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Influence of Some Meteorological Variables on PM_{10} and NO_x in Gurgaon, Northern India

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

[1]Department of Applied Sciences, Dronacharya College of Engineering Gurgaon Haryana, India
[2]Department of Chemistry, Government Senior Secondary School Kakoria, Rewari Haryana, India
*Corresponding author: ramchhavisharma@yahoo.com

Abstract Urban air pollution is rapidly becoming an environmental problem of public concern worldwide. It can influence public health and local/regional weather and climate. In the present study, airborne particulate pollutants PM_{10} and NO_x data were collected for a period of one year (January 2014 to December 2014) at Vikash Sadan location in Gurgaon, a rapidly developing city in Haryana State in Northern India. The pollutants data were collected by the Haryana Pollution Control Board. The observed concentrations of PM_{10} ranged between 50.77µg/m^3 to 451.0µg/m^3 and of NO_x ranged between 9.83µg/m^3 to 216.25µg/m^3. The seasonal- and annual-average concentrations of the pollutant were mostly above Indian air quality standards. These pollutants concentration were correlated with meteorological variables such as temperature, humidity and rainfall. The regression correlation analysis has been performed between particulate pollutants and meteorological parameters to investigate the relationships between them. This statistic will give an idea about which meteorological parameter play a major role in modulating the pollutants concentrations over Gurgaon.

Keywords: *urban ambient air quality, particulate pollutants, meteorological variables, regression analysis*

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1. Introduction

The air pollutants generated mainly from anthropogenic emission sources, such as automobiles, industries, and domestic fuel combustion are detrimental to human health and environment. They cause negative impacts directly or indirectly, if at elevated concentrations, on vegetation, animal life, buildings and monuments, weather and climate, and on the aesthetic quality of the environment [1,2,3]. In recent years in Asian countries with monsoonal climates, such as India and China, the aerosol problem has become increasingly acute due to increased loadings of atmospheric pollutants from increasing vehicular and industrial emissions as well as from increasing energy demands associated with a rapid pace of industrialization and increasing energy demands for domestic uses [4,5,6]. It is well recognized that pollution problems are exacerbated by stable atmospheric conditions, such as subsidence and formation of inversion layers during the dry pre-monsoon season, or during monsoon break periods. During the monsoon season, heavy rain can wash out aerosols and clean the air. Recent studies have suggested that aerosols in the atmosphere can also affect the monsoon water cycle by significantly altering the energy balance in the atmosphere and at the surface [7,8] and by modulating cloud and rainfall processes [9,10,11,12]. The Indian subcontinent experiences tropical and subtropical climatic conditions resulting in extreme temperatures, rainfall, and relative humidity. These features introduce large variability in aerosol characteristics on a range of spatial and temporal scales over India [13]. Atmospheric particulate matter is the major air pollutant in India. In many Indian cities, the levels of particulate pollutants in the ambient air have been found to be above the permissible limit [14].

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. Its boundary touches the states of Rajasthan and Delhi and it makes Gurgaon to be an important strategically located place. On its north, it is bounded by the District of Jhajjar & the Delhi state; Faridabad District lies to its east. On south it shares boundaries with Mewat district whereas Rewari district lies in its west (please see Figure 1). 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 [15]. 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.

