# CHAPTER I

## CORRELATION BETWEEN AIR POLLUTION AND METEOROLOGICAL PARAMETERS FOR VADODARA CITY, GUJARAT. - TREND ANALYSIS FOR 2005 – 2007.

## 1.1 INTRODUCTION

The atmospheric stability influences the complexity of the pollutant discharge and its dispersion in the area. This transportation of pollutants from a source is beneficial as well as detrimental. All weather including pressure system, wind speed and direction, humidity, temperature and precipitation, ultimately results from the variable relationships of heat, pressure, wind and moisture. It is mainly the result of interactions between each of them with change in time. Interdependence of certain parameters, in atmosphere is found which is theoretically illogical but practically true and existing, for both seasonal and annual observations (Kumar *et al.,* 2005; Bao *et al.*, 2005 and Thacker *et al.,* 2009).

The movement of air on the ground is characterized by the whirls and eddies of gases and small particles in the atmosphere. (Committee On Air Pollution; 1948-1949.) Atmosphere plays a major role in the transport of pollutants from an emitting source to its dispersion in other areas of the region (Ashrafi and Hoshyaripour, 2010). If there was no movement of pollutants from its source, the atmosphere of that area will become almost intolerable for any living being to survive. Therefore the cleansing action for the movement of pollutants from its emitting source is an important role played by winds and its related meteorological parameters in nature which will enable it to move. Wind and vertical temperature gradient or the lapse rate, are the two most defined sources which help in pollutant dispersion from its sources.

### 1.1.1 Importance Of Air Pollution And Meteorology Correlation:

Atmosphere serves as a medium into which the air pollutants are released. The transportation and dispersion of these pollutants released are controlled significantly by meteorological parameters

(Helmis *et al.,* 1987; Melas *et al.,* 1998 and Kassomenos *et al.,* 1999). Thus, understanding air pollution meteorology and its influence in pollution dispersion is essential in understanding the effect of urbanization trend. These trends are thereby used by various air quality planners to help locate major air pollution monitoring stations and to develop implementation plans to bring ambient air quality into compliance with the prescribed standards. Meteorology is used in predicting the ambient impact of a new source of air pollution and to determine the effect on air quality from modifications to existing sources as conducted for any EIA study.

When meteorological conditions develop that are not conducive to pollutant dispersion, governmental air pollution agencies must act fast to ensure that air pollutants don't build up to unacceptable levels in the air we breathe. When pollutant levels become excessively high, an air pollution episode results and emissions into the atmosphere must be curtailed. Donora, Pennsylvania provides an extreme example of this situation. In 1948, Donora suffered a disastrous air pollution episode. Donora is located in the bottom of a valley surrounded by rolling hills. The townspeople were accustomed to receiving some emissions from the local steel mill, zinc smelter, and sulfuric acid plant. But, they were not prepared for the dangerously high concentrations of pollutants that built up and became trapped over the town. The meteorological conditions in Donora during this five-day period (high pressure system and strong temperature inversion) produced light winds and dense fog. The air was not able to move horizontally or vertically and just lingered over the town. The factories continued to operate, releasing their pollutants into the air. Many people became ill and 22 people died. Finally, high concentrations of pollutants subsided as the weather pattern broke, winds picked up and the valley experienced rain (Ahrens, 1993).

The air quality in a region varies depending upon the industrialization, population and traffic density; and meteorological and topographical properties (Celik and Kadi, 2007). In industrialized cities, the pollutants exhausted, emitted and discharged have significant effect in environment pollution. Mayer (1999), Sanchez-Ccoyllo and Andrade (2002) in their studies have investigated the relationship between air pollution and meteorological factors statistically in the city of San Paulo. Kandilkar and Ramchandran (2000) had shown the consequences of particulate air pollution in Urban India. Aggarwal (2001) and Sharma *et al.,* (2002) have proved that Air Quality Index (AQI) forecasting model is useful for information, dissemination to general public. Hence, in the present study an attempt is made by applying source receptor modeling to find the interdependence between the meteorological parameters and the observed pollution level in the city so as to figure out the trend in the Vadodara city and predict the future trends with respect to the human respiratory health effects in the city (Kumar *et al.*, 2005 and Bao *et al.*, 2005). Vadodara being an industrial hub is likely to show significant effect with respect to environmental pollution.

## 1.2 MATERIALS AND METHOD

### 1.2.1 Study Area:

The present study is carried out for Vadodara City. It is located at 22°18'N 73°11'E in western India at an elevation of 39 metres (123 feet). It is the 18th largest city of India with an area of 148.95 km² and a population of 1.6 million according to the 2001 census. The Vadodara district is bounded by Panchmahal and Dahod districts to the north, Anand and Kheda district to the west, Bharuch and Narmada distict to the south and the state of Madhya Pradesh to the east. The tallest point of the region is the hill of Pavagadh. The city sits on the banks of the River Vishwamitri, in central Gujarat, which frequently dries up in the summer, leaving only a small stream of water. The city is located on the fertile plain between the Mahi & Narmada Rivers. According to the Bureau of Indian Standards, the town falls under seismic zone-III, in a scale of I to V.

There are three main seasons: Summer, Monsoon and Winter. Except for the monsoon season, the climate for the city is dry. The weather is hot for the months of March to July - the average maximum is 36 °C (97 °F), and the average minimum is 23 °C (73 °F). From November to February, the average maximum temperature is 30 °C (85 °F), the average minimum is 15 °C (59 °F), and the climate is extremely dry. The southwest monsoon brings a humid climate from mid-June to mid-September. The average rainfall is 931.9mm. Industrial and infrastructure development in the city has led to increase in the pollution level, following which has made Vadodara undoubtedly state's one of the severely polluted city in 2010 as declared by the MOEF based on the CEPI values.

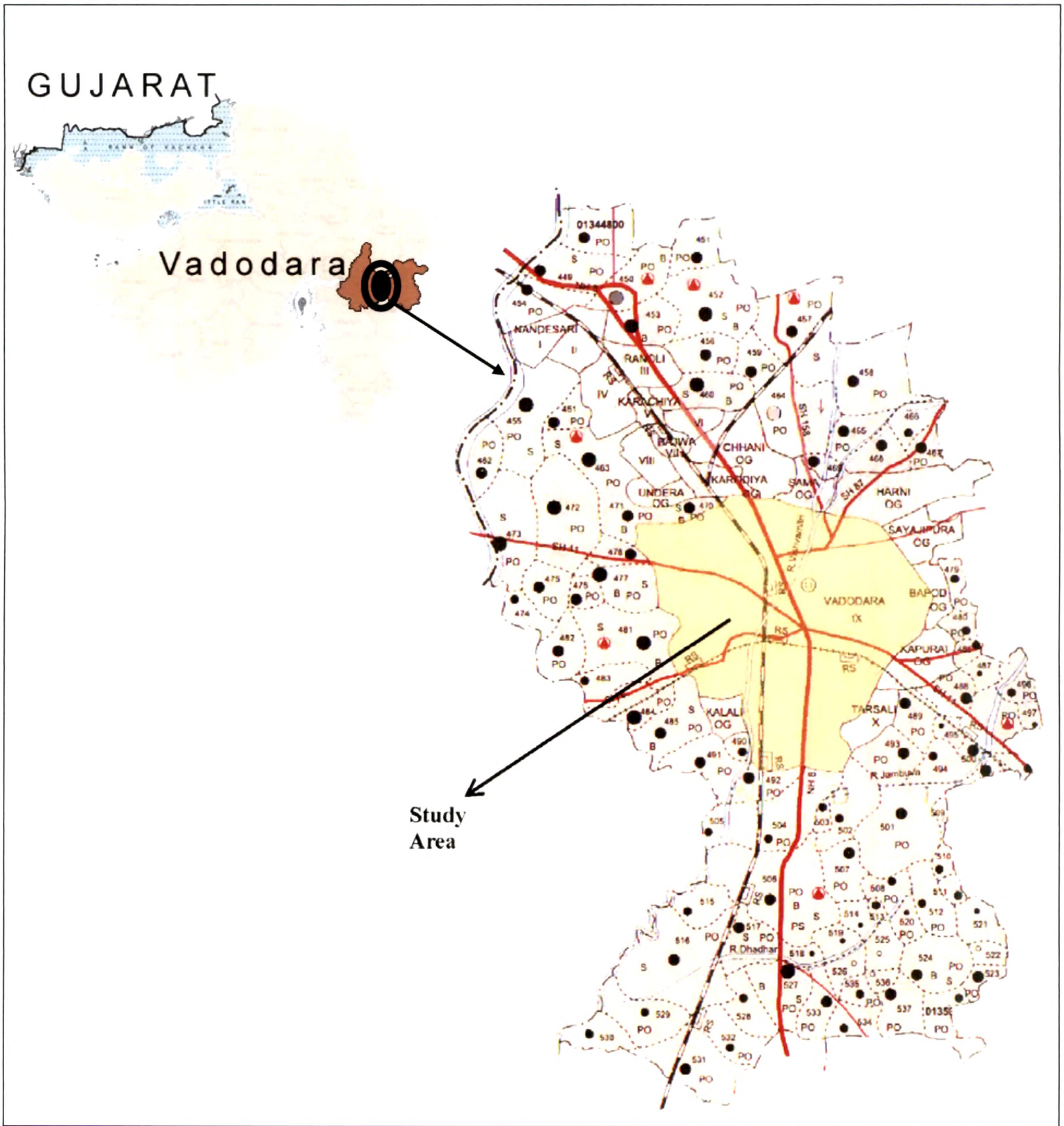



**Fig.1.1: Location Of The Study Area**

*(Source: Census Data Book)*

### 1.2.2 Study parameters:

To understand the inter-relationship of the meteorological parameters and pollutions, 8 meteorological parameters viz., Height of Lowest Layer, Cloud Cover, Maximum Temperature, Minimum Temperature, Windspeed, Rainfall, Relative Humidity and Vapor Pressure along with 3 pollutants viz., $SO_2$, $NO_X$ and RSPM were considered for the present work.

### A. Meteorological Parameters:

The meteorological data was collected from the Indian Meteorological Department (IMD), Ahmedabad for 3 years i.e 2005 to 2007 for Maximum temperature, Minimum Temperature, Windspeed, Rainfall, Relative humidity, Height of Lowest layer, Cloud cover and Vapour pressure.

### 1. Height of Lowest Layer

The troposphere is the lowest layer of atmosphere which begins at the surface and extends to between 9 km (30,000 ft) at the poles and 17 km (56,000 ft) at the equator, with some variation due to weather. The troposphere is mostly heated by transfer of energy from the surface, so on average the lowest part of the troposphere is warmest and temperature decreases with altitude. Stable atmospheric conditions occur when warm air above is cool air and the mixing depth is significantly restricted. This condition is called a "**temperature inversion**". Mixing height (MH) is one of the most important parameters requested by different atmospheric pollution models as an input data for forecasting the air quality. Wind speed and boundary layer height are key variables for studies on the status of air pollution scenario.

## 2. Cloud Cover:

Cloud cover plays a major role in governing the pollution level of an area. The more the cloud cover, lesser will be the dispersion of pollutants from its source as the cloud cover will affect the intensity and duration of sunshine thereby decreasing the surface temperature of the region. Cloud cover is known to affect the surface temperature of the region directly thereby handling the rate of dispersion of the pollutants.

## 3. Maximum & Minimum Temperature:

Temperature defines the capacity of matter to transfer heat from hotter to cooler bodies and vice a versa. Air temperature is the intensity aspect of sun's energy that strikes the earth's surface. Because the amount of energy from the sun reaching the earth varies from day to day, from season to season, and from latitude to latitude, temperatures also varies resulting into the maximum and minimum temperature of the day, season and year.

## 4. Windspeed:

Wind is defined as the air in motion. On a global scale or macroscale wind patterns are built up due to unequal heating of earth surface by solar radiation at the equator and the polar regions, rotation of the earth and the difference between conductive capacities of land and ocean masses. Secondary or mesoscale circulation patterns develop because of the geographical structure of the region. Mountain ranges, cloud cover, water-bodies, deserts, forestation, etc., influence wind patterns on scales of a few hundred kilometers. Accordingly a wind pattern is setup which is broadly categorized into the seasonal and annual patterns.

Windspeed plays a major role in any dispersion modeling carried out. It is the governing factor to analyse the rate by which the pollutant is going to travel from its emitting source and in which direction it is going to be dispersed.

**5. Rainfall:**

Rainfall / Precipitation acts as an effective cleansing agent of pollutants in the atmosphere, as it washes out / scavenges the large particles by the raindrops / snowflakes. Pollutant and other small particles get accumulated in the form of raindrops / snowflakes and come down, which becomes a source of drain off. Also, the gaseous pollutants get removed by dissolution or absorption.

**6. Relative Humidity:**

Relative humidity will have an indirect impact on the air pollution of an area and direct impact on the indoor / outdoor air quality of the area in terms of the microbial growth. High relative humidity provides the moisture necessary to promote harmful chemical reactions in materials and, in combination with high temperature, encourages mold growth and insect activity. Extremely low relative humidity, which can occur in winter in centrally heated buildings, may lead to desiccation and embrittlement of some materials.

**7. Vapor Pressure:**

Vapor pressure is also found to have an indirect impact on the air quality of the area. Vapor pressure of the area depends on the wind speed and the sunshine / solar radiation received in the area. These two factors are directly related to the dispersion of the air pollutants in the atmosphere.

**B. Pollutants:**

Three major pollutants data for the pollution level analysis in the city was recorded viz., for $SO_2$, $NO_X$ and RSPM for the same study period from the GPCB (Gujarat Pollution Control Board; Vadodara). High volume samplers were used for sampling the pollutants and the collected data was analyzed in an in-house GPCB laboratory. Six different monitoring locations were defined by the board, out of which 5 are falling within the city i.e. Alembic Ltd. in the north of the city, Harni in North West, Dandia bazaar in East of the city, Makarpura GIDC in South and Race Course in West of the city. Sixth location being Nandesari, was selected being the industrial hub lying in North-West region of the district.


**Fig. 1.2: Monitoring Locations.**

**1. Sulfur Dioxide ($SO_2$):**

$SO_2$ is a colourless gas. It smells like burnt matches. It can be oxidized to sulphur trioxide, which in the presence of water vapour is readily transformed to sulphuric acid mist. $SO_2$ can be oxidized to form acid aerosols. $SO_2$ is a precursor to sulphates, which are one of the main components of respirable particles in the atmosphere. $SO_2$ concentration is dependent on the temperature. As temperature increases, concentration of $SO_2$ decreases. Concentration of $SO_2$ and temperature are correlated which depicts that combustion of fossil fuels and the effect of urbanization are also inter-related. Health effects caused by exposure to high levels of $SO_2$ include breathing problems, respiratory illness, and changes in the lung's defenses, worsening respiratory and cardiovascular disease.

**2. Nitrogen Oxides ($NO_X$):**

$NO_2$ is a reddish-brown gas with a pungent and irritating odor. It transforms in the air to form gaseous nitric acid and toxic organic nitrates. Nitrogen dioxide is a well known pollutant in the atmosphere for its toxic effects on the living species, as it forms photochemical ozone ($O_3$) and acid rain in the form of nitric acid ($HNO_3$). It is also a precursor to nitrates, which contribute to increased respirable particle levels in the atmosphere. Source of nitrogen oxides in ambient atmosphere is through combustion of fossil fuels at high temperatures which releases them as a by-product and gives energy to run the vehicle.

**3. Respirable Particulate Matter:**

Particulate matter is the general term used for a mixture of solid particles and liquid droplets in the air. It includes aerosols, smoke, fumes, dust, ash and pollen. The composition of particulate matter varies with place, season and weather conditions. Meteorology not only plays an important role in dispersion of RSPM but it also determines concentration of heavy metals in RSPM. Unstable meteorological conditions results in higher concentration of particulate matter owing to re-suspension making it an external source of pollutant. Whereas, low wind speed, low temperature and high relative humidity favors in maintaining the low concentration of the pollutants.

### 1.2.3 Statistical Analysis By Application On SPSS

An approach of Statistical modeling by SPSS is widely used to give a co-relation and addressing the effects of meteorology on air pollution (Gupta *et al.,* 2008 and Tiwari *et al.,* 2011). These models quantify and give a better visualizing of the nature of pollutant inter-dependency to individual meteorological parameters as they bring about the source receptor modeling which is directly applicable to the patterns that arise from the observed data (Schlink *et al.,* 2006). However, these techniques do not endeavor to fully describe the formation and accumulation of air pollutants in their chemical, physical, and meteorological processes (Schlink *et al.,* 2006). Correlation analysis forms one such method but does not provide a clear view of multiple interactions in the data. Thus, eigenvector analysis was used to convert the correlation data into multivariate information. Factor Analysis is the name given to one of the variety of forms of eigenvector analysis (Gupta, 1997). A correlation analysis between the pollutants and meteorological variables are widely conducted using SPSS. The analysis of the direction, strength, and statistical meaning of the variables can be carried out to find the determination of the coefficients that can be used in the calculation of percentage of relationship between the parameters used in the study or the interdependency of them on each other (Thompson *et al.,* 2000; Akpinar *et al.,* 2007 and Icaga and Sabah, 2009). Hence, it is a well accepted fact that statistical modeling is a widely used, effective learning tool for a variety of air quality applications and is most capable of providing insight into the potential impacts through development of observational foundations (Thompson *et al.,* 2000; Schlink *et al.,* 2006 and Jacob and Winner, 2009). In the context of changing climate these foundations provide a gateway into the possible extent of climate change impacts on air quality (Camalier *et al.,* 2007).

Considering the fact, these 11 study parameters were then applied on SPSS 12.0, software termed as Statistical Package for Social Sciences version 12.0. It is through this package that receptor modeling is performed and the extent of interdependence among these 11 parameters and the trend of interdependence for last three years were analyzed.

**Source Receptor Modeling**

In the meteorological studies, many variables are measured to personify the system. However, it is an interesting fact that all of the variables are not independent and hence there is a need to develop mathematical techniques that permit the study of these simultaneous variations of multiple variables. One such analysis i.e. the correlation is based on identifying the relationships between pairs of variables.

The varied application methods have resulted in different terminologies such as factor Analysis, Principal Component Analysis, Principal Component Factor Analysis, Empirical Orthogonal Function Analysis, etc. depending upon the way the data are scaled before analysis or how the resulting vectors are treated after the eigenvector analysis is completed.

