Effects of Meteorological Conditions on Air Pollution and Air Pollutant Trends in Shimla

A PROJECT

Submitted in fulfillment of the requirements for the award of the degree of

BACHELOR OF TECHNOLOGY

IN

CIVIL ENGINEERING

Under the supervision of

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By

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CERTIFICATE

This is to certify that the work which is being presented in the project title **"Effects of Meteorological Conditions on Air Pollution and Air Pollutant Trends for Shimla"** in partial fulfillment of the requirements for the award of the degree of Bachelor of technology and submitted in Civil Engineering Department, Jaypee University of Information Technology, Waknaghat is an authentic record of work carried out by Hardik Siroha during a period from August 2015 to June 2016 under the supervision of **Dr Rajiv Ganguly** Associate Professor, Civil Engineering Department, Jaypee University of Information Technology, Waknaghat.

The above statement made is correct to the best of my knowledge.

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The success of any project depends largely on the encouragement and guidelines of many others. Therefore I take this opportunity to express my sincere gratitude to the people who have been instrumental in the successful completion of the project. I would like to express my sincere appreciation and gratitude to my guide **Dr Rajiv Ganguly** without whose able guidance, tremendous support and continuous motivation, the project would not have been carried to perfection. I sincerely thank him for spending all his valuable time and energies during the execution of project.

I take this opportunity to express my sincere gratitude to the Head of Department of Civil Engineering, **Prof. Ashok Kumar Gupta** for all his support and valuable inputs. I thank him for reviving Civil Engineering as the overall mentor by leading with a vision and teaching us with a knowledge-imparting attitude.

The successful compilation of final year project depends on the knowledge and attitude inculcated in the total length of the course. So I want to express my sincere gratitude to all the faculties who taught us during the four years of B.Tech.

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Abstract:

The increasing air pollution level in urban areas, particularly in hilly region like Shimla city. are seriously affecting the health of the inhabiting citizens .Shimla being the capital of Himachal Pradesh, it is the principal commercial, cultural, and educational center of the state and its abundant natural beauty attracts tourists. In the present study detailed statistical analysis of ambient air quality with respect to Sulphur Dioxide (SO_2), Nitrogen Dioxide (NO_2), Suspended Particulate Matter (SPM) and Respirable Suspended Particulate Matter (RSPM) of the Shimla city is analyzed in conjunctions with the adverse effect of these pollutants on humans health and their effect on ecologically sensitive areas of Himalayan region. The results of the analysis shows that, expect Sulphur Dioxide, the annual mean concentration of other two pollutants are above or near the permissible limit at most of the monitoring sites (residential and ecologically sensitive).

Meteorological conditions play a crucial role in ambient air pollution by affecting both directly and indirectly the emissions, transport, formation, and deposition of air pollutants. In this paper, the effects of meteorological conditions on local air quality pollutants are quantitatively assessed by determining the relationships between concentrations of sulphur dioxide (SO_2) and nitrogen dioxide (NO_2), suspended particulate matter (SPM), respirable suspended particulate matter (RSPM) with meteorological parameters such as minimum temperature (Tm), maximum temperature (TM), average temperature (Tavg), precipitation (P) and relative humidity (R.H) on monthly basis. Moreover Shimla also includes ecologically sensitive area, but a little is known about air pollutants and meteorological parameters for ecologically sensitive area. This study includes detailed statistical analysis for both residential and ecologically sensitive area, using the multi-linear regression technique to develop a relationship and predicting the ambient air quality pollutants (i.e SPM, RSPM, SO_2 and NO_2) in conjunctions with meteorological parameters (i.e Tm, TM, Tavg, P, R.H) of the Shimla city. The results of the analysis shows high correlation between the air pollutants and meteorological parameters, further the analysis facilitated prediction of SO_2 and NO_2 with in the scatter range of ±10%, and for SPM and RSPM in range of ±26%.

Keywords: Air Pollution, SO_2, NO_2, SPM, RSPM, Meteorological Conditions, Multi-Linear Regression, Shimla.

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Chapter-1

Introduction

Air Quality has been a complex issue in most of the urban areas due to a variety of source contribution through fugitive and line emissions. Air pollution results in long-term reduction of productivity leading to deterioration of economic condition of a country. Therefore, controlling air pollution to reduce risk of poor health, to protect the natural environment and to contribute to our quality of life is a key component of sustainable development. All the anthropogenic air pollution emissions could be attributed to industries, mobile sources, construction, garbage burning, agriculture etc. The sources are becoming more complex day by day as also emissions. Ambient air monitoring programme of India has been guiding the policy makers, however, inadequacies of quality assurance/quality control in the overall monitoring, data gathering and interpretations add more complexity to the problem.

The increasing air pollution level in urban areas, particularly in hilly region like Shimla city, is seriously affecting the health of the inhabiting citizens and damaging the ecologically sensitive areas. Shimla being the capital of Himachal Pradesh, it is the principal commercial, cultural, and educational center of the state and its abundant natural beauty attracts tourists. It is situated in northern part of the country and lies in the South-Western part of Himalayas geographically, Shimla lies at 31.1048° North latitude and 77.1734° East longitude and its mean elevation is 2397.59 meters above the mean sea level (M.C.S 2008). The existing town resembles an irregular crescent with a 9.2 km stretch from one end to the other, covering a total land area of 35.34 Sq.km. (Figure 1). Total forest area of Shimla is 8.6 Sq.km. and total numbers of registered vehicles are 16,449 (M.C.S. 2008, General profile). And total population according to last census 2011 is 814010 (Economic Survey of Himachal Pradesh, 2014-2015).

During a year, Shimla has mean annual minimum and maximum temperature of 12.74 °C and 22.27 °C respectively and having a annual mean relative humidity and precipitation of 64.63% and 63.10cm. in this region the SO_2 and NO_2 concentration are within the national guidelines (National air quality Standards 2009) but SPM and RSPM concentration are higher than the national guidelines even for ecologically sensitive area. Recently, concern was raised over haze formation in winter months and alarmingly high concentration of SPM and RSPM during summer and winter months, and these are seriously affecting the health and economic and social activities of inhabiting citizens of Shimla. The deteriorating air quality of Shimla apprehends to increase breathing and heart related diseases (Economic Survey of Himachal Pradesh, 2012-2013; Economic Survey of Himachal Pradesh, 2013-2014; Economic Survey of Himachal Pradesh, 2014-2015).

The vehicles emit a mixture of air pollutants of which the following may be ecologically important: nitrogen oxides (NOx), volatile organic compounds (VOCs), sulphur (SOx), polycyclic aromatic hydrocarbons (PAHs), metals and suspended particulate matter. Ammonia (NH_3) and nitrous acid (HNO_2) are also potentially important, particularly at the roadside. Several studies show the adverse effect of air pollutants on tree species such as Oak tree, and the beech tree and other vegetation due to emission from vehicles (Keeley L., 2007). The studies till now are focused mainly on the mega cities like Beijing, Shanghai, and Guangzhou, Cairo, Oklahoma (Hongliang., 2015; Nicole R., 2013; Harrision, 1997) and have indicated that both physical and dynamic properties of atmosphere plays vital role in determining the air pollutant concentration. In India such investigation are still low in number and limited in scope. A very few researchers have focused on ecologically sensitive area. This makes it difficult to predict the potential adverse effect of air pollutants emission, and thus limited development of effective air quality strategies due to high percentage of scientific uncertainty.

As a result this study is carried out on Shimla city because it includes both residential area with significant population with large traffic movement throughout the year and ecologically sensitive area. The study includes, role of meteorological parameters in determining the concentration of SO_2, NO_2, SPM, and RSPM in Shimla. Further the relationship between the local air pollutants concentration and meteorological parameters, along with inter-site variation and relation between parameters.

Chapter 2

Literature Review:

1. **Deswal, Chadha (2010)** studied the Effects of meteorological conditions on concentration of air pollutants in Delhi. In it the effects of meteorological parameters were quantitatively assessed by determining the relationship between concentrations of suspended particulate matter, respirable suspended particulate matter, sulphur dioxide and nitrogen dioxide with meteorological parameters. They divided the Delhi's temperature into three periods namely, summer, monsoon and winter. Further a linear regression was carried out on air quality and meteorological data to study the effect of individual meteorological parameter on air quality parameters.

2. **Duvall, Norris, et al. (2011)** investigated the intra urban variability in air pollution using receptor modeling of daily speciated $PM_{2.5}$ measurements collected at residential outdoor locations across Detroit,MI(Wayne County) for summer and winter for years 2004-2006.Sources were quantified using EPA Chemical Mass Balance Model (CMB 8.2).Contributions from motor vehicles, steel manufacturing, and mixed industrial sources varied across the monitoring areas.

3. **Burke, Zufall, et al. (2001)** used Stochastic Human Exposure and Dose Simulation (SHEDS-PM) model for a case study of $PM_{2.5}$ exposure for population of Philadelphia . A mass balance equation was used to calculate indoor PM concentrations for the residential microenvironment from ambient outdoor PM concentrations and physical factor data (e.g., air exchange, penetration, deposition) , as well as emission strengths for indoor PM sources (e.g., smoking, cooking) . PM concentrations in nonresidential microenvironments were calculated using equations developed from regression analysis of available indoor and outdoor measurement data for vehicles, offices, schools, stores, and restaurants / bars. Additional model inputs include demographic data for the population being modeled and human activity pattern data from EPA's Consolidated Human Activity Database (CHAD) . Model outputs include distributions of daily total PM exposures in various microenvironments (indoors, in vehicles, outdoors) , and the contribution from PM of ambient origin to daily total PM exposures in these microenvironments.

4. Verma, Sheokand, et al. (2016) reports the analysis of ambient air quality in Noida city employing the Air Quality Index (AQI). Increased industrial, vehicular traffic and other activities contribute towards increase in air pollution in the city. In order to indicate the level of severity and disseminate the information on air pollution, Air Quality Index (AQI) is used as a tool. The 24- hourly average concentration of three major criteria pollutants, viz. Particulate matter PM_{10}, Sulphur Dioxide (SO_2), and Nitrogen Dioxide (NO_2) for a period of one year from January 2015 to December 2015 at two different station namely, Station-1: Gee Pee Electroplating work (Sector-6) and Station-2: Regional Office (Sector-1) in Noida were selected for analysis. The AQIs were calculated using IND-AQI procedure. From the analysis, it has been observed that the calculated AQI values NO_2 and SO_2 fall under 'good' category; whereas,the calculated AQI values of PM_{10} fall under 'moderately polluted' categories with varying percentages. The overall AQI was found to fall under the category 'moderately polluted' owing to PM_{10}. Thus, it is observed that PM_{10} is critical pollutant in Noida city. the present study concludes that the air of Noida city is moderately polluted. Therefore to protect the environment and ecology of the study area, the existing environmental legislations should be strictly followed and implemented. Air pollution control measures and initiatives are urgently required so as to bring down the levels of PM_{10} at a much faster rate, so as to improve the health of citizens and to keep environment safe.

