0.38	20.19	98.6	23.16	9.80	Clean	Very clean
I4	231.1	60.41	19.46	7.51	56.09	23.91	48.88	17.12	Fairly clean	Clean

Table 7. Premonsoon and postmonsoon ambient air quality status in various residential locations of Burdwan municipality (Except AQI, all values are expressed in μg/m³).

Sites	RSPM		SO_2		NO_2		AQI		Status	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
R1	203.30	22.80	4.37	7.06	238.19	44.05	69.15	22.29	Moderately polluted	Clean
R2	174.70	15.46	0.88	1.47	161.79	90.73	33.87	14.76	Fairly clean	Clean
R3	230.00	34.26	2.13	BDL	109.74	230.51	43.79	16.60	Fairly clean	Clean
R4	303.30	38.92	0.34	10.60	29.19	163.69	16.75	47.25	Clean	Fairly clean
R5	267.30	71.80	2.21	6.95	63.15	191.21	38.77	71.37	Fairly clean	Moderately Polluted
R6	285.80	16.30	3.18	12.53	87.16	168.70	49.83	37.76	Fairly clean	Fairly clean
R7	99.40	40.97	0.6	9.11	36.77	129.66	15.04	42.29	Clean	Fairly clean
R8	135.17	32.63	0.34	3.94	88.36	193.90	18.51	33.90	Clean	Fairly clean
R9	119.16	10.00	3.17	20.34	63.04	207.12	33.38	40.38	Fairly clean	Fairly clean
R10	137.77	69.62	4.37	16.95	220.87	426.28	59.22	92.29	Moderately polluted	Polluted
R 11	323.10	112.80	6.93	5.45	140.43	79.05	78.90	42.35	Polluted	Fairly clean
R12	264.40	102.46	3.22	5.60	3.79	166.70	17.15	53.07	Clean	Moderately polluted
R13	69.61	47.16	2.69	1.32	16.10	30.34	16.76	14.34	Clean	Clean
R14	168.90	7.11	9.75	4.55	54.71	45.97	52.02	16.62	Moderately polluted	Clean
R15	96.54	141.00	2.72	6.00	158.82	97.99	40.24	50.60	Fairly clean	Moderately polluted

Table 8. Premonsoon and postmonsoon ambient air quality status in various sensitive locations of Burdwan municipality (Except AQI, all values are expressed in μg/m³).

Sites	RSPM		SO_2		NO_2		AQI		Status	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
S1	123.60	10.95	2.68	BDL	77.49	39.94	72.45	13.49	Moderately polluted	Clean
S2	191.70	45.60	2.64	7.30	158.58	207.11	105.94	100.79	Heavily polluted	Heavily polluted
S3	156.40	130.45	12.71	12.94	62.62	48.98	122.63	106.99	Heavily polluted	Heavily polluted
S4	363.60	87.15	2.72	21.96	101.46	209.28	114.13	181.04	Heavily polluted	Severely polluted
S5	60.00	40.62	0.57	3.80	79.57	937.25	34.29	128.93	Fairly clean	Severely polluted
S6	54.45	4.48	3.50	3.42	191.87	54.33	81.52	23.10	Polluted	Clean