Principal Component Analysis (PCA) is an important chemometric tool (Jackson, 1991 and Jolliffe, 1986) that can be used to establish combinations of variables, capable of describing the principal data tendencies observed (Kendall, 1980; Jolliffe, 1986 and Richman, 1986). This technique has been successfully used to study coastal water contamination (Reisenholer *et al.*, 1996) receptor modeling of air (Pinto *et al.*, 1998 and Bellheimer, 2001) as well as for characterization and determination of sources of contamination and eutrophication in lake waters (Reisenhofer, 1995].

In Environmental Impact Assessment, Factor Analysis plays a very important role. Ying and Liu have proposed an approach of objective weighting by using a procedure of PCFA, which suits specifically those parameters measured directly by physical scales, in 1995 (Ying, 1995). PCA has been applied to evaluate the effect of pollution on the ecosystems. In a study to identify the possible effects of thermal pollution on the macrobenthic communities and to compare them with the main influencing factors PCA was found to be the most powerful technique in evidencing the effect.

Factor analysis has also been applied by a number of researchers to interpret water quality data. It has been used to classify the stretch of a river into pollution zones. It has been also used to find out the dominating variables at different locations and to evaluate the sampling network and frequency. As in air quality application, it helps in identifying the nature of the sources in a broad sense with respect to mineralisation in and around a location. Mehloch first applied this technique to interpret the water quality data in 1974 (Mehloch, 1974). These applications have been broadly applied in domains that are used to study the climatic variables with increasing frequency and they are important tools in meteorology/climatology (Sneyers and Goossens, 1988; Sneyers *et al.,* 1989; White and Richman, 1991; Prudhomme and Reed, 1999; Huang and Antonelli, 2000 and Stathis and Myronidis, 2009).

**The Factor Analysis Model**

The mathematical model for factor analysis is similar to multiple regression analysis. Each variable is expressed as combinations of factors that are not actually observed.

The model for ith standardized variable is:

$$Xi = Ai1F1 + Ai2F2 + \ldots\ldots + AikFk + Ui$$

Where:

Fi's = common factors (all variables are expressed as functions of them) &

Ui = unique factor (uncorrelated)

These factors are common factors because all the variables are expressed as functions of them. The unique factors are assumed to be uncorrelated with each other and with the common factors.

The factors are labels for group of variables i.e. they are linear combinations of variables that characterize these concepts. The factors are inferred from observed variables and can be estimated as linear combinations of them. For example, the factor Fj can be expressed as:

$$Fi = \Sigma Wji\ Xi = Wji\ Xi + Wj2\ X2 + \ldots + Wjp\ Xp$$

Where:

Wi's = factor score coefficients and

P = number of variables

It is quite possible that all the variables might contribute to the factor Fj, but then by convention it seems that only a few subsets of variables characterize Fj, as indicated by their large coefficients.

**Steps involved in FA**

Factor analysis basically involves data reduction in the form of matrices involving the use of Eigenvalues and Eigenvectors. Thus, before discussing the steps involved in FA, it is essential to understand the concepts, which is outlined here.

The eigenvalue problem is a problem of considerable theoretical interest and wide-ranging application. For example, this problem is crucial in solving systems of differential equations, analyzing population growth models, and calculating powers of matrices (in order to define the exponential matrix). Other areas such as physics, sociology, biology, economics and statistics have focused considerable attention on "Eigenvalues" and "Eigenvectors" - their applications and their computations.

**By the Definition,** Let *A* be a square matrix. A non-zero vector *C* is called an **eigenvector** of *A* if and only if there exists a number (real or complex) λ such that::

$$AC=\lambda C$$

If such a number λ exists, it is called an **eigenvalue** of *A*. The vector *C* is called eigenvector associated to the eigenvalue λ. The eigenvector *C* must be non-zero since we have:

$$AO=O=\lambda O$$

For any number λ.

**Correlation Coefficient**

The matrix of either the correlations or covariances, called the **dispersion matrix**, can be obtained from the original or transformed data matrices. The choice of dispersion function depends on the nature of the variables being measured. Another use of the correlation coefficient is that it can be interpreted in a statistical sense to test the null hypothesis as to whether a linear relationship exists between the pairs of variables being tested. It is important to note that the existence of a correlation coefficient that is different from zero does not prove that a cause and effect relationship exists.

Also, it is important to note that the use of probabilities to determine if correlation coefficients are significant is very questionable for environmental data.

In the development of those probability relationships, explicit assumptions are made that the underlying distributions of the variables in the correlation analysis are normal. For most environmental variables, normal distributions are uncommon. Generally, the distributions are positively skewed and heavily tailed. Thus great care should be taken in making probability arguments regarding the significance of pair wise correlation -coefficients between variables measured in environmental samples.

It is then very important to examine the correlation matrix since the major aim of factor analysis is to help explain the correlations, the factor model must be related to each other for the model to be appropriate. If correlations between variables are small it is unlikely that they share common factors. Thus, certain tests are performed to evaluate the correlation matrix such as follows:

**Factor Extraction by Principal Component Analysis**

This section outlines the factor extraction based on principal component analysis, which is most commonly used. Several different methods are used to obtain estimates of the factors which include Maximum likelihood algorithm, Principal axis factoring etc. The first principal component is the linear combination that accounts for the largest amount of variance in the sample. The second principal component accounts for the next largest amount of variance and is uncorrelated with the first. For example, consider the simplest case and try to understand principal component analysis when only two variables are present.

Let x1 =10.530 x2 = 11.133 and

s1 = 1.132 s2 – 0.636

r12 = -0.6809

Where: x1 and x2 are the means of two variable and s1 and s2 are the standard deviations

We define a simple measure of simultaneous variability of all variables involved i.e., the sum of the variances, called the total variance.

s2 total =s (X1) + s2 (X2) = 1.1322 + 0.6362 =1.686

Variable X1 has a proportion of 76.1% of the total variance. For the principal components F1 and F2 one obtains the same sum of variances, that is

s2 (F1) + s2 (F2) =s (X1) + s (X2) =s2 total'

F1 has a proportion of 89% of the total variance. This proportion depends crucially on the correlation between the variables under analysis, and approaches 100% if the, correlation lies near 1 in absolute value. As a general rule we say that the first principal component reproduces the data well if its proportion of the total variance is sufficiently large, e.g. larger than 80% or 90%.

Another important information about this type of analysis is that if there is perfect correlation (one) between the variables, the first principal component will account for 100% of the total variance and determining the second principal component becomes unnecessary in this case. On the other hand if the correlation is absent (zero), it results in the original variables being the principal component.

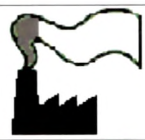
### Number of Retained Factors

It is important to examine the percentage of total variance explained by each in order to decide how many factors are needed to represent the data. For simplicity in most of the cases all variables and factors are expressed in standardized form i.e. with a mean of 0 and a standard deviation of 1. Percentage of total variance and cumulative percentage attributable to each factor is calculated.

Several procedures have been proposed for determining the number of factors to use in a model. One criterion suggests that only factors that account for variances greater than 1 (eigenvalue greater than 1) should be included.

### 1.2.4 Application On Shaft Diagrams:

Shaft diagrams are described as a mode of representing the ensemble data for huge period of time which otherwise may be very difficult to represent in a single diagram. Characteristic legends are used for the purpose and each of them in itself represents the character through visual anomalies. As per the study purpose these diagrams are presented as follows:

| SYMBOL | REPRESENT | SYMBOL | REPRESENT |
|---|---|---|---|
|  | Wind direction is Calm. |  | Maximum temperature in $^{o}C$. Eg.: Here temperature is 25 $^{o}C$. |
|  | Wind is blowing from South. |  | Minimum temperature in $^{o}C$. Eg.: Here temperature is 10 $^{o}C$. |
|  | Wind is blowing from North. |  | Rainfall in mm. Eg.: Here rainfall is 100 mm. |
|  | Wind is blowing from East. |  | Cloud cover in oktas. Eg.: Here cloud cover is 1 oktas. |
|  | Wind is blowing from West. |  | Height of lowest layer. Eg. Here the height of lowest layer is 6. |
|  | Wind direction and speed. Eg. Here wind is blowing from north at the speed of 2 m/s. |  | $SO_2$ concentration in $mg/m^3$. Eg. Here the $SO_2$ concentration is 10 $mg/m^3$. |
|  | Vapor pressure in hpa. Eg.: Here it is 1 Hpa. |  | $NO_2$ concentration in $mg/m^3$. Eg. Here the $NO_2$ concentration is 10 $mg/m^3$. |
|  | Relative humidity in %. Eg.: Here it is 75 %. |  | RSPM concentration in $mg/m^3$. Eg.: Here RSPM concentration is 50 $mg/m^3$. |

### 1.2.5 Application On Windrose:

A wind rose is defined as "An illustrative way of presenting the wind data used by meteorologists to give a glimpse of how wind speed and direction are typically distributed at a particular site. It is drawn by polar coordinate system of gridding, where the frequency of winds over a time period are plotted by wind direction, with designated color bands showing wind speed ranges. The direction of the rose with the longest spoke depicts the wind direction with the greatest frequency in that particular direction".

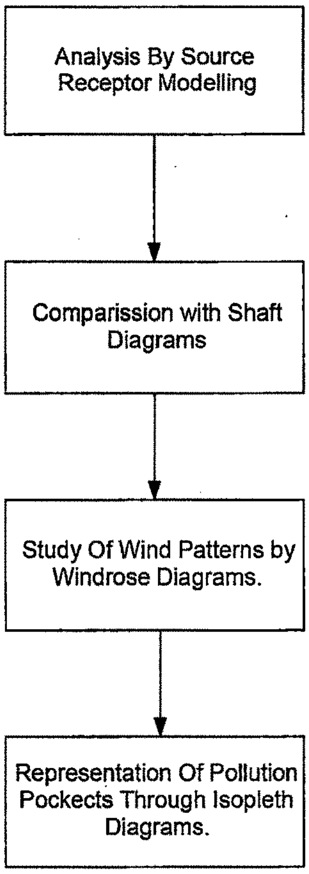
Comparisons of the trajectory analysis and the regime analysis with the data from the wind rose evaluations can be used to find significant microscale or synoptic scale meteorological anomalies that lead to some identifiable exceedances.

### 1.2.6 Application On ISCST3 Models to give Isopleth:

ISCST3 (Industrial Source Complex Short Term) is a steady-state Gaussian plume model which is used to assess pollutant concentrations. The regulatory default model option in ISCST3 can be selected for urban-wide applications (U.S. EPA, 1995b). The ISCST3 model computes with hourly concentration for each receptor (U.S. EPA, 1995b). The averaging period selected is based on the intended use. Annual average air concentrations are generally needed for use in chronic (long-term) exposure studies. Shorter term ambient concentrations are usually needed for determining acute exposure. It requires the coordinates of the specified receptors, for which locations should be selected based on a case-to-case determination.

The word isopleth (meaning 'quantity') is used for contour lines that depict a variable which cannot be measured at a point, but which instead must be calculated from data collected over an area.

To summarize the sequential statistical analysis and depiction for the present study, the results so obtained with the SPSS software were compared with the shaft diagrams, wind roses and isopleths which helps in understanding the relative importance of meteorological variables and pollutant concentrations.



## 1.3 RESULTS & DISCUSSIONS:

The results for the study are made annually and seasonally in terms of total variance and the total number of components extracted in SPSS, **table 1.1** to **1.12, 1.23** to **1.26, 1.37** and **1.38**. These observations are represented in the form of shaft diagrams (**Fig. no. 1.6 to 1.8, 1.12, 1.26** and **1.39**). The observations were then extrapolated on the windrose diagrams (**Fig. no. 1.13, 1.27** and **1.40**) and isopleths derived from the ISCST3 modeling (**Fig. no. 1.15 to 1.23, 1.29 to 1.37, 1.42** to **1.50**) carried out to study the pockets for pollutants in the city and its dispersion rate.

**Results On SPSS:**

**Total variance:**

The **tables 1.1, 1.3, 1.5, 1.7, 1.9, 1.11, 1.23, 1.25** and **1.37** represents the eigenvalues, variance explained and cumulative variance explained for the factor solution. The first panel gives values based on initial eigenvalues. For the initial solution, there are as many components or factors as there are variables i.e 11 variables. The "total" column gives the amount of variance in the observed variables accounted for by each component or factor. The "% of Variance" column gives the percent of variance accounted for by each specific factor or component, relative to the total variance in all the variables. The "Cumulative %" column gives the percent of variance accounted for by all factors or components up to and including the current one. For instance the Cumulative % for the second factor is the sum of the % of Variance for the first and second factors. In a good factor analysis, there are a few factors that explain a lot of the variance and the rest of the factors explain relatively small amounts of variance. The Extraction Sums of Squared Loadings group gives information regarding the extracted factors or components. For principal components extraction, these values will be the same as those reported under Initial Eigenvalues. The factor rotation results in the "Rotation Sums of Squared Loadings" group. The variance accounted for by rotated factors or components are normally different from those reported for the extraction but the Cumulative % for the set of factors or components will always be the same.

**Extraction of components & component matrix:**

The total variance is explained by a number of factors that equals the number of variables, however, only a few factors are responsible for characterizing the maximum variance, which has to be extracted selectively from the total variance analysis or from the cumulative variance data. However, one of the most frequently used methods for extraction of factors is the **Scree Plot**, which shows the variation of Eigenvalue with the number of components, thereby making it easy for the extraction of the components defining maximum variance.

The component matrix reports the factor loadings for each variable on the unrotated components or factors. Each number represents the correlation between the item and the unrotated factor. These correlations are be used to formulate an interpretation of the factors or components. This is done by looking for a common thread among the variables that have large loadings for a particular factor or component. It is common to see many items with large loadings on several of the unrotated factors, which can make interpretation difficult. In these cases, it can be helpful to examine a rotated solution. The component matrix for each year is represented in **Tables 1.2 1.4, 1.6, 1.8, 1.10, 1.12, 1.24, 1.26** and **1.38** along with the Scree plots (**Fig. no. 1.3, 1.4, 1.5, 1.9 1.10, 1.11, 1.24, 1.25** and **1.38** adjacent to the tables showing the number of extractable variables to define the maximum variance.

### 1.3.1 Annual Observations:

**Table 1.1: Total Variance for 2005**

| | Initial Eigenvalues | | | Extraction Sums of Squared Loadings | | |
|---|---|---|---|---|---|---|
| Component | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % |
| 1 | 6.993 | 63.571 | 63.571 | 6.993 | 63.571 | 63.571 |
| 2 | 2.038 | 18.524 | 82.095 | 2.038 | 18.524 | 82.095 |
| 3 | .986 | 8.965 | 91.061 | | | |
| 4 | .388 | 3.526 | 94.586 | | | |
| 5 | .307 | 2.787 | 97.373 | | | |
| 6 | .110 | .997 | 98.371 | | | |
| 7 | .089 | .807 | 99.178 | | | |
| 8 | .063 | .572 | 99.749 | | | |
| 9 | .017 | .154 | 99.903 | | | |
| 10 | .011 | .096 | 100.000 | | | |
| 11 | .000 | .000 | 100.000 | | | |

**Table 1.2: Component Matrix For 2005**

| | Component | |
|---|---|---|
| | 1 | 2 |
| wndspd | .642 | .244 |
| MxT | .095 | **.963** |
| MnT | **.820** | **.545** |
| RF | **.905** | -.169 |
| RH | .788 | -.578 |
| VP | **.969** | -.095 |
| CC | **.859** | -.360 |
| LL | -.859 | .188 |
| $SO_2$ | -.725 | -.214 |
| $NO_X$ | -.781 | -.415 |
| RSPM | -.953 | .003 |

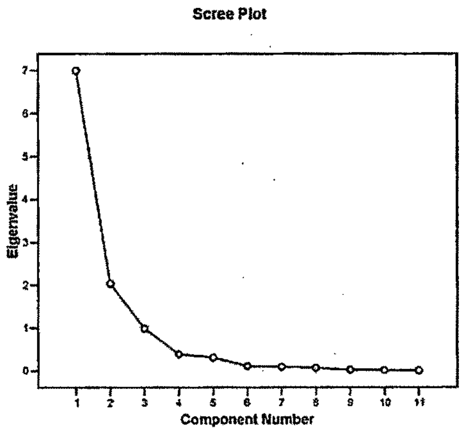



**Fig. no. 1.3: Scree Plot For 2005**

The **Table 1.1, 1.2** with scree plot (**Fig. no. 1.3**) shows 2 components are extracted showing 82% of the variations. In the matrix, the 1st factor shows higher relation between MnT, RF, VP and CC. whereas the 2nd factor shows correlation between minimum and MxT. None of the pollutants on the annual matrix showed correlation with any of the meteorological parameters.

**Table 1.3: Total Variance for 2006**

| | Initial Eigenvalues | | | Extraction Sums of Squared Loadings | | |
|---|---|---|---|---|---|---|
| Component | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % |
| 1 | 6.644 | 60.400 | 60.400 | 6.644 | 60.400 | 60.400 |
| 2 | 1.749 | 15.904 | 76.305 | 1.749 | 15.904 | 76.305 |
| 3 | 1.423 | 12.939 | 89.243 | 1.423 | 12.939 | 89.243 |
| 4 | .803 | 7.297 | 96.540 | | | |
| 5 | .185 | 1.686 | 98.226 | | | |
| 6 | .113 | 1.026 | 99.252 | | | |
| 7 | .042 | .384 | 99.636 | | | |
| 8 | .027 | .243 | 99.879 | | | |
| 9 | .012 | .105 | 99.984 | | | |
| 10 | .002 | .014 | 99.998 | | | |
| 11 | .000 | .002 | 100.000 | | | |

**Table 1.4: Component Matrix For 2006.**

| | Component | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| Wndspd | .723 | ***.836*** | -.037 |
| MxT | -.346 | ***.831*** | ***.413*** |
| MnT | .790 | .471 | ***.439*** |
| RF | .797 | -.298 | .013 |
| RH | ***.979*** | -.446 | .043 |
| VP | ***.951*** | .058 | .268 |
| CC | ***.977*** | -.152 | .043 |
| LL | -.965 | .048 | -.209 |
| $SO_2$ | -.530 | -.425 | .681 |
| $NO_X$ | -.588 | -.218 | .719 |
| RSPM | .744 | -.073 | .185 |

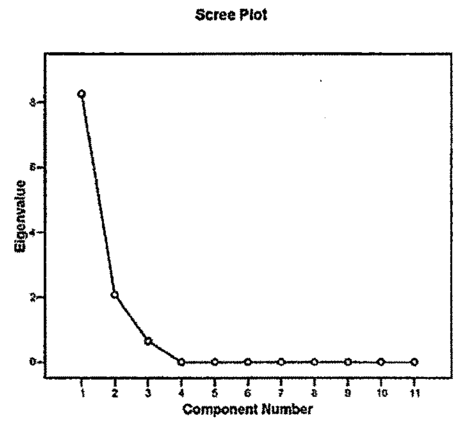



**Fig. no. 1.4: Scree Plot For 2006**

A total of three components showing 89.24% of variation was extracted. Total variance (**table 1.3**) and component matrix (**table 1.4**) shows 2 component extracted along with the scree plot (**Fig. no. 1.4**). In the matrix, the 1st factor shows higher relation between RH, CC and VP. 2nd component shows correlation between Wndspd and MxT whereas the 3rd component shows strong correlation between MxT and MnT only. A noticeable RSPM participation is exhibited in 2006 which was not seen in 2005.