5. Ramsey, Klein, et al. (2014) This study shows the impact that global climate change will have on both regional and urban air quality. As air temperatures continue to rise and mid-latitude cyclone frequencies decrease, the overall air quality is expected to degrade. Climate models are currently predicting an increased frequency of record setting heat and drought for Oklahoma during the summer months. A statistical analysis was thus performed on ozone and meteorological data to evaluate the potential effect of increasing surface temperatures and stagnation patterns on urban air quality in the Oklahoma City Metropolitan area.

Compared to the climatological normal, the years 2011 and 2012 were exceptionally warm and dry, and were therefore used as case study years for determining the impact of hot, dry conditions on air quality. These results were then compared to cooler, wetter summers to show how urban air quality is affected by a change in meteorological parameters. It was found that an increase in summertime heat and a decrease in summertime precipitation will lead to a substantial increase in both the minimum and maximum ozone concentrations as well as an increase in the total number of exceedance days. During the hotter, drier years, the number of days with ozone concentrations above the legal regulatory limit increased nearly threefold. The length of time in which humans and crops are exposed to these unsafe levels was also doubled. Furthermore, a significant increase was noted in the overnight minimum ozone concentrations. This in turn can lead to significant, adverse affects on both health and agriculture statewide.

6. Saraswat and Deswal (2016) This paper shows that concentration of SPM is above the permissible limit for whole period of study, average value varied from 300 to 600 μg/m3 which is much more than the permissible value i.e. 40 μg/m3, in summer season these values are at the peak which may be due to dusty storms from touching desert areas. On comparing maximum values in the year we observed that maximum values are found in the year 1999 i.e.578.91 μg/m3 whose probable reason found are industrial emission and bricks kilns.

In the seasonal variation January month is found to have the maximum values which is 558.35 μg/m3,this value may be due to westerly wind whose velocity is very high in the day time hours so the spm particles remain in the suspension, while in the night hours the calm condition allow the particles to settle and so concentration decreases.

The SO_2 concentration is found mostly lower than permissible limit but with great variations in the year 1990 to 1994 they varied between 22.45 μg/m3 to 24.41 μg/m3. After 1994 there is consistent fall in the concentration to a value of 4.5 μg/m3 in 2002 and it is the least value observed whose main reason was shutting down more than 100

small foundries ,iron and steel foundry, set up of wet scrubber by industries. Under the exposure condition of stone for two years, SO_2 in the form of soluble sulphate has penetrated to a depth of 0.3 mm. One important observation made from the month of October to March that the emission of SO_2 from 30 km upward oil refinery, which was carried to Tajmahal with westerly wind, is corroding granite stone with very high intensity.

The NO_2 concentration in the later period of study i.e. after 2001 to 2006 shows drastic rise in the concentration from 8.2 μg/m3 to 28.3 μg/m3 whose component is founded to be acidic in nature, which is causing corrosion to stones and affecting visibility.

7. Chan Wai-Shin et al, (2007) This study dealt with the adverse effects of air pollution not only on the respiratory system, but also on the cardiovascular system (WHO, 2004). Physical damage functions relating health (mortality and morbidity) to air pollution levels have been estimated over a number of years in different countries).. The major air pollutants discussed in the present study are sulfur dioxide, nitrogen oxides, ammonia, carbon monoxide, TSP and PM10.The harmful effects of these pollutants are discussed here in detail:
Sulfur Dioxide (SO2): Elevated concentrations of SO2 can be indicated by an odor of „burning matches" and are associated with human health impacts, including respiratory (breathing) effects, especially asthma. Vegetation, especially lichens, can be very sensitive to SO2 at relatively low concentrations (Air Quality Monitoring Network, 2008)[3]. The gas irritates airways and eyes and is known to cause longer-term heart diseases, other cardiovascular ailments, and bronchitis. It also readily causes shortness of breath and coughing amongst asthma sufferers. SO2 is also a major contributor to acid rain, which damages the environment and upsets ecosystems.

8. Naik S., (2005): This study dealt with the affects and sources of Suplhur Dioxide i.e, SO_2. The gas is produced by the combustion of fossil fuels Sources include industrial activities such as flaring at oil and gas facilities and diesel power generation, commercial and home heating and vehicle emissions. The amount of SO_2 emitted is directly related to the sulfur content of the fuel.

Chapter-3

Material and Methodology

3.1 Study Site Description:

The city of Shimla (latitude- 31.1048° N and longitude 77.1734° E) is the capital of Himachal Pradesh. Temperatures typically range from −4 °C (25 °F) to 31 °C (88 °F) over the course of a year. The average temperature during summer is between 19 and 28 °C (66 and 82 °F), and between −1 and 10 °C (30 and 50 °F) in winter. Monthly precipitation varies between 15 millimetres (0.59 in) in November and 434 millimetres (17.1 in) in August. It is typically around 45 millimetres (1.8 in) per month during winter and spring and around 175 millimetres (6.9 in) in June as the monsoon approaches. The average total annual precipitation is 1,575 millimetres (62 in), which is much less than most other hill stations but still much heavier than on the plains. Snowfall in the region, which historically has taken place in the month of December, has lately (over the last fifteen years) been happening in January or early February every year. The maximum snowfall received in recent times was 38.6 centimetres (15.2 in) on 18 January 2013. On two consecutive days (17 and 18 January 2013) the town received 63.6 centimetres (25.0 in) of snow. Spread in 25km^2 is one of the major tourist destinations of India and received 3415307 tourists in 2015. Since it doesn't have any industries the major source of pollution here is the vehicular traffic, which gets exacerbated due to high tourist influx, especially in season of summer and spring. From 1st April 2014 to 31st March 2015, 6458 vehicles were added to Shimla that too only of locals and natives.

3.2 Description of Monitoring Sites:

Shimla's climate has four significant seasons showing considerable variations during a year:

1. Winter (December-February)
2. Spring (March-May)
3. Summer (June-August)

4. Autumn (September-November)

During a year Shimla has mean temperature of 17.57°C, which varies from minimum of 12.73°C to maximum of 22.27°C; mean relative humidity of 64.428%. Studies undertaken elsewhere (such as,Jiang et al.,2004,2005; Sun et al., 2004; Leong and Laortanakul,2003) have indicated that both dynamic and physical properties of atmosphere play important roles in determining air pollutant concentration. Li et al. (2005) observed that diurnal variation of gaseous pollutant concentration is closely related to changes in atmospheric stability and mean kinetic energy in atmospheric boundary layer in Beijing area. In India generally, such investigations are very few in number and limited, in scope. This makes it difficult to assess the potential adverse effects of air emissions, and consequently limits development of effective air quality management strategies due to high degree of scientific uncertainties.

Through this particular section of this project, a study has been carried out in order to assess the role of meteorological conditions in determining the concentrations of pollutants and oxides of Nitrogen such as NO_2.

Figure 1:Map of Shimla

3.3 Data Selected:

Air quality data used in this study are concentrations of SO_2, NO_2, SPM, RSPM measured at two long-term monitoring sites, Tekka Bench Ridge (Ecologically Sensitive) and Bustand Winter Field (Residential), located in Shimla, Himachal Pradesh. The selected sites location are based on following parameters:

- The available records for these six sites are relatively long (>5 years)
- Both of these sites formed part of the National Air Quality Monitoring Programme (NAMP).
- The use of data for these locations facilitates examination of weather-induced variability in air quality of the Shimla.

The meteorology data selected for this study is daily wind speed, wind direction, temperature, and humidity for the period 2004-2014. However, the daily wind speed and direction data available for year 2010 onwards only.

The reasons for choosing them are:

- The available records for them were relatively long.
- Each of them have been shown to have significant impact on pollutant concentration of a region (Deswal and Chadha, 2010).
- In a region like Shimla, where there aren't any major industries in the vicinity, meteorological parameters gained more importance as compared to a similar study done in places like New Delhi.

First, the inter-site variation and trends of monthly mean concentrations of air quality parameters is studied for the mentioned categories of monitoring sites,

- Residential (*R*)
- Sensitive (*S*)

After analysing the inter-site variation between sites, the seasonal influence of changing meteorological conditions on the monthly mean air pollutant concentrations is analysed at both monitoring sites.

In the last, the multiple linear regression and the principal component analysis techniques are used to quantify the relation between monthly mean air pollution data and meteorological data.

3.4 Transport:

A large number of Shimla inhabitants especially students rely on public transport to travel to and from their home and destinations. The city also lacks car parking spaces, suffers traffic bottlenecks due to limited roads. The buses both public and private cater the major public transportation facility, besides that there have been addition of numerous cabs and taxis also with taxi aggregator Ola being the latest entrant. Public buses cover almost all parts of the city, except certain restricted zones.

3.4.1 Vehicular Volume:

Meanwhile there has been a subtle yearly increase in vehicle's volume in Shimla, as evident from the following data obtained from Shimla RTO.

Area/Source	**No. of Vehicles**
STA Shimla	2036
RTO Shimla	2029
Shimla (Rural)	1010
Shimla (Urban)	1087
Total	6162

Table 1:Vehicular Volume from 1 April 2013 to 31 March 2014

Area/Source	No. of Vehicles
STA Shimla	1939
RTO Shimla	1848
Shimla (Rural)	1209
Shimla (Urban)	1462
Total	6458

Table 2:Vehicular Volume from 1 April 2014 to 31 March 2015

Chapter-4

Results and Discussion:

4.1 Comparison with WHO and NAAQS Standards:

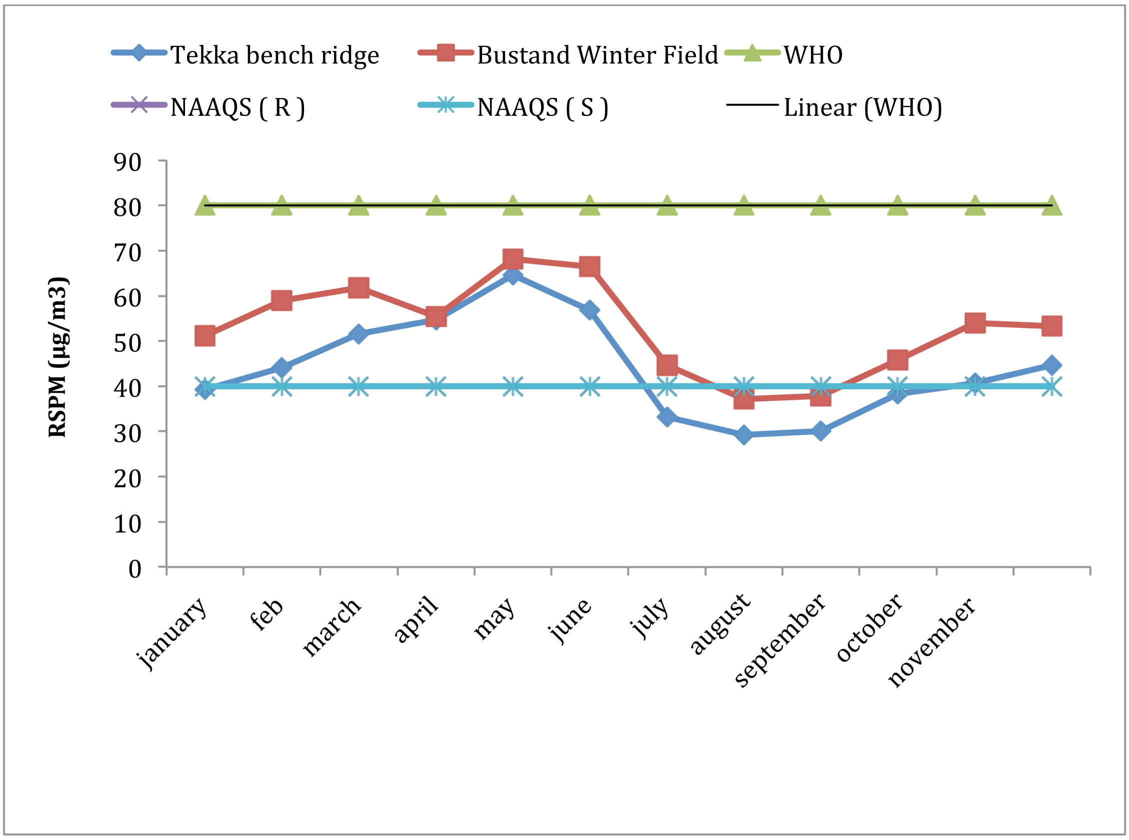


Figure 2: Monthly mean concentration of RSPM compared with WHO and NAAQs standards

An important trend that emerges is that concentration of SPM and RSPM have been crossing the standards set by NAAQS and WHO.