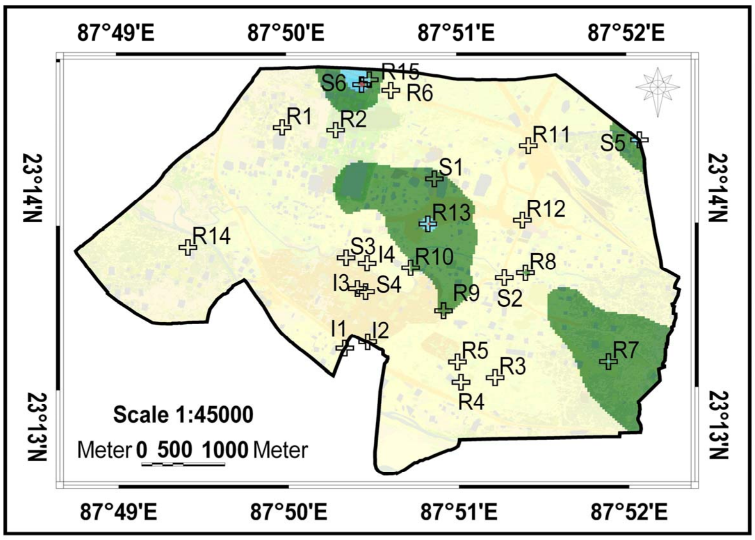
only at site S3 and S4. This might be due to their locational disadvantages as because both these two places were located in the region where majority rice mills factories of the town are situated. So, in spite of monsoonal wash out of dust particle they reflected a high level of RSPM than the standard. Maximum RSPM level during premonsoon was found in S4 site, which was not only beside rice mills but also beside a main road. So, such a high level of RSPM might be attributed to resuspension of road dust, soil dust and vehicular traffic and nearby industrial emission.

Digital elevation model (DEM) with respect spatio-temporal distribution of RSPM in the study area were presented in **Figures 4(a)** and **(b)**.

Table 9. Statistical summary of ambient air quality status of Burdwan municipality during pre and postmonsoon season.

Statistics	RSPM (μg/m^3)		SO_2 (μg/m^3)		NO_2 (μg/m^3)	
	Premonsoon	Postmonsoon	Premonsoon	Postmonsoon	Premonsoon	Postmonsoon
Average	188.56	53.03	5.12	8.51	92.51	162.85
Maximum	363.6	141	26.69	23.11	238.19	937.25
Minimum	54.45	4.48	0.34	BDL*	3.79	23.91
Standard deviation	88.63	38.27	6.27	7.11	64.78	184.80

*BDL indicated below detection limits



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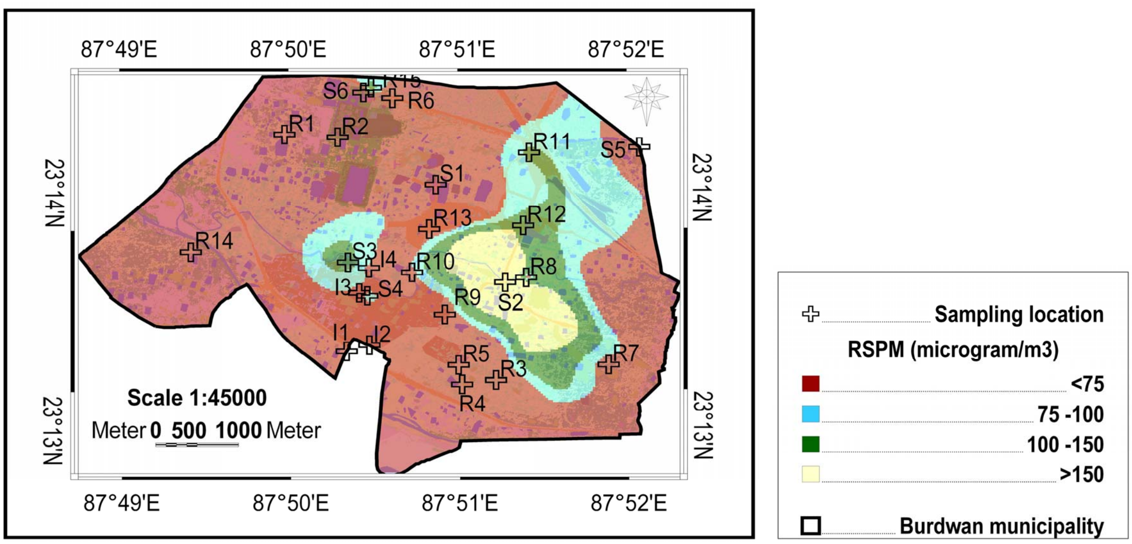


(b)

Figure 4. Digital Elevation Model (DEM) on spatio-temporal distribution of RSPM over the study area in (a) Premonsoon (b) Postmonsoon.

