View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by Online Publishing @ NISCAIR

e-ISSN No.: 2582-4228

Journal of Indian Association for Environmental Management

Journal homepage: www.http://op.niscair.res.in/index/php/JIAEM/index

An Extensive Assessment of Ambient Air Quality in City Delhi: Air Quality Monitoring, Source Apportionment and Analysis

Deo Nandan Kumar[1] and Kumari Priyanka[2]

[1]Department of Chemistry, Deshbandhu College, (University of Delhi), Kalkaji, New Delhi-110019, India
Email: dnandan2002@gmail.com
[2]Department of Mathematics, Shivaji College, (University of Delhi), New Delhi 110027, India
Email: priyanka.ism@gmail.com

Submitted: Jan. 23, 2021 Revised: April 23, 2021 Accepted: April, 27, 2021

Abstract: The Analysis of air quality data for three consecutive years 2018, 2019 and 2020 showed that there was a significant reduction in the concentration of almost all pollutants in year 2020 except for ozone and benzene. In 2020 the decrease in concentration may be observed due to various restrictions imposed during lockdown called due to COVID - 19 pandemic. However, ozone showed an increasing trend, this may be due to more heat and sunlight as ozone primarily results from photochemical reactions involving nitrogen oxides and volatile organic compounds in the presence of sunlight and heat. Concentration of benzene has increased in 2020, this may be due to certain industries, especially those consuming or releasing benzene, might have started operating, resulting in the increase. Local influence of emissions on monitoring stations is also a possibility during lockdown period in 2020. A relative reduction of 35.38% in PM_{10}, 38.79% in $PM_{2.5}$, 23.90% in NO_2, 8.22% in SO_2 , 17.64% in CO, 22.36% in NO and 9.98% in NH_3 have been observed in 2020 when compared to 2019. Correlation and p-value analysis indicates that there is significant correlation between some of the pollutant pairs but the same pattern is not retained over time. The Principal component analysis (PCA) reflects that only first four principal components are significant, which identifies the pollution caused due to vehicles as primary and major source of air pollution in Delhi. Regional atmospheric transfer of pollutants from nearby areas from burning of agricultural waste, coal etc. were found to be the secondary major source of air pollution in Delhi. The objective of the present work is to analyze the distribution of eleven major pollutants namely particulate matters (PM_{10} and $PM_{2.5}$), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), ozone (O_3), nitric oxide (NO), oxides of nitrogen (NOx), ammonia (NH_3), carbon monoxide (CO), benzene (C_6H_6), toluene along with meteorological parameters, air temperature (AT), wind speed (WS), wind direction (WD), barometric pressure (BP), solar radiation (SR) and relative humidity (RH) in the mega city Delhi for the three consecutive years 2018, 2019 and 2020.

Keywords: **Air pollution, correlation analysis, principal component analysis, meteorological parameters**

I. INTRODUCTION

Air pollution has become one of the major global problems and a serious threat to health, climate and other materials. The adverse effect of air pollution also causes damage to building materials and cultural objects[1]. Air pollution is severely influenced by multiple environmental or meteorological factors, traffic pattern, size, and land use[2,3]. Exposure to air pollution depends on socio-economic and socio-cultural differences. A majority of slums in India are located close to factories and highways[4]. Exposure to such high levels of air pollution increases the risk of lung cancer, cardiovascular disease, chronic and acute respiratory illness and infertility[5]. Beside air quality and human health, air pollution also affects climate and agricultural productivity[6]. Exposure to outdoor fine particulate matter ($PM_{2.5}$) is a serious and leading risk factor for mortality also[7].

The major components of air pollution in urban city are ambient particulate matter (PM), household air pollution and to some extent ozone in the troposphere. The main sources of ambient particulate matter pollution are burning of coal for thermal power production, industry emissions, construction activity and brick kilns, transport vehicles, road dust, residential and commercial biomass burning, waste burning, agricultural stubble burning and use of diesel generators. High levels of particulate matter (PM) may have severe impact on health. There is a strong correlation between ambient particulate matter concentration and increase in mortality and hospitalizations due to respiratory diseases[8]. Epidemiological studies[9] have linked Particulate Matter 10 (aerodynamic diameter ≤ 10 µm) referred as PM_{10} and Particulate Matter 2.5 (aerodynamic diameter ≤ 2.5 µm) referred as $PM_{2.5}$ with significant health problems, including premature mortality, chronic respiratory disease, aggravated asthma, acute respiratory symptoms, and decrease in lung function. Ground level ambient ozone is produced when nitrogen oxide and volatile organic compounds emitted from transport vehicles, power plants, factories, and other sources react in the presence of sunlight[10]. It primarily results from photochemical reactions involving nitrogen oxides (NOx = NO + NO2) and volatile organic compounds (VOCs) in the presence of sunlight[11] . Ozone is a strong oxidant, and it can react with wide range of cellular components and biological materials which may damage lung cells and cause several diseases[12].

