American Journal of Environmental Protection, 2018, Vol. 6, No. 1, 14-21
Available online at http://pubs.sciepub.com/env/6/1/3

DOI:10.12691/env-6-1-3

Statistical Investigation of Effect of Rainfall on Air Pollutants in the Atmosphere, Haryana State, Northern India

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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, the washout effect of rain on surface air pollutants ($PM_{2.5}$, O_3, NO_x, NO_2, NO ,SO_2, and CO) has been investigated over three ambient air quality monitoring stations (Gurugram, Rohtak and Panchkula) in Haryana state in Northern India. The airborne particulate pollutants data were collected by the Haryana State Pollution Control Board (HSPCB) for a period of one year (January 01, 2016 to December 31, 2016) at Vikash Sadan location in Gurugram, MDU location in Rohtak and HSPCB Sector 6 location in Panchkula.. The rainfall data for the study period has been taken from rainfall Statistics in India-2016, India Meteorological Department. The regression correlation analysis has been performed to investigate the effect of rainfall on surface air pollutants. The concentration of air pollutants are found to decrease with increase of rainfall. It has been observed that, $PM_{2.5}$ is most effected and O_3 is least effected by rainfall. Most of the pollutants under study show statistically significant negative correlations between their concentrations and rainfall due to washout and convection but their sensitivity towards rain significantly varies. O_3 shows either positive correlation or weak negative correlation with rainfall depending on the meteorological season and observing site.

Keywords: *human health, gaseous pollutants, particulate matters, rainfall, regression analysis*

Cite This Article: Ram Chhavi Sharma, and Niharika Sharma, "Statistical Investigation of Effect of Rainfall on Gaseous Pollutants in the Atmosphere, Haryana State, Northern India." *American Journal of Environmental Protection*, vol. 6, no. 1 (2018): 14-21. doi: 10.12691/env-6-1-3.

1. Introduction

Air pollution is one of the most challenging problems which our cities face today as their atmospheres are getting highly polluted due to discharge of gaseous pollutants and particulate matters from various household, industrial and vehicular sources. Because of the great impact of air pollutants on human health and ecological environments, it is important to better understand the removal mechanism of these pollutants from the atmosphere. The removal of air pollutants by rainfall remains of great interest to the scientific community and many theoretical and experimental studies carried out to understand the wet scavenging of air pollutants by rain fall. [1,2,3,4,5]. The washout mechanism of sulfur dioxide (SO_2) and Nitrogen dioxide (NO_2) by rainfall has been a main global and regional concern, since these compounds play an important role in producing acid precipitation. Carbon monoxide (CO) and ozone (O_3) are much less soluble in water than NO_x (NO_2 + NO) & SO_2 [6]. O_3 concentration was observed to increase under rainy conditions [7]. It may be due to vertical mixing of the stratospheric and tropospheric O_3 concentrations during convective rain activity and thunderstorm. A significant negative correlation between monthly averaged aerosol concentration and rain intensity has been reported over some region in Russia [8]. Influence of rainfall on concentration of PM_{10} and NO_x has been studied at Gurgaon city [2] and reported negative correlation between rainfall and air pollutants PM_{10} and NO_x. The inter correlation of air pollutants in different meteorological seasons has been studied in Haryana state [9] and observed significant variation in correlation in monsoon and other seasons. Since it is very difficult to separate the washout effect from other gas – phase processes such as dry deposition, atmospheric mixing, and chemical transformation and so the correlation analysis between various air pollutants and rainfall could be helpful for investigating their interactions and long term trends [10].

In the present study, the washout effect of rain on surface air pollutants ($PM_{2.5}$, O_3, NO_x, NO_2, NO, SO_2, and CO) has been investigated over three rapidly developing cities (Gurugram, Rohtak and Panchkula) during the year 2016. The airborne particulate pollutants data were collected by the Haryana State Pollution Control Board for a period of one year (January 01, 2016 to December 31, 2016). The rainfall data for the study period has been taken from rainfall Statistics in India-2016,

India Meteorological Department [11]. The regression correlation analysis has been performed to investigate the effect of rainfall on surface air pollutants.

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. The detail information's about the sampling sites are given in our previous publication [9].

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

Table 1. Information on Monitoring Sites

Monitoring Site	Site Classification	Description
Gurugram, Vikas Sadan Between the 27°, 39' and 28° 32' 25'' latitude and 76° 39' 30'' & 77° 20' 45'' longitude	Urban, situated in vicinity of Delhi (National Capital Region), faster pace of development	An urban location near to National Highway – 8. Industrial units like Hero Group, Honda and Maruty Udyog are situated in the district. Faster pace of development and thickly populated. Gurugram experiences a monsoon influenced humid subtropical climate
Rohtak, MDU 30° 1' N and 75° 17' E	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 is sub-tropical, semi arid, continental and monsoon type.
Panchkula, HSPCB, Sector 6 31° 41' N and 76° 52' E	Urban, Residential, Himalayas boundary fault zone.	Panchkula district has a sub tropical continental monsoon climate having, hot summers, cool winters and 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. Mornii hills constitute the highest point of the district as well as of Haryana state.