**Table 1.5: Total Variance for 2007**

| Component | Initial Eigenvalues | | | Extraction Sums of Squared Loadings | | |
|---|---|---|---|---|---|---|
| | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % |
| 1 | 5.869 | 53.354 | 53.354 | 5.869 | 53.354 | 53.354 |
| 2 | 1.988 | 18.071 | 71.425 | 1.988 | 18.071 | 71.425 |
| 3 | 1.690 | 15.362 | 86.788 | 1.690 | 15.362 | 86.788 |
| 4 | .684 | 6.220 | 93.008 | | | |
| 5 | .359 | 3.268 | 96.275 | | | |
| 6 | .216 | 1.959 | 98.235 | | | |
| 7 | .130 | 1.178 | 99.412 | | | |
| 8 | .054 | .487 | 99.900 | | | |
| 9 | .010 | .087 | 99.986 | | | |
| 10 | .002 | .014 | 100.000 | | | |
| 11 | .000 | .000 | 100.000 | | | |

**Table 1.6: Component Matrix For 2007.**

| | Component | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| Wndspd | .582 | .567 | .303 |
| MxT | -.183 | **.625** | .116 |
| MnT | .735 | **.611** | .015 |
| RF | **.882** | -.240 | .206 |
| RH | **.882** | -.432 | .133 |
| VP | **.853** | .151 | .199 |
| CC | **.847** | -.217 | .159 |
| LL | -.977 | .101 | -.141 |
| $SO_2$ | -.526 | -.078 | **.895** |
| $NO_X$ | -.415 | .085 | **.803** |
| RSPM | -.436 | -.316 | .559 |

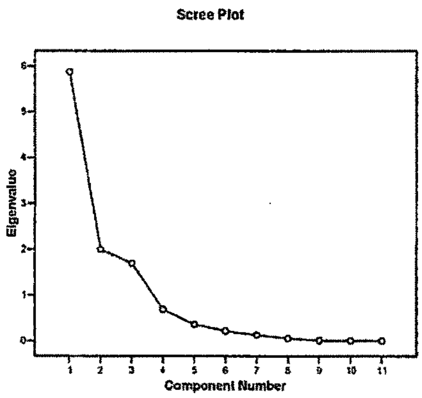



**Fig. no. 1.5: Scree Plot For 2007**

**Table 1.5** and **1.6** along with the scree plot (**Fig. no. 1.5**) shows 3 components are extracted to show 87% of the variations. In the matrix, the 1st factor shows higher relation between RF, RH, VP and CC. 2nd factor shows correlation between MxT and MnT only. Whereas 3rd factor shows the correlation between $SO_2$ and $NO_X$ only. As compared to the 2005 and 2006 annual observations, $SO_2$ and $NO_X$ shows interdependence among each other only and not with any of the meteorological parameters.

## Shaft diagrams:

**Fig. no. 1.6:** Shaft diagram for 2005 showed no significant correlation of Meteorological Data with the Ambient Air Quality in the region.

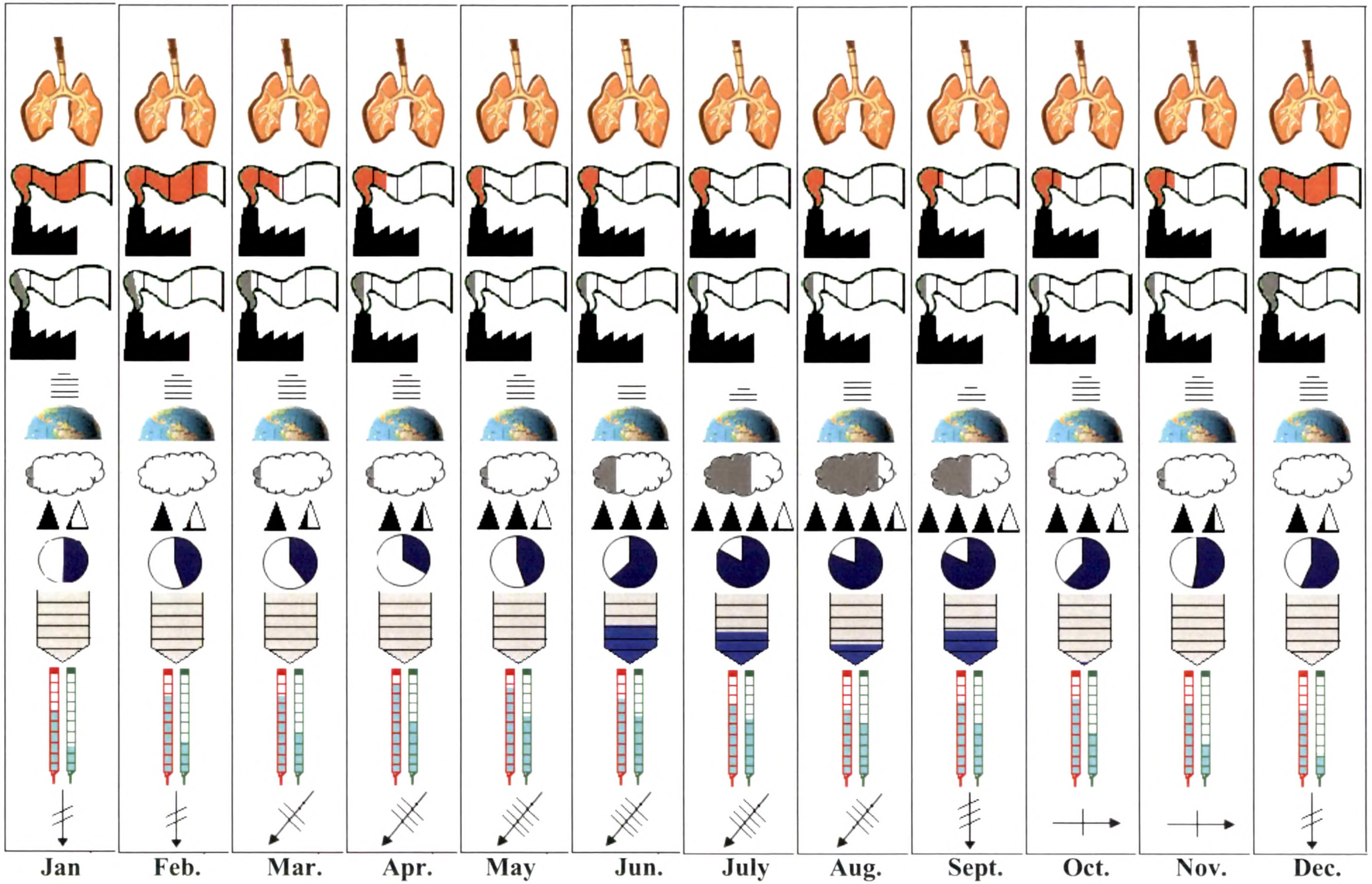


**Fig. 1.7:** Shaft diagram for 2006 showed significant correlation of Meteorological Data with the Ambient Air Quality in the region.

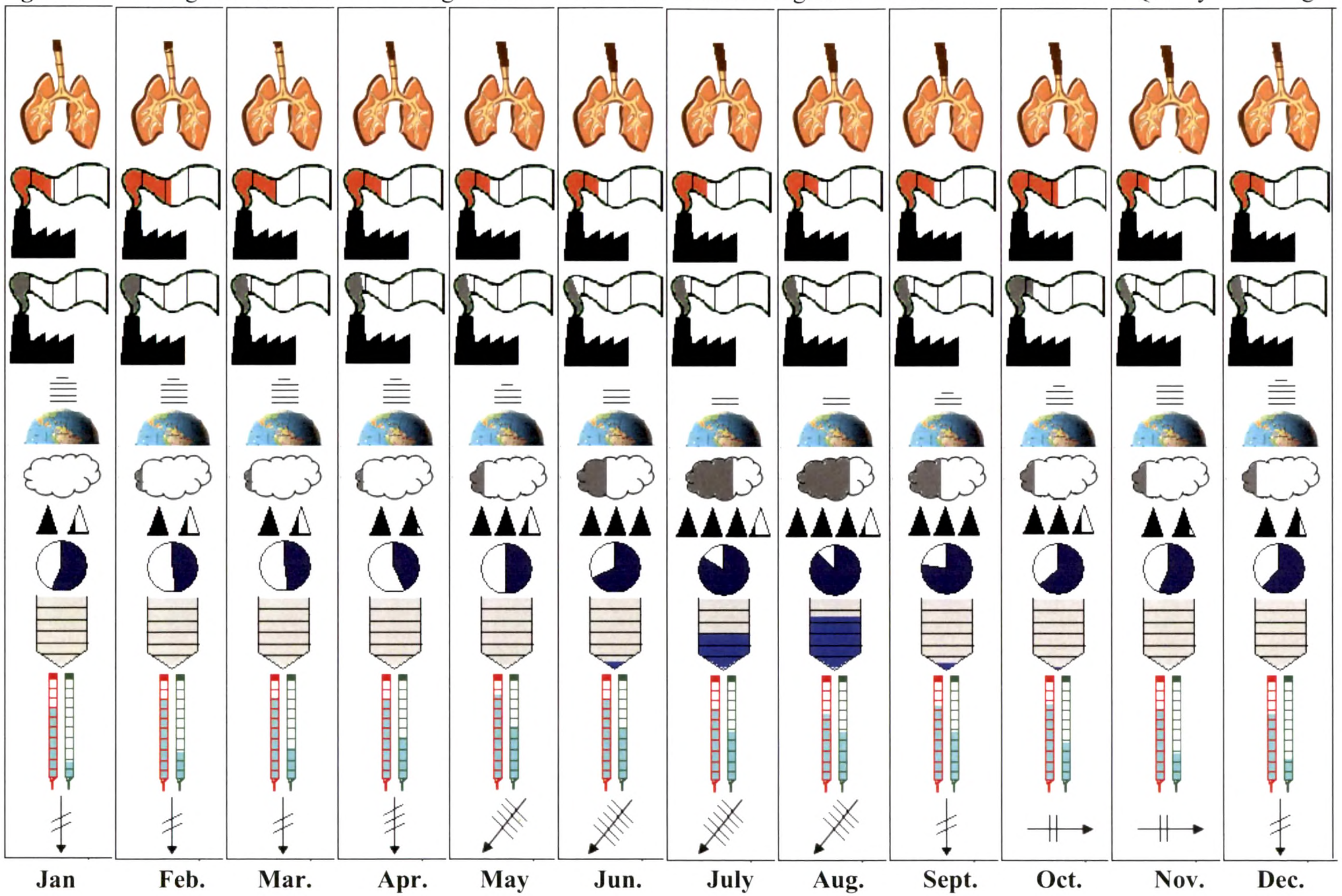
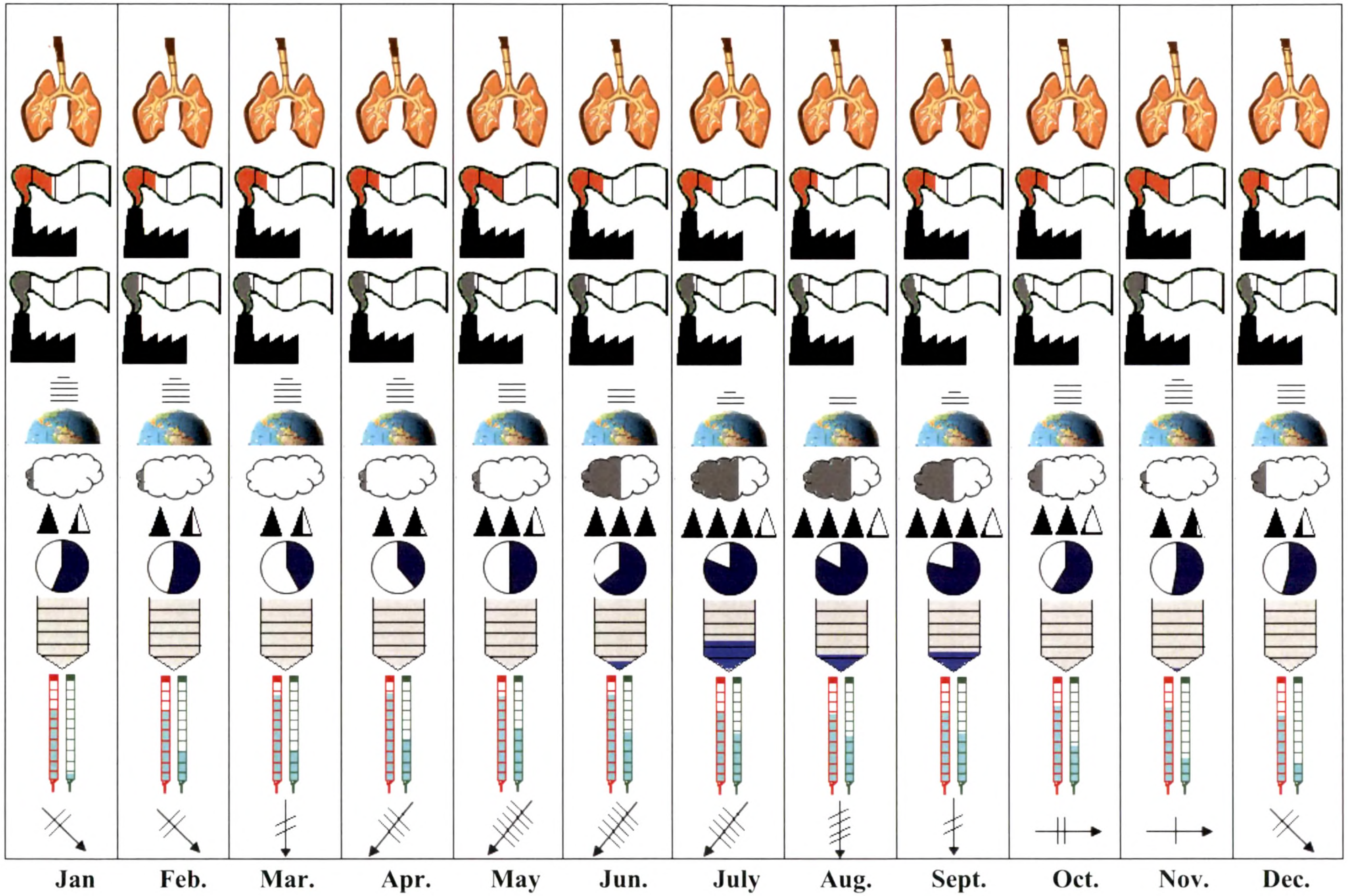


**Fig. 1.8:** Shaft diagram for 2007 showed no significant correlation of Meteorological Data with the Ambient Air Quality in the region



Hence, the annual SPSS analysis **(table 1.1** to **1.6)** established the fact that, of all the meteorological factors studied it was **RF, VP** and **CC** represented a good interdependence for all the three years (i.e. 2005 – 2007). **MnT** evoked its correlation with the common factors only in 2005 and 2006. However **RH** represented good correlation in 2006 and 2007. The presence of **MxT** in 2005 and **RH** in 2007 does not result in correlation with **RSPM**. However, the combination of these two factors (**MxT** and **RH**) in 2006 has possibly resulted into the participation of **RSPM**, which is well represented in shaft diagrams and showed an increasing trend from end of summer season to the initial phase of winter season. Seasonal observation were little deviating from the annual pattern (**Table no. 1.7** to **1.12, 1.23** to **1.26** and **1.37** to **1.38**).

### 1.3.2 Summer Observations:

**Table 1.7: Total Variance for 2005 Summer**

| Component | Initial Eigenvalues | | | Extraction Sums of Squared Loadings | | |
|---|---|---|---|---|---|---|
| | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % |
| 1 | 8.266 | 75.142 | 75.142 | 8.266 | 75.142 | 75.142 |
| 2 | 2.087 | 18.972 | 94.114 | 2.087 | 18.972 | 94.114 |
| 3 | .647 | 5.886 | 100.000 | | | |
| 4 | .000 | .000 | 100.000 | | | |
| 5 | .000 | .000 | 100.000 | | | |
| 6 | .000 | .000 | 100.000 | | | |
| 7 | .000 | .000 | 100.000 | | | |
| 8 | .000 | .000 | 100.000 | | | |
| 9 | .000 | .000 | 100.000 | | | |
| 10 | .000 | .000 | 100.000 | | | |
| 11 | .000 | .000 | 100.000 | | | |

**Table 1.8: Component Matrix For 2005 Summer**

| | Component | |
|---|---|---|
| | 1 | 2 |
| wndspd | **.982** | -.140 |
| MxT | .266 | -.852 |
| MnT | **.860** | -.511 |
| RF | **.859** | **.442** |
| RH | **.911** | **.401** |
| VP | **.985** | .107 |
| CC | .799 | **.431** |
| LL | -.907 | -.395 |
| $SO_2$ | -.897 | **.442** |
| $NO_X$ | -.891 | **.419** |
| RSPM | -.946 | -.021 |

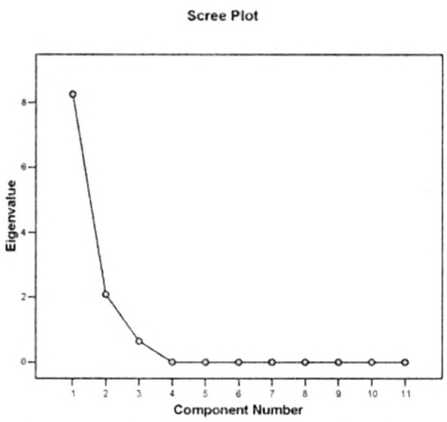



**Fig. no. 1.9: Scree Plot For 2005 Summer**

The **table 1.7** and **1.8** along with the scree plot (**Fig no. 1.9**) shows that 2 components were extracted illustrating 94% of the variations. In the matrix, the 1st factor shows higher relation between wndspd, MnT, RF, RH and VP. whereas the 2nd factor shows between RF, RH, CC, $SO_2$ and $NO_X$. In summer season the pollutants participated positively and showed a good correlation with the meteorological parameters.