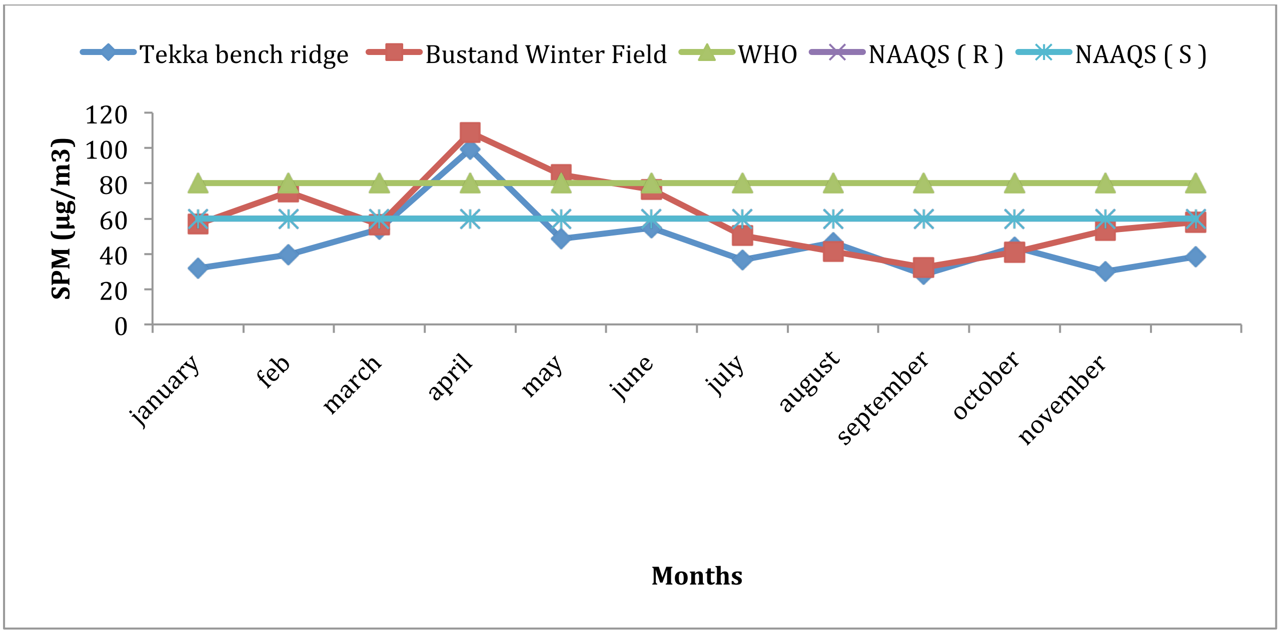


Figure 3: Monthly mean concentration of SPM compared with WHO and NAAQs standards

Considering SPM concentration, when we look at monthly mean value of it especially in month of April and May we can observe that it has surpassed the threshold set by both NAAQS and WHO. This is a worrisome trend as higher SPM concentrations have been directly linked with respiratory problems affecting population's health. This has been evident in Delhi where higher concentration of SPM has affected thousands of people every year (Chan Wai-Shin et al, (2007)).

The graphical plot reveals that, first maxima of air pollutant concentration occur during the pre-monsoon period (i.e from April to June). This maxima of air pollutant concentration coincides with pre-monsoon meteorological condition in Shimla, like increase in maximum minimum and average temperature, and having lower precipitation and relative humidity.

During the monsoon season (ie from July to September) a minima in air pollutants concentration is well developed. The minima of air pollutant concentration during the monsoon season is mainly due to the Prevailing meteorological factors from July to September, such as precipitation, high relative humidity, which leads to the wash out of pollutants from ambient air. This minima is followed by again increase in air pollutants concentration during the post monsoon season (i.e from October to December), mainly because of lower minimum temperature, and maximum temperature, and less precipitation. These adverse meteorological condition, which marks the beginning of winter season increases the atmospheric stability and hence air pollutants concentration increases. Further the graphical plots reveals the second minima during the winter months (i.e from January to March) coincides with moderate precipitation, increased relative humidity in the region. Due to this moderate climatic condition, the atmosphere become unstable which in turns reduces the severity of air pollutants in ambient air.

4.2 Intersite Pollutant Concentrations:

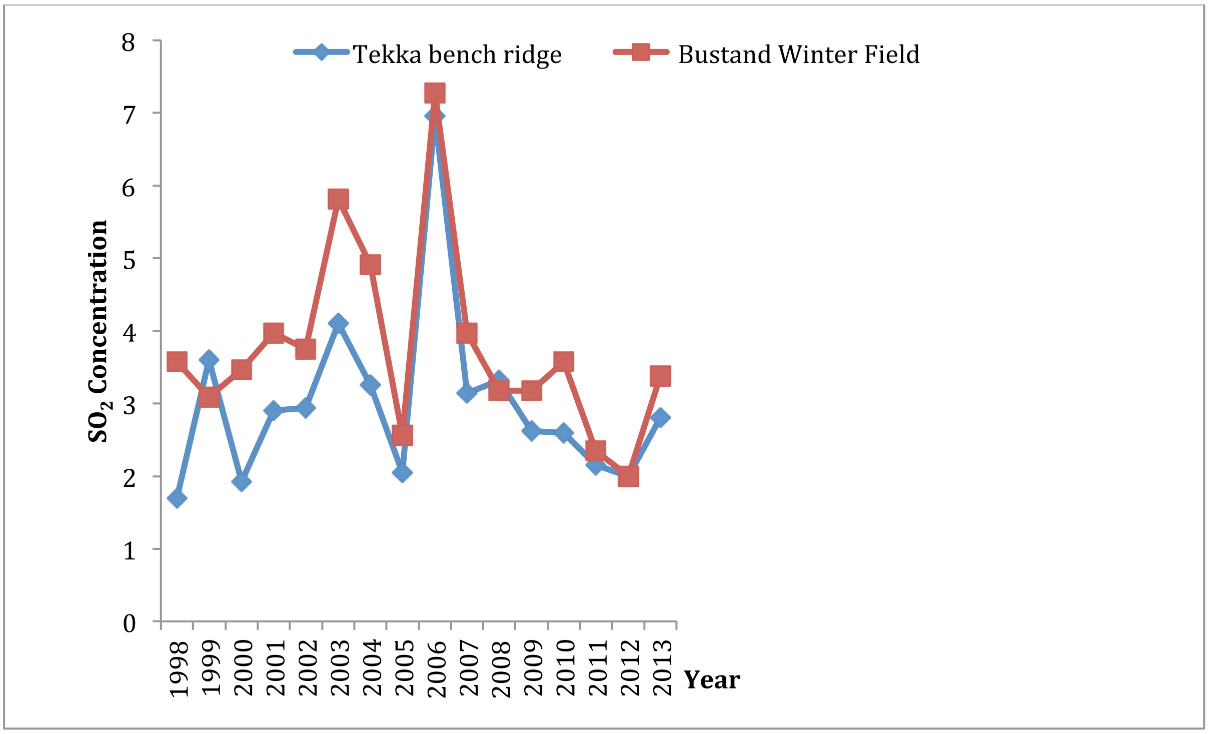


Figure 4:Annual mean SO_2 concentration

The peak in SO_2 can be attributed to high temperature observed during that year as it haves a positive correlation with maximum temperature, minimum temperature and average temperature. Same can be observed for year 2004.

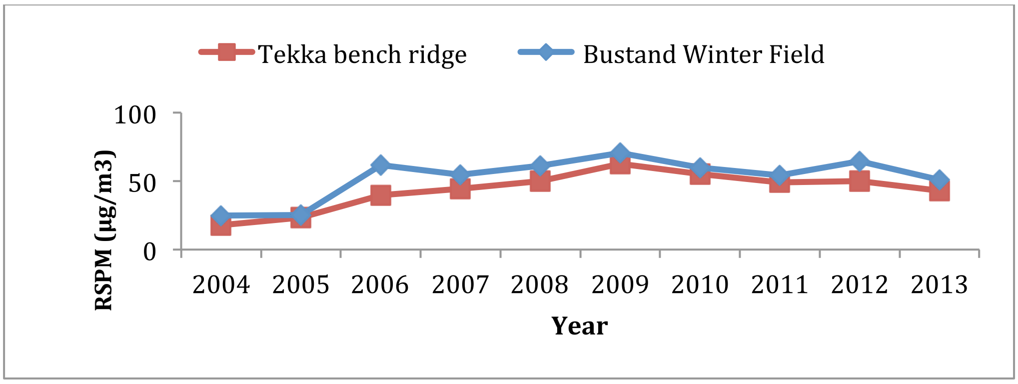


Figure 5: Annual mean RSPM concentration

Similar results are observed for RSPM, although wind velocity wasn't relatively high for this year another factor might have been tourist influx but since data for that year isn't available it couldn't be corroborated.