3. Methods and Materials

For the present study, we used ambient air quality data collected by the Haryana State Pollution Control Board (HSPCB) for a period of one year from January 01, 2016 to December 31, 2016. The $PM_{2.5}$, O_3, NO_x, NO_2, NO, SO_2, and CO data were collected by the HSPCB using their respective analyzers having sampling duration 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, NO_2 and NOx in ambient air quality. The CO analyzer works on the principle of non-dispersive absorption and SO2 analyzer operates on the principle of light absorption, where the SO2 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 SO2 concentration. The O_3 analyzer also works on the absorption principle i.e. O3 molecules absorbs UV light at 254nm wavelength. The degree of absorption is directly related to O_3 concentration as described by Beer-Lambert law [12,13,14]. O_3 measurements are automatically corrected for gas temperature/pressure changes and can be displayed in units of ppm, $\mu g/m^3$ or mg/m^3. The particulate pollutants samples were collected using commercially available and calibrated Respirable Dust Sampler (APM460BL) using appropriate filters [15]. In this study the linear regression correlation analysis, which establish functional relationship called Regression equation between study variables and explanatory variables and determine coefficient of correlation and coefficient of determination, has been performed between rainfall & $PM_{2.5}$, O_3, NO_x, NO_2, NO, SO_2, and CO for different meteorological seasons to investigate the relationships between them. This analysis will give an idea about washout effect of rainfall on $PM_{2.5}$, O_3, NO_x, NO_2, NO, SO_2, and CO over the sampling sites and also how rainfall affects the $PM_{2.5}$, O_3, NO_x, NO_2, NO, SO_2, and CO concentration under different meteorological conditions.

4. Results and Discussion

In this study, we have analyzed and correlated the surface air pollutants ($PM_{2.5}$, O_3, NO_x, NO_2, NO, SO_2, and CO) data with Rainfall at Gurugram, Rohtak and Panchkula in Haryana state Northern India for the period from January 01, 2016 to December 31, 2016. The effects of rainfall on concentration of $PM_{2.5}$, O_3, NO_x, NO_2, NO, SO_2, and CO in ambient air were analyzed using regression analysis. The graphs are presented in Figure 2 - Figure 25 and results of regression analysis are presented in Table 2 – Table 4.

4.1. Influence of Rainfall on concentration of $PM_{2.5}$, O_3, NO_x, NO_2, NO, SO_2 and CO in Gurugram

In Gurugram, the monthly average rainfall ranges between 0.5 mm and 186.8 mm. Average rainfalls varies

between 0 – 16.2mm in spring, 0.5mm – 38.8mm in pre-monsoon, 35.7mm-186.8mm in monsoon and 0-15.4mm in post monsoon season. Minimum rainfall has been recorded in the month of April and maximum in the month of July. No rainfall recorded in the months of January, February, November and December. The average rainfall in Gurugram from January 2016 to December 2016 is depicted graphically in Figure 2. The season wise variations of rainfall and its influence on the concentration of $PM_{2.5}$, O_3, NO_x, NO_2, NO SO_2 and CO are presented in Figure 3 – Figure 9. The results of regression analysis study are presented in Table 2 – Table 4.