**Table 1.9: Total Variance for 2006 Summer**

| | Initial Eigenvalues | | | Extraction Sums of Squared Loadings | | |
|---|---|---|---|---|---|---|
| Component | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % |
| 1 | 8.928 | 81.160 | 81.160 | 8.928 | 81.160 | 81.160 |
| 2 | 1.607 | 14.612 | 95.772 | 1.607 | 14.612 | 95.772 |
| 3 | .465 | 4.228 | 100.000 | | | |
| 4 | .000 | .000 | 100.000 | | | |
| 5 | .000 | .000 | 100.000 | | | |
| 6 | .000 | .000 | 100.000 | | | |
| 7 | .000 | .000 | 100.000 | | | |
| 8 | .000 | .000 | 100.000 | | | |
| 9 | .000 | .000 | 100.000 | | | |
| 10 | .000 | .000 | 100.000 | | | |
| 11 | .000 | .000 | 100.000 | | | |

**Table 1.10: Component Matrix For 2006 Summer.**

| | Component | |
|---|---|---|
| | 1 | 2 |
| wndspd | **.975** | .221 |
| MxT | -.497 | **.799** |
| MnT | **.840** | **.540** |
| RF | **.848** | -.529 |
| RH | **.941** | -.268 |
| VP | **.994** | .068 |
| CC | **.988** | -.053 |
| LL | -.941 | -.018 |
| $SO_2$ | -.980 | .194 |
| $NO_X$ | -.839 | -.404 |
| RSPM | **.952** | .260 |

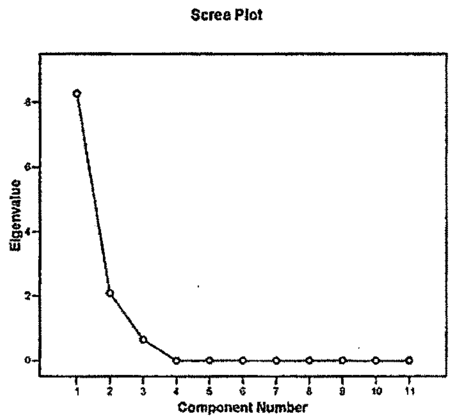



**Fig. no. 1.10: Scree Plot For 2006 Summer**

**Table 1.9** and **1.10** along with the scree plot (**Fig. no.1.10**) shows 2 components extracted demonstrating 96% of the variations. In the matrix, the 1st factor shows strong relation between wndspd, MnT, RF, RH, VP, CC and RSPM. On the other hand, 2nd factor shows correlation between MnT and MxT only. Unlike observed in 2005 summer extraction results, the RSPM was found to be participating rather than $SO_2$ and $NO_X$.

**Table 1.11: Total Variance for 2007 Summer**

| | Initial Eigenvalues | | | Extraction Sums of Squared Loadings | | |
|---|---|---|---|---|---|---|
| Component | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % |
| 1 | 6.442 | 58.560 | 58.560 | 6.442 | 58.560 | 58.560 |
| 2 | 2.868 | 26.075 | 84.635 | 2.868 | 26.075 | 84.635 |
| 3 | 1.690 | 15.365 | 100.000 | 1.690 | 15.365 | 100.000 |
| 4 | .000 | .000 | 100.000 | | | |
| 5 | .000 | .000 | 100.000 | | | |
| 6 | .000 | .000 | 100.000 | | | |
| 7 | .000 | .000 | 100.000 | | | |
| 8 | .000 | .000 | 100.000 | | | |
| 9 | .000 | .000 | 100.000 | | | |
| 10 | .000 | .000 | 100.000 | | | |
| 11 | .000 | .000 | 100.000 | | | |

**Table 1.12: Component Matrix For 2007 Summer.**

| | Component | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| Wndspd | **.900** | -.063 | .432 |
| MxT | -.529 | **.843** | .096 |
| MnT | .768 | -.056 | **.638** |
| RF | .774 | .559 | -.296 |
| RH | **.961** | .203 | -.186 |
| VP | **.966** | .188 | .176 |
| CC | **.874** | .453 | -.178 |
| LL | -.920 | -.348 | .181 |
| $SO_2$ | -.403 | **.667** | **.627** |
| $NO_X$ | .413 | -.720 | **.558** |
| RSPM | -.602 | **.687** | .407 |

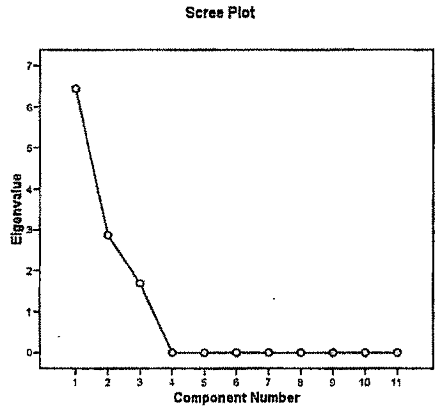



**Fig. no. 1.11: Scree Plot For 2007 Summer**

**Table 1.11** and **1.12** along with the scree plot (**Fig. no. 1.11**) shows 3 components are extracted to represent 100% of the variations. In the matrix, the 1st factor exhibited higher relation between wndspd, RH, VP and CC. 2nd factor shows correlation between MxT, $SO_2$ and RSPM only. Whereas 3rd factor shows good correlation between MnT, $SO_2$ and $NO_X$ only. As compared to the 2005 and 2006 summer observations, all three pollutant parameters are showing their interdependence with one or the other group of meteorological parameters.

**Fig. no. 1.12: Shaft diagram comparing the Summer data for 3 years:**

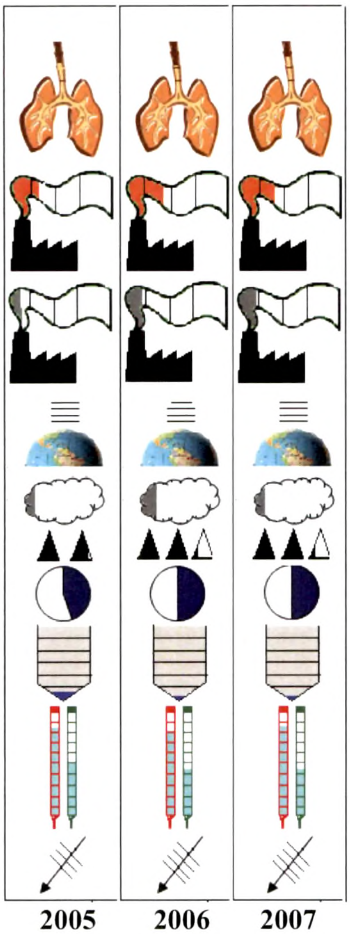


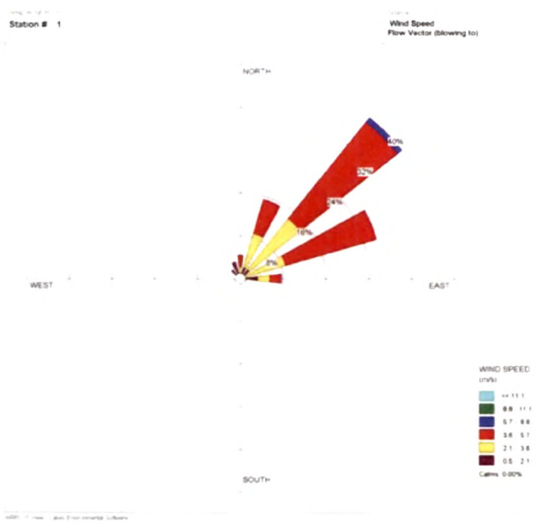

**Table 1.13: Average values for Summer from 2005 – 2007**

| Year | Wndspd | MxT | MnT | RF | RH | VP | CC | LL | $SO_2$ | $NO_X$ | RSPM |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **2005** | 3.3 | 42.3 | 25.4 | 154.9 | 45.3 | 19.8 | 1.4 | 8.1 | 5.6 | 13.2 | 73.5 |
| **2006** | 3.5 | 41.1 | 21.9 | 28.0 | 50.1 | 21.5 | 2.1 | 7.5 | 8.2 | 17.3 | 84.4 |
| **2007** | 3.8 | 42.9 | 21.9 | 29.7 | 48.8 | 21.7 | 1.7 | 7.8 | 8.8 | 16.5 | 57.0 |

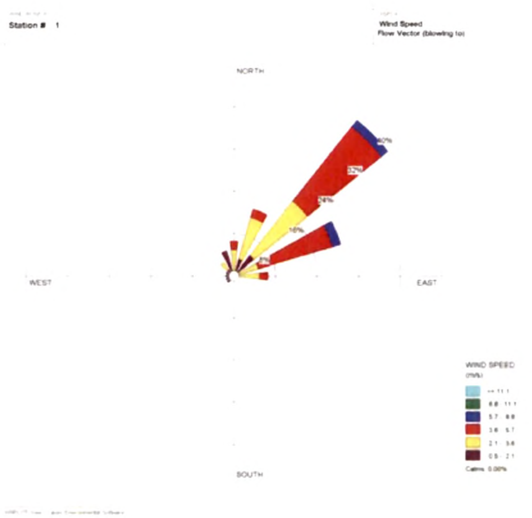
As seen in the **fig 1.12**, 2006 shows a higher cloud cover as compared to 2005 and 2007. As a result of this the pollutant concentration is also observed to be higher as compared to the observations of 2005 and 2007.

## Wind Rose Diagrams:

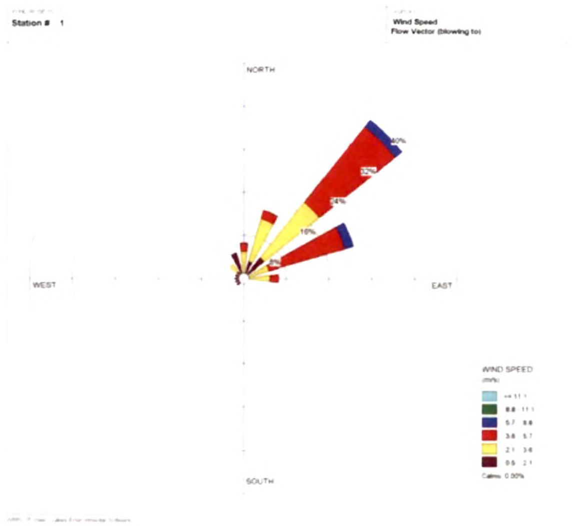
**Fig. no. 1.13: Representing Wind Rose Pattern For Summer Season (2005 – 2007).**




**a.) 2005**



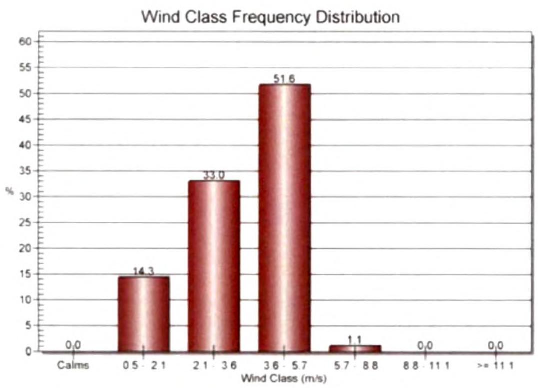

**b.) 2006**



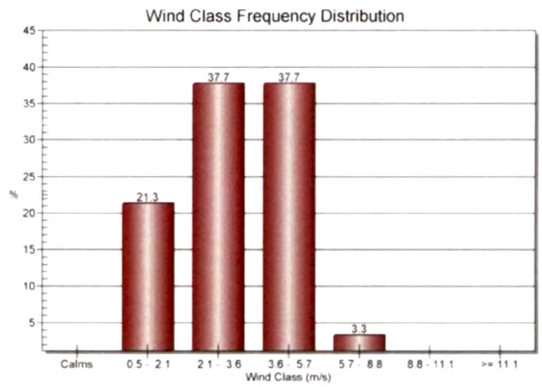

**c.) 2007**

The wind was predominantly blowing towards the North-East direction in all the three years. (**Fig. no. 1.13**).

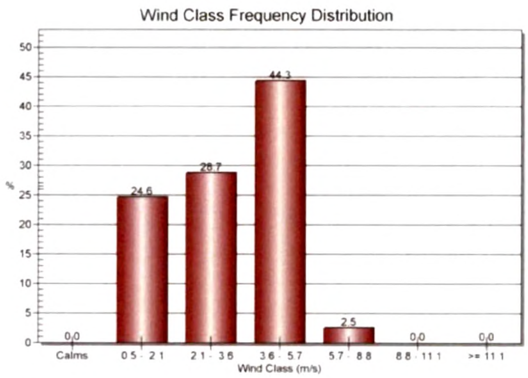
**Fig. 1.14: Wind Class Frequency Distribution For Summer 2005 – 2007.**




**a.)  2005**




**b.)  2006**




**c.)  2007**

The maximum wind speed was ranging from 3.6 – 5.7 m/s in 2005 and 2007 whereas it was 2.1 – 5.7 m/s in 2006.

## Isopleths:

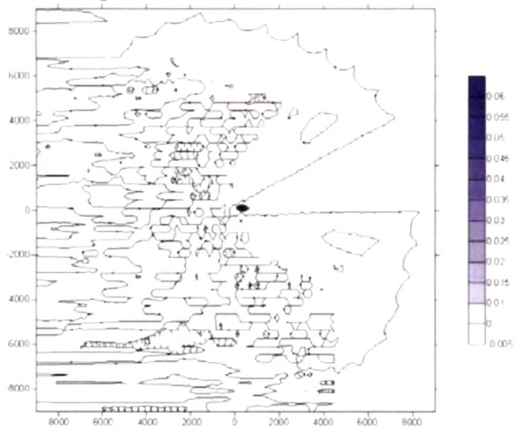


Fig. 1.15: Isolpleth For $SO_2$ Concentration In Summer 2005

| Table: 1.14 Highest GLC of $SO_2$ in 2005 Summer | | | |
|---|---|---|---|
| Highest Values | $SO_2$ – 2005 Concentration | X Co-ord (mts) | Y Co-ord (mts) |
| 1 | 0.02477 | 216.51 | 125 |
| 2 | 0.02252 | 0 | -250 |
| 3 | 0.02017 | 191.51 | 160.7 |
| 4 | 0.01704 | 160.7 | 191.51 |
| 5 | 0.01484 | 234.92 | 85.51 |
| 6 | 0.0139 | 125 | 216.51 |
| 7 | 0.01217 | 0 | -500 |
| 8 | 0.00786 | -43.41 | -246.2 |
| 9 | 0.00777 | 246.2 | 43.41 |
| 10 | 0.00736 | 433.01 | 250 |

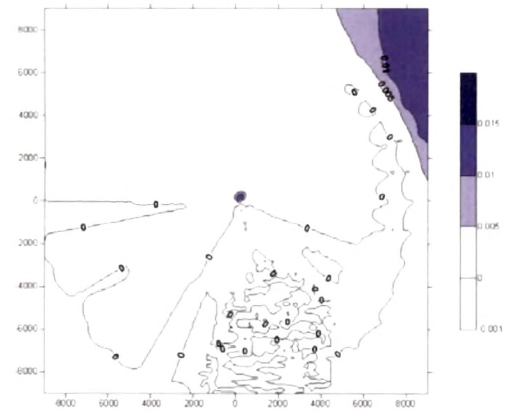


Fig. 1.16: Isolpleth For $SO_2$ Concentration In Summer 2006

| Table: 1.15 Highest GLC of $SO_2$ in 2006 Summer | | | |
|---|---|---|---|
| Highest Values | $SO_2$ – 2006 Concentration | X Co-ord (mts) | Y Co-ord (mts) |
| 1 | 0.02476 | 191.51 | 160.7 |
| 2 | 0.02273 | 216.51 | 125 |
| 3 | 0.02154 | 160.7 | 191.51 |
| 4 | 0.01644 | 125 | 216.51 |
| 5 | 0.01444 | 234.92 | 85.51 |
| 6 | 0.01059 | 7.79 | 4.5 |
| 7 | 0.01049 | 85.51 | 234.92 |
| 8 | 0.00986 | 8.46 | 3.08 |
| 9 | 0.00913 | 6.89 | 5.79 |
| 10 | 0.00846 | 246.2 | 43.41 |

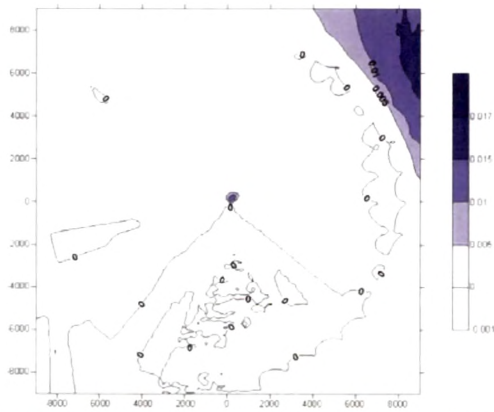
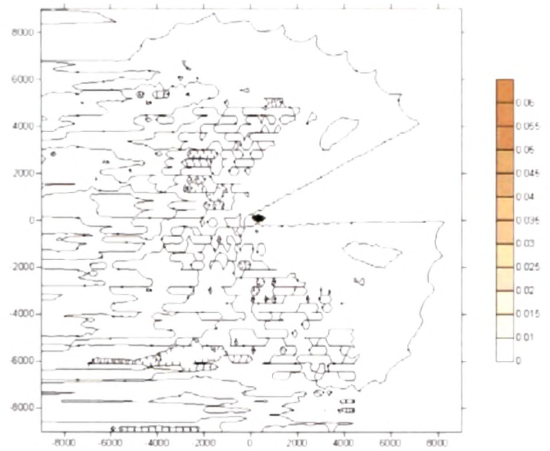


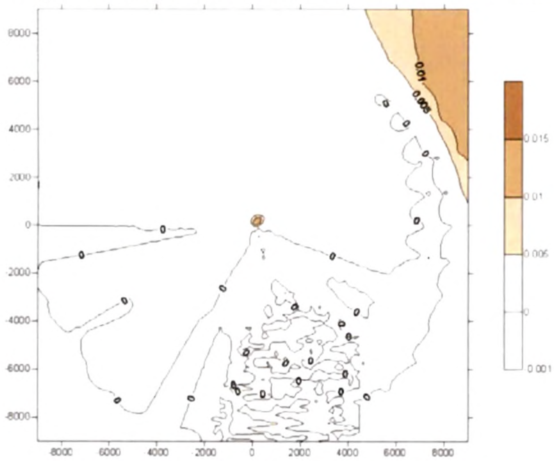
Fig. 1.17: Isolpleth For $SO_2$ Concentration In Summer 2007

| Table: 1.16 Highest GLC of $SO_2$ in 2007 Summer | | | |
|---|---|---|---|
| Highest Values | $SO_2$ – 2007 Concentration | X Co-ord (mts) | Y Co-ord (mts) |
| 1 | 0.02846 | 216.51 | 125 |
| 2 | 0.02669 | 191.51 | 160.7 |
| 3 | 0.01618 | 160.7 | 191.51 |
| 4 | 0.01383 | 234.92 | 85.51 |
| 5 | 0.01125 | 7.79 | 4.5 |
| 6 | 0.01076 | 125 | 216.51 |
| 7 | 0.01025 | 6.89 | 5.79 |
| 8 | 0.01009 | 85.51 | 234.92 |
| 9 | 0.00991 | 8.46 | 3.08 |
| 10 | 0.00906 | 43.41 | 246.2 |