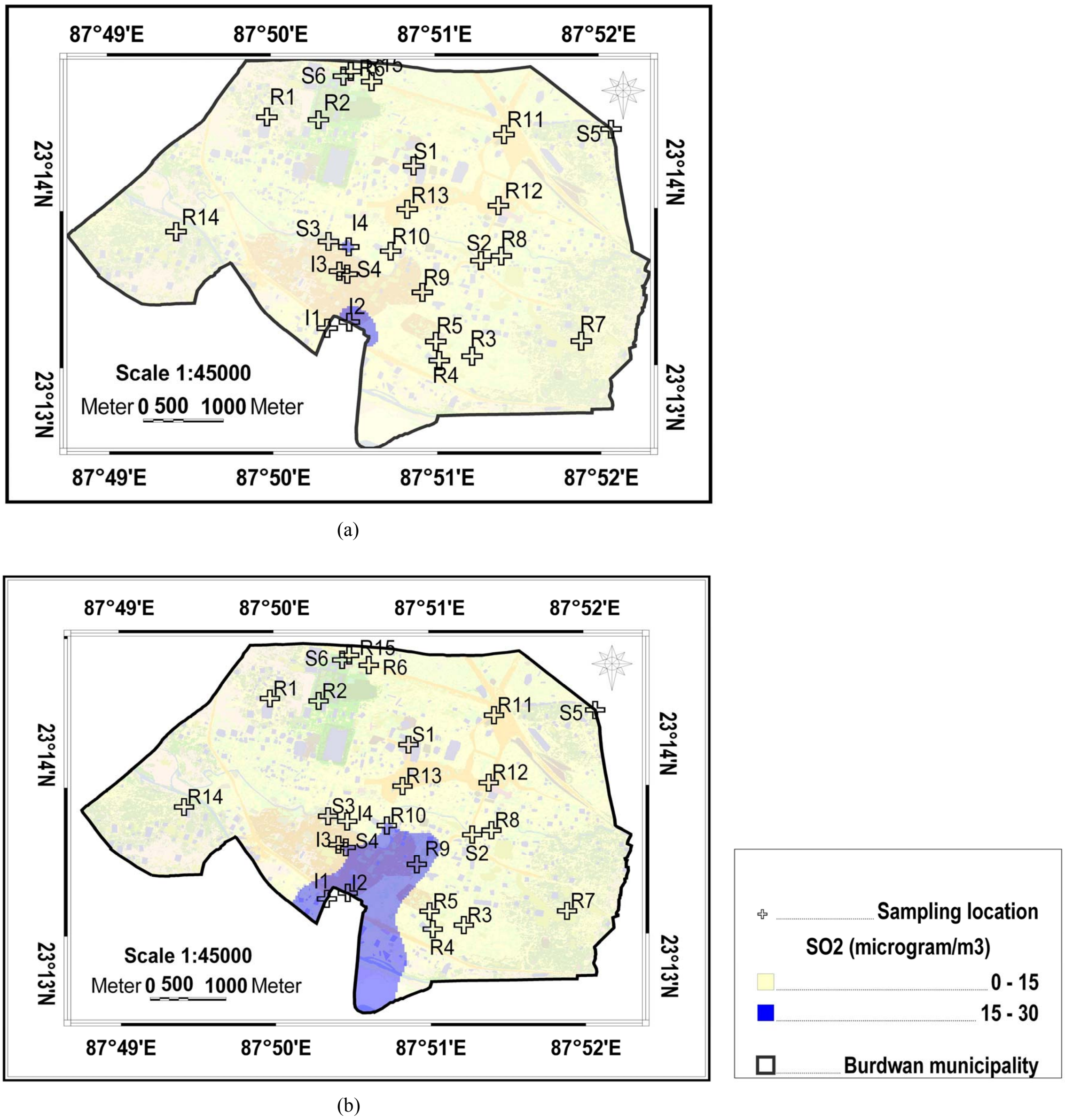


Figure 5. Digital Elevation Model (DEM) on spatio-temporal distribution of SO_2 over the study area in (a) Premonsoon (b) Postmonsoon.