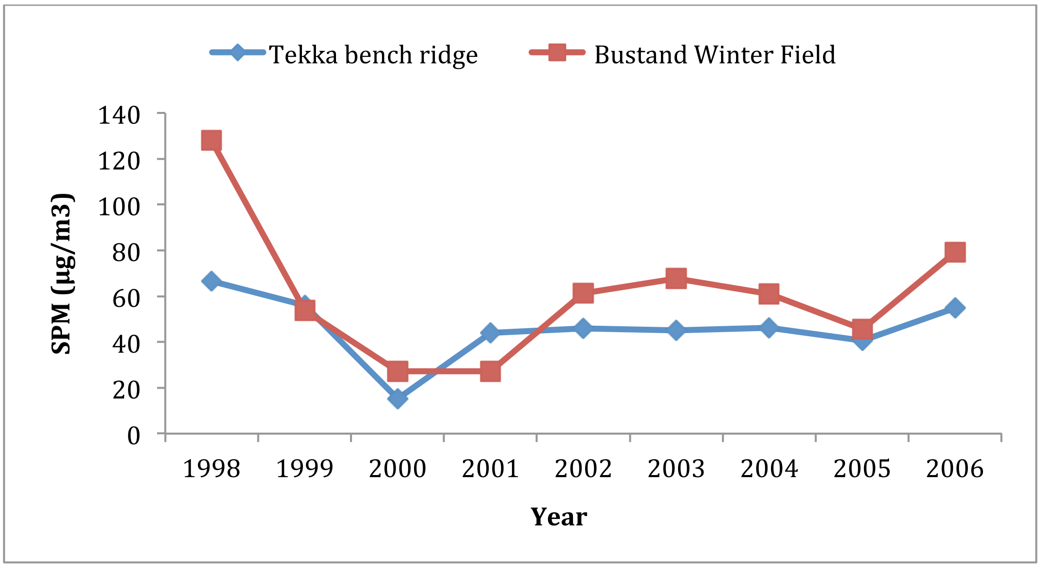


Figure 6: Annual mean SPM concentration

Discussing intersite variations there have been relatively good correlations between SO_2 and RSPM concentrations But SPM is showing differing values for two sites

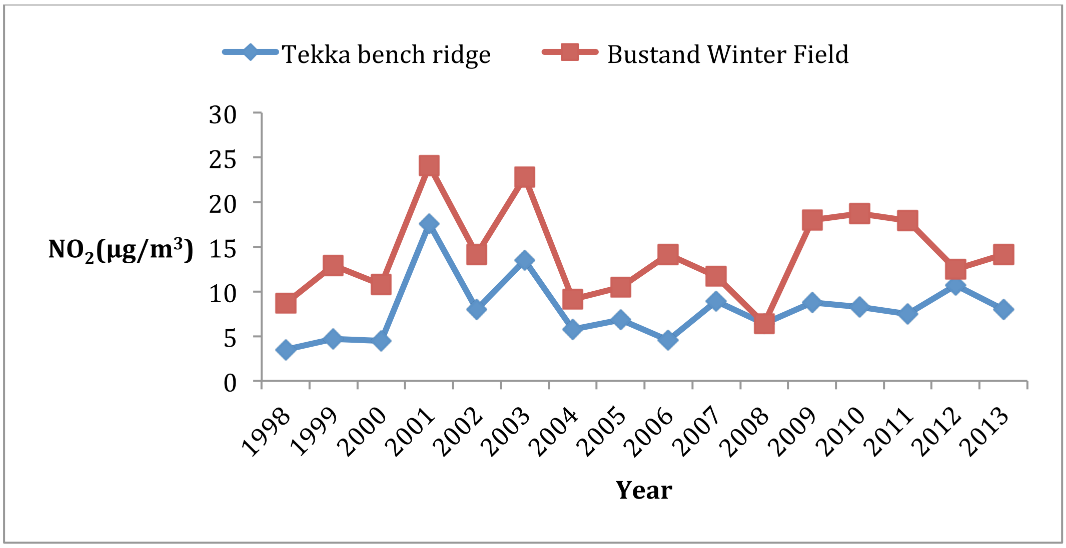


Figure 7: Annual mean NO_2 concentration

Now coming to NO_2 , it shows a negative correlation with all the meteorological parameters that we have used, only relation that could explain this trend is vehicle density, this also explains why there is a large difference in Bus stand and Ridge readings as bus stand experiences more vehicular inflow as compared to ridge.

From the above figure we can see the trends of $SO_{2,}$,NO_2, SPM and RSPM.

Except RSPM, another trend that can be observed is that in case of every other pollutant, Bus stand Winter field Station shows a higher concentration, the possible reason for this is the high vehicular traffic in that area. The vehicular data has been provided earlier in the report and this can be corroborated with that data.

4.3 Effects of Meteorological Conditions:

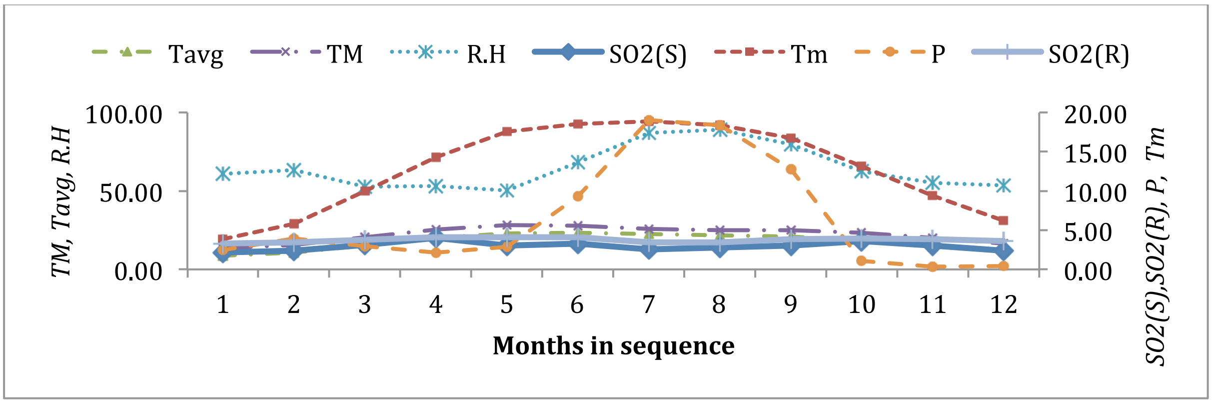


Figure 8: Variation of SO_2 concentrations in µg/m^3; P in cm; T_m, T_M, T_{avg} in °C; RH in %

The graphical plots reveal that, first maxima of air pollutant concentration occur during the pre-monsoon period (i.e from April to June). This maxima of air pollutant concentration coincides with pre-monsoon meteorological condition in Shimla, like increase in maximum minimum and average temperature, and having lower precipitation and relative humidity.

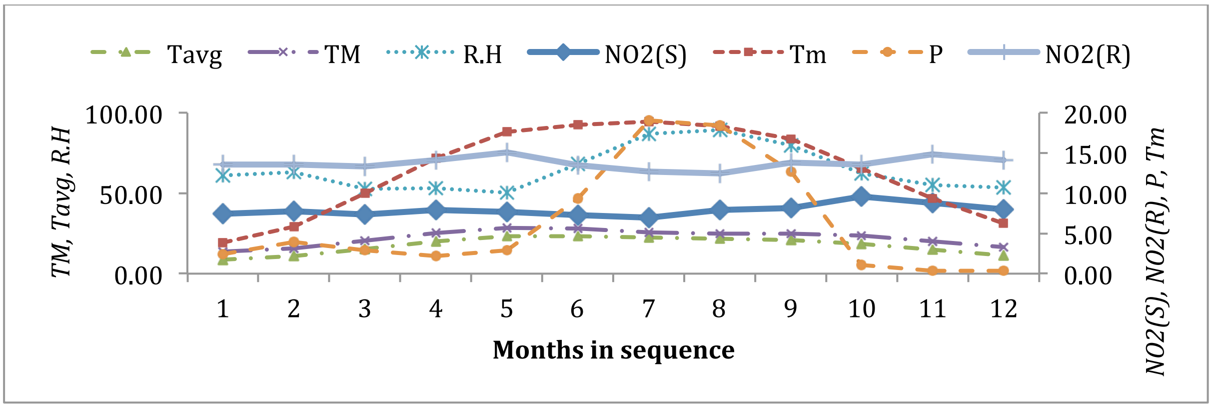
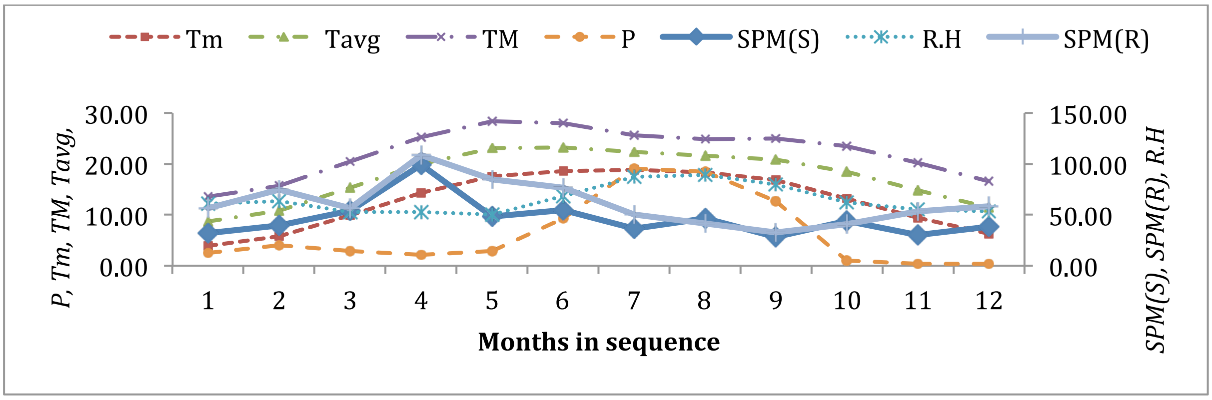


Figure 9: Variation of NO_2 concentrations in µg/m^3; P in cm; T_m, T_M, T_{avg} in °C; RH in %

During the monsoon season (i.e. from July to September) a minima in air pollutants concentration is well developed. The minima of air pollutant concentration during the monsoon season is mainly due to the Prevailing meteorological factors from July to

September, such as precipitation, high relative humidity, which leads to the wash out of pollutants from ambient air. This minima is followed by an increase in air pollutants concentration during the post monsoon season (i.e. from October to December), mainly because of lower minimum temperature, and maximum temperature, and less precipitation. These adverse meteorological condition, which marks the beginning of winter season increases the atmospheric stability and hence air pollutants concentration increases. Further the graphical plots reveals the second minima during the winter months (i.e. from January to March) coincides with moderate precipitation, increased relative humidity in the region. Due to these moderate climatic conditions, the atmosphere become unstable which in turns reduces the severity of air pollutants in ambient air.