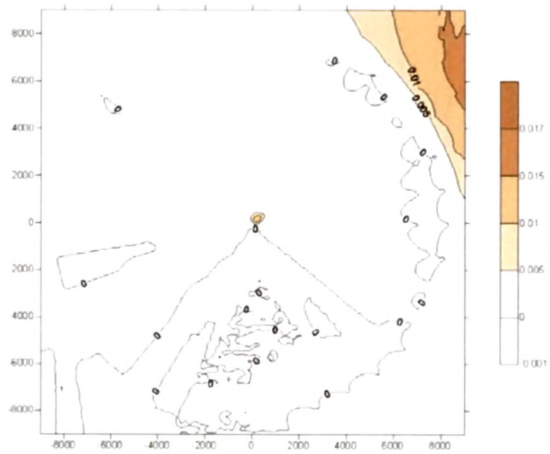
| Table: 1.17 Highest GLC of $NO_X$ in 2005 Summer | | | |
|---|---|---|---|
| Highest Values | $NO_X$ – 2005 Concentration | X Co-ord (mts) | Y Co-ord (mts) |
| 1 | 0.02477 | 216.51 | 125 |
| 2 | 0.02252 | 0 | -250 |
| 3 | 0.02017 | 191.51 | 160.7 |
| 4 | 0.01704 | 160.7 | 191.51 |
| 5 | 0.01484 | 234.92 | 85.51 |
| 6 | 0.0139 | 125 | 216.51 |
| 7 | 0.01217 | 0 | -500 |
| 8 | 0.00786 | -43.41 | -246.2 |
| 9 | 0.00777 | 246.2 | 43.41 |
| 10 | 0.00736 | 433.01 | 250 |

**Fig. 1.18: Isolpleth For $NO_X$ Concentration In Summer 2005**



| Table: 1.18 Highest GLC of $NO_X$ in 2006 Summer | | | |
|---|---|---|---|
| Highest Values | $NO_X$ – 2006 Concentration | X Co-ord (mts) | Y Co-ord (mts) |
| 1 | 0.02476 | 191.51 | 160.7 |
| 2 | 0.02273 | 216.51 | 125 |
| 3 | 0.02154 | 160.7 | 191.51 |
| 4 | 0.01644 | 125 | 216.51 |
| 5 | 0.01444 | 234.92 | 85.51 |
| 6 | 0.01059 | 7.79 | 4.5 |
| 7 | 0.01049 | 85.51 | 234.92 |
| 8 | 0.00986 | 8.46 | 3.08 |
| 9 | 0.00913 | 6.89 | 5.79 |
| 10 | 0.00846 | 246.2 | 43.41 |

**Fig. 1.19: Isolpleth For $NO_X$ Concentration In Summer 2006**



| Table: 1.19 Highest GLC of $NO_X$ in 2007 Summer | | | |
|---|---|---|---|
| Highest Values | $NO_X$ – 2007 Concentration | X Co-ord (mts) | Y Co-ord (mts) |
| 1 | 0.02846 | 216.51 | 125 |
| 2 | 0.02669 | 191.51 | 160.7 |
| 3 | 0.01618 | 160.7 | 191.51 |
| 4 | 0.01383 | 234.92 | 85.51 |
| 5 | 0.01125 | 7.79 | 4.5 |
| 6 | 0.01076 | 125 | 216.51 |
| 7 | 0.01025 | 6.89 | 5.79 |
| 8 | 0.01009 | 85.51 | 234.92 |
| 9 | 0.00991 | 8.46 | 3.08 |
| 10 | 0.00906 | 43.41 | 246.2 |

**Fig. 1.20: Isolpleth For $NO_X$ Concentration In Summer 2007:**

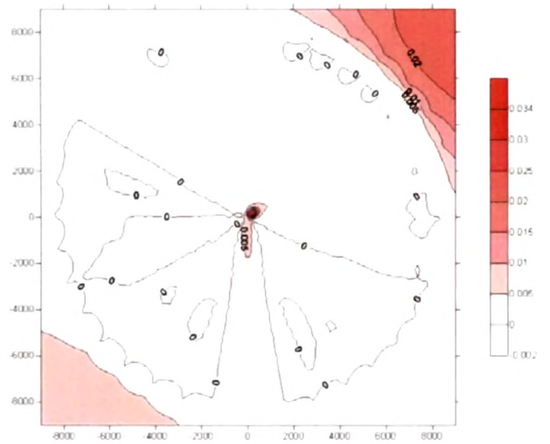


Fig. 1.21: Isolpleth For RSPM Concentration In Summer 2005

**Table: 1.20 Highest GLC of RSPM in 2005 Summer**

| Highest Values | RSPM – 2005 Concentration | X Co-ord (mts) | Y Co-ord (mts) |
|---|---|---|---|
| 1 | 0.06134 | 216.51 | 125 |
| 2 | 0.05573 | 0 | -250 |
| 3 | 0.05097 | 191.51 | 160.7 |
| 4 | 0.04288 | 160.7 | 191.51 |
| 5 | 0.03631 | 234.92 | 85.51 |
| 6 | 0.03517 | 125 | 216.51 |
| 7 | 0.03029 | 0 | -500 |
| 8 | 0.02029 | -43.41 | -246.2 |
| 9 | 0.0189 | 246.2 | 43.41 |
| 10 | 0.0183 | 433.01 | 250 |

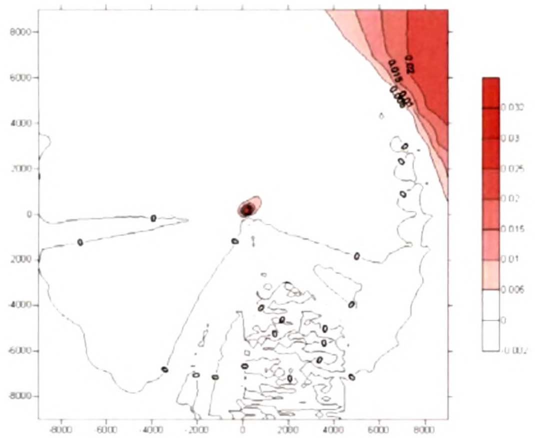


Fig. 1.22: Isolpleth For RSPM Concentration In Summer 2006

**Table: 1.21 Highest GLC of RSPM in 2006 Summer**

| Highest Values | RSPM – 2006 Concentration | X Co-ord (mts) | Y Co-ord (mts) |
|---|---|---|---|
| 1 | 0.05725 | 191.51 | 160.7 |
| 2 | 0.05229 | 216.51 | 125 |
| 3 | 0.05096 | 160.7 | 191.51 |
| 4 | 0.0393 | 125 | 216.51 |
| 5 | 0.03279 | 234.92 | 85.51 |
| 6 | 0.02521 | 85.51 | 234.92 |
| 7 | 0.01907 | 246.2 | 43.41 |
| 8 | 0.01793 | 7.79 | 4.5 |
| 9 | 0.01686 | 383.02 | 321.39 |
| 10 | 0.01673 | 6.89 | 5.79 |

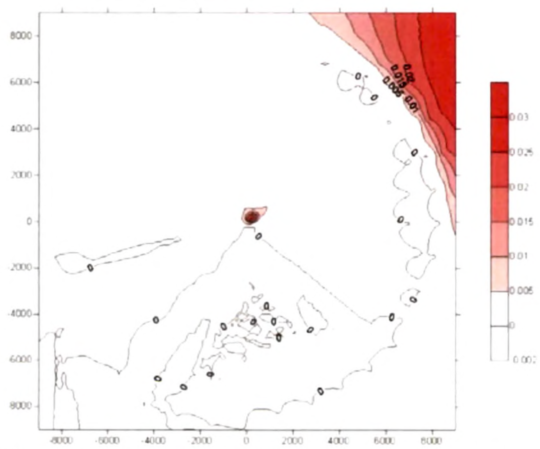


Fig. 1.23: Isolpleth For RSPM Concentration In Summer 2007

**Table: 1.22 Highest GLC of RSPM in 2007 Summer**

| Highest Values | RSPM – 2007 Concentration | X Co-ord (mts) | Y Co-ord (mts) |
|---|---|---|---|
| 1 | 0.05618 | 216.51 | 125 |
| 2 | 0.05362 | 191.51 | 160.7 |
| 3 | 0.03283 | 160.7 | 191.51 |
| 4 | 0.02704 | 234.92 | 85.51 |
| 5 | 0.02166 | 125 | 216.51 |
| 6 | 0.02058 | 7.79 | 4.5 |
| 7 | 0.02019 | 85.51 | 234.92 |
| 8 | 0.01897 | 8.46 | 3.08 |
| 9 | 0.01823 | 43.41 | 246.2 |
| 10 | 0.01815 | 6.89 | 5.79 |

**Summer:**

The meteorological factors **wndspd, RH, VP** and **CC** were found to be in common factors extracted for all the summer seasons of 2005 – 2007. As far as expression of the pollutants in combination with the meteorological factors are concerned there was a differential pattern. In 2005 and 2007, $SO_2$ and $NO_X$ showed a good correlation and in 2006 as well as 2007 **RSPM** showed an active participation. It is an established fact that $SO_2$ and $NO_X$ concentration are temperature dependent and thus the increased concentration is an obvious phenomenon to occur (Mickely *et al.*, 2004).

Haritash and Kaushik (2006) in their studies on seasonal assessment of **RSPM** in sub-urban area have reported that low Wndspd, low temperature and high relative humidity maintain low concentration of the pollutants. In the present study, being a pure urban area probably it differs with the work of Haritash and Kaushik (2006). However, Borchert (2004) in his studies have reported that cloud cover affects the surface temperature and thus responsible for directly handling the dispersion of the the pollutants. Thus the observations of the present studies in which **CC** and **VP** showed a direct correlation with the **RSPM** concentration.

These results were extrapolated on the wind rose and isopleths to give a better understanding of the pollution level in the city. When observed on the wind rose diagrams it was found that the wind was predominantly blowing towards the NE i.e. upto 40 % for the year 2005 and 2006 with the wind speed ranging ranging from 2.1 to 5.7 m/s. Whereas in 2007, the wind was found to be inclined more towards the north direction along with the north east direction. Wind circulation pattern is dependent on the geographical structure of the region. Wind speed plays a major role in dispersion and is an important governing factor for emitting the pollutant in a particular direction. The convection also causes air with low horizontal momentum to rise, and finally be replaced by air with greater momentum from the higher layers. That is the probable cause for winds in daytime being usually stronger than during night-time. A reduction in the surface wind speed would occur when the convective momentum gets reduced. The simulative study by Jacobson and Kaufman suggests that aerosol particles may reduce near-surface wind speeds by up to 8% locally (Jacobson and Kaufman, 2006).

The dispersion pattern of the pollutant can be very well represented with ISCST3 (**Fig. no. 1.15 to 1.23**). Hence in the present study to confirm the pollution pockets in the city modeling studies were carried out. For this study each of the pollutant was plotted separately. $SO_2$ and $NO_X$ concentration in 2005 (**Table no. 1.14** and **1.17**) represented an even dispersion pattern with concentration level ranging from 0.0247 $\mu g/m^3$ to 0.007 $\mu g/m^3$. Whereas in 2006 and 2007 it was found to be concentrating more towards the edge of NE direction and center point of the city (Railway station). The concentration level for 2006 (**Table no. 1.15** and **1.18**) and 2007 (**Table no. 1.16** and **1.19**) ranged from 0.0247 $\mu g/m^3$ to 0.008 $\mu g/m^3$ and 0.028 $\mu g/m^3$ to 0.009 $\mu g/m^3$.

Wind speed in 2005 was comparatively less then compared to 2006 and 2007 and hence the bi directional accumulation of the RSPM i.e. in SW as well in the NE regions of the study area is suggestive of the pollutant concentrated pockets of the city. The values were also a bit higher in 2005 (**Table no. 1.20**, 0.061 $\mu g/m^3$ to 0.0183 $\mu g/m^3$) and was comparatively less in the two consecutive years i. e. 0.057 $\mu g/m^3$ to 0.016 $\mu g/m^3$ in 2006 (**Table no. 1.21**) and 0.056 $\mu g/m^3$ to 0.018 $\mu g/m^3$ in 2007 (**Table no. 1.22**).

## 1.3.3 Monsoon Observations:

**Table 1.23: Total Variance for 2006 Monsoon**

| | Initial Eigenvalues | | | Extraction Sums of Squared Loadings | | |
|---|---|---|---|---|---|---|
| Component | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % |
| 1 | 9.307 | 84.612 | 84.612 | 9.307 | 84.612 | 84.612 |
| 2 | 1.098 | 9.978 | 94.591 | 1.098 | 9.978 | 94.591 |
| 3 | .595 | 5.409 | 100.000 | | | |
| 4 | .000 | .000 | 100.000 | | | |
| 5 | .000 | .000 | 100.000 | | | |
| 6 | .000 | .000 | 100.000 | | | |
| 7 | .000 | .000 | 100.000 | | | |
| 8 | .000 | .000 | 100.000 | | | |
| 9 | .000 | .000 | 100.000 | | | |
| 10 | .000 | .000 | 100.000 | | | |
| 11 | .000 | .000 | 100.000 | | | |

**Table 1.24: Component Matrix For 2006 – Monsoon.**

| | Component | |
|---|---|---|
| | 1 | 2 |
| Wndspd | **.908** | **.361** |
| MxT | -.830 | -.081 |
| MnT | **.914** | -.402 |
| RF | **.989** | **.372** |
| RH | **.993** | -.062 |
| VP | **.978** | -.202 |
| CC | **.997** | .071 |
| LL | -.998 | -.041 |
| $SO_2$ | -.903 | **.307** |
| $NO_X$ | -.943 | .296 |
| RSPM | -.729 | -.596 |

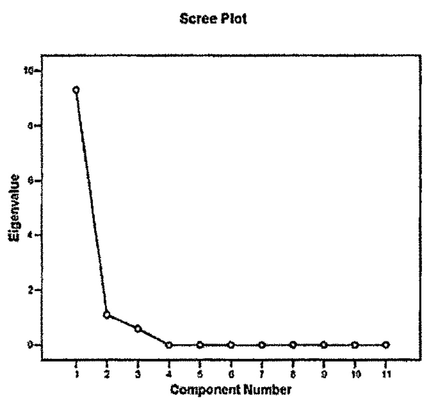



**Fig. no. 1.24: Scree Plot For 2006 Monsoon**

The **table 1.23** and **1.24** along with the scree plot (**Fig. no. 1.24**) shows 2 components were extracted having 95% of the variations. In the matrix, the 1st factor shows higher relation between wndspd, MnT, RF, RH, VP and CC. On the other hand, 2nd factor shows correlation between wndspd, RF and $SO_2$ only. Thus in 2006 monsoon, of the components extracted $SO_2$ was found to have interdependence with Wndspd and rainfall in the region.

**Table 1.25: Total Variance for 2007 Monsoon**

| | Initial Eigenvalues | | | Extraction Sums of Squared Loadings | | |
|---|---|---|---|---|---|---|
| Component | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % |
| 1 | 8.863 | 80.577 | 80.577 | 8.863 | 80.577 | 80.577 |
| 2 | 1.822 | 16.561 | 97.138 | 1.822 | 16.561 | 97.138 |
| 3 | .315 | 2.862 | 100.000 | | | |
| 4 | .000 | .000 | 100.000 | | | |
| 5 | .000 | .000 | 100.000 | | | |
| 6 | .000 | .000 | 100.000 | | | |
| 7 | .000 | .000 | 100.000 | | | |
| 8 | .000 | .000 | 100.000 | | | |
| 9 | .000 | .000 | 100.000 | | | |
| 10 | .000 | .000 | 100.000 | | | |
| 11 | .000 | .000 | 100.000 | | | |

**Table 1.26: Component Matrix For 2007 Monsoon.**

| | Component | |
|---|---|---|
| | 1 | 2 |
| Wndspd | **.892** | -.112 |
| MxT | -.838 | .328 |
| MnT | **.987** | -.062 |
| RF | **.960** | .277 |
| RH | **.965** | -.256 |
| VP | **.979** | -.182 |
| CC | **.967** | -.256 |
| LL | -.967 | .240 |
| $SO_2$ | .785 | **.820** |
| $NO_X$ | .501 | **.846** |
| RSPM | **.918** | .361 |

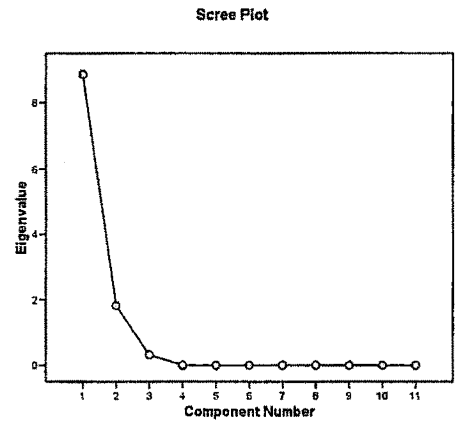



**Fig. no. 1.25: Scree Plot For 2007 Monsoon**

The **table 1.25** and **1.26** along with the scree plot (**Fig. no. 1.25**) shows 2 components extracted to illustrate 100% of the variations. In the matrix, the 1st factor shows higher relation between wndspd, MnT, RF, RH, VP, CC and RSPM. Whereas 2nd factor shows the correlation between $SO_2$ and $NO_X$ only. As compared to 2006 monsoon observations, RSPM was actively found correlating with the meteorological parameters whereas, $SO_2$ and $NO_X$ were found to be grouped among themselves only and not interdependent on the meteorological parameters.