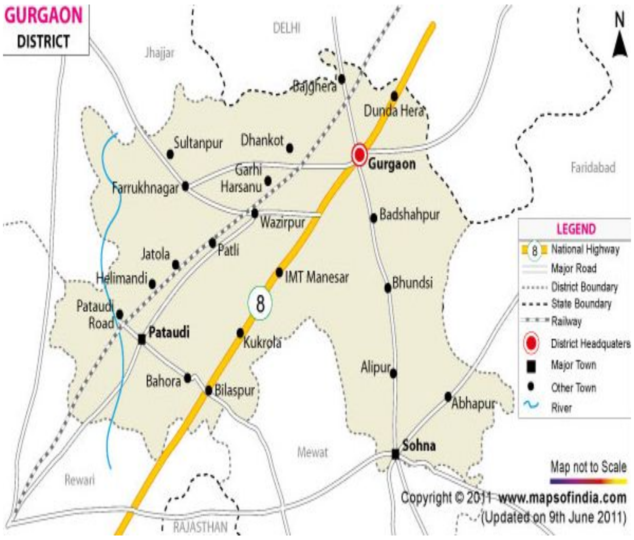

Figure 1. Description of study area

In the present study, the levels of air pollutants PM_{10} and NO_x were measured at Vikash Sadan (Mini secretariat) station within Gurgaon and these pollutants concentration were statistically compared with meteorological variables such as temperature, humidity and rainfall. It examines the influences of temperature, relative humidity and rainfall on concentration variation of particulate pollutant PM_{10} and NO_x with respect to seasonal variation in 2014.

2. Sources and Health Effect of PM_{10} and NO_x

PM_{10} is directly emitted or is formed in the atmosphere as a result of mixing of various gaseous pollutants. Primary particles are directly emitted from sources, such as biomass burning, incomplete combustion of fossil fuels and traffic-related suspension of road, soil, dust, sea salt and biological materials. Secondary particles are formed by gas-to-particle conversion in the atmosphere. Concentration, composition and size distribution of atmospheric aerosol particles are temporally and spatially highly variable. The predominant particle components of air particulate matter (PM) are sulfate, nitrate, ammonium, sea salt, mineral dust, organic compounds and black or elemental carbon [16]. Major human health concerns from PM_{10} exposure include effects on respiratory systems, damage to lung tissue, cancer and even premature death [17].

The Tropospheric NO_x (NO and NO_2) has a variety of natural and anthropogenic sources [18]. The main source of NO in the troposphere is from fossil fuel burning and vehicles emission. Natural source include lightning discharges and some biogenic production. Indirect sources are NH_3 from fertilizers and from N_2O (produced in soil by microbial action and in biomass burning) through photo-dissociation at near-UV wavelengths or through reaction with odd oxygen.

The main sources of air pollution in Gurgaon are vehicles, industries and natural dust. Pollution from local factories and industrial units such as automobile industries, brick kilns, thermocol, plastic, rubber, leather, textile, garments, electronic, handloom, information technology, chemical & pharmaceuticals and cement factories has affected the health of humans, crops and animals. Air pollution is linked to industrial estates in Gurgaon and in the nearby towns of the cities. Numbers of vehicle have increased over the last 20 years. Old vehicles plying in the town, mushrooming industrial units with boilers and furnaces — particularly those using wood, rice husk and coal and the two thermal power plants at Faridabad and Badarpur (Neighboring cities) are some of the major sources of air pollution.

3. Data and Analysis Techniques

For the present study, we used ambient air quality data collected by the Haryana Pollution Control Board (HPCB) at Vikash Sadan (Mini secretariat) sampling site shown in Figure 2 in Gurgaon over a period of one year from January 01, 2014 to December 31, 2014. The particulate pollutants samples were collected by the HPCB with commercially available Respirable Dust Sampler (RDS) [19]. The RDS had a free flow condition without filter and the flow rate of air sampler varied between 0.9 and 1.4 m^3/min. It 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 of India (CPCB). Whatmann micro fiber filter papers (EPM, 2000) were used for the collection of PM_{10} particles. Oxides of nitrogen analyzer use proven Chemi-luminescence technology to measure NO_x in ambient air quality. Data about the micro meteorological conditions required for air quality assessment viz. temperature, relative humidity and rainfall were collected from the India Meteorological Department. A basic statistical analysis was carried out for both pollutants and meteorological variables. These basic statistics include maximum, minimum and mean of each variable .In this study the regression correlation analysis has been performed between particulate pollutants and meteorological data (temperature, relative humidity and rainfall) to investigate the relationships between them. This statistic will give an idea about which meteorological parameter play a major role in PM_{10} and NO_x concentrations over Gurgaon.