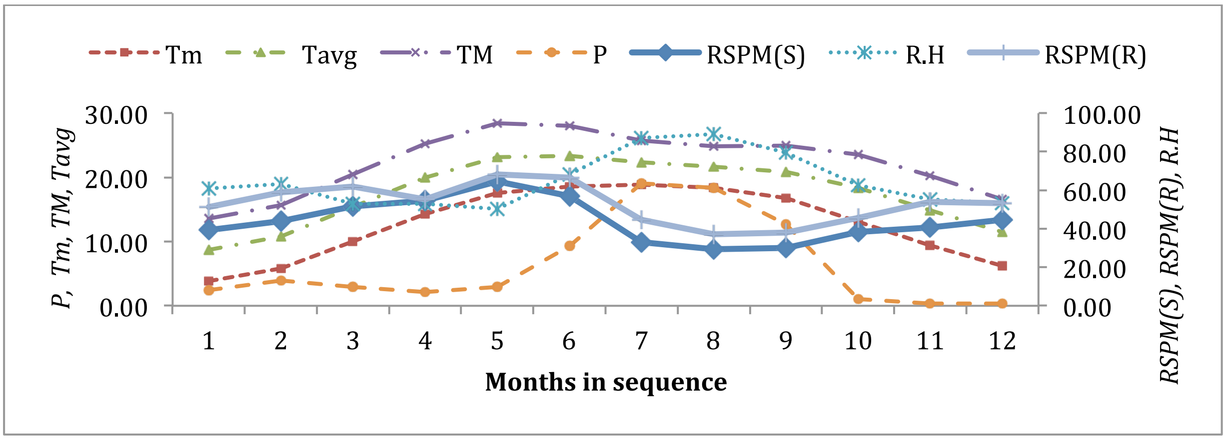


Figure 10: Variation of SPM and RSPM concentrations in µg/m3; SO2 and NO2 concentrations in µg/m3; P in cm; Tm, TM, Tavg in °C; RH in %

The seasonal influence of varying metrological condition on monthly mean concentration of SPM, RSPM, and NO_2 are well shown in above graphical plots (with their annual cycle having two maxima and minima. Even though the seasonal variation of SO_2 is not large for the residential site, but it shows a predictable variation for the sensitive site. It can be possibly due to following reasons.

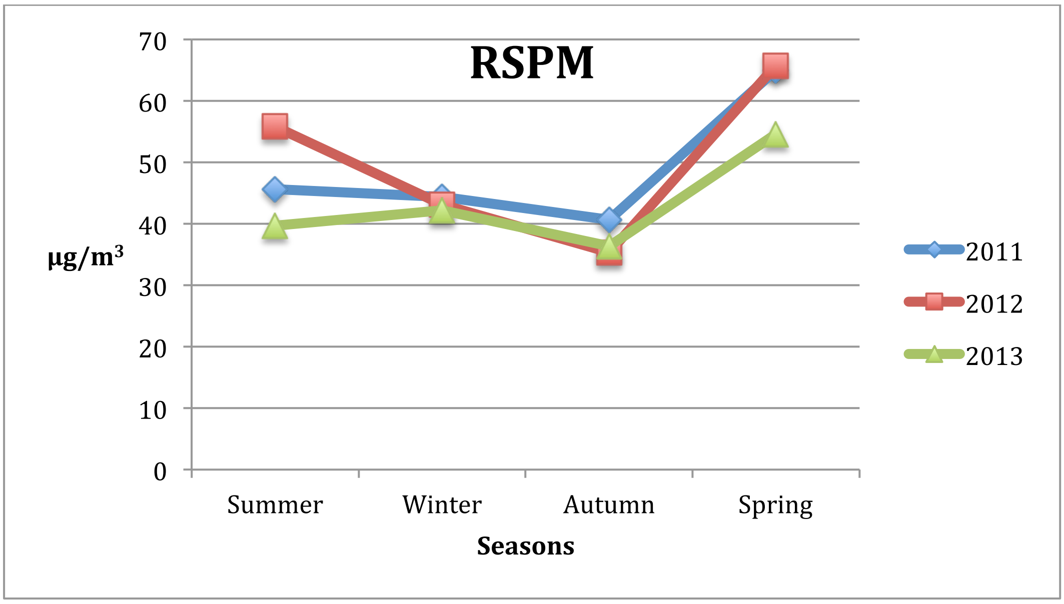
- Shimla being the hilly region, vehicular traffic is less as compared to metropolitan cities like Delhi.
- Numbers of industries are less because of elevated and mountainous terrain; also the industrial emission shows no seasonal trend.

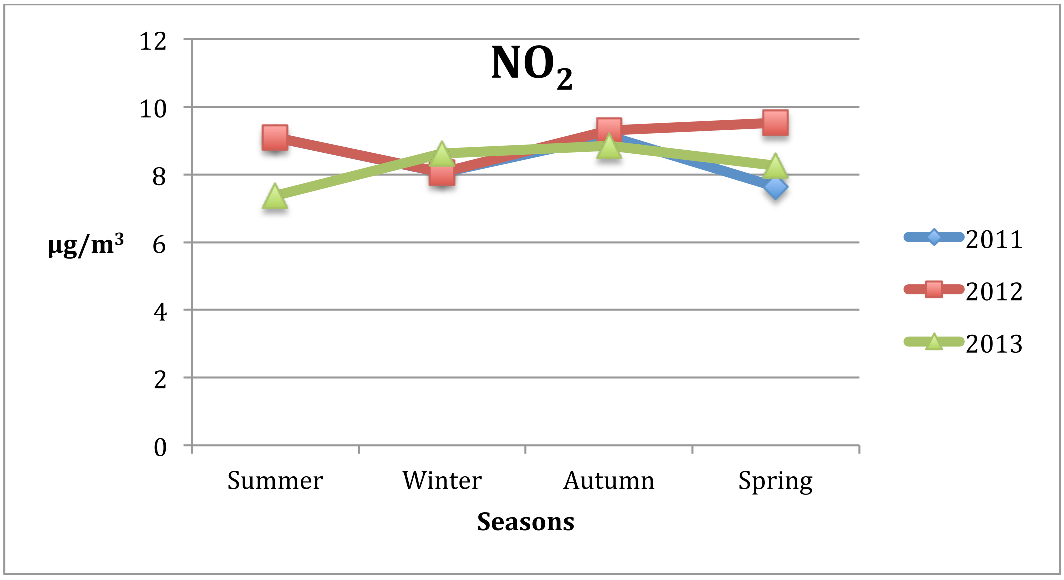
The graphical plots also reveals that there is very less difference between the monthly mean concentration of SO_2 for residential and sensitive site throughout the year; however, the NO_2 concentration are higher for residential site than the sensitive site throughout the year. Also SPM and RSPM concentration is higher throughout the year for residential site in comparison to sensitive site, except for SPM during the monsoon season when sensitive site dominates in monthly mean concentration of air pollutants than residential site. Dominance in monthly mean concentration of air pollutants for residential site throughout the year is possibly because of following reasons:

- High vehicular traffic in residential area.
- Less no of industries and economic activities in ecologically sensitive areas.
- Lush green environment of ecologically sensitive sites which absorb air pollutants

4.4 Seasonal Variations

A seasonal analysis for years 2011-13 has been performed for three pollutants that are SO_2, NO_2 and RSPM.





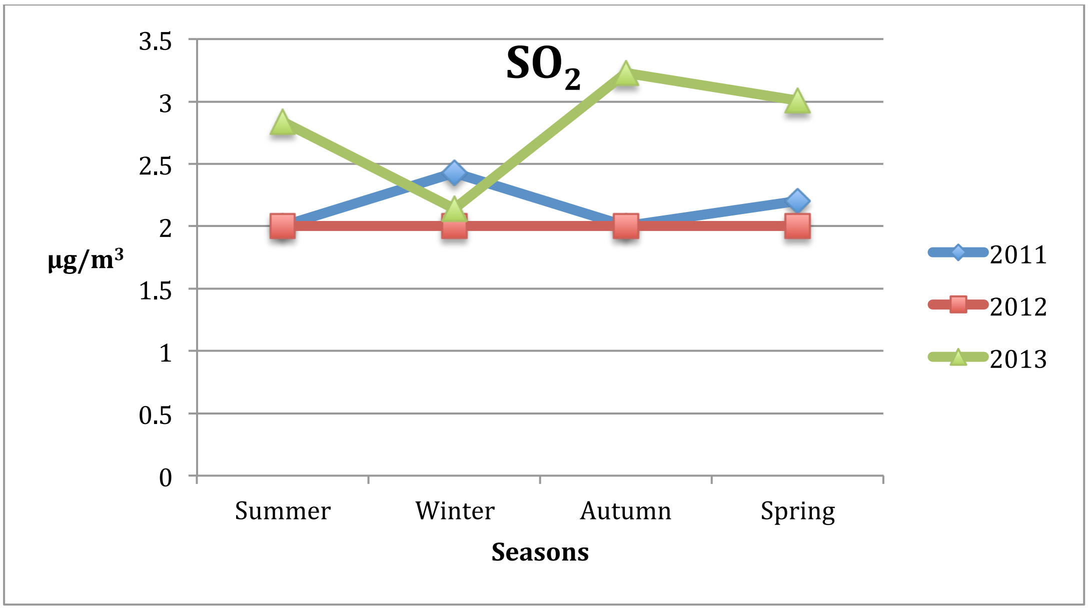


Figure 11: Seasonal variation of pollutants

Here the evident trend is that in summer season we area having a high concentration of SO_2 that decreases in winter and autumn before peaking in spring. This coincides with typical summer behavior of high temperature, dry atmosphere having low precipitation, lower wet day frequency, increasing cloud cover and decreasing diurnal temperature.

Now after it in winter and autumn season we can observe a decrease in concentration, which is probably due to prevailing meteorological conditions such as washout by rains and suppressed wind erosion due to highest precipitation, highest cloud cover and lowest diurnal temperature during that period.

Subsequent peak that is observed in spring is due to a stable atmosphere with conditions such as low cloud cover and low wet day frequency; these factors in turn lead to greater severity of air pollution.