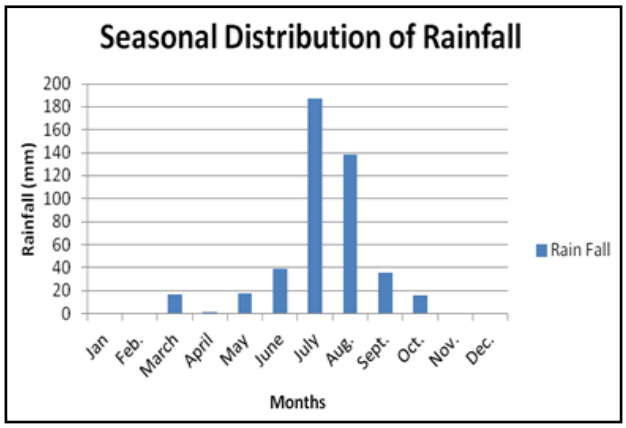

Figure 2. Seasonal variation of Rainfall in Gurugram

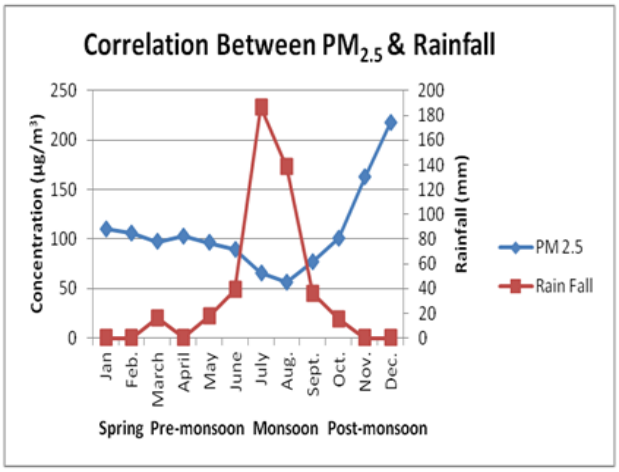

Figure 3. Correlation between Rainfall and $PM_{2.5}$

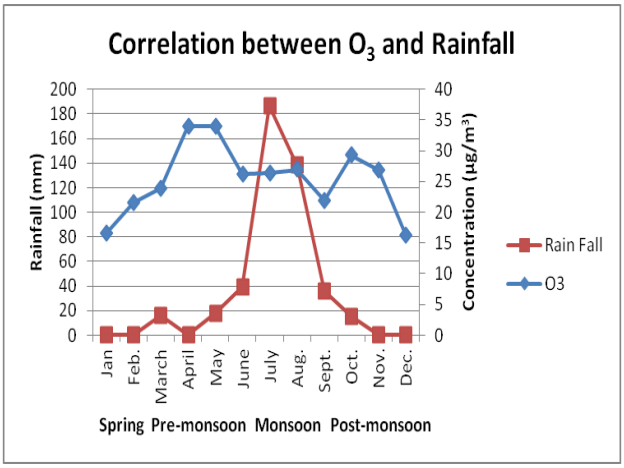

Figure 4. Correlation between Rainfall and O_3

Regression analysis reveals that, in Gurugram, $PM_{2.5}$, O_3, NO_x, NO_2, NO SO_2 and CO are negatively correlated with rainfall, but their degree of correlation significantly varies. PM2.5 is found to be most affected while O_3 is found to be least affected by rainfall. The degree of correlation based on the coefficient of determination is found as $PM_{2.5}$ (r^2 = 0.7937) > CO (.r^2 = 3671) > SO_2 (r^2= O.2362) > NO_2 (r^2 = 0.2311) > NO_x (r^2 = 0.2170) > NO (r^2 = 0.1138) > O_3 (r^2 = 0.0837).