**Fig. 1.26: Shaft diagram comparing the Monsoon data for 3 years:**

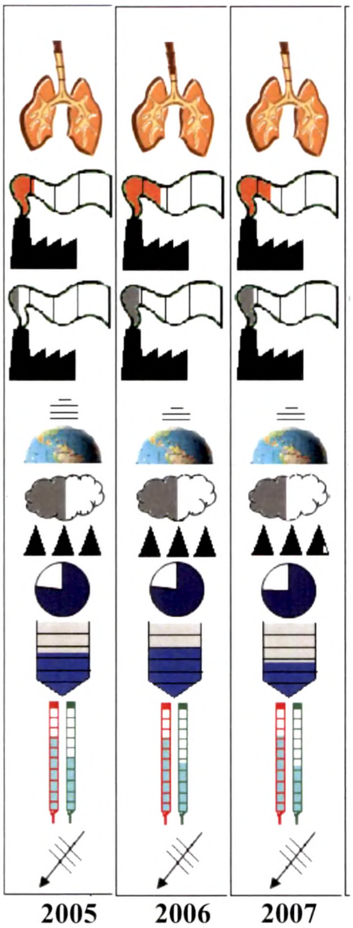
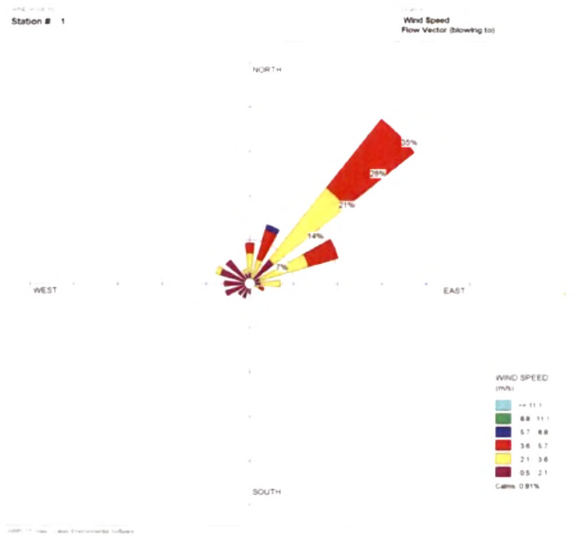



**Table 1.27: Average values for Monsoon from 2005 – 2007**

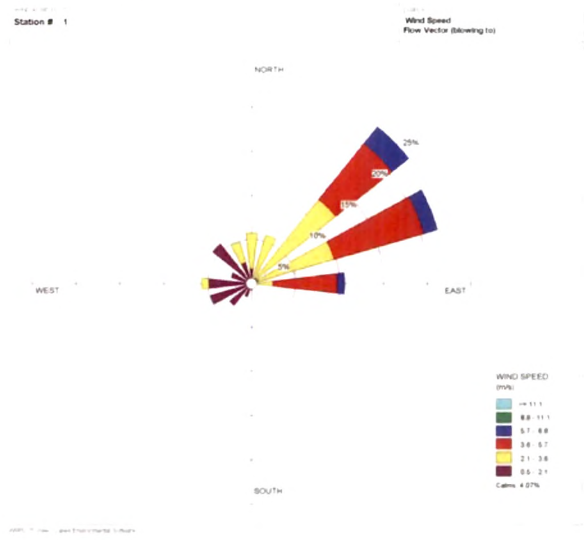
| Year | Wndspd | MxT | MnT | RF | RH | VP | CC | LL | $SO_2$ | $NO_X$ | RSPM |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **2005** | 2.8 | 35.9 | 24.5 | 340.9 | 76.9 | 29.9 | 5.1 | 6.5 | 4.0 | 11.4 | 46.2 |
| **2006** | 3.3 | 36.2 | 22.9 | 399.2 | 77.7 | 29.3 | 5.0 | 5.1 | 9.1 | 17.8 | 123.9 |
| **2007** | 3.0 | 35.4 | 22.4 | 272.9 | 75.4 | 28.7 | 4.8 | 5.5 | 8.2 | 15.1 | 51.0 |

As seen in the **fig 1.26**, 2006 shows a higher rainfall as compared to 2005 and 2007. As a result of this the pollutant concentration is also observed to be higher as compared to the observations of 2005 and 2007.

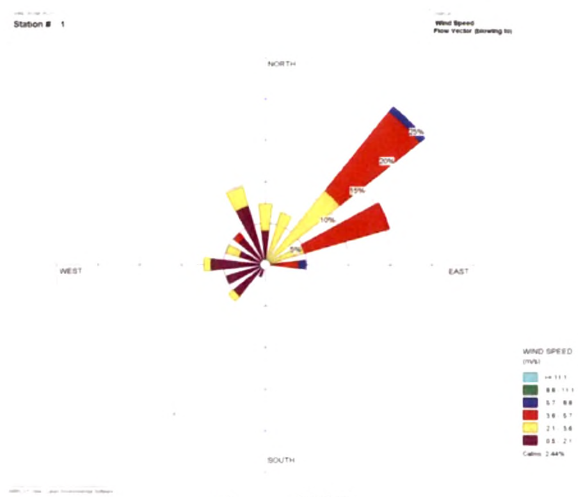
**Fig. 1.27: Representing Wind Rose For Monsoon Season (2005 – 2007):**




**a.) 2005**



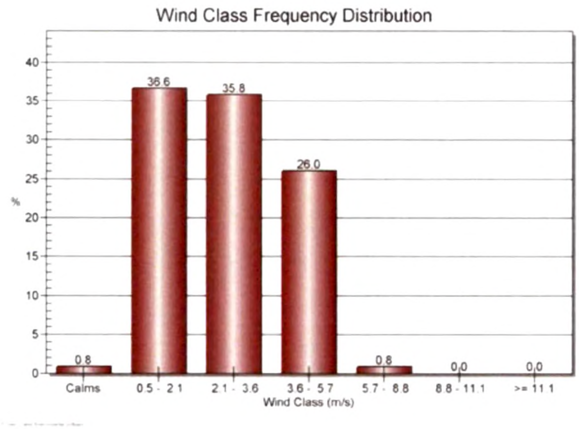

**b.) 2006**



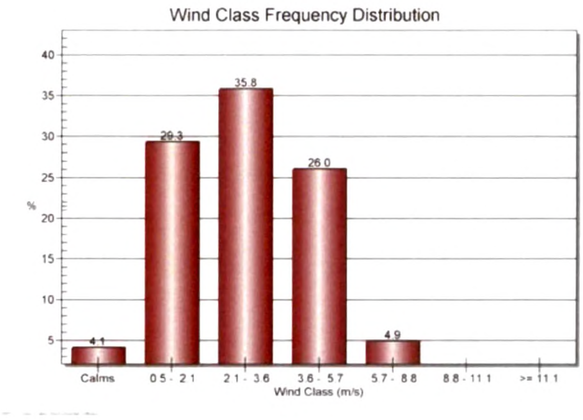

**c.) 2007**

The wind was predominantly blowing towards the North-East direction for the entire season (**Fig. no. 1.27**). In 2007, the wind was predominantly blowing towards the North-East direction as well as the East of North-East direction with high wind speed as compared to 2005. Also, the wind pattern has moved towards the West and North-West direction in 2007 as compared to minor blowing rate as found in 2005 and 2006 monsoon results.

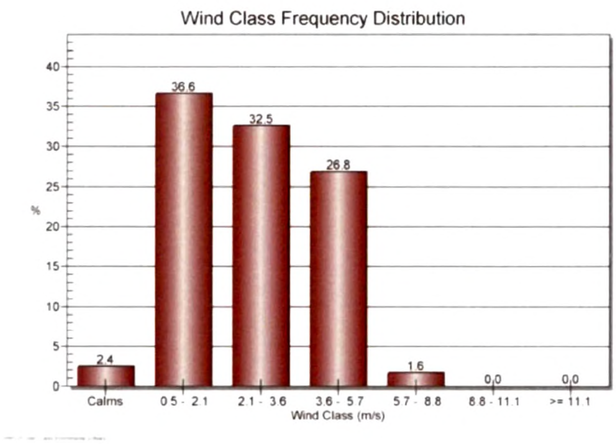
**Fig. 1.28: Wind Class Frequency Distribution For Monsoon Season (2005 – 2007).**




**a.) 2005**




**b.) 2006**




**c.) 2007**

The maximm wind speed was ranging between 0.5 to 2.1 m/s in 2005and 2007 whereas it was 2.1 to 3.6 m/s in 2006 (**Fig. no. 1.28**).

## Isopleths:

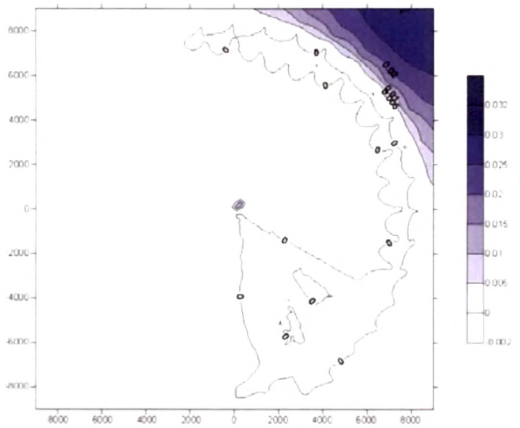


Fig. 1.29: Isolpleth For $SO_2$ Concentration In Monsoon 2005

**Table 1.28: Highest GLC of $SO_2$ in 2005 Monsoon**

| Highest Values | $SO_2$ – 2005 Concentration | X Co-ord (mts) | Y Co-ord (mts) |
|---|---|---|---|
| 1 | 0.02679 | 160.7 | 191.51 |
| 2 | 0.02395 | 191.51 | 160.7 |
| 3 | 0.02005 | 216.51 | 125 |
| 4 | 0.01756 | 5.79 | 6.89 |
| 5 | 0.01737 | 6.89 | 5.79 |
| 6 | 0.0162 | 4.5 | 7.79 |
| 7 | 0.01476 | 7.79 | 4.5 |
| 8 | 0.01455 | 125 | 216.51 |
| 9 | 0.01274 | 3.08 | 8.46 |
| 10 | 0.01136 | 234.92 | 85.51 |

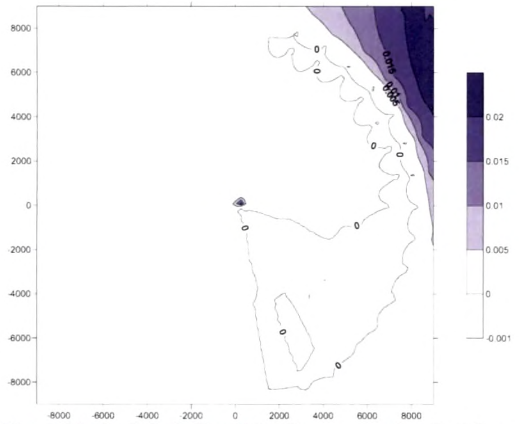


Fig. 1.30: Isolpleth For $SO_2$ Concentration In Monsoon 2006

**Table 1.29: Highest GLC of $SO_2$ in 2006 Monsoon**

| Highest Values | $SO_2$ – 2006 Concentration | X Co-ord (mts) | Y Co-ord (mts) |
|---|---|---|---|
| 1 | 0.01955 | 234.92 | 85.51 |
| 2 | 0.01705 | 216.51 | 125 |
| 3 | 0.01676 | 191.51 | 160.7 |
| 4 | 0.01651 | 246.2 | 43.41 |
| 5 | 0.01556 | 7.79 | 4.5 |
| 6 | 0.01523 | 8.46 | 3.08 |
| 7 | 0.01375 | 160.7 | 191.51 |
| 8 | 0.01323 | 6.89 | 5.79 |
| 9 | 0.01232 | 8.86 | 1.56 |
| 10 | 0.00972 | 5.79 | 6.89 |

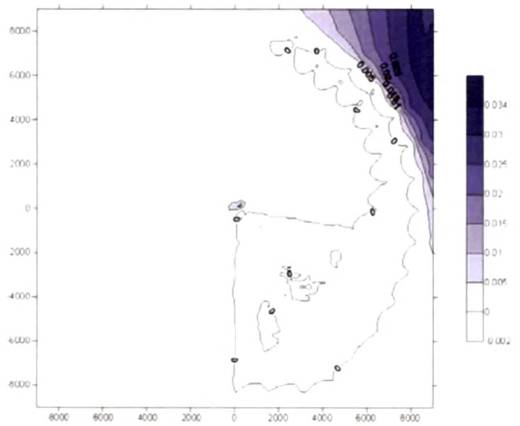
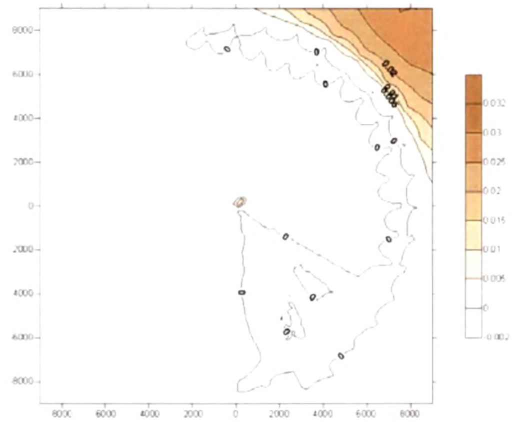


Fig. 1.31: Isolpleth For $SO_2$ Concentration In Monsoon 2007

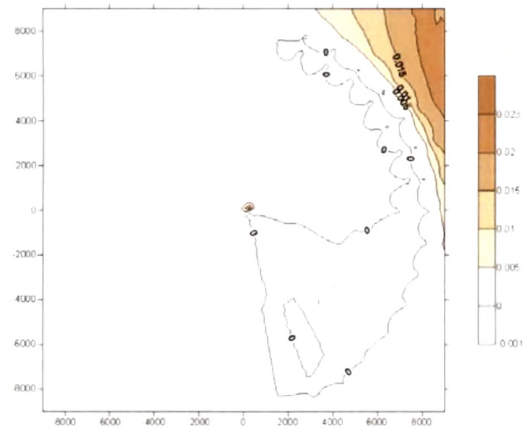
**Table 1.30: Highest GLC of $SO_2$ in 2007 Monsoon**

| Highest Values | $SO_2$ – 2007 Concentration | X Co-ord (mts) | Y Co-ord (mts) |
|---|---|---|---|
| 1 | 0.02317 | 7.79 | 4.5 |
| 2 | 0.02149 | 8.46 | 3.08 |
| 3 | 0.02137 | 191.51 | 160.7 |
| 4 | 0.0206 | 6.89 | 5.79 |
| 5 | 0.0193 | 216.51 | 125 |
| 6 | 0.01662 | 8.86 | 1.56 |
| 7 | 0.01447 | 5.79 | 6.89 |
| 8 | 0.01322 | 160.7 | 191.51 |
| 9 | 0.01136 | 234.92 | 85.51 |
| 10 | 0.0105 | 9 | 0 |



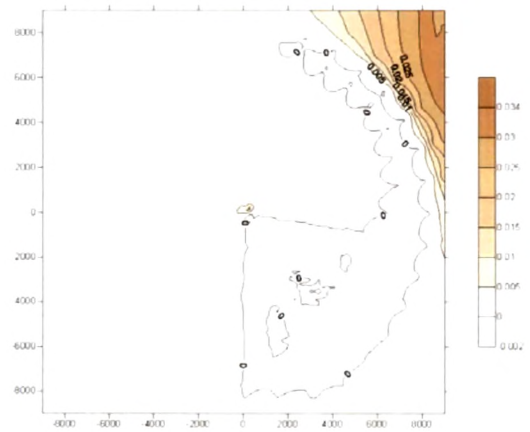
| Table 1.31: Highest GLC of $NO_X$ in 2005 Monsoon | | | |
|---|---|---|---|
| **Highest Values** | **$NO_X$ – 2005 Concentration** | **X Co-ord (mts)** | **Y Co-ord (mts)** |
| 1 | 0.02679 | 160.7 | 191.51 |
| 2 | 0.02395 | 191.51 | 160.7 |
| 3 | 0.02005 | 216.51 | 125 |
| 4 | 0.01756 | 5.79 | 6.89 |
| 5 | 0.01737 | 6.89 | 5.79 |
| 6 | 0.0162 | 4.5 | 7.79 |
| 7 | 0.01476 | 7.79 | 4.5 |
| 8 | 0.01455 | 125 | 216.51 |
| 9 | 0.01274 | 3.08 | 8.46 |
| 10 | 0.01136 | 234.92 | 85.51 |

**Fig. 1.32: Isolpleth For $NO_X$ Concentration In Monsoon 2005**



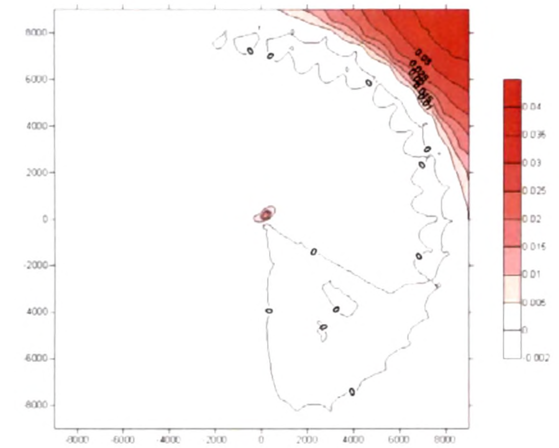
| Table 1.32: Highest GLC of $NO_X$ in 2006 Monsoon | | | |
|---|---|---|---|
| **Highest Values** | **$NO_X$ – 2006 Concentration** | **X Co-ord (mts)** | **Y Co-ord (mts)** |
| 1 | 0.01955 | 234.92 | 85.51 |
| 2 | 0.01705 | 216.51 | 125 |
| 3 | 0.01676 | 191.51 | 160.7 |
| 4 | 0.01651 | 246.2 | 43.41 |
| 5 | 0.01556 | 7.79 | 4.5 |
| 6 | 0.01523 | 8.46 | 3.08 |
| 7 | 0.01375 | 160.7 | 191.51 |
| 8 | 0.01323 | 6.89 | 5.79 |
| 9 | 0.01232 | 8.86 | 1.56 |
| 10 | 0.00972 | 5.79 | 6.89 |