Urban environment is also dominated by another critical pollutant, Carbon monoxide (CO). It is toxic and have appreciable mass in atmosphere. It is mainly produced from incomplete combustion. CO rapidly diffuses across alveolar, capillary and placental membrane. Approximately 80-90% of absorbed CO binds with hemoglobin (Hb) to form Carboxyhemoglobin (COHb), which is a specific biomarker of exposure in blood. The affinity of Hb for CO is 200-250 times than that of oxygen[13].

Due to increased number of vehicles in urban areas, the pollutant Nitrogen dioxide (NO_2) has become another threat to the environment. It is generated by combustion processes. About 70-90% of NO_2 can be absorbed in the respiratory tract of human on inhalation which may cause severe disorders[14].

Urban areas are also suffering from the pollutant, Sulphur dioxide (SO_2), which is a toxic gas and released naturally by volcanic activity but it is also generated by human activities such as burning of fossil fuel like coal, oil and natural gas. Some amount is also released from industrial process such as extracting metal from ore. Inhalation of SO_2 may cause breathing problem particularly in asthmatic persons. It is soluble in aqueous media and affects mucous membrane of the nose and upper respiratory tract[15]. It has environmental impact too as it combines with water vapours in atmosphere, forming sulphuric acid, which falls on the ground as acid rain that acidify rivers and lakes and becomes harmful for aquatic animals. Ammonia is another harmful gas, which originate from agriculture i.e., manure and fertilizer application. The main source of benzene is from forest fire, volcanic eruption and cigarette smoke. However, the pollutant toluene is present in paints, thinner tobacco smokes etc.

Currently almost entire world is being affected by the global pandemic caused due to zoonotic virus named Coronaviruses, which may cause Severe Acute Respiratory Syndrome (SARS-CoV). Those living in areas with higher levels of air pollution face greater risk of infection and can experience more severe Coronavirus disease (COVID-19) symptoms and outcomes. Some study also indicate that higher level of fine particulate matter $PM_{2.5}$ are associated with higher death rates from COVID-19[16].

Delhi being the important node in the international corporate and financial network across the globe so became more vulnerable to the infection due to COVID-19 and now it is facing the stage of community spread. Efforts have been made to address the impact of COVID-19 on airpollution[17, 18].

The problems due to air pollution is multi-dimensional as well as multi-sectorial, which requires a potent and contemplate approaches that takes into account the best available epidemiological evidences, cost-analysis of various interventions, and a strong communications platform to ensure broad awareness of the health impacts of air pollution and the advantages of reduction in air pollution. However, prior to development of any interventions and policy recommendations, rigorous analysis of recent available data becomes essential. For analysis of the air pollution data, statistical tools such as multivariate statistical analysis, which includes correlation and p-value analysis, principal component analysis etc. may be used.[19 - 21]

Motivated with the above arguments and recent article[22], in the present study, the average annual air pollution data recorded from 36 air quality monitoring stations in the mega city Delhi have been analyzed for three consecutive year 2018, 2019, 2020 on the basis of concentration of major pollutants and meteorological parameters. Correlation and p-value analysis have been carried out to determine the linear association between the pollutants. To identify possible sources of various pollutants the Principal component analysis (PCA) have been carried out for all the three years. Comparative study has also been carried out for the distribution of pollutants in the national capital city Delhi for the years 2018, 2019 and 2020 for all air quality monitoring stations for which the data was available. The present study may be useful in identifying the primary and secondary sources of pollutants, which may help in determining appropriated measures or policies to reduce the level of pollutants in future.

II. MATERIALS & METHOD

Study area and selection of Air quality monitoring stations

The study area is the critically polluted city Delhi, which is a mega city and a union territory of India containing New Delhi, the capital of India. According to "The world's cities in 2016", United Nations, the National Capital Territory of Delhi is the second leading megacity having second largest urban area in the world. It is a massive metropolitan area located in northern part of the India with approximately 1.68 crore inhabitants. It exhibit a decadal growth rate of 21% with population density of 11297 person per square kilometer[23]. It has now emerged as an important node in the international corporate and financial network across the globe. It also shares its boundaries with cities Noida, Ghaziabad, Faridabad and Gurgaon, which contributes to an enormous flux of vehicles into the city.