4.4.1) Respirable Suspended Particulate Matter

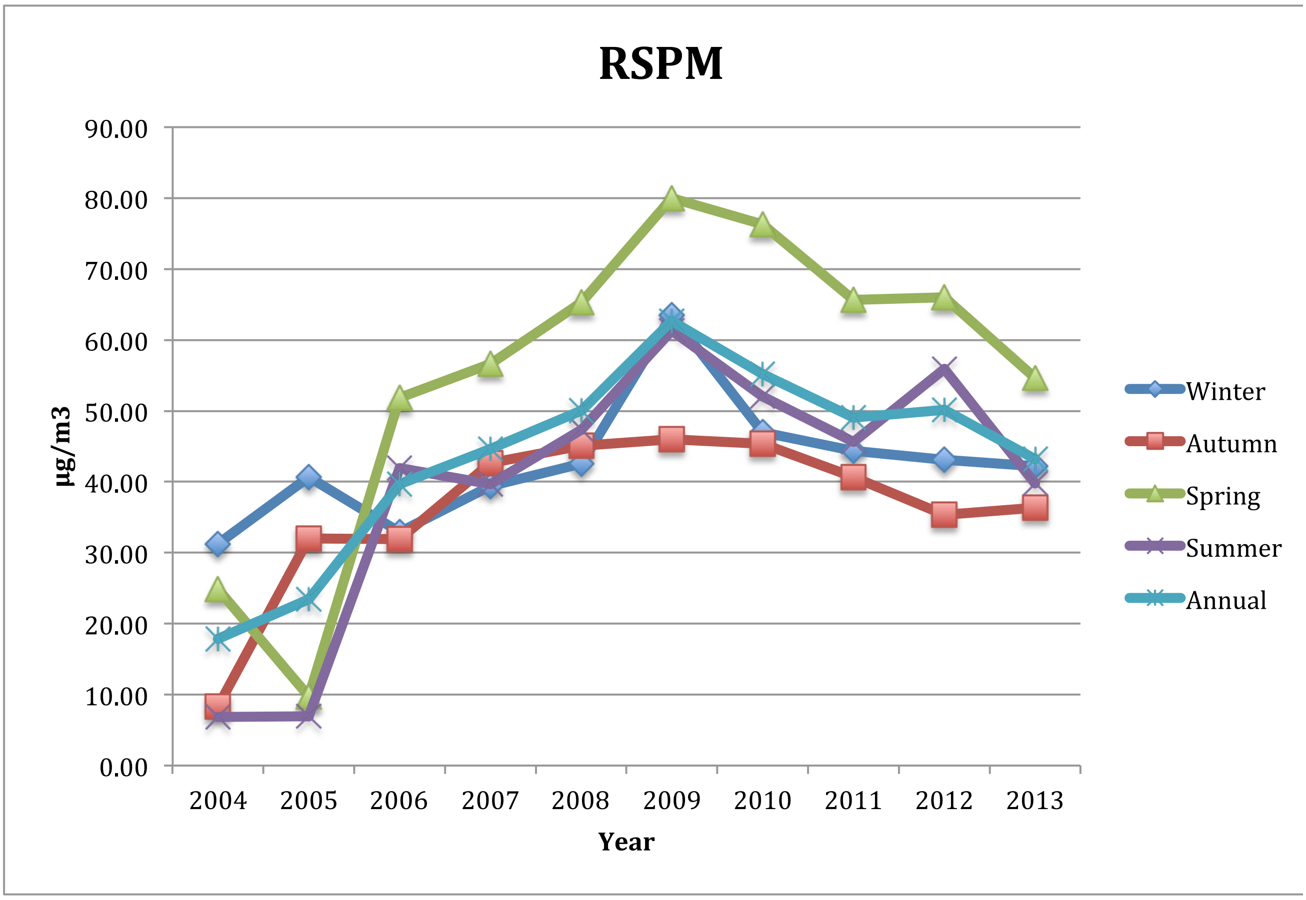
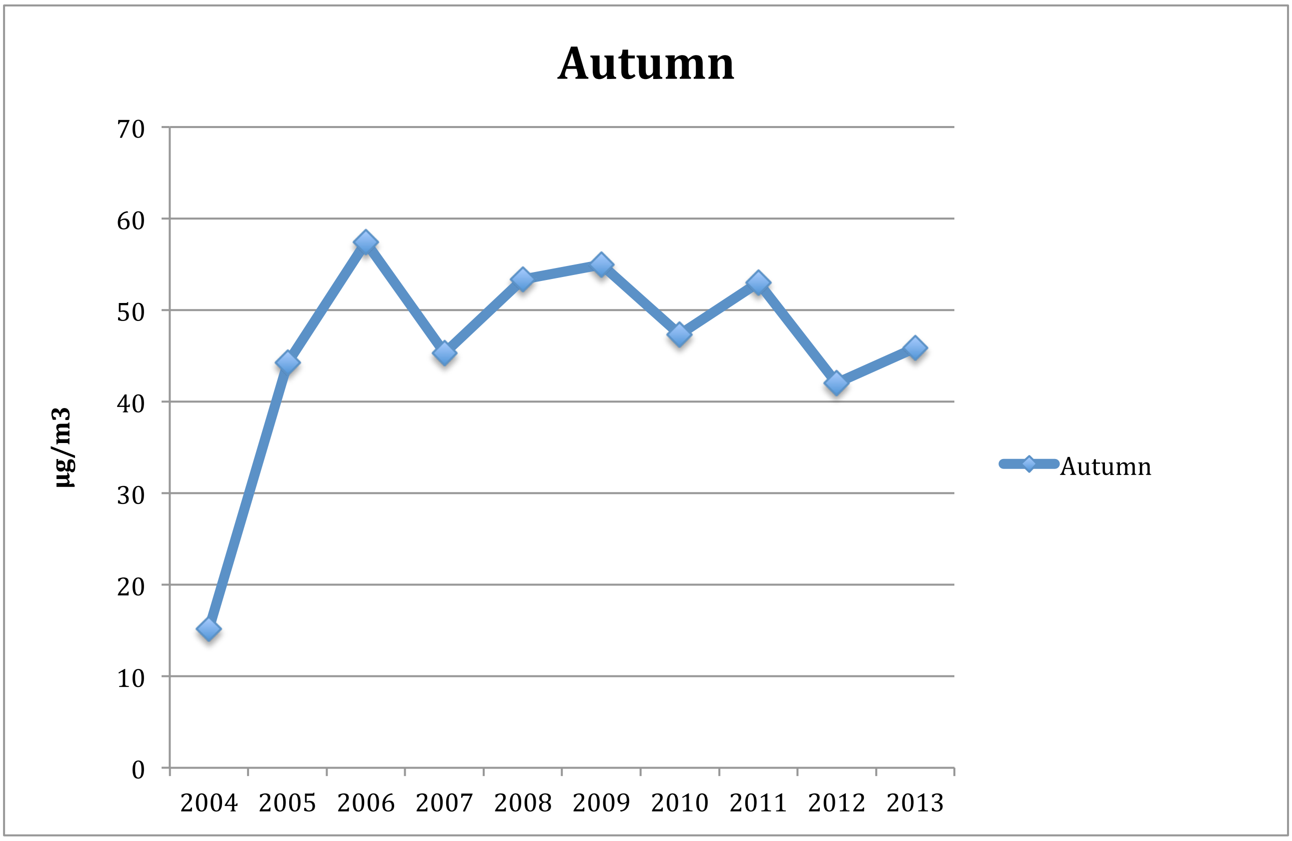
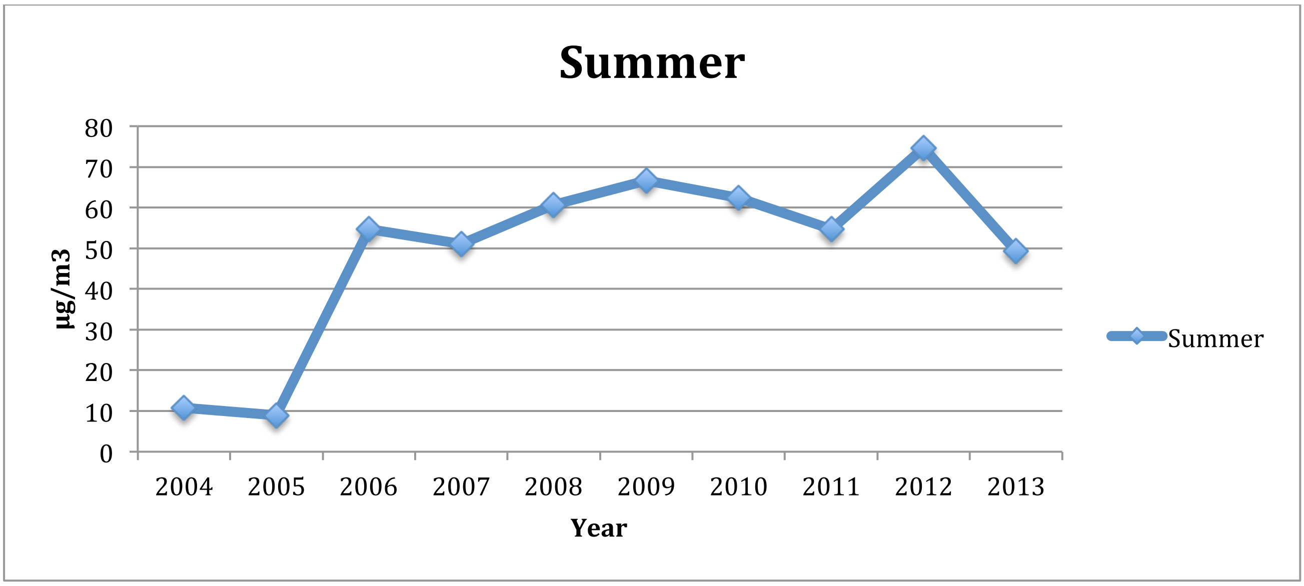


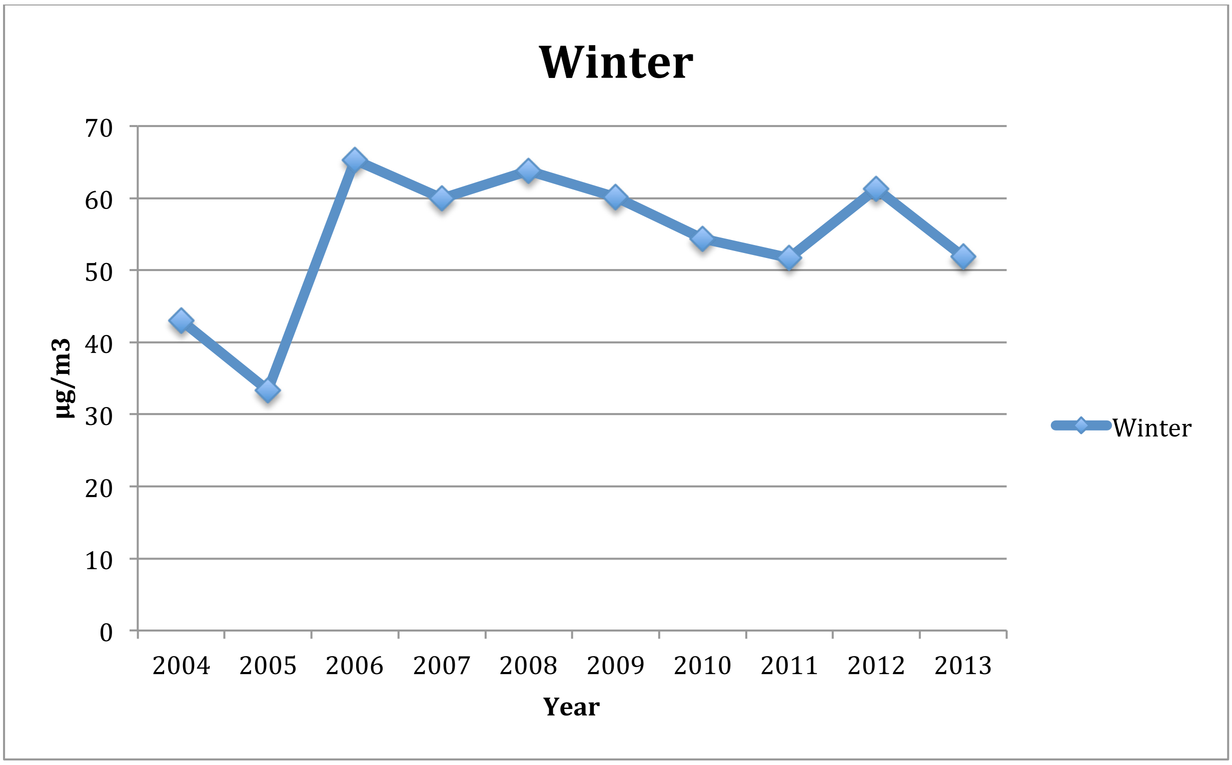
Figure 12: Annual seasonal mean concentration of RSPM

Now looking at a comparison of seasonal and annual average what is becoming evident is that spring is having highest concentration of RSPM even surpassing Annual average concentration. The main reasons for it can be relatively high windspeed in spring season especially in March, except spring, winter and summer seasons are also having peaks in 2012 and summer season has got another peak in 2012 with winter not being as high as in previous case but still giving a relatively high value. For summer season the possible reason can be high influx of tourist in 2009, which may have contributed to road dust and in turn, increasing the RSPM concentration; this can be corroborated by stats provided by Himachal Tourism department as 2,608,835 tourist visited Shimla in 2009. In winter especially in months of January and February, wind speed is usually high which also might have contributed to RSPM. Besides this the

RSPM also shows a negative correlation with relative humidity and precipitation and as both of them decreases in winter season, RSPM could have increased as a result of it.