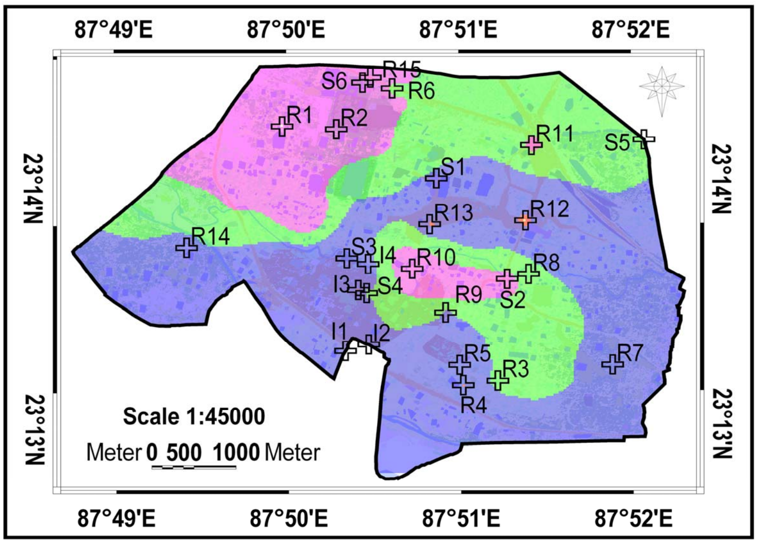
3.2. SO_2 Scenario

The concentration of SO_2 was comparatively lower in both the seasons than the prescribed standard of NAAQS in all the monitoring sites. Similar kind of SO_2 status was also highlighted by other research workers such as Reddy and Ruj 2003 [21] and Gupta *et al.* 2008 [8]. Among industrial, residential and sensitive sites maximum SO_2 level was observed in industrial sites *i.e.* 26.69 μg/m^3 during premonsoon and 23.11 μg/m^3 during postmonsoon. This might possibly be due to emission from industrial boiler, heating and cooking sources. Within industrial sites except I1, rest of the three sites had low SO_2 level during postmonsoon. While in case of residential sites most of the sites has higher level of SO_2 concentration during postmonsoon except R3, R11, R13, R14 sites. Burning of coal by local people might influence it. Similar trend also followed by most of the sensitive sites except S1 and S6.

Spatio-temporal distribution of SO_2 concentration are represented in **Figures 5(a)** and **(b)**.