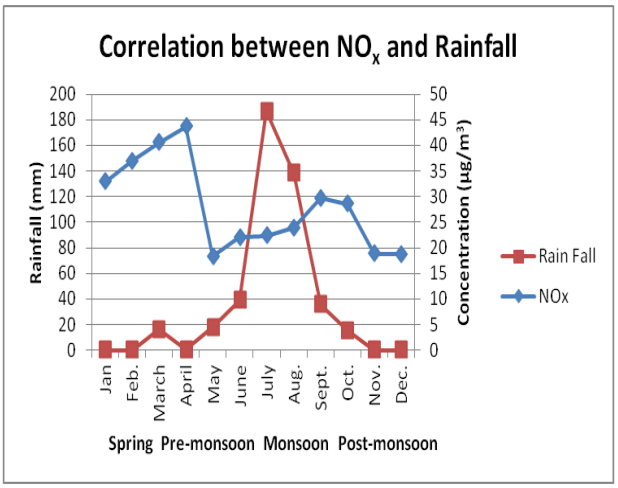

Figure 5. Correlation between Rainfall and NO_x

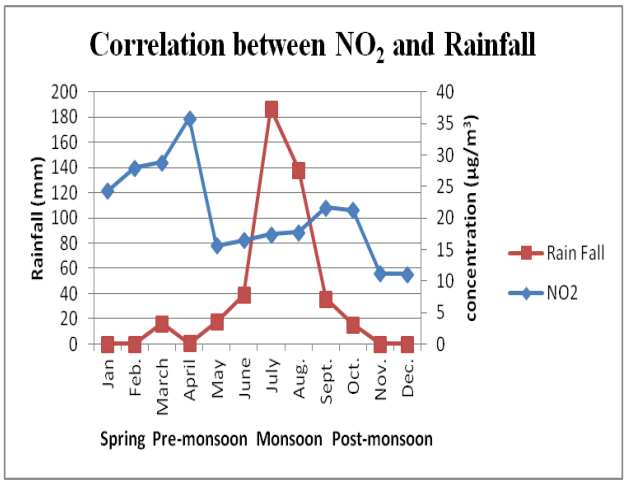

Figure 6. Correlation between Rainfall and NO_2

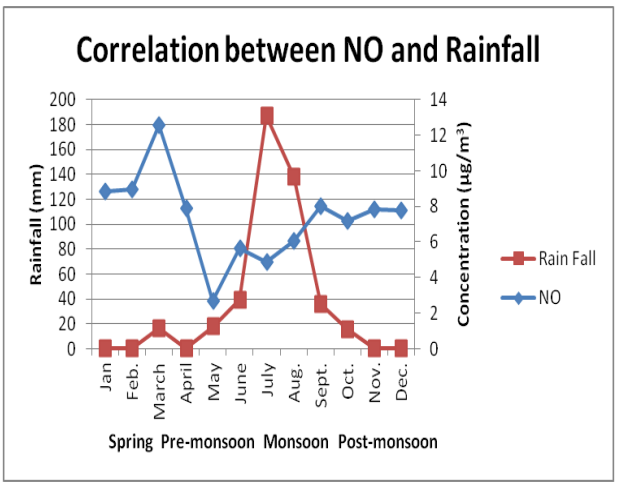

Figure 7. Correlation between Rainfall and NO

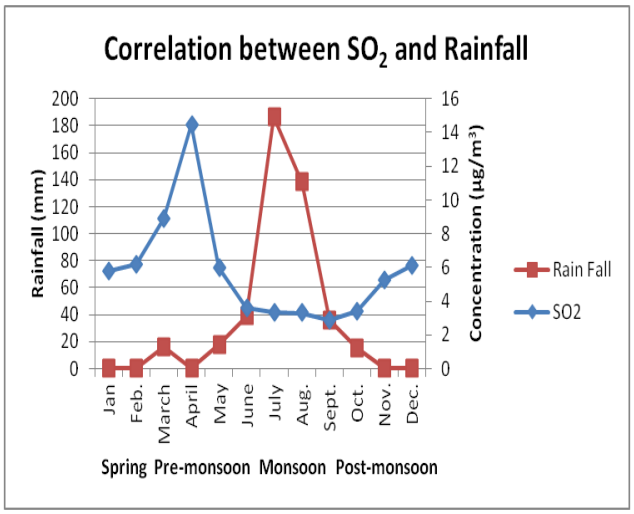

Figure 8. Correlation between Rainfall and SO_2

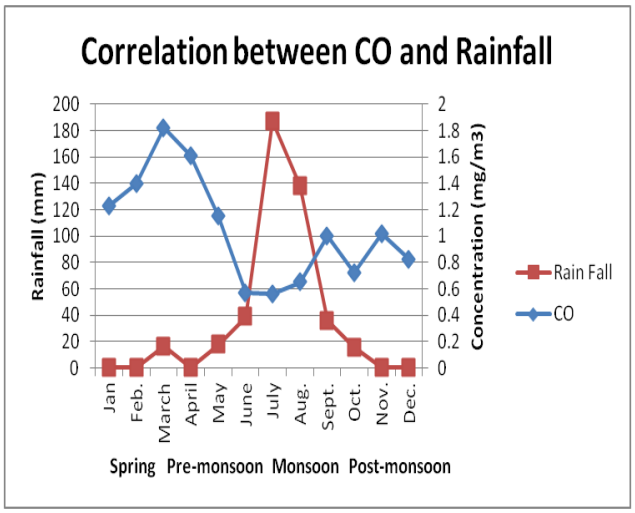

Figure 9. Correlation between Rainfall and CO

Table 2. Coefficient of Performance and regression equations between rainfall, $PM_{2.5}$ and SO_2

Observing Site	Rainfall Range (Monthly mean) (mm)	r^2	$PM_{2.5}$ Equation	r^2	SO_2 Equation
Gurugram	0.5 – 186.8	0.7937	$PM_{2.5}$= -0.2288R +98.364	0.2362	SO_2= -0.0292RF + 7.3578
Rohtak	0.2 – 122.7	0.5183	$PM_{2.5}$= -0.1109RF+ 46.949	0.2853	SO_2=-0.0901RF = 4.1235
Panchkula	2.3 – 165.6	0.3213	$PM_{2.5}$=-0.1468RF + 5.733	0.2524	SO_2=-0.0125RF + 6.0009

4.2. Influence of Rainfall on concentration of $PM_{2.5}$, O_3, NO_x, NO_2, NO, SO_2 and CO in Rohtak

In Rohtak, the monthly average rainfall ranges between 0.2 mm and 122.7 mm. Average rainfalls varies between 0 – 15.3mm in spring, 16.5mm – 21.5mm in pre-monsoon and 8.0mm – 122.5 mm in monsoon. Minimum rainfall has been recorded in the month of February and maximum in the month of August. No rainfall recorded in the months of January, April, October, November and December. The average rainfall in Rohtak from January 2016 to December 2016 is depicted graphically in Figure 10. The season wise variations of rainfall and its influence on the concentration of $PM_{2.5}$, O_3, NO_x, NO_2, NO SO_2 and CO are presented in Figure 11 – Figure 17. The results of regression analysis study are presented in Table 2 – Table 4.

