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Influence of Oxides of Nitrogen, Carbon Monoxide and Sulpher Dioxide on Surface Ozone Level in Different Meteorological Seasons in Haryana State, Northern India

Ram Chhavi Sharma[1,*], Niharika Sharma[2]

[1]Department of Physics, Faculty of Physical Sciences, Shree Guru Gobind Singh Tricentenary (SGT) University Gurgaon, Haryana, India
[2]Department of Chemistry, Government Senior Secondary School Kakoria Rewari, Haryana, India
*Corresponding author: ramchhavisharma@yahoo.com

Abstract Surface Ozone concentrations are valuable indicators of possible health and environmental impacts. Increasing concentration of Tropospheric ozone (O_3) is a serious air pollution problem faced commonly by the urban people. In the present study ozone (O_3), Oxides of Nitrogen (NO_x) Carbon monoxide (CO) and Sulpher dioxide (SO_2) data were collected for a period of one year (January 01, 2015 to December 31, 2015) at three ambient air quality monitoring stations (Gurgaon now Gurugram, Rohtak and Panchkula) in Haryana state in Northern India. The O_3, NO_x CO, and SO_2 data were collected by Haryana State Pollution Control Board. The concentration of O_3 is correlated with the concentration of NO_x, CO, and SO_2 in different meteorological seasons. The regression correlation analysis has been performed between NO_x, CO, SO_2 and O_3 to investigate the relationship between them. It was found that the variation in concentration of NO_x, CO and SO_2 influenced the changes in the concentration of O_3 in different seasons of the year. The investigation data showed that NO_x, CO and SO_2 had the important influence on O_3 concentration variations in monsoon session (r^2 = -0.256, -0.322, -0.137 for Gurgaon, r^2= 0.997, -0.829 and 0.843 for Rohtak and r^2= – 0.854, -0.829 and 0.262 for Panchkula). The influence of SO_2 on O_3 concentration has been observed to be different from NO_x and CO. O_3 and NO_x were observed to be inversely related in most of the seasons (r2= 0.124, 0.389, -0.256 and -0.694 in Gurgaon, r^2 = -0.797, -0.819, 0.997 and -0.797 in Rohtak & r^2=0.971,-0.074, -0.854 & 0.784 in Panchkula for spring, pre-monsoon, monsoon and post monsoon season respectively). The regression equations have been obtained which correlates O_3 with NO_x, CO and SO_2.

Keywords: *ozone, oxides of nitrogen, carbon monoxide, sulpher dioxide, urban ambient air quality, correlation, regression analysis*

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1. Introduction

Air Pollution is a challenging problem as it would hinder sustainable development all over the globe [1]. The factors responsible for occurrence of air pollution include meteorological factors, earth surface topographic features and released air pollutants from various sources. Meteorological factors such as wind velocity, wind direction, temperature, and relative humidity together with earth surface roughness are effective agents for mixture of air pollutants. The most important role of meteorology is in the dispersion, transformation and removal of air pollutants from atmosphere. The wind speeds determine the amount of dispersion of pollutants while temperature contributes transformation of pollutants in the atmosphere. The topography and solar heating of region surrounding a particular pollution source affects the concentration. High pollution levels can be expected during fair weather conditions resulting local wind system and strong temperature inversions in cities situated in mountainous region. Air pollution may be classified into two types according to the nature of formation: primary pollutants which are emitted from their sources directly to the atmosphere such as industry, traffic, domestic heating in winter season and secondary pollutants which results from the chemical reaction between the primary pollutants. Examples of primary pollutants are oxides of nitrogen (NO_x), carbon monoxide (CO) and sulphur dioxide (SO_2). Examples of secondary pollutants are photochemical oxidants and ozone (O_3).

Oxides of Nitrogen in the atmosphere originate either from natural processes or anthropogenic activity. In the lower atmosphere, nitric oxide (NO) is converted to nitrogen dioxide (NO_2) by reaction with proxy-radicals (RO_2) or O_3. The NO_2 generated is then undergoes photo dissociation in the atmosphere and the atomic oxygen released combines with molecular oxygen to form O_3 [2]. The life time of NO_x ($NO+NO_2$) in the troposphere ranges from less than one day in summer to several days in the absence of active photochemistry.

Carbon monoxide is an important trace gas in the earth's atmosphere, which performs several important roles in the troposphere. There are a variety of sources, both natural and anthropogenic, for ambient CO. Natural sources include oxidation of methane and natural hydrocarbons, ocean emissions, and emissions from vegetation. In rural areas, these are the most dominant sources; therefore, in a remote location, CO is one of the most dominant precursors for photo-chemical ozone production. In urban areas, however anthropogenic sources including fossil fuel combustion, industrial activities, motor vehicles, biomass burning, and oxidation of anthropogenic hydrocarbons, contribute far more to the concentration of CO than natural sources. The lifetime of CO is approximately 1-3 months, representing the slow rate of mixing and the consumption by reaction with OH. In the troposphere, a significant CO background concentration exists based on continuous CO production from the oxidation of methane and its long lifetime [2].