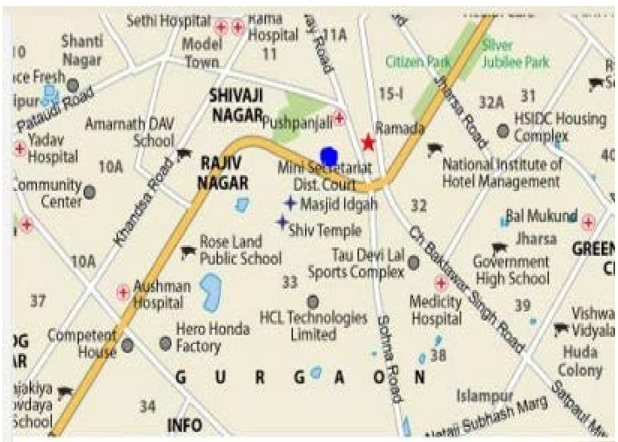

Figure 2. Location of sampling station, ● Vikash Sadan, Mini Secretariat Gurgaon (MapsofIndia.com)

4. Results and Discussion

4.1. Influence of Temperature on Concentration of PM_{10} and NO_x.

Meteorological parameter such as temperature, humidity and rainfall plays a crucial role in ambient distributions of air pollution. In fact, there is a strong seasonality in meteorological variables that modulate air quality levels [20]. Seasons are defined as spring (January, February and March), pre-monsoon (April, May and June), monsoon (mid June–July– August and September), and post-monsoon (October, November and December) as per Indian Meteorological Department (IMD) classification**.** December and January are peak winter months, while May and June are peak summer months. The temperature recorded in the study area ranged between 8.78°C - 27.61°C during spring, 19.62°C - 37.73°C during pre-monsoon, 19.62°C - 40.08°C during monsoon and 9.9°C - 28.98°C during post monsoon seasons. The minimum temperature of 8.78°C was recorded during January 2014 and maximum of 40.08°C during August 2014. The monthly minimum, maximum and mean temperatures recorded from January2014 to December2014 are depicted graphically in Figure 3.

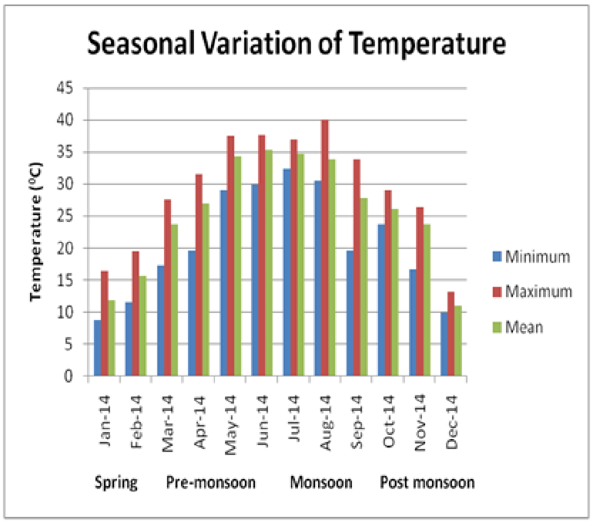

Figure 3. Seasonal Variation of Temperature in2014

The temperature variations and their influences on concentration of PM_{10} and NO_x in the ambient air were analyzed for the spring, pre-monsoon, monsoon and post-monsoon. The graphs are presented in Figure 4 & Figure 5 respectively and the results of regression analysis are presented in Table 1.

Table 1. Correlation coefficient and the regression equation between temperature and pollutants (NO_x and PM_{10})

Season	Temp. Range (°C)	r^2	NO_x Equation	r^2	PM_{10} Equation
Spring	8.78-27.61	-0.513	NO_x=1.124T+33.589	0.955	PM_{10}=3.975T+236.094
Pre-monsoon	19.62-37.73	-0.961	NO_x=-0.472T+83.048	-0.058	PM_{10}=2.700T+12.145
Monsoon	19.62-40.08	-0.147	NO_x=0.883T+33.949	0.348	PM_{10}=1.520T+58.125
Post-monsoon	9.90-28.98	0.466	NO_x=1.233T+30.329	--0.998	PM_{10}=-0.108T+120.18