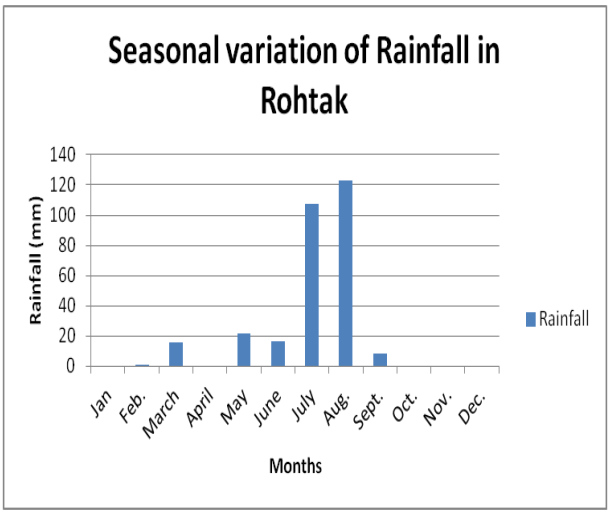

Figure 10. Seasonal variation of Rainfall in Rohtak

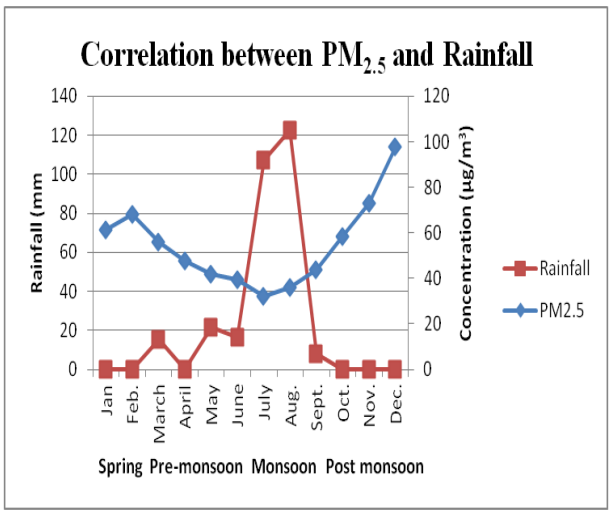

Figure 11. Correlation between Rainfall and $PM_{2.5}$

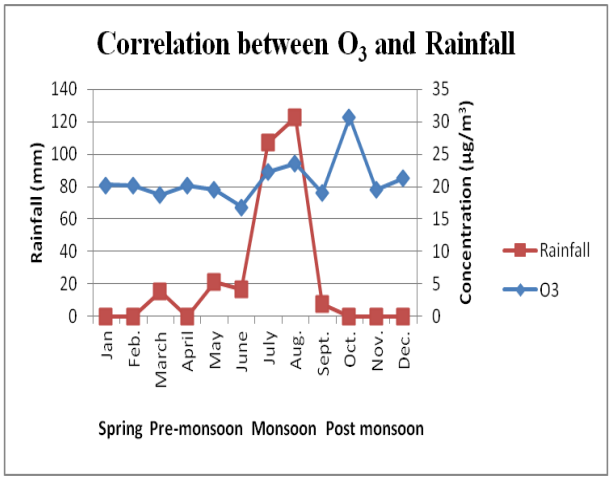

Figure 12. Correlation between Rainfall and O_3

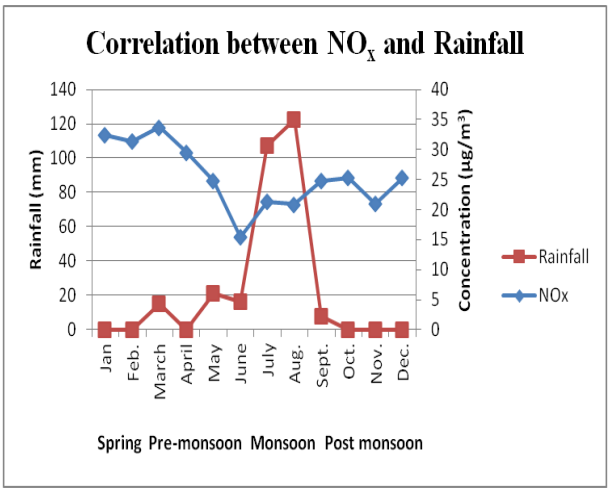

Figure 13. Correlation between Rainfall and NO_x

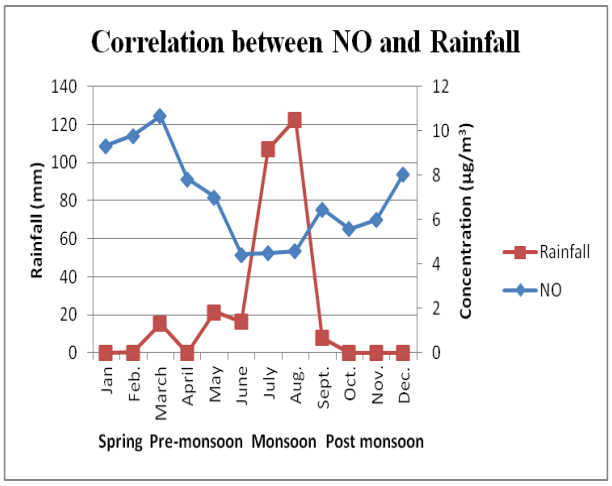

Figure 15. Correlation between Rainfall and NO

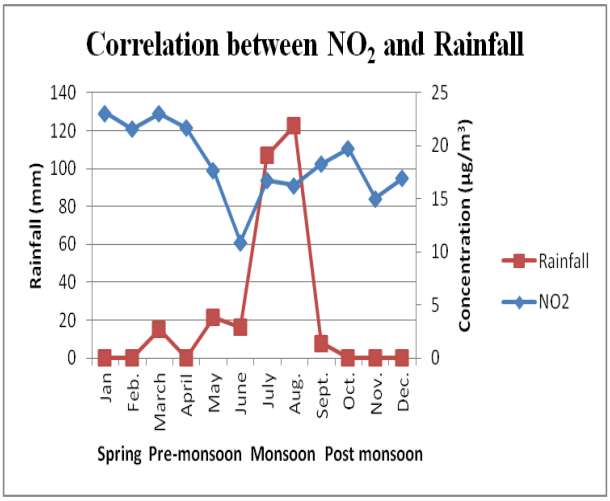

Figure 14. Correlation between Rainfall and NO_2

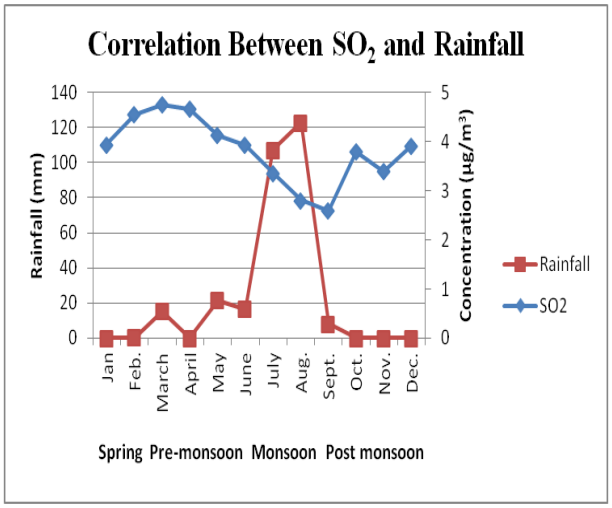

Figure 16. Correlation between Rainfall and SO_2

Table 3. Coefficient of Performance and regression equations between rainfall, O_3 and CO