Sulfur dioxide is a major air pollutant and has significant impacts upon human health. Sulfur dioxide emissions are a precursor to acid rain and atmospheric particulates. It influenced O_3 formation. Role of SO_2 in O_3 formation is dependent on HO_2 produced from SO_2 [3]. The utmost anthropogenic sources of SO_2 consequences are from the burning of fossil fuels and from the smelting sulphide ores [4]. Among man made sources fuel combustion, industry and transportation are the main contributors. A significant feature of SO_2 is that, once it is emitted from the atmosphere, it can be converted through complex oxidation reactions in to fine particulate sulphate and removed from the atmosphere by wet or dry deposition [5,6].

Ozone is a major environmental concern because of its adverse impact on human health [7,8] and also because of its impacts on crops and forest ecosystems [9,10]. Tropospheric O_3 may originate by interchange with the stratosphere and/or photochemical production. In the urban atmosphere, NO_x and volatile organic compounds may either increase or decrease O_3 concentrations. O_3 formation is closely related to meteorological parameters such as temperature, solar radiation, and wind speed [11].

A thorough understanding of the relationship among O_3, NO_x, SO_2 and CO under various atmospheric conditions is urgently needed to improve our understanding of the chemical coupling among these pollutants [12,13,14,15,16]. Seasonal variation effects on gaseous pollutants are of great significance to the life span and cycle of any pollutant in the lower atmosphere [17].

In the present study, the levels of air pollutants NO_x, CO, SO_2 and O_3 were measured at three urban locations (Gurgaon, Rohtak and Panchkula) in Haryana state (Figure 1) for a period of one year from January 01,2015 to December 31, 2015. The concentrations of NO_x, CO and SO_2 were statistically correlated with concentration of O_3 using regression analysis in spring, pre-monsoon, monsoon and post monsoon seasons. The regression equations have been obtained which correlates O_3 with NO_x, CO and SO_2.

2. Description of the Study Area

Haryana is the 20th state of India that came into being on 1st November 1966. It is situated in the North Western region surrounded by Himachal Pradesh from North, Uttrakhand from North East, Rajasthan from the South, U.P and Delhi from East and Punjab from North West. Three districts, Gurgaon, Rohtak and Panchkula of Haryana state have been selected for the present study. The brief information's about sampling sites are given in Table 1.

Figure 1. Map of Haryana state showing study area: Gurgaon (now Gurugram), Rohtak and Panchkula

Table 1. Information on Monitoring sites

Monitoring sites	Site Classification	Description
Gurgaon Vikas Sadan	Urban, faster pace of development.	An urban location near to National Highway-8. Industrial units like Hero group, Honda and Maruti Udyog are situated in the district. Faster pace of development and thickly populated. Gurgaon experiences a monsoon-influenced humid subtropical climate
Rohtak, MDU	Urban, Eastern Haryana Plain	Rohtak district constitutes a major part of eastern Haryana plain. The district has witnessed rapid industrialization, urbanization, diversification in agriculture and change in occupation structure. The district is situated on the National Highway No. 10.The climate of Rohtak district is sub-tropical, semi arid, continental and monsoon type.
Panchkula HSPCB, Sector 6	Urban Residential, Himalayas boundary fault zone	Panchkula district has a sub tropical continental monsoon climate having, hot summers, cool winters, good monsoon rainfall. It has great variation in temperature (-1 °C to 43 °C). Sometimes winter frost occurs during December and January. The district lies in the Himalayas boundary fault zones and earthquakes of moderate to high intensity have occurred in the past. Morni hills constitute the highest point of the district as well as of Haryana.

Gurgaon district falls in the southern most region of the state of Haryana. To its advantage of being situated in vicinity of Delhi, Gurgaon falls under National Capital Region. It lies in between the 27° 39’ and 28° 32’25’’ latitude, and 76° 39’ 30’’ and 77° 20’ 45’’ longitude. Gurgaon is the sixth largest city of Haryana State and is situated on both sides of National highway 8. It accommodates a population of 1514432 (2011 Population census figures), 5.97 percent of the state population. Its density according to 2011 population census is 1204 persons per Sq. km. against 573 in the state, which get further compounded due to migration of people from different part of country in search of job. It has been on the faster pace of the development and emerged as the industrial and financial hub of Haryana. Rapid urbanization, increasing industrialization and enhanced men made perturbations added excess pollutants in the atmosphere resulting environmental degradation and climate change [18].

Rohtak district is located in southeastern part of Haryana State (30^{o} 1’N, 75^{o} 17’E) and constitutes a major part of eastern Haryana plain. The climate of Rohtak district is sub-tropical, semi arid, Continental and monsoon type. Thus, it has hot summers, cool winters and small rainy season. Due to less rainfall and its short duration the agricultural activities is mostly dependent upon canal irrigation and Tube wells. According to the 2011 census Rohtak district has a population of 1,058,683[1]. The district has a population density of 607 inhabitants per square kilometer. Its population growth rate over the decade 2001-2011 was 12.61%.The district has witnessed rapid industrialization, urbanization, diversification in agriculture and change in occupation structure. The district is situated on the National Highway No. 10.