In Delhi, the air quality is monitored and managed by the Central Pollution Control Board (CPCB) of India under the Ministry of Environment and Climate change, The System of Air Quality and Weather Forecasting and Research (SAFAR) and Delhi Pollution Control Committee (DPCC). Delhi encompasses the total area of 573.0 square miles and have currently 38 air quality monitoring stations having capacity to monitor and record various pollutants present in air. Delhi has been declared as critically polluted as per annual report 2014-2015, CPCB.

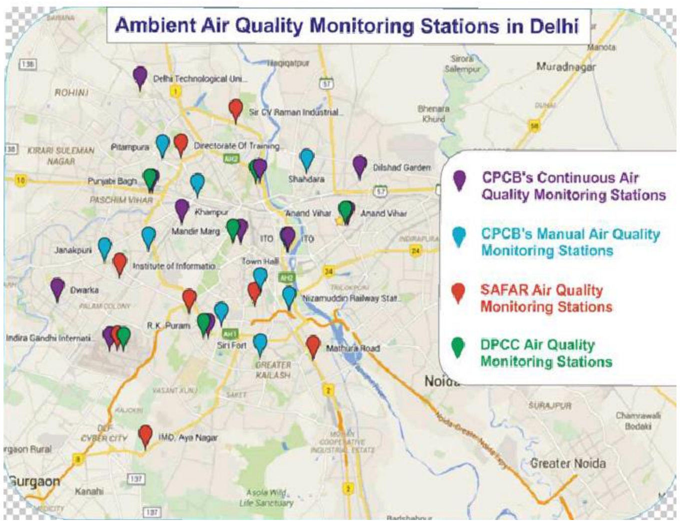

Fig. 1a: Location of air quality monitoring stations in Delhi.[24]

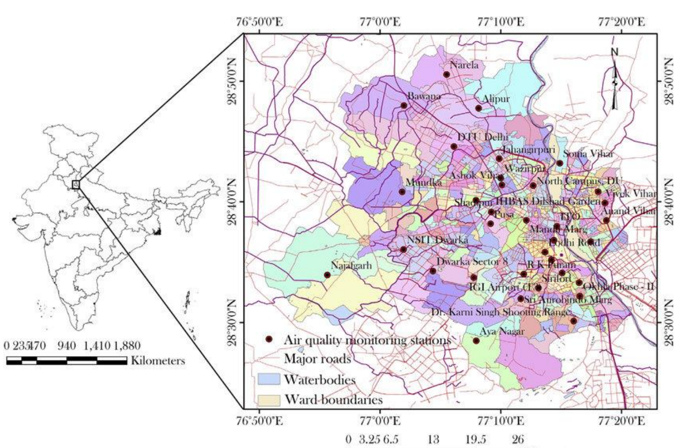

Fig. 1b: Reference Map of the NCT of Delhi showing Location of air quality monitoring stations along with their latitude and longitude.[25]

Air Pollution Data Description and Visualization

There are 38 air quality monitoring stations in Delhi. Their locations are shown in Fig. 1. In the present study all 38 air quality monitoring stations of Delhi have been observed for three consecutive years 2018, 2019 and 2020. The monitoring stations Anand Vihar, Bawana, Narela, Okhla PH2, Patparganj and Wazirpur are located in industrial cum residential areas, however the remaining stations are located in residential areas. The air pollutants investigated and analyzed in the study were particulate matter ($PM_{2.5}$, PM_{10}), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3), nitric oxide (NO), oxides of nitrogen (NOx), ammonia (NH_3), carbon monoxide (CO), benzene (C_6H_6), toluene along with meteorological parameters which were air temperature (AT), wind speed (WS), wind direction (WD), barometric pressure (BP), solar radiation (SR) and relative humidity (RH) . The data of annual average concentration of the pollutants and meteorological parameters have been collected from the official website of Central Pollution Control Board of India[26]. It was observed that the data for some parameters were missing for some monitoring stations. For the year 2018, complete data on all considered pollutants were found from 25 monitoring stations. However, the complete informations on all pollutants have been obtained from 18 and 21 monitoring stations for the year 2019 and 2020 (upto October, 2020) respectively. The concentration of pollutants and meteorological parameters, which were observed from various monitoring stations for the years 2018, 2019 and 2020 have been plotted in Fig. 2(a) –Fig. 2(q). The stations with missing data were dropped from the study. The standard methods of measurement of pollutant concentrations[27] as prescribed by National Ambient Air Quality Standard (NAAQS), is used by Central Pollution control Board, India to compute the concentration of pollutants.