**Fig. 1.33: Isolpleth For $NO_X$ Concentration In Monsoon 2006**



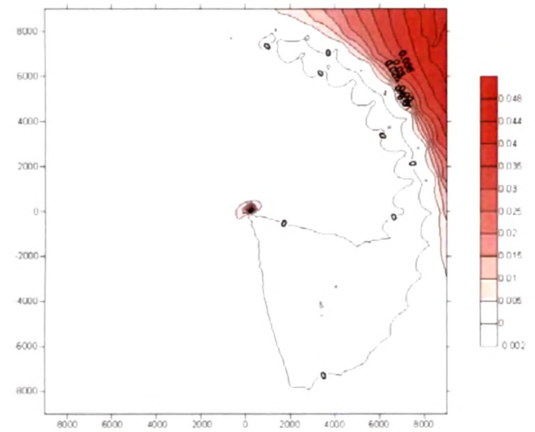
| Table 1.33: Highest GLC of $NO_X$ in 2007 Monsoon | | | |
|---|---|---|---|
| **Highest Values** | **$NO_X$ – 2007 Concentration** | **X Co-ord (mts)** | **Y Co-ord (mts)** |
| 1 | 0.02317 | 7.79 | 4.5 |
| 2 | 0.02149 | 8.46 | 3.08 |
| 3 | 0.02137 | 191.51 | 160.7 |
| 4 | 0.0206 | 6.89 | 5.79 |
| 5 | 0.0193 | 216.51 | 125 |
| 6 | 0.01662 | 8.86 | 1.56 |
| 7 | 0.01447 | 5.79 | 6.89 |
| 8 | 0.01322 | 160.7 | 191.51 |
| 9 | 0.01136 | 234.92 | 85.51 |
| 10 | 0.0105 | 9 | 0 |

**Fig. 1.34: Isolpleth For $NO_X$ Concentration In Monsoon 2007**



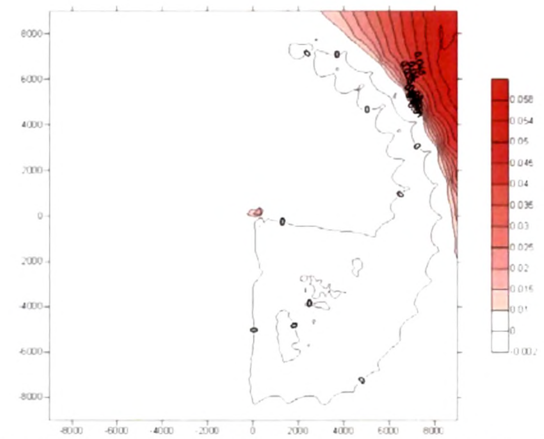
| Table 1.34:Highest GLC of RSPM in 2005 Monsoon | | | |
|---|---|---|---|
| Highest Values | RSPM – 2005 Concentration | X Co-ord (mts) | Y Co-ord (mts) |
| 1 | 0.04039 | 160.7 | 191.51 |
| 2 | 0.03573 | 191.51 | 160.7 |
| 3 | 0.02944 | 216.51 | 125 |
| 4 | 0.02284 | 125 | 216.51 |
| 5 | 0.02222 | 5.79 | 6.89 |
| 6 | 0.02221 | 6.89 | 5.79 |
| 7 | 0.0202 | 4.5 | 7.79 |
| 8 | 0.01919 | 7.79 | 4.5 |
| 9 | 0.01629 | 234.92 | 85.51 |
| 10 | 0.01513 | 3.08 | 8.46 |

**Fig. 1.35: Isolpleth For RSPM Concentration In Monsoon 2005**



| Table 1.35:Highest GLC of RSPM in 2006 Monsoon | | | |
|---|---|---|---|
| Highest Values | RSPM – 2006 Concentration | X Co-ord (mts) | Y Co-ord (mts) |
| 1 | 0.04226 | 234.92 | 85.51 |
| 2 | 0.03691 | 216.51 | 125 |
| 3 | 0.03652 | 191.51 | 160.7 |
| 4 | 0.0344 | 246.2 | 43.41 |
| 5 | 0.03011 | 7.79 | 4.5 |
| 6 | 0.02999 | 160.7 | 191.51 |
| 7 | 0.0288 | 8.46 | 3.08 |
| 8 | 0.02754 | 6.89 | 5.79 |
| 9 | 0.02268 | 5.79 | 6.89 |
| 10 | 0.02257 | 8.86 | 1.56 |

**Fig. 1.36: Isolpleth For RSPM Concentration In Monsoon 2006**



| Table 1.36:Highest GLC of RSPM in 2005 Monsoon | | | |
|---|---|---|---|
| Highest Values | RSPM – 2007 Concentration | X Co-ord (mts) | Y Co-ord (mts) |
| 1 | 0.04018 | 7.79 | 4.5 |
| 2 | 0.0393 | 191.51 | 160.7 |
| 3 | 0.03765 | 8.46 | 3.08 |
| 4 | 0.03549 | 6.89 | 5.79 |
| 5 | 0.03466 | 216.51 | 125 |
| 6 | 0.02938 | 8.86 | 1.56 |
| 7 | 0.0249 | 5.79 | 6.89 |
| 8 | 0.02466 | 160.7 | 191.51 |
| 9 | 0.02037 | 234.92 | 85.51 |
| 10 | 0.01899 | 9 | 0 |

**Fig. 1.37: Isolpleth For RSPM Concentration In Monsoon 2007**

**Monsoon:**

Monsoon season in 2005 did not show any significant correlation between pollutants and meteorological parameters. For 2006 (**Table no. 1.23** and **1.24**) $SO_2$ was showing some correlation with the Wndspd and rainfall contrary to this in 2007 (**Table no. 1.25** and **1.26**) monsoon, RSPM clearly showed interdependence with Wndspd, MnT, RF, RH, VP and CC. Shaft diagrams depicted an appreciable amount of rainfall 2005 which marginally increased in 2006 and again decreased in 2007. Similar results were obtained by Park *et al.,* (2005) wherein the correlation of season with the pollution trend in the city was studied along with its impact on human health. The height of lowest layer in 2005 was highest as compared to 2006 and 2007 making it a prime factor in 2005 for pollutants and meteorological parameters not to give any component extraction. Schafer *et al.,* in 2006 and Khandokar *et al.,* in 2010 had also quoted in his results that more the height of the lowest layer more will be space for pollutants to disperse.

When interpreted on wind rose diagrams the wind pattern showed very interesting variation. It was predominantly in NE direction in 2005 (**Fig. no. 1.29** and **1.32**); in 2006 (**Fig. no. 1.30** and **1.33**) and 2007 (**Fig. no. 1.31** and **1.34**) there was not only a a slight angular movement more towards NEE but also diversified wind pattern in small scale starting from SW to E which probably led to the dispersion to all the direction except the SE. When observed on isopleths more or less same pattern and pockets of $SO_2$, $NO_X$ and RSPM were observed. Pollution packets were mainly seen to be accumulated in the center point of the city (Railway station) as well as in the NE direction (Harni region). The concentration value ranged from 0.026 $\mu g/m^3$ to 0.0113 $\mu g/m^3$ in 2005 (**Table no. 1.28** and **1.31**) , 0.0195 $\mu g/m^3$ to 0.0097 $\mu g/m^3$ in 2006 (**Table no. 1.29** and **1.32**) and 0.0231 $\mu g/m^3$ to 0.0105 $\mu g/m^3$ in 2007 (**Table no. 1.30** and **1.33**). RSPM concentration values ranged from 0.0403 $\mu g/m^3$ to 0.015 $\mu g/m^3$ in 2005, 0.042 $\mu g/m^3$ to 0.022 $\mu g/m^3$ in 2006 and 0.040 $\mu g/m^3$ to 0.018 $\mu g/m^3$ in 2007.

### 1.3.4 Winter Observations:

**Table 1.37: Total Variance for 2007 Winter**

| | Initial Eigenvalues | | | Extraction Sums of Squared Loadings | | |
|---|---|---|---|---|---|---|
| Component | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % |
| 1 | 6.223 | 56.576 | 56.576 | 6.223 | 56.576 | 56.576 |
| 2 | 4.012 | 36.475 | 93.051 | 4.012 | 36.475 | 93.051 |
| 3 | .764 | 6.949 | 100.000 | | | |
| 4 | .000 | .000 | 100.000 | | | |
| 5 | .000 | .000 | 100.000 | | | |
| 6 | .000 | .000 | 100.000 | | | |
| 7 | .000 | .000 | 100.000 | | | |
| 8 | .000 | .000 | 100.000 | | | |
| 9 | .000 | .000 | 100.000 | | | |
| 10 | .000 | .000 | 100.000 | | | |
| 11 | .000 | .000 | 100.000 | | | |

**Table 1.38: Component Matrix For 2007 Winter.**

| | Component | |
|---|---|---|
| | 1 | 2 |
| Wndspd | -.074 | **.990** |
| MxT | **.834** | .549 |
| MnT | .741 | -.625 |
| RF | **.988** | .095 |
| RH | .294 | **.950** |
| VP | **.859** | .194 |
| CC | -.024 | **.841** |
| LL | .491 | -.808 |
| $SO_2$ | **.999** | .008 |
| $NO_X$ | **.996** | .088 |
| RSPM | **.970** | -.144 |

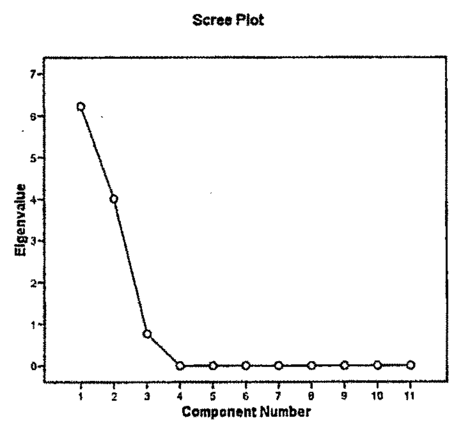



**Fig. no. 1.38: Scree Plot For 2007 Winter**

The **table 1.37** and **1.38** along with the scree plot (**Fig. no. 1.38**) shows 2 components extracted to give 93% of the variations. In the matrix, the 1st factor shows higher relation between MxT, RF, VP, $SO_2$, $NO_X$ and RSPM. Whereas 2nd factor shows the correlation between wndspd, RH and CC only. As compared to 2005 and 2006 winter observations, where no extraction of components had taken place, for 2007 winter all the three pollutant parameters were found to be correlated with the meteorological parameters.

**Fig. 1.39: Shaft diagram comparing the Winter data for 3 years:**

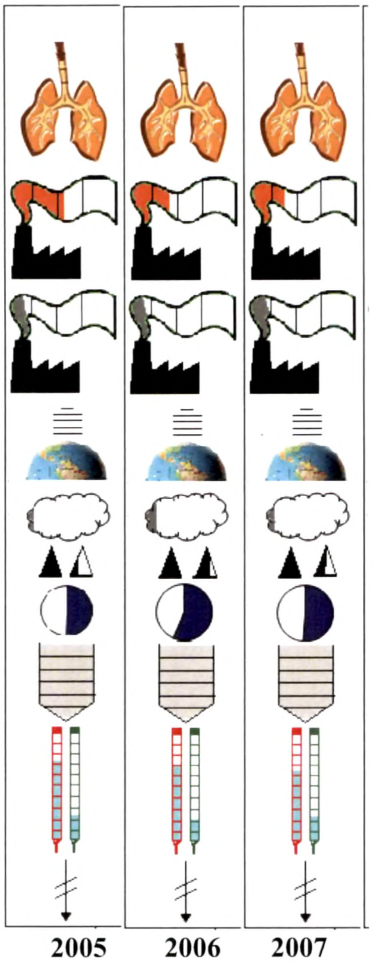
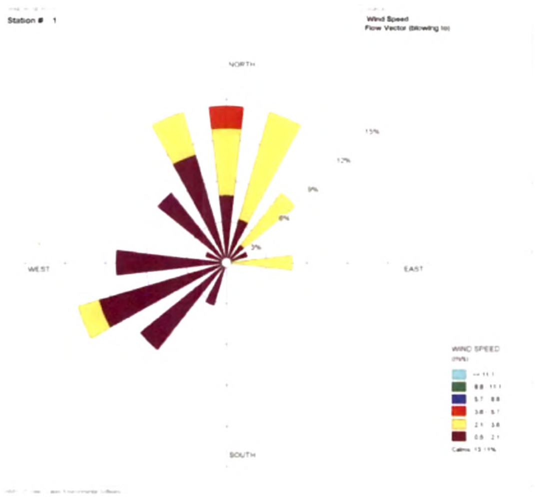



**Table 1.39: Average values for Winter from 2005 – 2007**

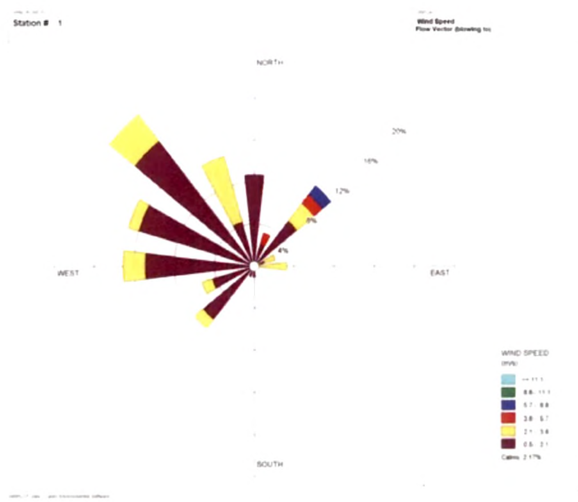
| Year | Wndspd | MxT | MnT | RF | RH | VP | CC | LL | $SO_2$ | $NO_X$ | RSPM |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **2005** | 1.8 | 36.2 | 12.8 | 0.0 | 52.8 | 13.9 | 0.6 | 8.9 | 8.5 | 22.2 | 75.2 |
| **2006** | 2.0 | 34.7 | 11.4 | 0.0 | 56.4 | 15.8 | 1.6 | 8.6 | 8.4 | 16.5 | 90.6 |
| **2007** | 2.0 | 32.5 | 12.1 | 0.5 | 51.3 | 14.5 | 1.3 | 8.7 | 9.1 | 15.3 | 48.9 |

As seen in the **fig 1.39**, 2006 shows a higher rainfall as compared to 2005 and 2007. As a result of this the pollutant concentration is also observed to be higher as compared to the observations of 2005 and 2007.

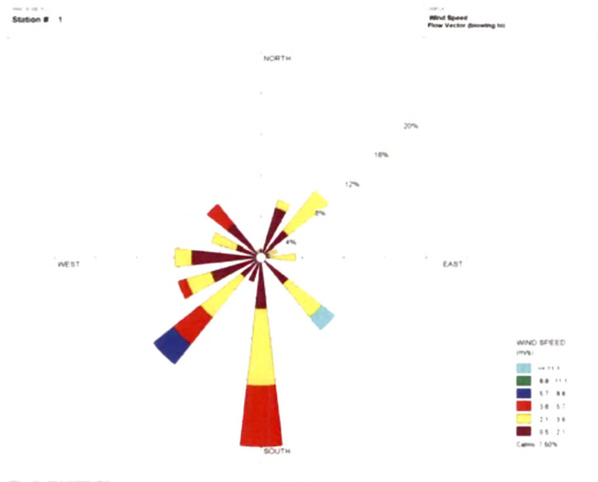
**Fig. 1.40: Representing Wind Rose For Winter Season (2005 – 2007):**




**a.) 2005**



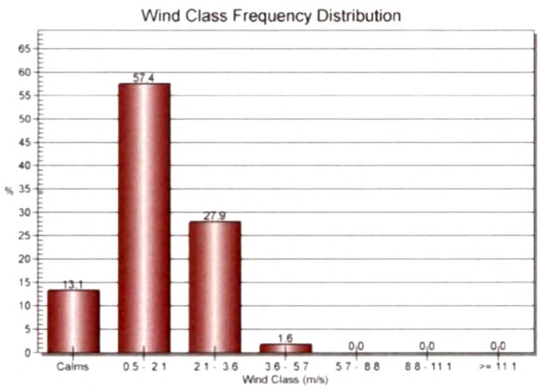

**b.) 2006**



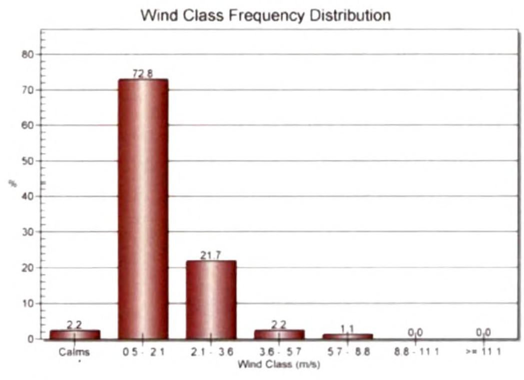

**c.) 2007**

Unlike 2005 and 2006 wind pattern, the wind rose pattern for 2007 was found to be varying completely (**Fig. no. 1.40**). The wind was found to be predominantly blowing in South and South-West direction. Being a mixed type of wind pattern, small proportions of wind were also found in the South East direction.

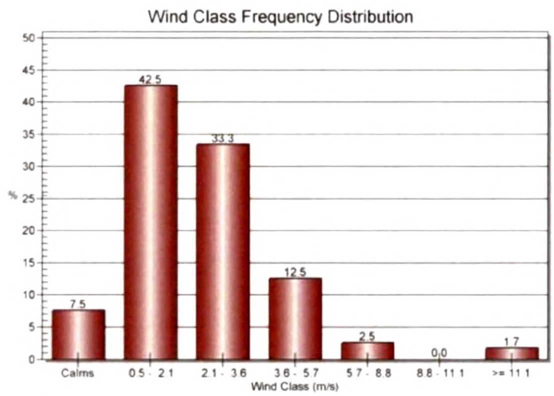
**Fig. 1.41: Wind Class Frequency Distribution For Winter Season (2005 – 2007).**




**a.) 2005**




**b.) 2006**




**c.) 2007**

The maximum wind speed was found to be comparatively low, ranging between 0.5 m/s to 2.1 m/s throughout the season from 2005 to 2007 (**Fig. no. 1.41**).