Panchkula (30^{o}41’ N and 76^{o}52’ E) district has a sub tropical continental monsoon climate having, hot summers, cool winters, good monsoon rainfall. It has great variation in temperature (-1 °C to 43 °C). Sometimes winter frost occurs during December and January. The district also receives winter rains from the western disturbance. The rainfall is mostly received in the monsoon. Morni hills constitute the highest point of the district as well as of Haryana. The Ghaggar is the only perennial river, which is very shallow outside of the monsoon. Generally the slope of the district is from north east to south west and in this direction, most of the rivers/streams rain-fed torrents flow down and spread much gravel and pebbles in their beds. The soils in the district are mainly light loam. The district lies in the Himalayas boundary fault zones and earthquakes of moderate to high intensity have occurred in the past. According to 2011 census of India, it was the least populous district of Haryana and had a population of 558890.The district has a population density of 622 inhabitants per square kilometer. Its population growth rate over the decade 2001-2011 was 19.32% [18,19].

3. Methods & Materials

For the present study, we used ambient air quality data collected by the Haryana State Pollution Control Board (HSPCB) using Ozone analyzer (O-342M), NOx analyzer (AC-32M), CO analyzer (CO-12M), and SO2 analyzer (AF-22M) [20] for a period of one year from January 01, 2015 to December 31, 2015. The NO_x, CO, SO_2 and O_3 samples were collected by the HSPCB using their respective analyzers which could be operated up to 28 hrs and the sampling duration was 24 hrs as accepted by the Environmental Protection Agency (EPA) of the U.S.A. and the Central Pollution Control Board (CPCB) of India. Oxides of nitrogen analyzer use proven chemi-luminescence technology to measure NO_x in ambient air quality. The CO analyzer works on the principle of non-dispersive absorption and SO_2 analyzer operates on the principle of light absorption, where the SO_2 molecules are excited by absorbing light at one wavelength and later decay to a lower energy state by emitting UV light at a different wavelength which is proportional to SO_2 concentration. The O_3 analyzer also works on the absorption principle i.e. O_3 molecules absorbs UV light at 254nm wavelength. The degree of absorption is directly related to O_3 concentration as described by Beer-Lambert law [21,22,23]. O_3 measurements are automatically corrected for gas temperature / pressure changes and can be displayed in units of ppm, µg/m^3 or mg/m^3. In this study the regression correlation analysis has been performed between O_3 & NO_x, CO and SO_2 for different meteorological seasons to investigate the relationships between them. This analysis will give an idea about which season and meteorological conditions play a major role in regulating O_3, CO, SO_2 and NO_x concentrations over the sampling sites and also how SO_2, NO_x and CO concentration affects O_3 under different meteorological conditions.

4. Results and Discussion

In this study, we have analyzed and correlated the NO_x, CO and SO_2 data with O_3 concentrations obtained at three sites in Haryana State in Northern India for spring, pre-monsoon, monsoon and post-monsoon seasons for the period from January 01, 2015 to December 31, 2015. The NO_x, CO and SO_2 variations and their influences on concentration of O_3 in the ambient air were analyzed using regression analysis. The graphs are presented in Figure 2-Figure 10 and the results of regression analysis are presented in Table 2 - Table 4. A comparison of coefficient of determination for NO_x, CO and SO_2 with O_3 at Gurgaon, Rohtak and Panchkula for spring, pre-monsoon, monsoon and post monsoon seasons is presented in Figure 11.

4.1. Influence of NO_x, CO and SO_2 on Concentration of O_3 in Gurgaon

The NO_x, CO and SO_2 variations and their influences on concentration of O_3 in the ambient air for Gurgaon are presented in Figure 2, Figure 3 & Figure 4 and the results of regression analysis are presented in Table 2.

It can be seen that the monthly mean concentration of O_3 was observed to be maximum in the month of September and minimum in the month of July while NO_x, CO and SO_2 observed to be maximum in the month of April, June and June respectively and minimum in the months of November, September and August respectively. Low O_3 concentration (17.5 µg m^{-3} in the month of July) was observed in monsoon due to the strong winds that dilute air by carrying O_3 precursors away from the site. The observed results of O_3 can be attributed to lower vertical mixing due to lower planetary boundary layer height, stronger titration by NO_x due to higher emission related to heating and lower photochemical production due to lower temperature and solar radiations. The observed low values of NO_x can be attributed to stronger vertical mixing due to higher planetary boundary layer height, faster transition from NO_x to O_3 due to higher temperature and higher wet deposition due to precipitation [24]. The observed winter increase of NO_x may be attributed to weaker vertical mixing due to particularly low planetary boundary layer height, slowest chemical loss due to the lowest temperature, solar radiation and oxidant concentration and particularly much higher anthropogenic emission in winter [25,26]. Since Gurgaon is on faster pace of development and thickly populated and so this area has an envelope of dust and pollutants gases which in turn slow down photo oxidation of NO_x. The observed peak in CO and SO_2 in pre-monsoon season may be due to enhanced incomplete combustion of fuels, enhanced vehicular emission and chemical transformation of interacting gases in dry season [27].