Correlation and p-value analysis

Correlation is a method of establishing the degree of probability that a linear relationship exists between the variables taken in pair. If the change in one variable affects a change in the other variable, the variables are said to be correlated. If the two variables deviated in the same direction, then the correlation is said to be positive. But if they constantly deviate in the opposite direction, then the correlation is said to be negative. Pearson correlation coefficient represents the normalized measure of strength of linear relationship between the variable. The Pearson's correlation coefficient between two random variables 'X' and 'Y' (say) is denoted and defined as

$$r(X,Y) = \frac{Cov(X,Y)}{\sigma_X \ \sigma_Y} \qquad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where $Cov(X,Y)$ denote the covariance between the variables 'X' and 'Y'; σ_X and σ_Y denote the standard deviations of 'X' and 'Y' respectively.

The concept of correlation has been used here to measure strength of linear relationship between 11 pollutants (PM_{10}, $PM_{2.5}$, NO_2, SO_2, CO, O_3, NO, NOx, NH_3, Benzene and Toluene) considered in this study. Pearson's correlation coefficient has been computed for all possible pair of pollutants in terms of the correlation coefficient matrix and result obtained is expressed in Fig. 3.

p-value is another statistical concept used to evaluate how well the interpreted data rejects the null hypothesis, which states that there is no relationship between the variable pair considered. If the p value is smaller than the significance level (0.05), then the corresponding correlation between the variable pair is considered significant. For the considered data the p-values have been computed for each pair of pollutants and the results are presented in italic font in Fig. 3.

Principal Component Analysis

Since, the data considered for analysis consists of multiple pollutants so the principal component analysis (PCA) is used to identify the sources of pollutants. PCA is an exploratory multivariate data analysis technique used to reduce the dimensionality of dataset. It as a method of transforming the original (interrelated) variables into new, uncorrelated (independent) variables[28]. The new variables are called the principal components (PC). The amount of information conveyed by each PC is measured by its variance, so the PC's are arranged in order of decreasing variance. Each Principal Component is the linear combination of the original variables and all principal components are orthogonal to each other, so there is no redundant information. The first principal component accounts for maximum variance (information in data) in the original dataset. The second principal component is orthogonal (uncorrelated) to the first one and accounts for the largest amount of the remaining variance and so on. The number of components selected may be determined by examining the proportion of total variance explained by each component. The algorithm for implementing PCA is presented below:

(i) Standardized the initial variables so that each one of them contributes equally to the analysis. Mathematically this can be accomplished by subtracting the mean and then dividing the result by the standard deviation for each value of each variable.

(ii) Compute the covariance matrix 'A' (say) to understand how the variables of the input data set are varying from the mean with respect to each other.

(iii) Compute the eigenvalues of the covariance matrix "A" from its characteristics equation
$|A - \lambda I| = 0$, where λ is the eigenvalue and I is the identity matrix.

(iv) For each eigenvalue, a non-zero vector 'e' can be defined as $A e = \lambda e$, where the vector 'e' is called eigenvector of the covariance matrix 'A' associated with corresponding eigenvalue.

(v) The eigenvectors derived from the covariance matrix represent the mutually orthogonal linear combination of the matrix. Their associated eigenvalue represent the amount of total variance, which is explained by each eigenvectors.

(vi) The average eigenvalue of the centered and scaled data is just one, so only components with eigenvalues greater than one are considered important. This is termed as Kaiser Criterion[29].

The Eigenvalues and accumulated variance of the principal components have been computed for the considered air pollution data using MATLAB software and the results obtained are presented in Table 1. This technique have been used to identify the pollution sources of air, water and soil pollution[30, 31]. Applying Kaiser Criterion and Varimox Rotation, all factors showing the eigenvalues greater than one were included and presented in Table 1.