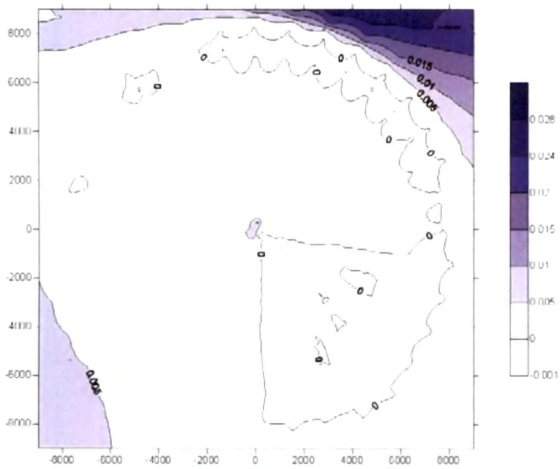


**Fig.1. 42: Isolpleth For $SO_2$ Concentration In Winter 2005**

| Table 1.40: Highest GLC of $SO_2$ in 2005 Winter | | | |
|---|---|---|---|
| **Highest Values** | **$SO_2$ – 2005 Concentration** | **X Co-ord (mts)** | **Y Co-ord (mts)** |
| 1 | 0.02164 | 3.08 | 8.46 |
| 2 | 0.01978 | 1.56 | 8.86 |
| 3 | 0.01872 | 4.5 | 7.79 |
| 4 | 0.01492 | 43.41 | 246.2 |
| 5 | 0.01408 | 0 | 9 |
| 6 | 0.01394 | 85.51 | 234.92 |
| 7 | 0.01331 | 5.79 | 6.89 |
| 8 | 0.01167 | -160.7 | -191.51 |
| 9 | 0.0116 | -191.51 | -160.7 |
| 10 | 0.0114 | -216.51 | -125 |

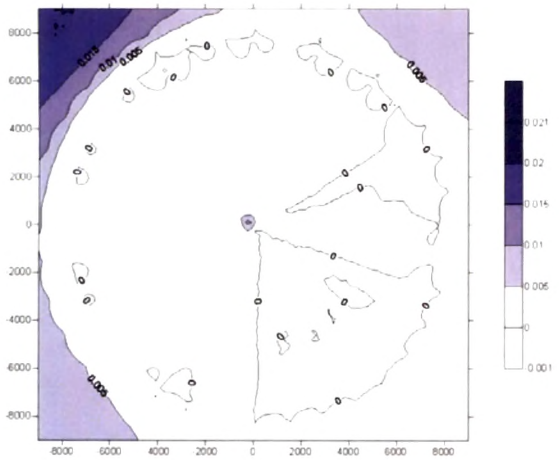


**Fig. 1.43: Isolpleth For $SO_2$ Concentration In Winter 2006**

| Table 1.41: Highest GLC of $SO_2$ in 2006 Winter | | | |
|---|---|---|---|
| **Highest Values** | **$SO_2$ – 2006 Concentration** | **X Co-ord (mts)** | **Y Co-ord (mts)** |
| 1 | 0.01581 | -191.51 | 160.7 |
| 2 | 0.01363 | -216.51 | 125 |
| 3 | 0.01281 | -160.7 | 191.51 |
| 4 | 0.01221 | -234.92 | 85.51 |
| 5 | 0.01094 | -5.79 | 6.89 |
| 6 | 0.01084 | -85.51 | 234.92 |
| 7 | 0.01073 | -246.2 | 43.41 |
| 8 | 0.01069 | -6.89 | 5.79 |
| 9 | 0.01032 | -4.5 | 7.79 |
| 10 | 0.01028 | -250 | 0 |

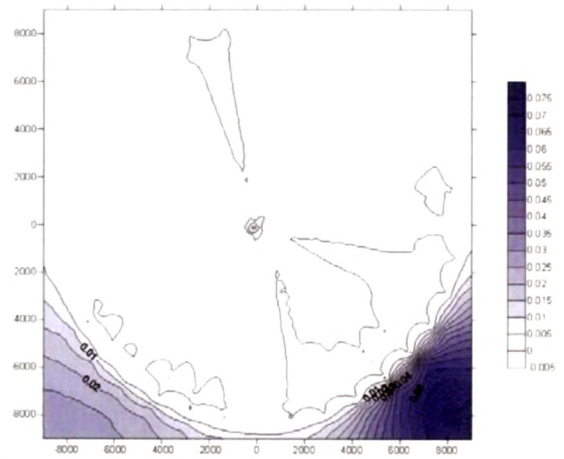


**Fig. 1.44: Isolpleth For $SO_2$ Concentration In Winter 2007**

| Table 1.41: Highest GLC of $SO_2$ in 2007 Winter | | | |
|---|---|---|---|
| **Highest Values** | **$SO_2$ – 2007 Concentration** | **X Co-ord (mts)** | **Y Co-ord (mts)** |
| 1 | 0.05449 | 6.89 | -5.79 |
| 2 | 0.04876 | 5.79 | -6.89 |
| 3 | 0.03636 | 0 | -250 |
| 4 | 0.03201 | 7.79 | -4.5 |
| 5 | 0.02843 | -191.51 | -160.7 |
| 6 | 0.02464 | -160.7 | -191.51 |
| 7 | 0.02434 | 4.5 | -7.79 |
| 8 | 0.01765 | -234.92 | -85.51 |
| 9 | 0.01711 | -4.5 | -7.79 |
| 10 | 0.01699 | -5.79 | -6.89 |

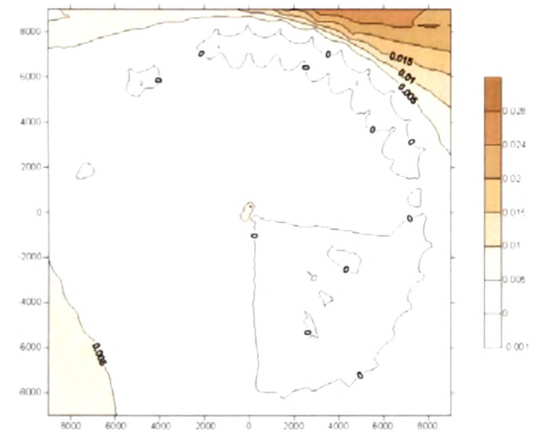


Fig.1.45: Isolpleth For $NO_X$ Concentration In Winter 2005

| Table 1.42: Highest GLC of $NO_X$ in 2005 Winter | | | |
|---|---|---|---|
| Highest Values | $NO_X$ – 2005 Concentration | X Co-ord (mts) | Y Co-ord (mts) |
| 1 | 0.02164 | 3.08 | 8.46 |
| 2 | 0.01978 | 1.56 | 8.86 |
| 3 | 0.01872 | 4.5 | 7.79 |
| 4 | 0.01492 | 43.41 | 246.2 |
| 5 | 0.01408 | 0 | 9 |
| 6 | 0.01394 | 85.51 | 234.92 |
| 7 | 0.01331 | 5.79 | 6.89 |
| 8 | 0.01167 | -160.7 | -191.51 |
| 9 | 0.0116 | -191.51 | -160.7 |
| 10 | 0.0114 | -216.51 | -125 |

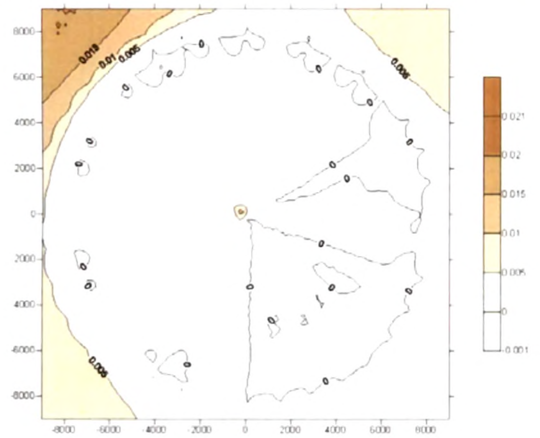


Fig. 1.46: Isolpleth For $NO_X$ Concentration In Winter 2006

| Table 1.43: Highest GLC of $NO_X$ in 2006 Winter | | | |
|---|---|---|---|
| Highest Values | $NO_X$ – 2006 Concentration | X Co-ord (mts) | Y Co-ord (mts) |
| 1 | 0.01581 | -191.51 | 160.7 |
| 2 | 0.01363 | -216.51 | 125 |
| 3 | 0.01281 | -160.7 | 191.51 |
| 4 | 0.01221 | -234.92 | 85.51 |
| 5 | 0.01094 | -5.79 | 6.89 |
| 6 | 0.01084 | -85.51 | 234.92 |
| 7 | 0.01073 | -246.2 | 43.41 |
| 8 | 0.01069 | -6.89 | 5.79 |
| 9 | 0.01032 | -4.5 | 7.79 |
| 10 | 0.01028 | -250 | 0 |

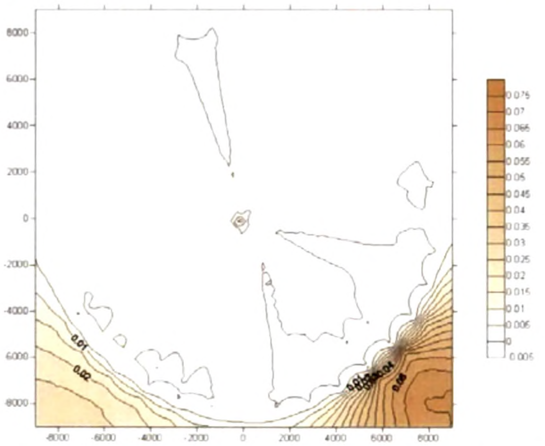


Fig. 1.47: Isolpleth For $NO_X$ Concentration In Winter 2007

| Table 1.44: Highest GLC of $NO_X$ in 2007 Winter | | | |
|---|---|---|---|
| Highest Values | $NO_X$ – 2007 Concentration | X Co-ord (mts) | Y Co-ord (mts) |
| 1 | 0.05449 | 6.89 | -5.79 |
| 2 | 0.04876 | 5.79 | -6.89 |
| 3 | 0.03636 | 0 | -250 |
| 4 | 0.03201 | 7.79 | -4.5 |
| 5 | 0.02843 | -191.51 | -160.7 |
| 6 | 0.02464 | -160.7 | -191.51 |
| 7 | 0.02434 | 4.5 | -7.79 |
| 8 | 0.01765 | -234.92 | -85.51 |
| 9 | 0.01711 | -4.5 | -7.79 |
| 10 | 0.01699 | -5.79 | -6.89 |

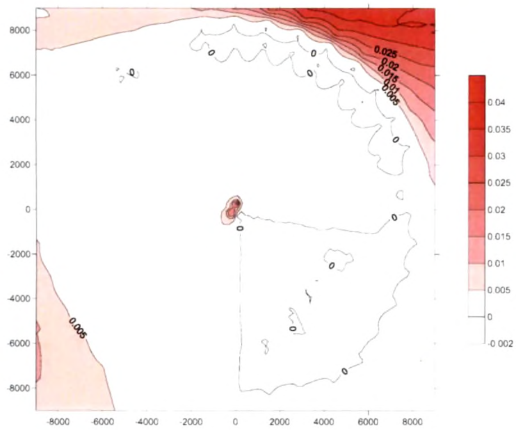



**Fig. 1.48: Isolpleth For RSPM Concentration In Winter 2005**

| Table 1.45: Highest GLC of RSPM in 2005 Winter | | | |
|---|---|---|---|
| **Highest Values** | **RSPM – 2005 Concentration** | **X Co-ord (mts)** | **Y Co-ord (mts)** |
| 1 | 0.03057 | 43.41 | 246.2 |
| 2 | 0.02953 | 3.08 | 8.46 |
| 3 | 0.02746 | 85.51 | 234.92 |
| 4 | 0.02699 | 4.5 | 7.79 |
| 5 | 0.02563 | 1.56 | 8.86 |
| 6 | 0.02354 | -160.7 | -191.51 |
| 7 | 0.02325 | -191.51 | -160.7 |
| 8 | 0.02278 | -216.51 | -125 |
| 9 | 0.02248 | -85.51 | 234.92 |
| 10 | 0.02166 | -125 | -216.51 |

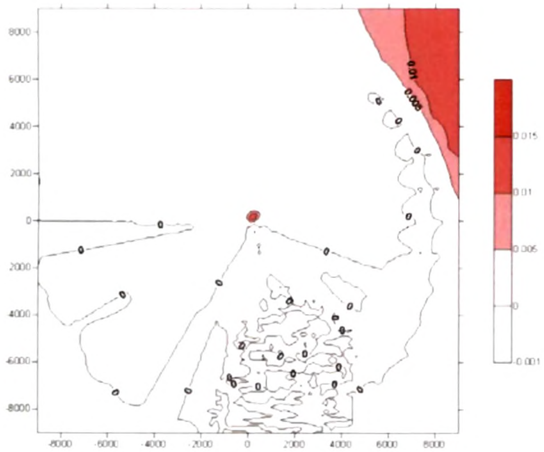


**Fig. 61: Isolpleth For RSPM Concentration In Winter 2006**

| Table 1.46: Highest GLC of RSPM in 2006 Winter | | | |
|---|---|---|---|
| **Highest Values** | **RSPM – 2006 Concentration** | **X Co-ord (mts)** | **Y Co-ord (mts)** |
| 1 | 0.02476 | 191.51 | 160.7 |
| 2 | 0.02273 | 216.51 | 125 |
| 3 | 0.02154 | 160.7 | 191.51 |
| 4 | 0.01644 | 125 | 216.51 |
| 5 | 0.01444 | 234.92 | 85.51 |
| 6 | 0.01059 | 7.79 | 4.5 |
| 7 | 0.01049 | 85.51 | 234.92 |
| 8 | 0.00986 | 8.46 | 3.08 |
| 9 | 0.00913 | 6.89 | 5.79 |
| 10 | 0.00846 | 246.2 | 43.41 |

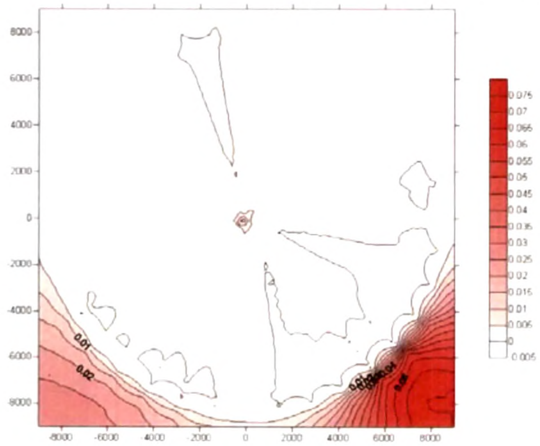


**Fig. 62: Isolpleth For RSPM Concentration In Winter 2007**

| Table 1.47: Highest GLC of RSPM in 2007 Winter | | | |
|---|---|---|---|
| **Highest Values** | **RSPM – 2007 Concentration** | **X Co-ord (mts)** | **Y Co-ord (mts)** |
| 1 | 0.05449 | 6.89 | -5.79 |
| 2 | 0.04876 | 5.79 | -6.89 |
| 3 | 0.03636 | 0 | -250 |
| 4 | 0.03201 | 7.79 | -4.5 |
| 5 | 0.02843 | -191.51 | -160.7 |
| 6 | 0.02464 | -160.7 | -191.51 |
| 7 | 0.02434 | 4.5 | -7.79 |
| 8 | 0.01765 | -234.92 | -85.51 |
| 9 | 0.01711 | -4.5 | -7.79 |
| 10 | 0.01699 | -5.79 | -6.89 |

**Winter:**

In 2005 and 2006, there was no extraction of components. Nevertheless in 2007 (**Table no. 1.37** and **1.38**) all the three pollutants were found to be participating and were well associated with MxT, RF and VP.. Shaft diagrams too supported the SPSS results. It indicates that seasonal change in the dispersion pattern which is dependent on the MxT. Hence, with the increase in the temperature the dispersion will be more. As reported by County in winter, pollution potential is related to the nighttime minimum temperature. In the winter, light winds at night, coupled with a surface-based inversion, and terrain blocking does not allow much dispersion of pollutants. According to Wittig in 2007, the low mixing layer height and consequently the process of mixing pollutants with ambient air is weakly perceptive. Thereby high loads and threshold exceedances of $NO_X$ and RSPM were observed. Kulkarni *et al.,* 1992 has also reported seasonal rainfall pattern over India. Singh and Singh (1996) has analysed the spatial and temporal variations of seasonal rainfall in Himalayan and Gangetic plains.

Wind pattern varied greatly from 2005 to 2007 (**Fig. no. 1.39**), in 2005, the wind was predominantly blowing towards the N and NW, but he maximum spikes were seen to be blowing in the N, NNW, NNE and WSW. This pattern then completely got altered in 2006 and was found to be predominantly blowing towards the NW direction with lower spikes in the W direction. Again in 2007, the wind pattern changed completely and the wind was principally seen to be blowing towards the S (Maximum spike) and SW direction. Similar results are obtained by Castaneda and Ratto (2009) and Garreand (2001), wherein he has reported variability of the wind direction preferentially of SW to NW direction indicating that moisture enters the region from different sources. Impact of this change in wind pattern was observed by the isopleths. In 2005 (**Fig. no. 1.42** and **1.45**), NE (Harni) showed the pollution pocket along with some pocket in SW, NW (Nandesari) and centre point (Railway Station). Higher concentrations of pollutants ($SO_2$ and $NO_X$) along with maximum dispersion in the NW direction make the NW direction the highest pollutant pocket in 2005 and 2006 (**Fig. no. 1.43** and **1.46**). Later in 2007 (**Fig. no. 1.44** and **1.47**), the pollutant pockets were towards SW and SE direction. The concentration values ranged from 0.0216 $\mu g/m^3$ to 0.011 $\mu g/m^3$ in 2005 (**Table no.1.40** and **1.43**), 0.0158 $\mu g/m^3$ to

0.0103 μg/m$^3$ in 2006 (**Table no.1.41** and **1.44**) and 0.054 μg/m$^3$ to 0.016 μg/m$^3$ in 2007(**Table no.1.42** and **1.45**). Thereby indicating that pollution level due to $SO_2$ was higher in 2007.

As far as the RSPM concentrations are concerned it was parallel with that of the $SO_2$ and $NO_X$ concentrations, however, it was in contrast for 2006. When observed for 2006 (**Fig. no. 1.49**), the main pocket was region above the Harni area in NE . The concentration values ranged from 0.030 μg/m$^3$ to 0.021 μg/m$^3$ in 2005 (**Table no. 1.46**), 0.0247 μg/m$^3$ to 0.008 μg/m$^3$ in 2006 (**Table no. 1.47**) and 0.054 μg/m$^3$ to 0.0169 μg/m$^3$ in 2007 (**Table no. 1.48**). Studies by Kaneyasu *et al.,* (1999); Okubo and Takahash (2009); in their studies have also reported that the winter season peaks in the urban areas are probably due to abundant artificial emissions and calm conditions.

## 1.5 CONCLUSSION:

The correlation between 8 meteorological parameters viz. wind speed, maximum temperature, minimum temperature, rainfall, relative humidity, vapor pressure, cloud cover and height of lowest layer and pollutants viz., $SO_2$, $NO_X$ and RSPM (Respirable particulate matter) for the Vadodara city over a period of 3 years, has revealed interesting facts with application of SPSS Shaft diagrams, Wind rose diagrams and Isopleths. The analysis has been carried out on seasonal and annual basis. It was observed that annual and seasonal variations of the conditions favorable to high pollution level and the definition of an area's micro climate in terms of air pollution is strongly supported. It can be established that such statistical analysis will help in predicting the air quality for pollutants in terms of meteorology. The analysis and results obtained from the present study is not only important for interaction of meteorological and pollutants, but also for urban planners and decision makers.