Table 2. Correlation coefficient and the regression equation between NOx, CO, SO_2 and O_3 in Gurgaon

Season (Gurgaon)	NO_x Range (Monthly mean) (μg/m^3)	r^2	O_3 Equation	CO Range (mg/m^3)	r^2	O_3 Equation	**SO_2 range (μg/m^3)**	**r^2**	**O_3 Equation**
Spring	31.99-37.99	-0.124	O_3 =-0.378 NO_x + 38.153	0.62-0.87	0.980	O_3 =-0.014 CO + 0.035	3.63-4.19	0.506	O_3=4.7401 SO_2+5.8921
Pre-monsoon	27.28-45.42	0.389	O_3 = 0.331 NO_x + 11.388	1.00-2.45	-0.999	O_3 = - 6.4x10-5 CO +0.036	4.28-5.06	0.605	O_3=4.7401 SO_2+5.8921
Monsoon	33.6– 37.45	-0.256	O_3 = 2.329 NO_x - 60.945	0.83-0.97	-0.322	O_3 = - 0.036 CO + 0.067	2.88-4.38	-0.137	O_3=4.7401 SO_2+5.8921
Post monsoon	18.73-30.67	- 0.694	O_3 = 0.229 NO_x + 13.530	0.85-1.49	0.356	O_3 = -0.016 CO + 0.046	3.91-5.05	0.922	O_3=4.7401 SO_2+5.8921