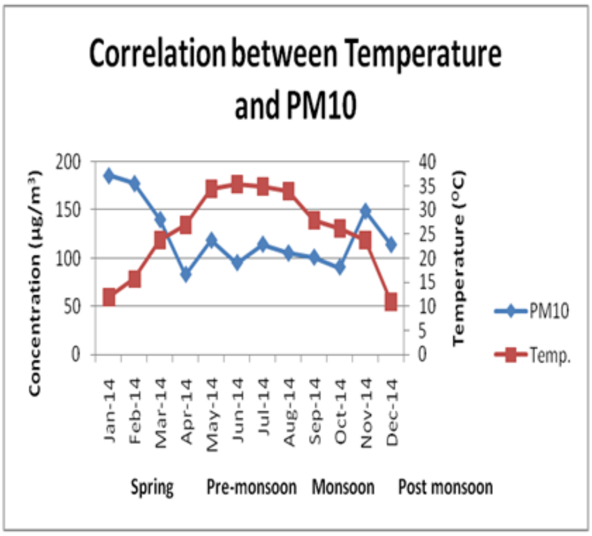

Figure 4. Correlation between Temperature and PM_{10}.

The result of regression revealed that PM_{10} has very weak and negative correlation with temperature during post monsoon (r^2= -0.998), strong positive correlation with temperature during spring (r^2=0.955) and monsoon (r^2=0.348) and weak positive correlation with temperature during pre-monsoon (r^2= -0.058). The study area experienced lower temperatures (9.9°C -29.98°C) during post- monsoon session resulting weak and negative correlation with temperature. The effects of seasonal variation on the concentrations of particulate matter in Delhi has been studied and reported that the SPM was positively and significantly associated with temperature [21]. NO_x has negative correlation with temperature during pre-monsoon (r^2= -0.961) and positive correlation with temperature during spring (r^2= -0.513), monsoon (r^2= -0.147) and post-monsoon (r^2=0.466). The weak negative correlation between temperature and NO_x may be due to minimum vertical mixing because of higher temperature range in this session (19.62°C -37.73°C). The lower temperature range during post-monsoon (9.9°C - 28.98°C) reduces the vertical mixing height, thus resulting significantly strong positive correlation of temperature with NO_x. The influence of temperature, relative humidity and seasonal variability on ambient air quality in a coastal urban area with respect to meteorological parameters has been studied and shown that NOx has negative correlation with temperature in summer while positive correlation with temperature during post-monsoon season [22].

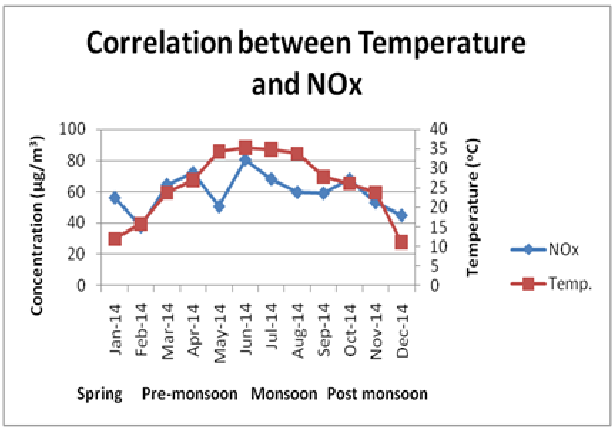

Figure 5. Correlation between Temperature and NO_x

4.2. Influence of Humidity on Concentration of PM_{10} and NO_x

Relative humidity ranged between 5.84% - 95.83% during spring, 40.87% - 86.94% during pre-monsoon, 48.91% -92.18% during monsoon and 41.97% - 79.71% during post monsoon. The minimum relative humidity of 5.84% is recorded in spring and maximum of 95.83% is also recorded in spring. The monthly minimum, maximum and mean relative humidity in the study area from January 2014 to December 2014 is depicted graphically in Figure 6.