3.3. NO_2 Scenario

Through out the study area NO_2 level was very high. Ma-



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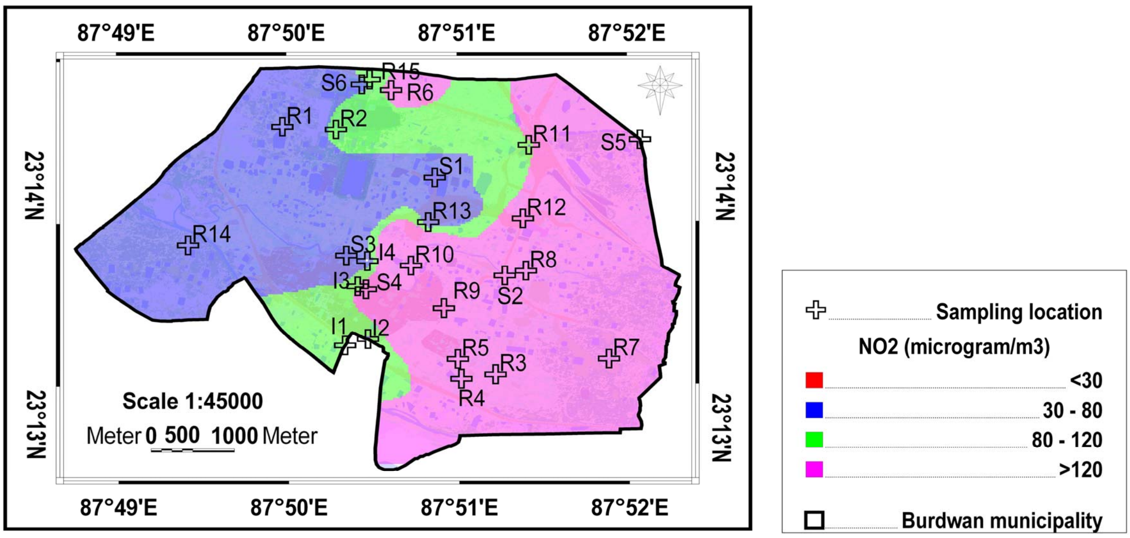


(b)

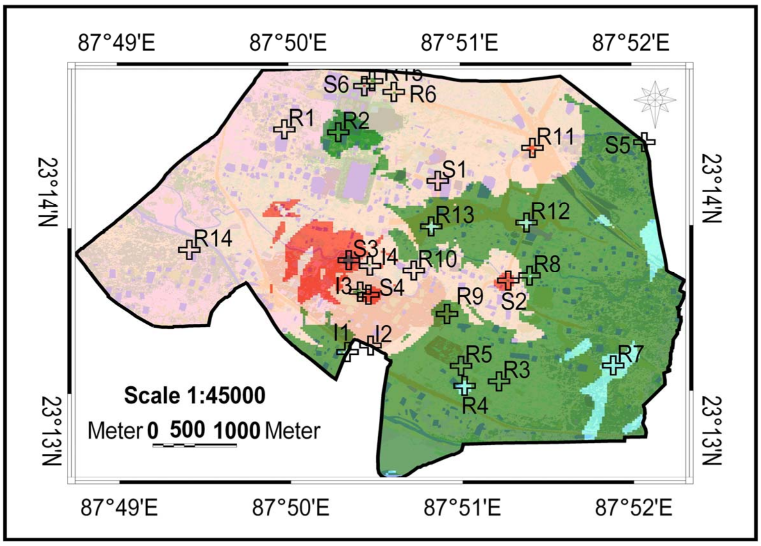
Figure 6. Digital Elevation Model (DEM) on spatio-temporal distribution of NO_2 over the study area in (a) Premonsoon (b) Postmonsoon.

ximum concentration was observed in S5 site in the tune of 937 µg/m^3. This elevated level might be attributed to the high traffic density of the town. This was also supported by a published work of [33]. Among industrial sites, I2 and I4 show the low level of NO_2 concentration in postmonsoon while in the same season high concentration was observed in site I1, I13. To explain the later it could be said NO_2 was not only dependent on rainfall but also dependent on vehicle density and the distance of the monitoring site from road [18]. Among all industrial sites only site I1 had the higher-level of NO_2 than the standard in postmonsoon season. Regarding residential sites, R1, R2, R3, R6, R8, R10, R11, R15 had higher level of NO_2 concentration in premonsoon season while in postmonsoon except R1, R11, R13, R14 all have shown higher level of NO_2 than the prescribed standard. In the sensitive sites both the pre and postmonsoon value of NO_2 were exceeded its standard.