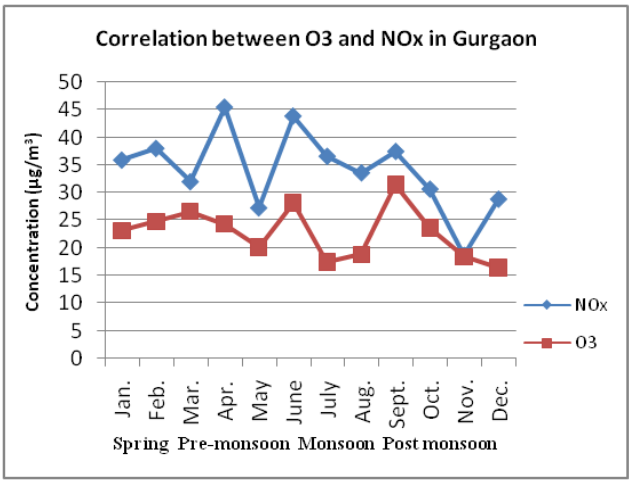

Figure 2. Correlations between NOx and O3 in Gurgaon

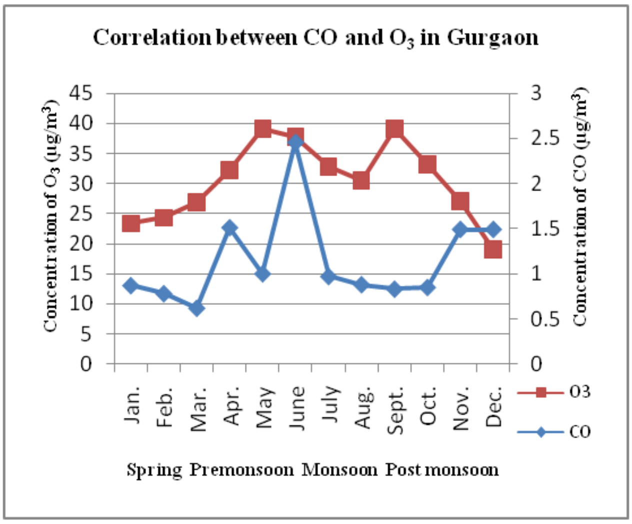

Figure 3. Correlations between CO and O_3 in Gurgaon

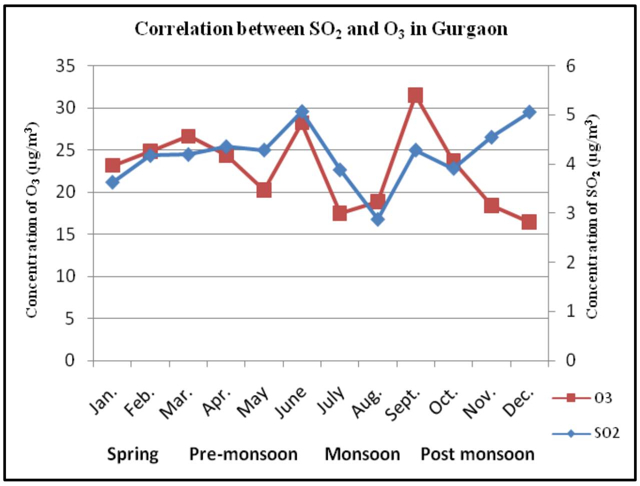

Figure 4. Correlations between SO_2 and O_3 in Gurgaon

Regression analysis reveals that O_3 is negatively correlated with NO_x in spring (r^2= -0.124), monsoon (r^2 = -0.256) and Post monsoon seasons (r^2 = -0.694) and positively correlated during pre-monsoon season (r^2 = 0.389) [23]. CO showed negative correlation with O_3 during pre-monsoon (r^2 =-0.999) and monsoon (r^2 = -0.322) seasons and positive correlation during spring (r^2=0.980) and post monsoon (r^2=0.356) seasons. SO_2 showed weak negative correlation with O_3 in monsoon (r^2= -0.137) season and positive correlation during spring (r^2 =0.506), pre-monsoon (r^2=0.605) and post monsoon (r^2=0.922) seasons. It can be seen that during monsoon season, NO_x, CO and SO_2 showed weak negative correlation with O_3 in Gurgaon [28]. During spring, the influence of CO & SO_2 on O_3 is opposite to that of NO_x while in pre-monsoon season, the influence of NO_x and SO_2 is opposite to that of CO. In post monsoon season, the influence of CO & SO_2 on O_3 is opposite to that of NO_x. However, the degree of correlation is different in different seasons. Negative correlation between NO_x and O_3 concentrations suggested that NO_x is not the only factor contributed to elevated O_3 concentrations [29].

4.2. Influence of NO_x, CO and SO_2 on Concentration of O_3 in Rohtak

The NO_x, CO and SO_2 variations and their influences on concentration of O_3 in the ambient air in Rohtak are presented in Figure 5, Figure 6 & Figure 7 and the results of regression analysis are presented in Table 3.

It can be seen that the monthly mean concentration of O_3 was observed to be maximum in the month of September and minimum in the month of July while NO_x, CO and SO_2 observed to be maximum in the month of July, January and February respectively and minimum in the months of November, October and July respectively.

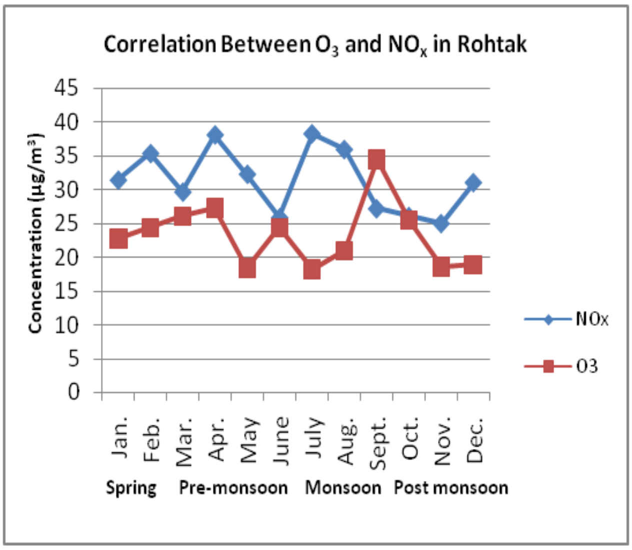

Figure 5. Correlation between NO_x and O_3 in Rohtak

The maxima of NO_x and minima of O_3 in month of July is significant and justify the chemistry of O_3 in the atmosphere in comparatively less polluted and less rainfall plain area[30].

Regression analysis results shows that, O_3 is negatively correlated with NO_x in spring (r^2= -0.797), pre-monsoon (r^2= -0.819) and Post monsoon (r^2= -0.797) seasons and positively correlated during monsoon (r^2= 0.997) season. It may be due to low rainfall in Rohtak in the year 2015. CO showed negative correlation with O_3 during monsoon (r^2=- 0.829) season and positive correlation during spring (r^2= 0.991), pre-monsoon (r^2=0.721) and post monsoon (r^2=0.997) seasons. SO_2 showed weak negative correlation with O_3 in pre-monsoon (r^2= - 0.148) season and positive correlation during spring (r^2=0.155), monsoon (r^2=0.843) and post monsoon (r^2=0.967) seasons. During monsoon season, NO_x and SO_2 showed positive correlation with O_3 while CO negative correlation. In spring and post monsoon, the influence of CO and SO_2 is opposite to that of NOx while in pre-monsoon, the influence of NO_x and CO on O_3 is opposite to that of SO_2.