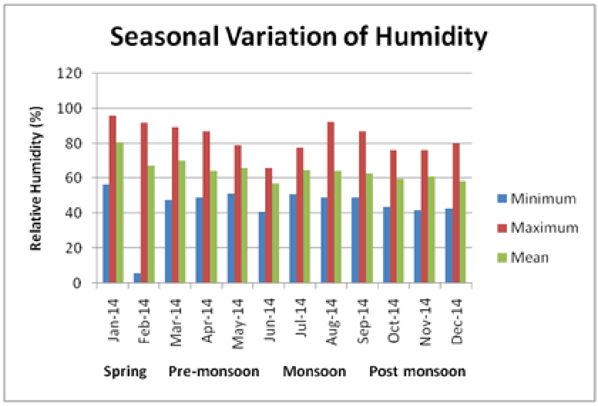

Figure 6. Seasonal variation of Humidity in 2014

The season wise variations of humidity and its influence on the concentration of PM_{10} and NO_x were analyzed and presented in Figure 7 & Figure 8 respectively and the results of regression study are presented in Table 2.

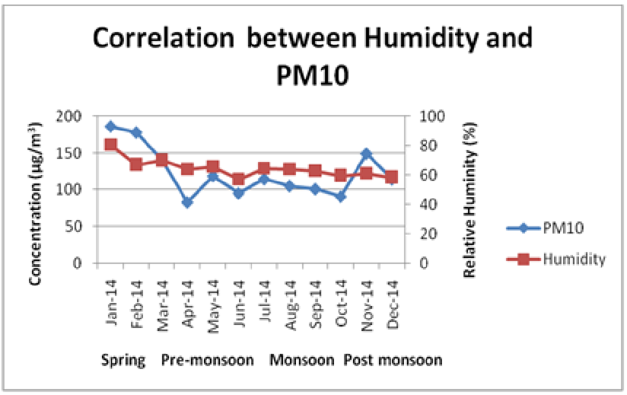

Figure 7. Correlations between Humidity and PM_{10}

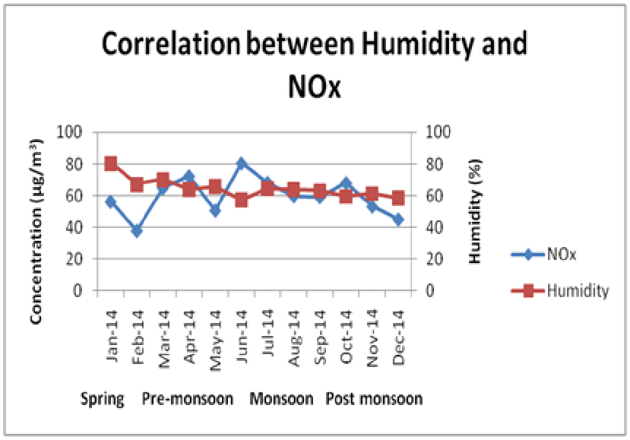

Figure 8. Correlation between Humidity and NO_x

Table 2. Correlation coefficient and the regression equation between Humidity and pollutants (NO_x and PM_{10})

Season	Humidity Range in %	r^2	NO_x Equation	r^2	PM_{10} Equation
Spring	5.84-95.83	-0.659	NOx=0.808H-5.865	-0.572	PM_{10}=1.597H+51.967
Pre-monsoon	40.87-86.94	0.387	NOx=-2.851H+245.716	0.754	PM_{10}=5.035H-146.097
Monsoon	48.91-92.18	0.745	NOx= 4.931H-252.762	0.682	PM_{10}=7.841H-394.091
Post monsoon	41.97-79.71	-0.889	NOx=2.137H-72.481	-0.049	PM_{10}=15.664H-819.049