Factor Analysis

Factor analysis is a multivariate statistical tool, which looks similar to PCA but they differ from each other. In PCA, the major objective is to select a number of components that explain as much of the total variance as possible. On the other hand, the factors obtained in factor analysis are selected mainly to explain the interrelationship among original variables. Ideally, the number of factors expected is known in advance. The major emphasis is placed on obtaining easily understandable factors that convey the essential information contained in original set of variables. The main numerical aspects of factor analysis are concerned with finding factor loadings, which are the correlations between the standardized variables and the factors. Hence, using the PCA the factors are identified and factor loadings for each factor is evaluated using MATLAB software and the results are presented in Table 1.

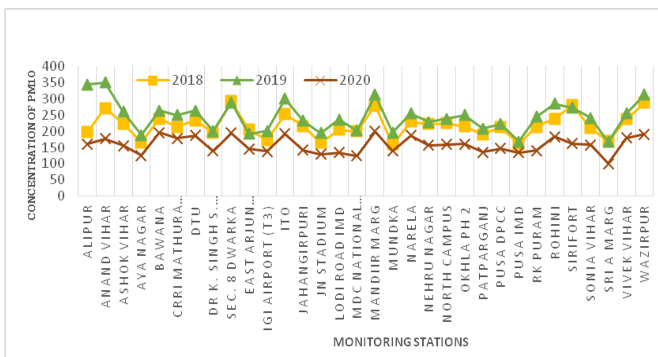

Fig. 2(a). Annual average variations of pollutant PM_{10}(in μ/m^3) during the study period: Year 2018 to 2020

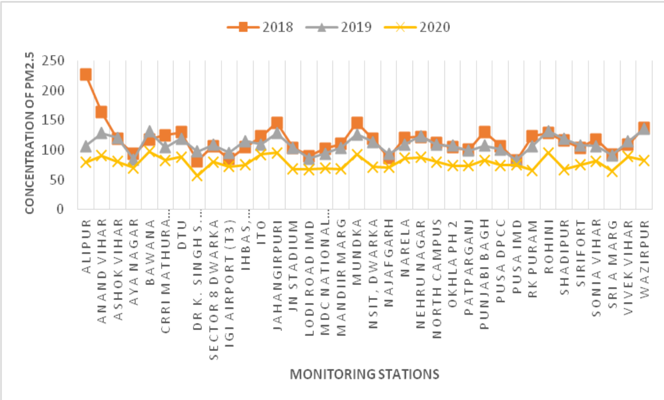

Fig. 2(b). Annual average variations of pollutant $PM_{2.5}$(in μ/m^3)during the study period: Year 2018 to2020

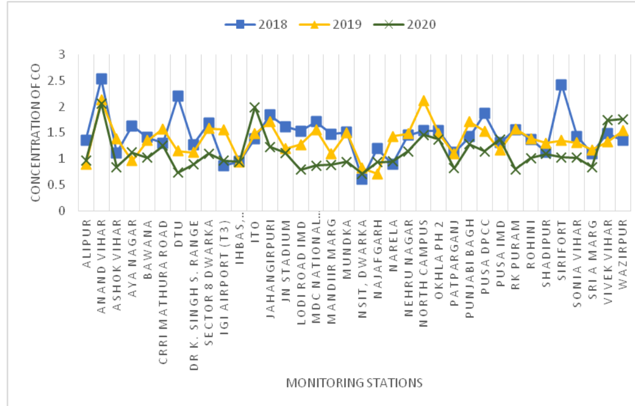

Fig. 2(e). Annual average variations of pollutant CO (in μ/m^3) during the study period: Year 2018 to 2020

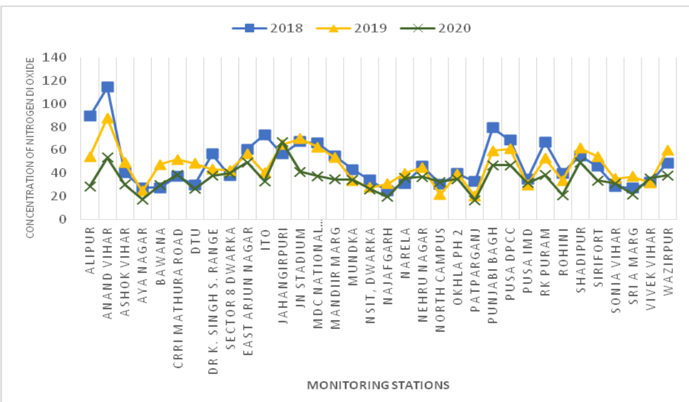

Fig. 2(c). Annual average variations of pollutant NO_2((in μ/m^3) during the study period: Year 2018 to2020