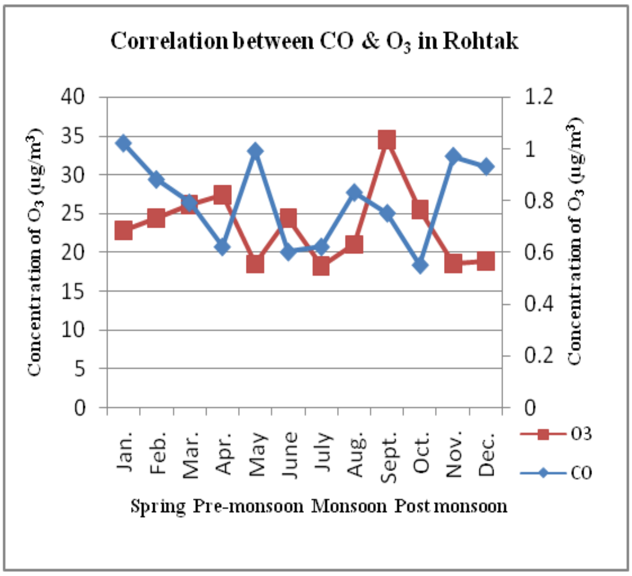

Figure 6. Correlation between CO and O_3 in Rohtak

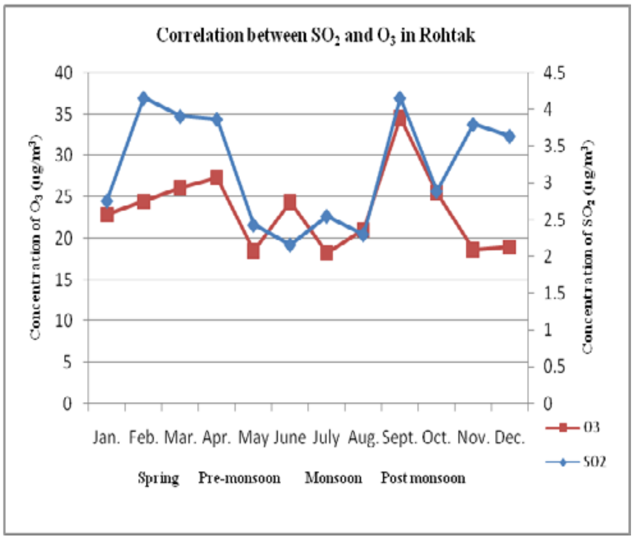

Figure 7. Correlation between SO_2 and O_3 in Rohtak

Table 3. Correlation coefficient and the regression equation between NOx, CO, SO_2 and O_3 in Rohtak

Season (Rohtak)	NO_x Range (Monthly mean) (µg/m³)	r^2	O_3 Equation	CO Range (mg/m³)	r^2	O_3 Equation	**SO_2 range (µg/m³)**	**r^2**	**O_3 Equation**
Spring	29.67-35.34	-0.797	O_3 = -0.179 NO_x + 30.295	0.79-1.02	0.991	O_3 =-0.013 CO + 0.037	2.76-4.16	0.155	O_3=1.6641 SO_2+18.4725
Pre-monsoon	25.90-38.07	-0.819	O_3 = 0.224 NO_x + 16.257	0.60-0.99	0.721	O_3 = -0.019 CO +0.038	2.16-3.87	-0.148	O_3=3.7260 SO_2+10.8732
Monsoon	27.23-38.24	0.997	O_3 = -1.501 NO_x + 75.349	0.62-0.83	-0.829	O_3 =0.024 CO + 0.007	2.30-4.16	0.843	O_3=8.2948 SO_2- 0.3055
Post monsoon	25.05-31.07	-0.797	O_3 = -0.385 NO_x + 31.580	0.55-0.97	0.997	O_3 = -0.017 CO + 0.035	2.89-3.80	0.967	O_3=-7.9436 SO_2+48.382

4.3. Influence of NO_x, SO_2 and CO on Concentration of O_3 in Panchkula

The NO_x, CO and SO_2 variations and their influences on concentration of O_3 in the ambient air in Panchkula are presented in Figure 8, Figure 9 & Figure 10 and the results of regression analysis are presented in Table 4. It can be seen that the monthly mean concentration of O_3 was observed to be maximum in the month of September and minimum in the month of December while NO_x, CO and SO_2 observed to be maximum in the month of October, April and November respectively and minimum in the months of August, July and July respectively. The averaged O_3 concentrations were lower in plains area compared with the mountainous area may be due to the titration effects of high NO_x emissions in urban areas and summer O_3 production in the plains and mountainous areas are found to be sensitive to NO_x.