Observing Site	Rainfall Range (Monthly mean)	r^2	O_3 Equation	r^2	CO Equation
Gurugram	0.5 – 186.8	0.0837	O_3= -0.0187RF +28.8 538	0.3671	CO = -0.0043RF +1.2526
Rohtak	0.2 – 122.7	0.7338	O_3 = +0.0384RF + 18.4157	0.4543	CO =-0.0046RF +1.0279
Panchkula	2.3 – 165.6	0.0933	O_3 = -0.0374RF + 32.497	0.1444	CO =0.0008RF + 0.7089

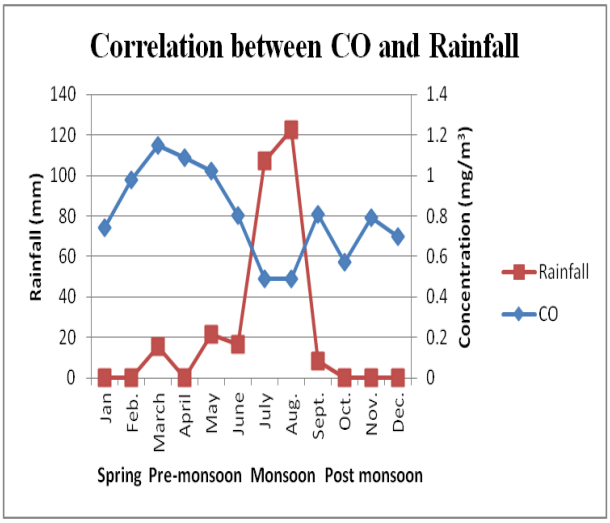

Figure 17. Correlation between Rainfall and CO

Regression analysis reveals that, in Rohtak, $PM_{2.5}$, NO_x, NO_2, NO SO_2 and CO are negatively correlated with rainfall, but their degree of correlation significantly varies. The behavior of O_3 is found to be different from other pollutants and is positively correlated with rainfall (r^2 = 0.7338). The degree of correlation based on the coefficient of determination is found as $PM_{2.5}$ (r^2 = 0.5183) > CO (.r^2 = 0.4543) > NO (r^2 = 0.3445)> SO_2 (r^2= O.2853) > NO_x (r^2 = 0.1635) > NO_2 (r^2 = 0.0763).

4.3. Influence of Rainfall on concentration of $PM_{2.5}$, O_3, NO_x, NO_2, NO SO_2 and CO in Panchkula

In Panchkula, the monthly average rainfall ranges between 0.3 mm and 165.6 mm. Average rainfalls varies between 0.3mm – 21.6mm in spring, 5.2mm – 62.5mm in pre-monsoon, 37.8mm – 165.6mm in monsoon and

2.3mm – 17.6mm in post monsoon season. Minimum rainfall has been recorded in the month of April and maximum in the month of July. No rainfall recorded in the month of November. The average rainfall in Panchkula from January 2016 to December 2016 is depicted graphically in Figure 18. The season wise variations of rainfall and its influence on the concentration of $PM_{2.5}$, O_3, NO_x, NO_2, NO SO_2 and CO are presented in Figure 19 – Figure 25. The results of regression analysis study are presented in Table 2 – Table 4.

Regression analysis reveals that, in Panchkula, $PM_{2.5}$, O_3, NO_x, NO_2 and SO_2 are negatively correlated with rainfall, but their degree of correlation significantly varies. CO (r^2 = 0.1443) and NO (r^2 = 0.1821) are positively correlated with rainfall but their correlation is observed to be very week. The degree of correlation based on the coefficient of determination is found as $PM_{2.5}$ (r^2 = 0.3213) > SO_2 (r^2= O.2524) > NO_2 (r^2 = 0.1557) > NO_x (r^2 = 0.1026) > O_3 (r^2 = 0.0933) [5].

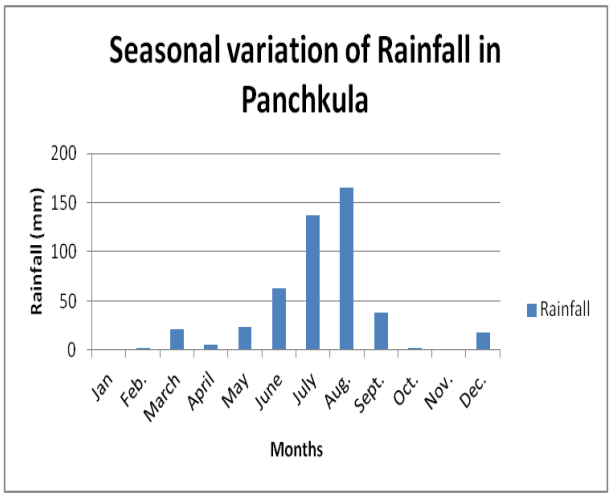

Figure 18. Seasonal variation of Rainfall in Panchkula

It was noted that, the degree of correlation significantly varies from pollutant to pollutant with same level of rainfall. Also, statistical correlation depends on the sources of production and other removal mechanism of pollutants at the the monitoring site. The negative correlation between $PM_{2.5}$ and NO_x in Gurugram confirm the findings of previous study [2]. The significant negative correlation between CO and rainfall at Gurugram and Rohtak is interesting in view of low water solubility of CO [16,17]. It may be due to other meteorological processes in addition to the wash out effect [8]. One of these processes is the active convection that under rainy conditions mixes air from aloft with air nearer the surface and this dilute compound with emission sources near the Earth surface. Weak negative correlation between O_3 and rainfall in Gurgugram and in Panchkula and positive correlation in Rohtak may be due to strong convection during heavy rain in monsoon which leads low level O_3 that vertically mixes upper level O_3 in the upper atmosphere down to the troposphere [18]. The washout effect of rainfall on NO_x, NO_2 and NO is observed to be negative in all three monitoring sites except for NO in Panchkula but their degree of correlation are of significance.