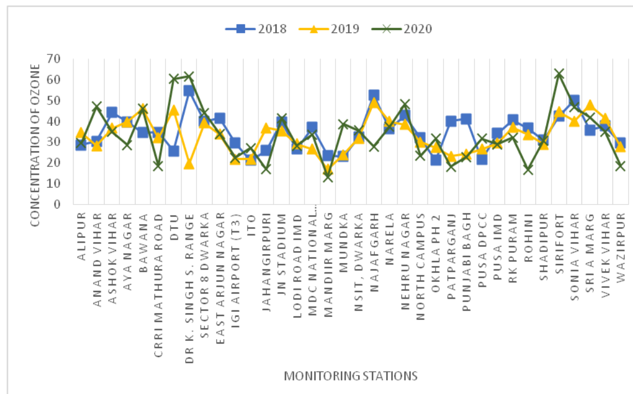

Fig. 2(f). Annual average variations of pollutant O_3(in μ/m^3) during the study period: Year 2018 to 2020

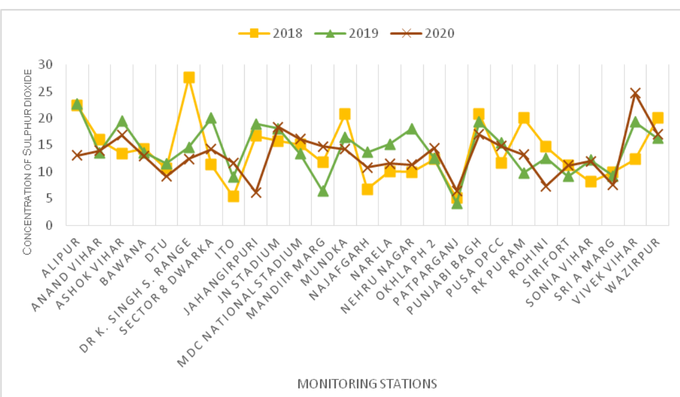

Fig. 2(d). Annual average variations of pollutant SO_2(in μ/m^3)during the study period: Year 2018 to 2020

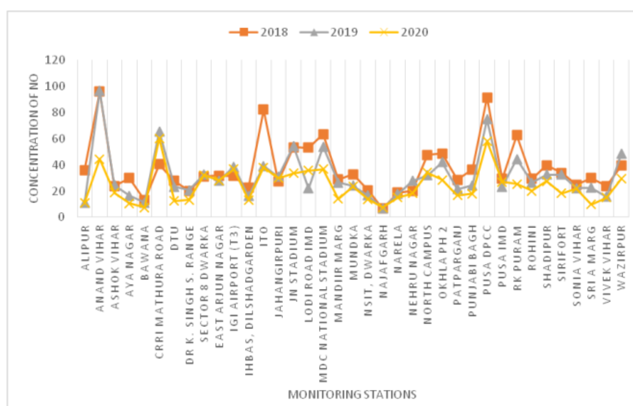

Fig. 2(g). Annual average variations of pollutant NO (in μ/m^3) during the study period: Year 2018 to 2020

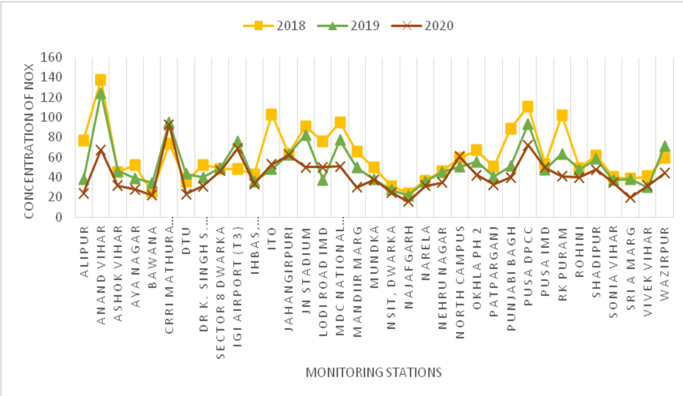

Fig. 2(h). Annual average variations of pollutant NOx(in ppb)during the study period: Year 2018 to 2020