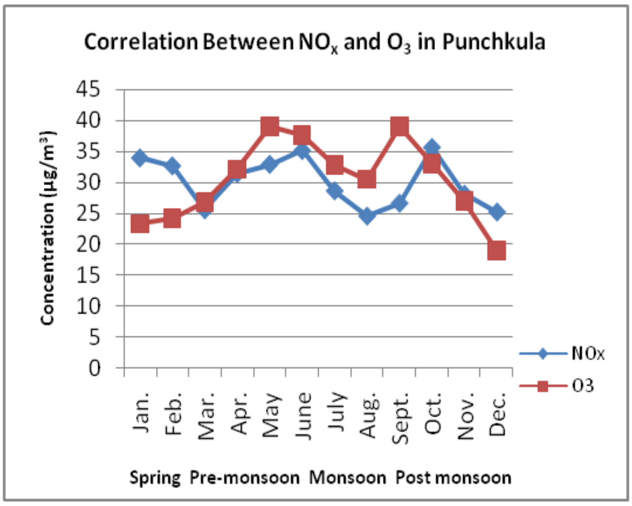

Figure 8. Correlation between NO_x and O_3 in Panchkula

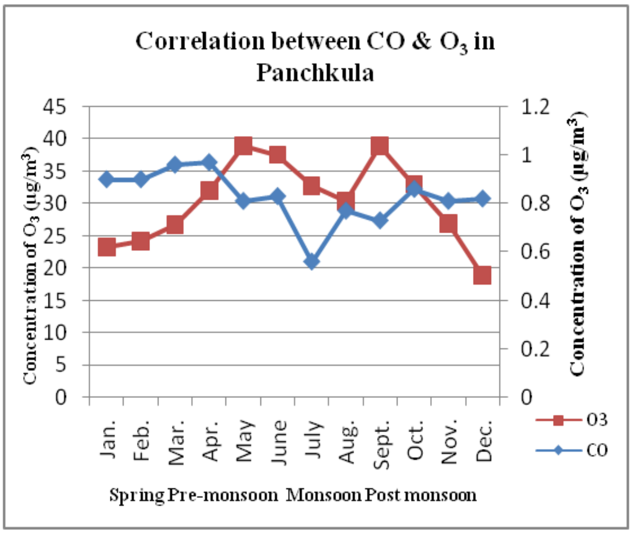

Figure 9. Correlation between CO and O_3 in Panchkula

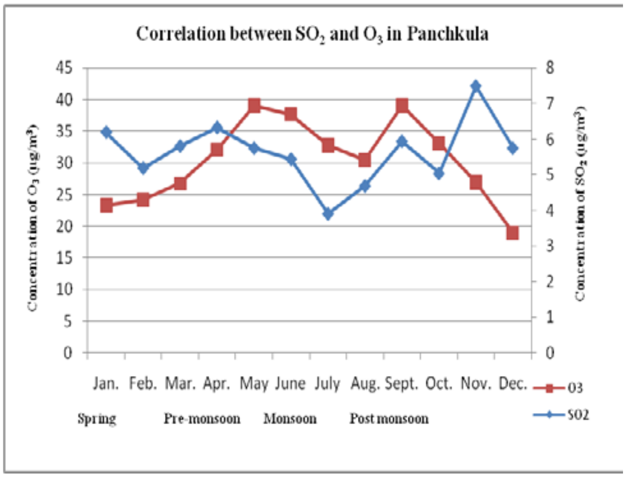

Figure 10. Correlation between SO2 and O3 in Panchkula

Table 4. Correlation coefficient and the regression equation between NOx, CO, SO_2 and O_3 in Panchkula

Season (Panchkula)	NO_x Range (Monthly mean) (µg/m³)	r^2	O_3 Equation	CO Range (mg/m³)	r^2	O_3 Equation	SO_2 range (µg/m³)	r^2	O_3 Equation
Spring	25.56-33.90	0.971	O_3 = -0.394 NO_x + 36.879	0.90- 0.96	0.991	O_3 = 0.049 CO - 0.020	5.19-6.20	-0.965	O_3=-0.4641 SO_2+27.431
Pre-monsoon	31.38-35.09	-0.074	O_3 = 1.324 NO_x – 7.605	0.81-0.97	0.721	O_3 = -0.042 CO +0.073	5.44-6.33	0.484	O_3=-6.9292 SO_2+76.703
Monsoon	24.55-28.61	-0.854	O_3 = 0.590 NO_x + 18.382	0.56-0.77	-0.829	O_3 =0.003 CO + 0.032	3.91-5.94	0.262	O_3=3.4404 SO_2+17.409
Post monsoon	25.21-35.58	0.784	O_3 = 1.247 NO_x – 10.606	0.81-0.86	0.997	O_3 = 0.187 CO - 0.129	5.04-7.49	-0.917	O_3=-1.1443 SO_2+33.299

Since Panchkula is situated in Hilly area and characterized with comparatively high rainfall, high peak temperature and less population density and so influence of NO_x, CO and SO_2 on O_3 is observed to be different from Gurgaon and Rohtak. The variation trends of O_3 & NO_x and O3 & CO observed to be similar but of O_3 & SO_2 observed to be different in post monsoon season.

Regression analysis shows that O_3 is negatively correlated with NO_x in pre- monsoon (r^2= - 0.074) and monsoon (r^2= -0.854) seasons and positively correlated during spring (r^2=0.971) and post monsoon (r^2=0.784) seasons. CO showed negative correlation with O_3 during monsoon (r^2= - 0.829) season and positive correlation during spring (r^2=0.991), pre-monsoon (r^2=0.0.721) and post monsoon (r^2=0.997) seasons. SO_2 showed negative correlation with O_3 in spring (r^2= - 0.965) and post monsoon (r^2= - 0.917) seasons and positive correlation during pre-monsoon (r^2=0.484) and monsoon (r^2=0.262) seasons. During monsoon season, NO_x and CO showed negative correlation with O_3.while SO_2 positive correlation. In spring, pre-monsoon and post monsoon, the influence of NO_x and CO on O_3 is opposite to that of SO_2, however the nature of correlation reverses. These results are graphically shown in Figure 11.