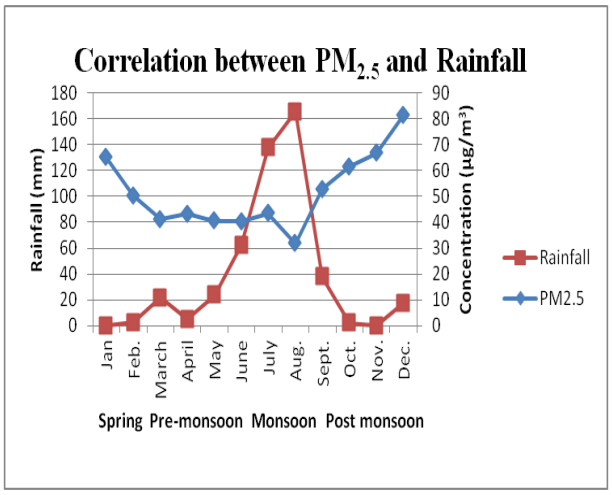

Figure 19. Correlation between Rainfall and $PM_{2.5}$

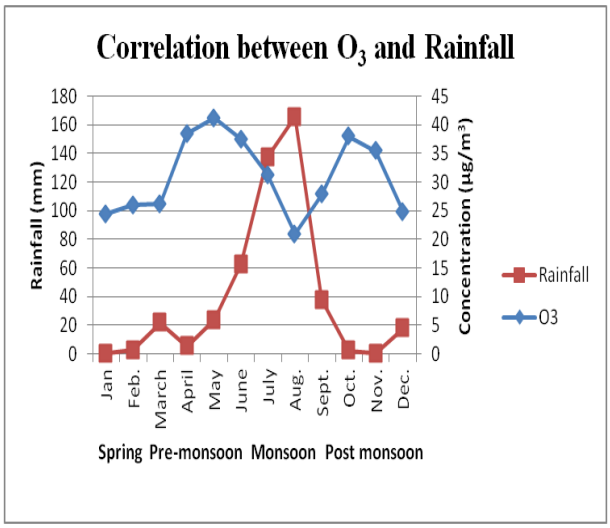

Figure 20. Correlation between Rainfall and O_3

Table 4. Coefficient of Performance and regression equations between rainfall, NO, NO_2 and NO_x

Observing Site	Rainfall Range (Monthly mean) mm	r^2	NO Equation	r^2	NO_2 Equation	r^2	NO_x Equation
Gurugram	0.5 – 186.8	0.1138	NO =-0.0144RF + 7.6718	0.2311	NO_2=-0.0499RF + 24.641	0.2170	NO_x = -0.0625RF +3.2139
Rohtak	0.2 – 122.7	0.3445	NO =-0.0265RF +7.6088	0.0763	NO_2= -0.0215RF +18.698	0.1635	NO_x=-0.0479RF +26.306
Panchkula	2.3 – 165.6	0.1821	NO = 0.0031RF + 3.4697	0.1557	NO_2=-0.0197RF + 22.122	0.1026	NO_x=-0.0162RF + 25.339