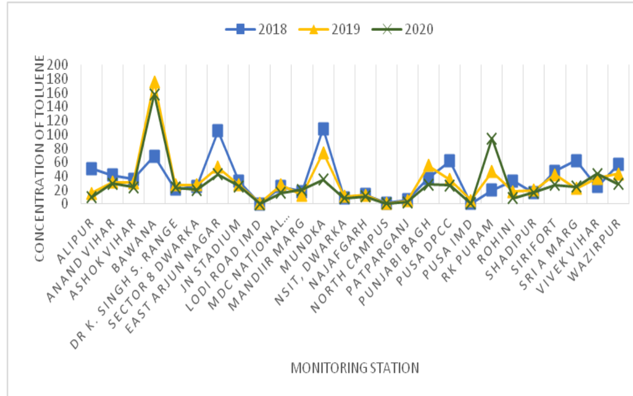

Fig. 2(k). Annual average variations of pollutant Toluene (in μ/m^3) during the study period:Year 2018 to 2020

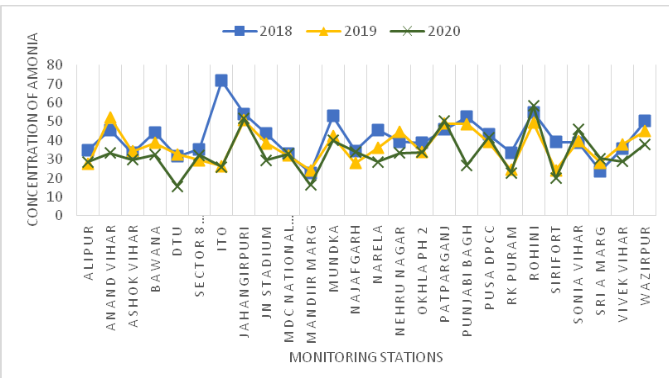

Fig. 2(i). Annual average variations of pollutant NH_3(in μ/m^3) during the study period: Year 2018 to 2020

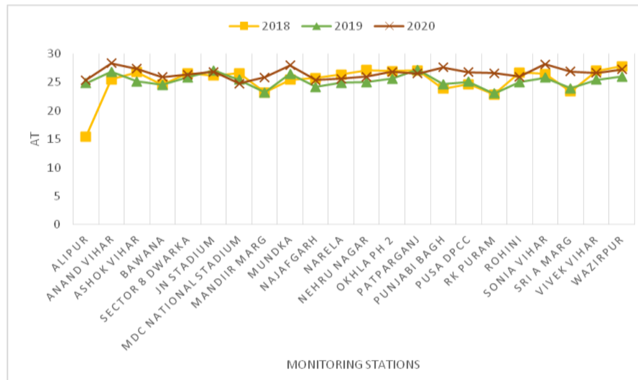

Fig. 2(l). Annual average variations of AT (in degree Celsius) during the study period: Year 2018 to 2020

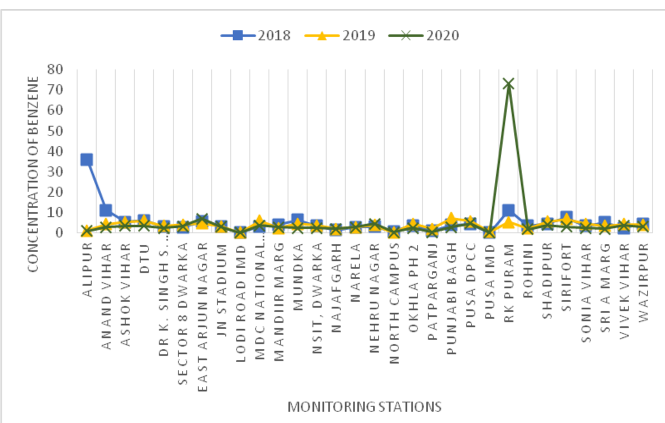

Fig. 2(j). Annual average variations of pollutant C_6H_6(in μ/m^3) during the study period: Year 2018 to 2020

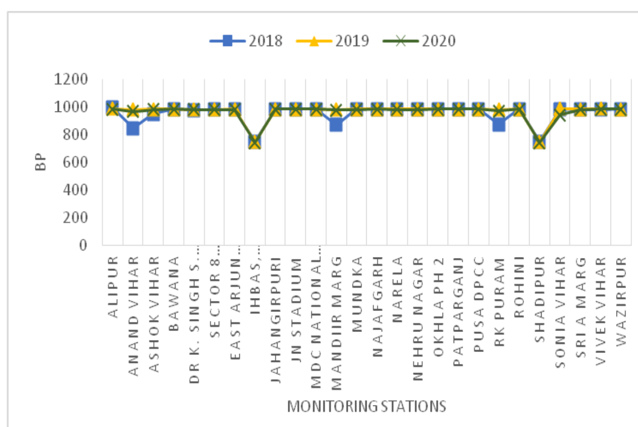

Fig. 2(m). Annual average variations of BP (mmHg) during the study period: Year 2018 to 2020