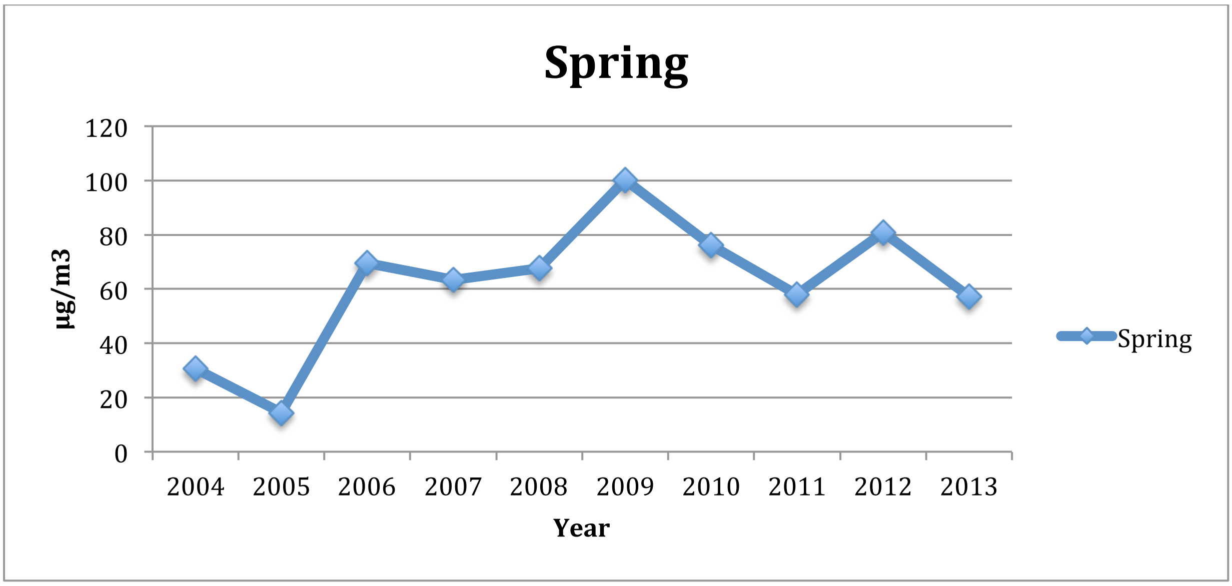


Figure 13: Annual individual seasonal mean concentration of pollutants

Here the trends shows that RSPM demonstrates that in summer of 2012 it went to be 74.7 **µg/m^3** and this was also the year which expereinced maximum number of tourists in recent years with tourists being 3354003 persons in number. In spring of 2009 also the value peaked at 100.1 **µg/m^3** this can be a result of moderate precipitation and high diurnal temperature which begins after end of March. This statement is further supported by corerelation of RSPM with maximum temperature.

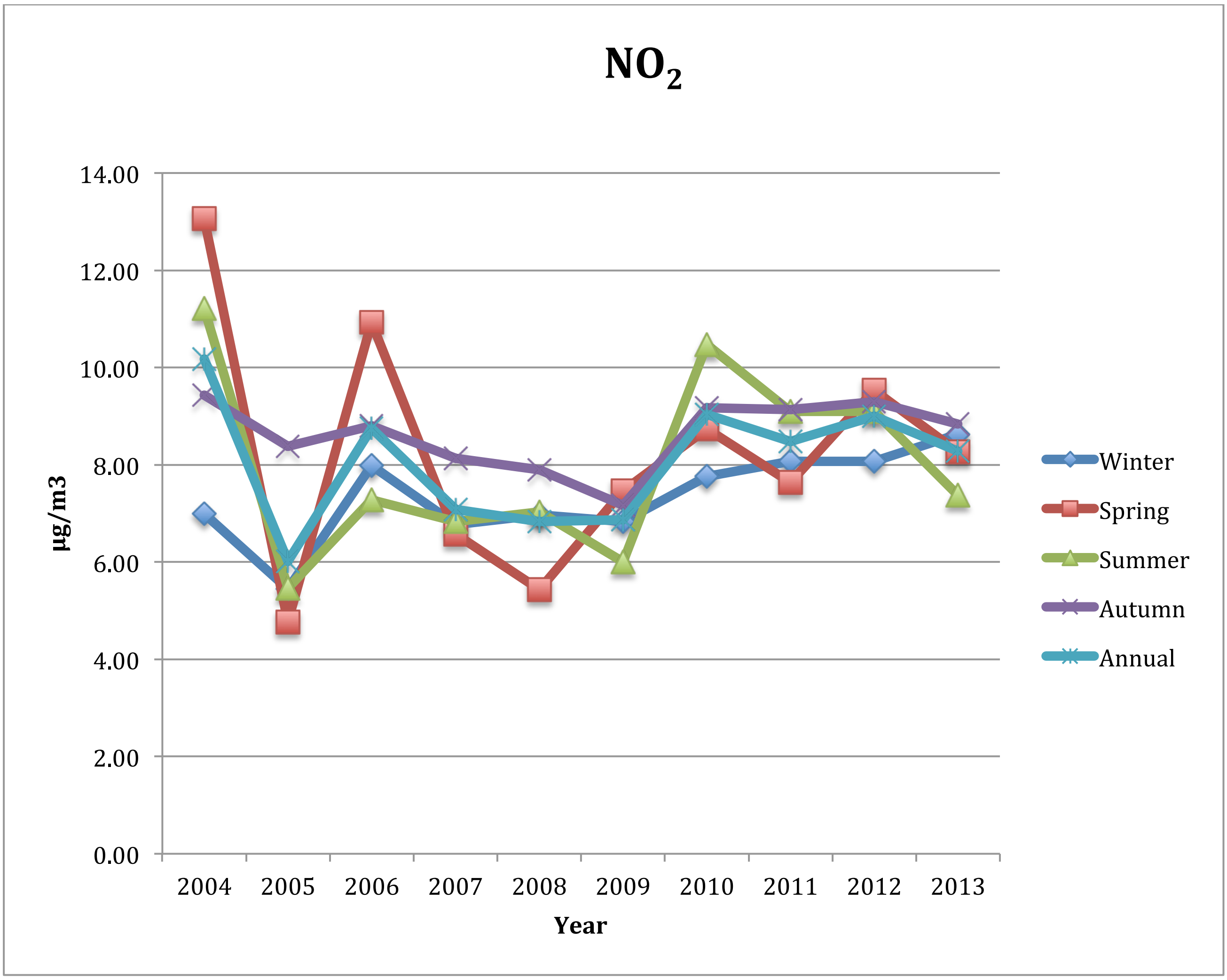


Figure 14: Annual and Seasonal comparison of NO_2 concentration

The value of NO_2 has been maximum in soring of year 2004 at 13.06 **µg/m3,** as spring marks the beginning of arrival of tourist so it is possible that it might be the reason for this peak, beside this NO_2 is showing a negative correlation with all meteorological parameters. Another rise is shown in spring of 2006 after that the values have remained low but increased in 2012, which was the year, which had maximum number of tourists in recent years.

4.5 Linear Regression

A linear regression is carried out on air quality and meteorological data to study the effect of individual meteorological parameter on air quality parameter.

The results reveal the following:

- The effects of meteorological conditions differ between air pollutants
- Highest correlation of air quality parameter is obtained with average temperature
- The relative humidity and precipitation are negatively correlated with air pollutants for both sites
- The minimum temperature is slightly negatively correlated with air pollutants for the residential site, where as positively correlated with air pollutants for ecologically sensitive site, it may because of less economic activities in hilly region with increase in minimum temperature
- Maximum Temperature and Average temperature are positively correlated for both the sites
- The effect of meteorological condition differs between air pollutants
- The analysis reveals significant correlation of air quality parameters with relative humidity and precipitation, followed by less correlation with minimum, maximum, and average temperature
- Local meteorological condition shows significant effect on air pollutants of Shimla. The annual cycles showing two maxima and minima is well correlated with monthly mean concentration trend of pollutants (SO_2, NO_2, SPM, RSPM)

- The first maxima coincide with minimum precipitation during the pre-monsoon months (i.e. April to June). The second maxima coincides with cold weather condition (i.e. from October to December), with increased minimum temperature and lower max temperature

- Air pollutants shows negative correlation with precipitation and relative humidity, hence decreases with increase in precipitation and relative humidity. Where as shows positive correlation with maximum temperature, and min temperature, and least dependent on average temperature. Also the impact of meteorological condition is different for all pollutants.

Below table suggests significant, though varying and contrary effects of meteorological conditions on air quality.

It has been obtained by carrying out a multi linear regression with the aim of studying the holistic impact of meteorological variables on air quality.

Met. ⇒ Parameters	T_{min}		T_{max}		T_{avg}		P		RH	
Air quality ⇓ parameters	**r**	**R^2**	**r**	**R^2**	**r**	**R^2**	**r**	**R^2**	**r**	**R^2**
SO_2 (S)	0.453	0.206	0.619	0.383	0.540	0.292	-0.192	0.037	-0.240	0.057
NO_2 (S)	-0.140	0.020	-0.051	0.003	-0.098	0.010	-0.419	0.176	-0.205	0.042
SPM (S)	0.235	0.055	0.360	0.130	0.301	0.091	-0.168	0.028	-0.309	0.095
RSPM (S)	0.02	0.000	0.24	0.056	0.13	0.016	-0.53	0.281	-0.73	0.535
SO_2 (R)	0.44	0.193	0.65	0.429	0.55	0.302	-0.31	0.097	-0.42	0.176
NO_2 (R)	-0.219	0.048	-0.001	0.000	-0.114	0.013	-0.711	0.506	-0.763	0.583
SPM (R)	-0.014	0.000	0.150	0.022	0.068	0.005	-0.381	0.145	-0.551	0.304
RSPM (R)	-0.168	0.028	0.028	0.001	-0.072	0.005	-0.552	0.305	-0.721	0.519

Table 3: Correlational between air quality and meteorological parameters

To ensure the accuracy of study, cross validation has been carried out too. The correlation coefficient (r) and coefficient of determination (R^2) for different combinations are obtained and presented below:

RSPM (R) = -58.501-15.982×T min+15.086×T max+0.436×P-0.752×Rh

SO_2 (R) = -1.531-0.331×T min+0.372×T max+1.180E-03×P+1.759E-02×Rh

NO_2 (R) = 14.0685-2.881E-02×T min+8.0142E-02×T max-4.797E-03×P-2.253E-02×Rh

SPM(R)=-145.792219708363-29.254212040273 × Tmin+28.0146374509789 × Tmax+0.838784416185499×P-1.50303098163594×Rh

The monthly mean concentration of air quality parameters predicted from above equations is plotted against the observed concentrations values in below figure. The SPM and RSPM values have been predicted with a scatter of 24% and that of SO_2 and NO_2 with a scatter of 10%.