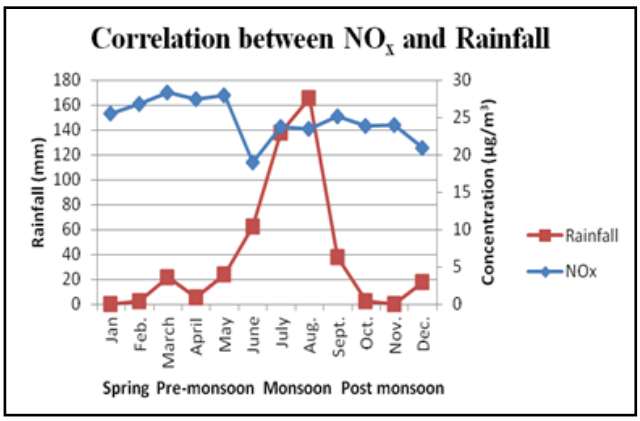

Figure 21. Correlation between Rainfall and NO_x

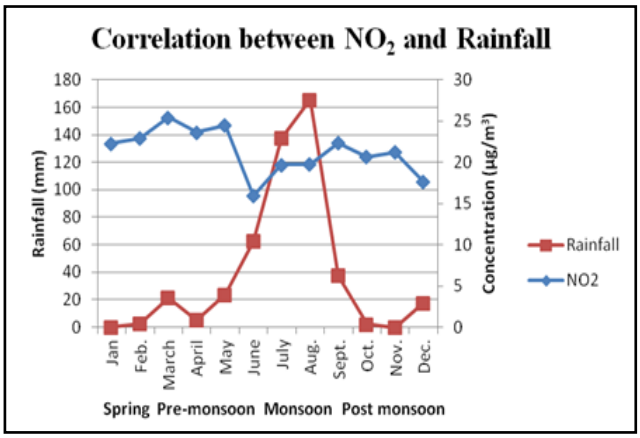

Figure 22. Correlation between Rainfall and NO_2

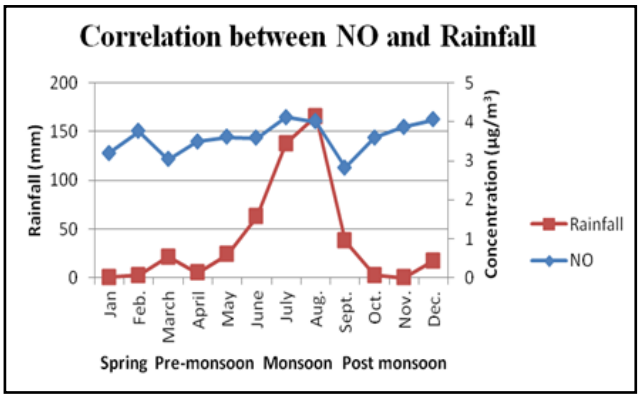

Figure 23. Correlation between Rainfall and NO

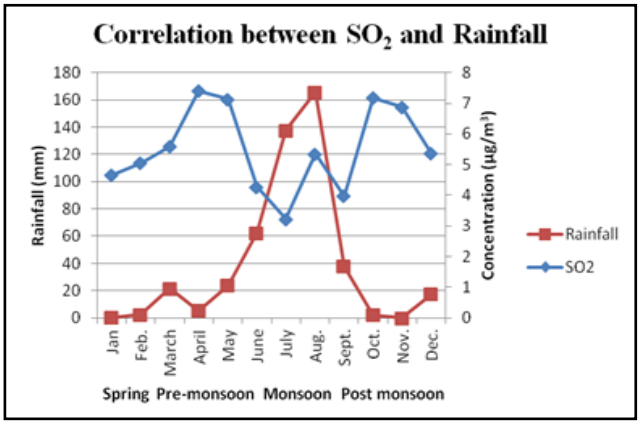

Figure 24. Correlation between Rainfall and SO_2

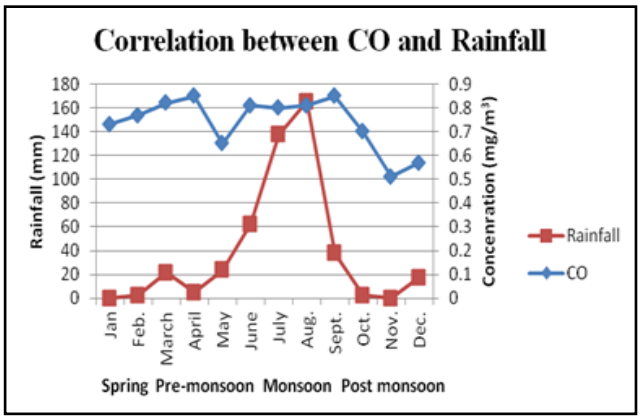

Figure 25. Correlation between Rainfall and CO

5. Conclusion

The statistical investigation of influences of rainfall on concentration of $PM_{2.5}$, O_3, NO_x, NO_2, NO ,SO_2, and C O were evaluated for the year 2016 at three monitoring sites of Haryana State , using regression analysis and the findings are stated below.

(i) In Gurugram, $PM_{2.5}$, O_3, NO_x, NO_2, NO SO_2 and CO are negatively correlated with rainfall, but their degree of correlation significantly varies. The degree of correlation based on the coefficient of determination is found as $PM_{2.5}$ (r^2 = 0.7937) > CO (.r^2 = 3671) > SO_2 (r^2= O.2362) > NO_2 (r^2 = 0.2311) > NO_x (r^2 = 0.2170) > NO (r^2 = 0.1138) > O_3 (r^2 = 0.0837).

(ii) In Rohtak, $PM_{2.5}$, NO_x, NO_2, NO SO_2 and CO are negatively correlated with rainfall, but their degree of correlation significantly varies. The behavior of O3 is found to be different from other pollutants and is positively correlated with rainfall (0.7338). The degree of correlation based on the coefficient of determination is found as $PM_{2.5}$ (r^2 = 0.5183) > CO (.r^2 = 0.4543) > NO (r^2 = 0.3445)> SO_2 (r^2= O.2853) > NO_x (r^2 = 0.1635) > NO_2 (r^2 = 0.0763).

(iii) In Panchkula, $PM_{2.5}$, O_3, NO_x, NO_2 and SO_2 are negatively correlated with rainfall, but their degree of correlation significantly varies. CO (r^2 = 0.1443) and NO (r^2 = 0.1821) are positively correlated with rainfall but their correlation is very week. The degree of correlation based on the coefficient of determination is found as $PM_{2.5}$ (r^2 = 0.3213) > SO_2 (r^2= O.2524) > NO_2 (r^2 = 0.1557) > NO_x (r^2 = 0.1026) > O_3 (r^2 = 0.0933).

(iv) It has been observed that, $PM_{2.5}$ is most effected and O_3 is least effected by rainfall.

The result of this study will be useful in further investigation in air pollution research to analyze the relative influence of the washout effect on the air pollutants and the impact of precipitation on air quality.

Acknowledgements

The authors thank the Haryana State Pollution Control Board for providing the O_3, NO_x, NO_2, NO, CO, SO_2 and PM2.5 data for the measuring sites Gurugram (NCR), Rohtak and Panchkula & Indian Meteorological Department for providing Rainfall data. The author Dr. Ram Chhavi

Sharma is grateful to Shree Guru Gobind Singh Tricentenary (SGT) University Gurugram for providing an excellent research environment, infrastructure facilities and encouragement during the course of this work.

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