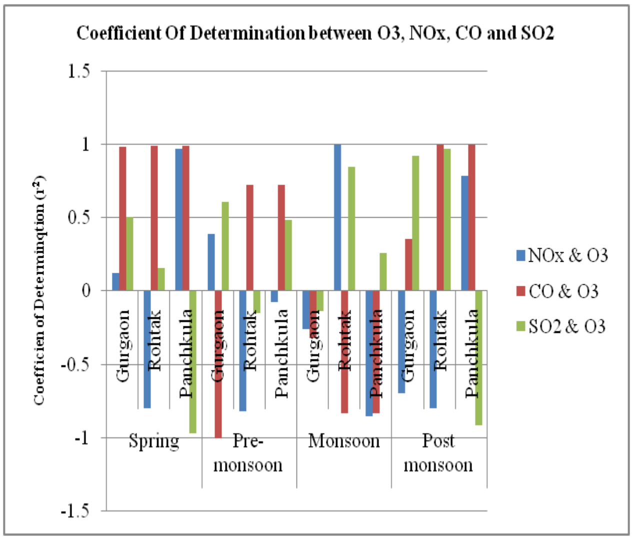

Figure 11. Correlation Coefficient between O3, CO and SO2 at three measuring sites

From above results, it can be seen that the seasonal effects plays significant role in regulating the concentration of O_3, NO_x, CO and SO_2 [31,32,33,34]. Change of season reverses the sign of correlation. The influence of NO_x and CO concentration on O_3 concentration observed to be similar for spring and post monsoon seasons but not for SO_2, The effect of rainfall in regulating the concentration of NO_x, CO and SO_2 and their influence in regulating the concentration of O_3 are of significance.

5. Conclusions

The influences of NO_x, CO and SO_2 concentrations on concentration of O_3 were evaluated for spring, pre-monsoon, monsoon and post monsoon seasons of 2015 in Gurgaon, Rohtak and Panchkula using regression analysis and the findings are stated below.

(i) In Gurgaon, O_3 is negatively correlated with NO_x in spring (r^2= -0.124), monsoon (r^2 = -0.256) and Post monsoon seasons (r^2 = -0.694) and positively correlated during pre-monsoon season (r^2 = 0.389). CO showed negative correlation with O_3 during pre-monsoon (r^2 =-0.999) and monsoon (r^2 = -0.322) seasons and positive correlation during spring (r^2=0.980) and post monsoon (r^2=0.356) seasons. SO_2 showed weak negative correlation with O_3 in monsoon (r^2= -0.137) season and positive correlation during spring (r^2 =0.506), pre-monsoon (r^2=0.605) and post monsoon (r^2=0.922) seasons. During monsoon season, NO_x, CO and SO_2 showed negative correlation with O_3.

(ii) In Rohtak, O_3 is negatively correlated with NO_x in spring (r^2= -0.797), pre-monsoon (r^2= -0.819) and Post monsoon (r^2= -0.797)seasons and positively correlated during monsoon (r^2= 0.997) season. CO showed negative correlation with O_3 during monsoon (r^2=- 0.829) season and positive correlation during spring (r^2= 0.991), pre-monsoon (r^2=0.721) and post monsoon (r2=0.997) seasons. SO_2 showed weak negative correlation with O_3 in pre-monsoon (r^2= - 0.148) season and positive correlation during spring (r^2=0.155), monsoon (r^2=0.843) and post monsoon (r^2=0.967) seasons. During monsoon season, NO_x and SO_2 showed positive correlation with O_3 while CO negative correlation.

(iii) In Panchkula, O_3 is negatively correlated with NO_x in pre- monsoon (r^2= - 0.074) and monsoon (r^2= -0.854) seasons and positively correlated during spring (r^2=0.971) and post monsoon (r^2=0.784) seasons. CO showed negative correlation with O_3 during monsoon (r^2= - 0.829) season and positive correlation during spring (r^2=0.991), pre-monsoon (r^2=0.0.721) and post monsoon (r^2=0.997) seasons. SO_2 showed negative correlation with O_3 in spring (r^2= - 0.965) and post monsoon (r^2= - 0.917) seasons and positive correlation during pre-monsoon (r^2=0.484) and monsoon (r^2=0.262) seasons. During monsoon season, NO_x and CO showed negative correlation with O_3.while SO_2 positive correlation.

(iv) Seasonal effects plays significant role in regulating the concentration of O_3, NO_x, CO and SO_2.

Change of season reverses the sign of correlation. The influence of NO_x and CO concentration on O_3 concentration observed to be similar for spring and post monsoon seasons but not for SO_2, The effect of rainfall in regulating the concentration of NO_x, CO and SO_2 and their influence in regulating the concentration of O_3 are of significance.

The results of this study will be useful for further research on interactions between atmospheric pollutants and Ozone in other region of Haryana and adjoining states in India.

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