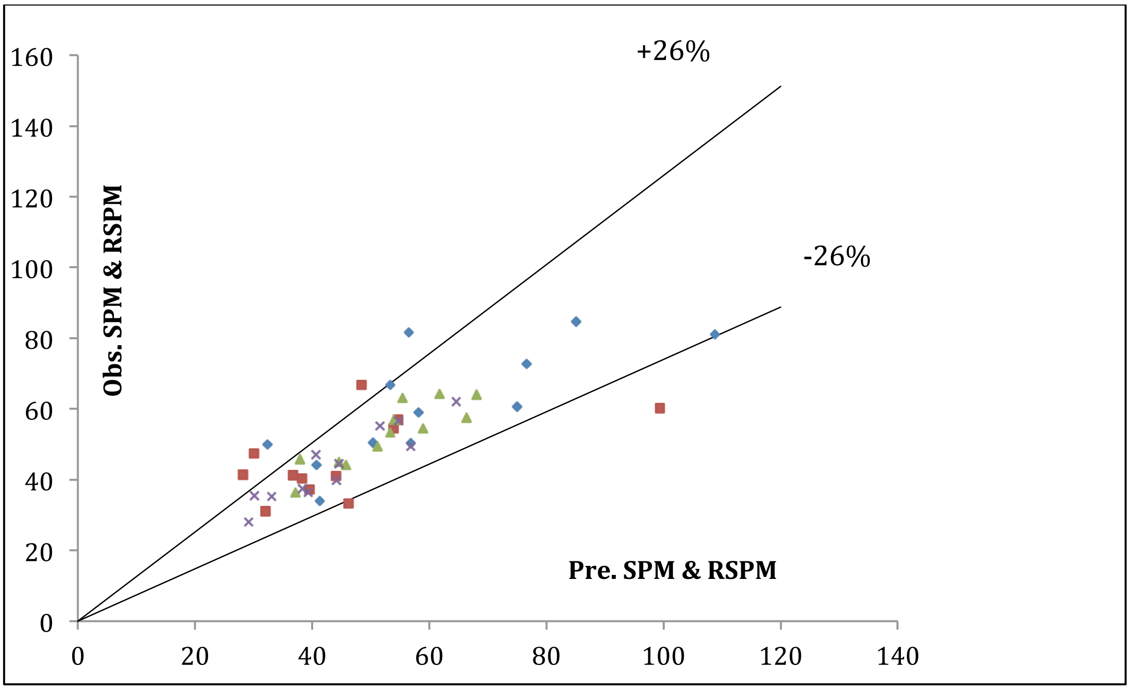


Figure 15: Observed SPM and RSPM

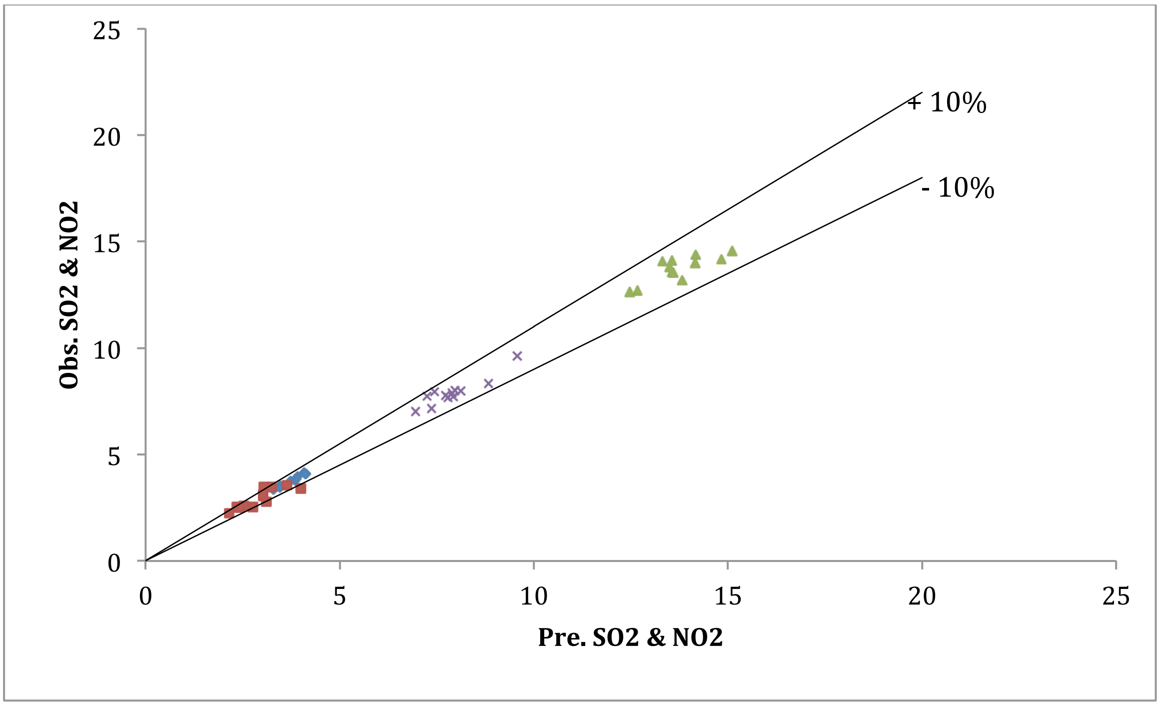


Figure 16: Observed $S0_2$ and NO_2

Chapter 5

Conclusion:

The effect of local meteorological condition on air pollutants (SO_2, NO_2, SPM, RSPM) concentration in Shimla have been analysed on monthly basis. The findings of present study are as follow:

Local meteorological condition shows significant effect on air pollutants of Shimla. The annual cycles showing two maxima and minima is well correlated with monthly mean concentration trend of pollutants (SO_2, NO_2, SPM, RSPM).

The first maxima coincides with minimum precipitation during the pre-monsoon months (i.e April to June). The second maxima coincides with cold weather condition (i.e from October to December), with increased minimum temperature and lower max temperature.

Air pollutants shows negative correlation with precipitation and relative humidity, hence decreases with increase in precipitation and relative humidity. Where as shows positive correlation with maximum temperature, and min temperature, and least dependent on average temperature. Also the impact of meteorological condition is different for all pollutants.

The Multi-linear regression approach can be used for predicting the air pollution in Shimla, by predicting the concentration of SO_2, NO_2, SPM, RSPM using the equations, given by multi-linear regression analysis.

SO_2, NO_2 concentration are well predicted with in small range of ±10% which is considerably good, although the predicted concentration of SPM, RSPM was in the range of ±26% (Figure 16 and 17).

The present study concludes that multi-linear regression approach can be used to develop a relation between air quality and meteorological parameters in Shimla. Although the application of more holistic approach, Such as Principal Component analysis (Jiang et al., 2005a; Hongliang., 2015) may be helpful in further understanding the impacts of meteorological condition on local air quality.

5. References

AN LI, JAE-KIL JANG, ANDPETER A. SCHEFF "A population exposure model for particulate matter: Case study results for PM 2.5" School of Public Health, University of Illinois at Chicago, 2121 West Taylor Street, MC-922, Chicago, Illinois 60612-7260

Bo R. Larsen, Fulvio Amato (1998)"Receptor modeling of ambient and personal exposure samples" US EPA, National Exposure Research Laboratory, Research Triangle Park, North Carolina 27711

Claudio A. Belis, Bo R. Larsen, Fulvio Amato, Imad El Haddad, Olivier Favez, Roy M.Harrison, Philip K. Hopke, Silvia Nava, Pentti Paatero, André Prévôt, Ulrich Quass, Roberta Vecchi, Mar Viana (2014)"European Guide on Air Pollution Source Apportionment with Receptor Models 2014", page 6-9,12-15

Economic Survey of Himachal Pradesh (2012-2013) "Department of Economics and Statistics, Government of Himachal Pradesh"

Economic Survey of Himachal Pradesh (2013-2014) "Department of Economics and Statistics, Government of Himachal Pradesh"

Economic Survey of Himachal Pradesh (2014-2015) "Department of Economics and Statistics, Government of Himachal Pradesh"

JEFF CHARLTON "Pandemic planning: a review of respirator and mask protection levels" National Exposure Research Laboratory, U.S. Environmental Protection Agency, 109 TW Alexander Drive, Research Triangle Park, NC 27711, USA

Hongliang Zhang , YungangWang, JianlinHu. (2015) ' Relationships between meteorological parameters and criteria air pollutants in three megacities in China ' , Environmental Research, Vol 140.

Jiang, N., Hay, J.E. and Fisher, G.W. (2005) 'Effects of meteorological conditions on concentrations of nitrogen oxides in Auckland', *Weather and Climate*, Vol. 24, pp.15–34.

Keeley L, Bignal, Mike R. Ashmore, Alistair D. Headley. (2007) ' Ecological impacts of air pollution from road transport on local vegetation ' , Applied Geochemistry, Vol 22, Issue 6.

M.C.S. (2008), Geographical "Municipal corporation of Shimla, Government of HimachalPradesh", http://web.archive.org/web/20070403005805/http://www.shimlamc.org/mcshimla.htm

M.C.S. (2008), General profile "Municipal corporation of Shimla, Government of HimachalPradesh", http://web.archive.org/web/20070403005805/http://www.shimlamc.org/mcshimla.htm.

M.C.S. (2008), General profile "Municipal corporation of Shimla, Government of Himachal Pradesh" ,http://web.archive.org/web/20070403005805/http://www.shimlamc.org/mcshimla.htm

National air quality Standards (2009), *Central Pollution Control Board, Government of India* http://cpcb.nic.in/National_Ambient_Air_Quality_Standards.php.

Number of Vehicles by Regional Transport Office, Shimla

National Air Quality Index by Central Pollution Control Board 2014,15 pages 5,11,18,20 and 21

Philip K. Hopke, Ziad (2003) "Particulate Matter Epidemiology-Exposure Study" [a] Department of Chemical Engineering, Clarkson University, Box 5810, Potsdam, NY 13699-5810, USA [b] Department of Physics, University of Helsinki, Helsinki, Finland[c] US EPA, National Exposure Research Laboratory, Research Triangle Park, NC 27711, USA

Surinder Deswal and Pankaj Chadha "Effects of Meteorological Conditions on Concentration of Air Pollutants in Delhi", *Int. J. Environment and Pollution*, Vol 42. Nos. /1/2/3, 2010