It can be seen that PM_{10} in positively correlated with relative humidity for all the sessions but correlation has been weak during spring (r^2= -0.572), very weak during post monsoon (r^2= -0.049) and high during pre-monsoon (r^2=0.754) and monsoon (r^2=0.682). This might be due to the increase in rate of absorption of PM_{10} with the increase of relative humidity. NO_x is negatively correlated with relative humidity during pre-monsoon (r^2=0.387) while positively correlated during spring, monsoon and post monsoon .The correlation is very weak during spring (r^2= -0.659) and post monsoon (r^2= -0.899) but strong during monsoon (r^2=0.745). Relative humidity plays an important role in air quality, through its effect on the overall reactivity of the atmospheric system, either by affecting chain termination reactions or in the production of wet aerosols, which in turn affect the flux of ultraviolet radiation. Furthermore, the relative humidity is also considered to be a limiting factor in the disposition of NO_2 because high percentages of humidity favor the reaction of the NO_2 with particles of sodium chloride salt [23]. Relative Humidity can also act on air pollutants to create secondary aerosols, such as sulphate and nitrate ions, which contribute positively to PM_{10} concentrations.

4.3. Influence of Rainfall on concentration of PM_{10} and NO_x.

In year 2014, there has been rainfall in every month in Gurgaon and ranges between 5.0 mm and 258.7 mm. Average rainfalls ranged between 15.0 mm -20.3 mm during spring, 6.7 mm -54.9 mm during pre-monsoon, 127.8 mm-231.5 mm during monsoon and 5.0 mm-36.3 mm during post monsoon season.

Table 3. Correlation coefficient and the regression equation between Rainfall and PM_{10} & NO_x

Season	Av. Rainfall Range(mm)	r^2	PM_{10} Equation	r^2	NO_x Equation
Spring	15.0-20.3	-0.451	PM_{10} =4.463 RF+92.007	-0.758	NO_x =1.678 RF+24.246
Pre-monsoon	6.7-54.9	-0.997	PM_{10} =0.026 RF+98.367	-0.400	NO_x =0.335 RF+59.002
Monsoon	127.8-258.7	-0.294	PM_{10} =0.059 RF+94.667	-0.618	NO_x =0.027 RF+56.670
Post-monsoon	5.0-36.3	0.438	PM_{10}=-1.434RF+141.469	0.638	NO_x =0.613 RF+45.311

The maximum rainfall, 258.7 mm was recorded in the month of August and minimum rainfall 5.0 mm was recorded in the month of November. The average rainfall in the study area from January 2014 to December 2014 is depicted graphically in Figure 9. The season wise variations of rainfall and its influence on the concentration of PM_{10} and NO_x were analyzed and presented in Figure 10 & Figure 11 respectively. The results of regression study are presented in Table 3.