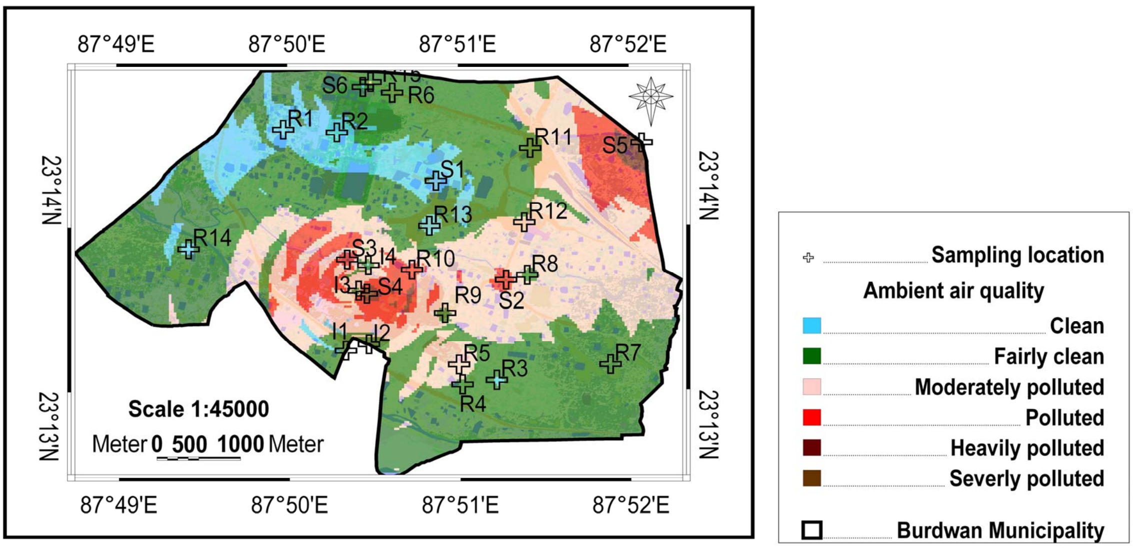
Digital elevation model with respect to spatio-temporal distribution of NO_2 were represented in **Figures 6(a)** and **(b)**.

3.4. Overall Scenario of RSPM, NO_2 and SO_2

Average concentration level of all the pollutants in both



(a)



(b)

Figure 7. Continuous surfaces from point data (AQI) by using Inverse Distance Interpolation (IDINT) technique in (a) Premonsoon (b) Postmonsoon.

the season was represented in **Table 9**. In general RSPM level varied from 363 to 54 μg/m^3 with a mean of 188 μg/m^3 in premonsoon and from 141 to 4.48 μg/m^3 with a mean of 53.03 μg/m^3 during postmonsoon season. NO_2 level varied from 3 to 238 μg/m^3 with a mean of 92 μg/m^3 and 23 to 937 μg/m^3 with a mean of 162 μg/m^3 respectively during premonsoon and postmonsoon season. Whereas SO_2 level varied from 0.34 to 26 μg/m^3 with a mean of 5 μg/m^3 and BDL to 23 μg/m^3 with a mean of 8 μg/m^3 respectively during premonsoon and postmonsoon season. Finally, to compare the pre and the postmonsoonal value of SO_2 and NO_2 in this town it was found that in most places the level of SO_2 as well as NO_2 was increased in postmonsoon season in spite of lowering down by rain. This might be explained by over crowded condition in the town of Burdwan, which was also the center of commercial activities in the district. The building structures were constructed literally wall to wall with very narrow streets separating one block from the other. Even the vehicular traffic was at most times bumper to bumper and sometimes at a stand still every time it rained. Hence, the increased amount of exhaust gases in the air negated the effect of the monsoon rains [32].