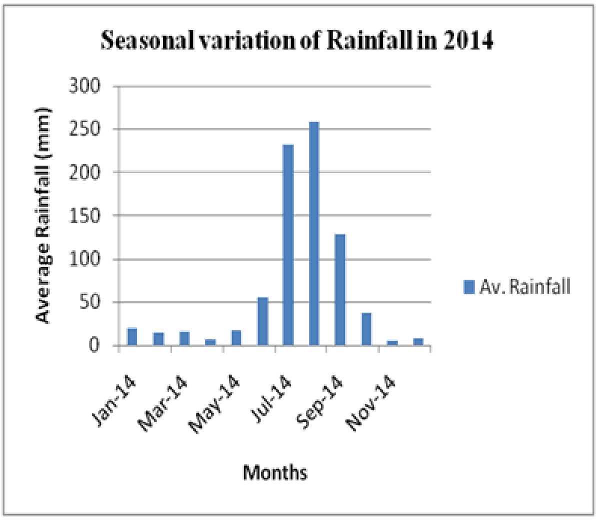

Figure 9. Seasonal variation of Rainfall in 2014

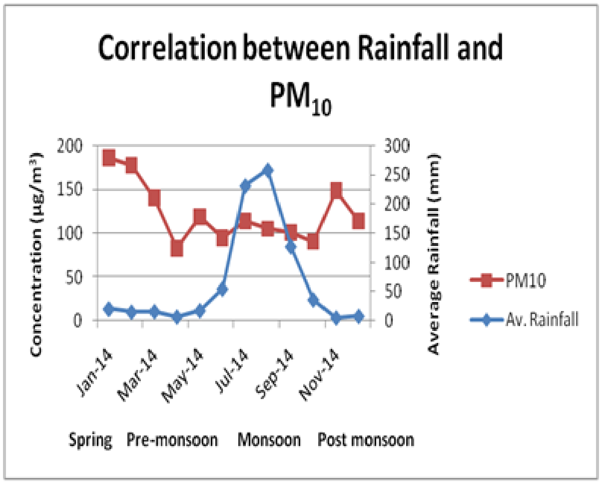

Figure 10. Correlation between Rainfall and PM_{10}

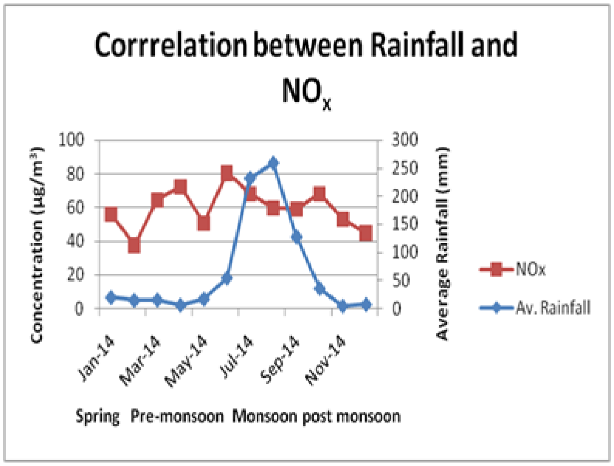

Figure 11. Correlation between Rainfall and NO_x

It was noted that PM_{10} showed a significant negative correlation with rainfall. The effect of rainfall on particulate PM_{10} during monsoon could be high to result in moderate negative correlation during monsoon (r^2= -0.294). Rainfall is one of the reasons for low particulate pollutants in the monsoon season as the pollutants are washed out by rain. Wet deposition by precipitation or wet removal is one of the main mechanisms for removal of aerosols from the atmosphere [24,25,26]. In post monsoon, the PM_{10} concentration has been higher because the percentages of accumulation of coarse particles were relatively higher than those of other seasons [27]. The impact of rain on NO_x was observed to be low during pre-monsoon (r^2= -0.400) and monsoon (r^2= -0.618) as compared to other seasons [28]. Rainfall is the only meteorological variable that is significantly negatively correlated with particulate pollutants except in spring as per regression analysis results. But the concentration of PM_{10} is observed to be high even in monsoon period during non-rainy times because of enhanced sources of pollutants due to rapid industrialization, real estate development, vehicular emission and manmade perturbations in the study region.

5. Conclusions

The influences of temperature, relative humidity and rainfall on the concentration of PM_{10} and NO_x were evaluated for spring, pre-monsoon, monsoon and post-monsoon seasons of 2014 in Gurgaon using regression analysis and the findings are stated below.

(i). PM_{10} had positive correlation with temperature in spring, pre-monsoon and monsoon season but very weak negative correlation during post monsoon. Positive correlation may be due to effect of increasing temperature on concentration of PM_{10} in the ambient air. NOx is negatively correlated with temperature during pre-monsoon and positively correlated during spring, monsoon and post-monsoon. However, the correlation has been observed to be weak during spring and post monsoon.

(ii). PM_{10} in positively correlated with relative humidity for all the sessions but correlation has been weak during spring, very weak during post monsoon and high during pre-monsoon and monsoon. NO_x is negatively correlated with relative humidity during pre-monsoon while positively correlated during spring, monsoon and post monsoon .The correlation is very weak during spring and post monsoon but strong during monsoon.

(iii). PM_{10} showed a significant negative correlation with rainfall. PM_{10} had weak correlation with rainfall in pre-monsoon, monsoon and post monsoon but strong correlation during spring. The impact of rain on NO_x was observed to be low during pre-monsoon and monsoon as compared to other seasons.

The results of this study will be useful for further research on interactions between atmospheric pollutants and meteorological variables in Gurgaon and National Capital Region in India.

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