Statistical significance (student t-test) of seasonal variation of air quality parameters were carried out for the combined data of pre- and postmonsoon. Result of t-test for the combined data was given in **Table 10**. The Table value (critical value) at 48 degree of freedom was 1.68 for left-sided alternative hypothesis. Since the computed values of t were greater than the critical value of 1.68 for all the parameters the difference of means between pre and postmonsoon was significant at 5% level. Hence, the results clearly indicated that there was significant monsoonal effect on mean values of RSPM, SO_2 and NO_2

4. Influence of Meteorological Parameters

In the study area premonsoon temperature ranged from 16 to 35℃ while in postmonsoon it varied from 16 to 33℃. Humidity ranged from 42 to 75% and 53 to 85% during premonsoon and postmonsoon season respectively (**Table 4**). Regarding rainfall study area received an average rainfall of 78 mm in premonsoon where as in postmonsoon it receives 324 mm. Windrose which was graphical representation of wind data giving the % frequencies of wind speed, wind direction for a given location was represented in **Figures 3** and **4** for premonsoon and postmonsoon season respectively. From windrose diagrams it was found that the percentage of calm condition is higher (11%) in postmonsoon than premonsoon season (3%). As a result, higher concentration of gaseous pollutants was observed in postmonsoon than the premonsoon in the study area of this town. The wind speed ranged between 0 to 18 km/hr. Wind blew almost from all direction. But during premonsoon the predominant direction was from North-East, South-East and South-West direction while in postmonsoon season it was mainly from South-East, South-Southwest and North direction also. The major significant changes in the spatial and temporal variation of the ambient air quality of the town were due to variation of rainfall in the two seasons which was also supported by the **Table 10**.

5. Season-Wise Classified Image on the Basis of Air Quality Index (AQI)

Air Quality Index of all the three categories of monitoring sites was represented in **Tables 6**, **7** and **8**. From AQI status of the all monitoring sites in both pre- and postmonsoon season it was found that 40% of the total monitoring sites (I4, I2, I3, R1, R2, R3, R11, R14, S6, S1) became less polluted in postmonsoon. Whereas 40% of the total monitoring sites (I1, S4, S5, R4, R5, R7, R8, R10, R12, R15) became more polluted in postmonsoon season and 20% of the total monitoring sites (R6, R9, R13, S2, S3) remained same in status *i.e.* they are indifferent of rainy season and by using IDINT technique, season wise continuous surfaces of AQI have been generated. The output surfaces generated by IDINT were unclassified grey scale images. Though output surfaces were smooth but it is difficult to compare these surfaces on the basis of seasonal trend. On the basis of AQI rating, and using classification technique, these seasonal images had been classified (**Figures 7(a)** and **(b)**). Premonsoon classified image revealed that the western part of the town mainly covered the moderately polluted area while the eastern part of the town covers the fairly polluted region. But after the offset of monsoon just opposite scenario was observed. The moderately polluted region was seemed to be shifted to eastern part while the fairly clean part was shifted to western part. This phenomenon was also influenced by meteorological phenomenon which might be supported by wind rose diagram. It was observed that in premonsoon season wind mainly blew from North-East, South-East and South-West direction. It looked that the pollutants were seemed to be dispersed more in these direction from the polluted region. In postmonsoon just opposite picture was found. The predominant wind direction was South, South-West and North direction. So, the just opposite dispersion of pollutants had been occurred from the heavily polluted region. According to IDINT surface classification on the basis of AQI clean and fairly clean area had increased upto 7% and 2% respectively in comparison to premonsoon, whereas moderately polluted classified area decreased to 23% (**Table 11**).

Table 10. Student t-test of mean difference between air quality parameters.

Parameter	Calculated t value	Tabulated value of t at 0.05 level	Significant/ Insignificant
RSPM	6.88	1.677	Significant
SO_2	–1.7519	1.677	Significant
NO_2	–1.7597	1.677	Significant

Table 11. Season-wise percentage area of different AQI status.

AQI status	Seasonal areal coverage (%)	
	Premonsoon	Postmonsoon
Clean	2.19	9.43
Fairly clean	41.09	52.02
Moderately polluted	53.37	30.18
Polluted	3.30	7.52
Heavily polluted	0.05	0.82
Severely polluted	Nil	0.03

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