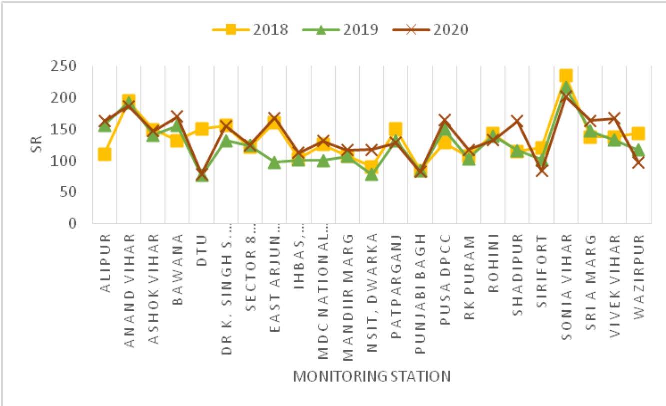

Fig. 2(n). Annual average variations of pollutant SR(in W/mt2) during the study period: Year 2018 to 2020

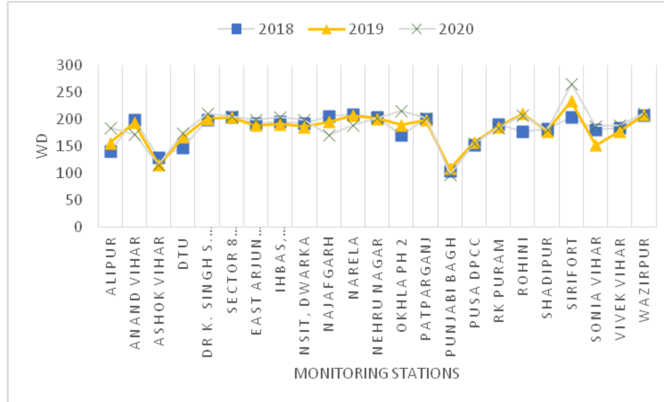

Fig. 2(p). Annual average variations of pollutant WD (degree) during the study period: Year 2018 to 2020

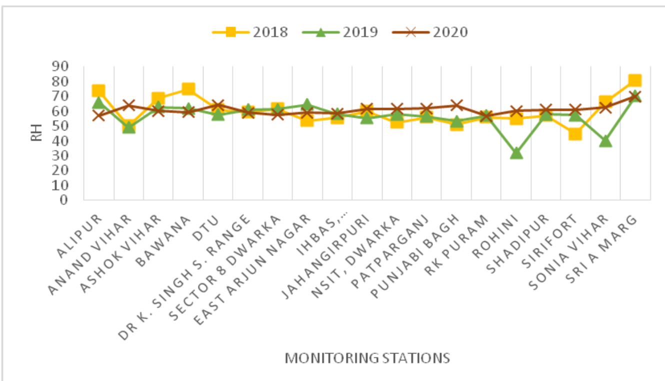

Fig. 2(o). Annual average variations of RH (%) during the study period: Year 2018 to Year 2020

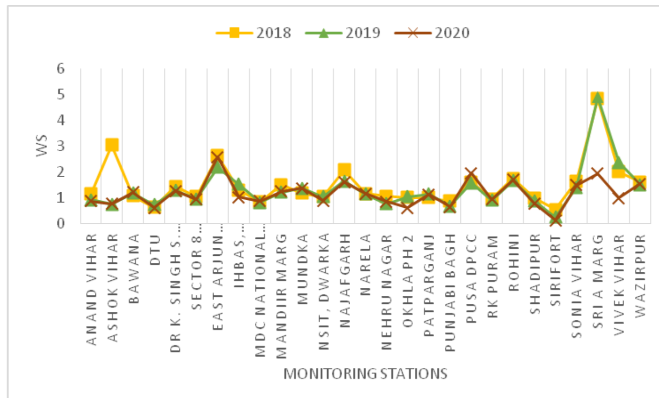

Fig. 2(q). Annual average variations of WS (in m/s) during the study period: Year 2018 to 2020

TABLE 1
Principal Component Analysis and Factor Analysis results for the whole study period

Parameter	2018				2019				2020			
	F 1	F 2	F 3	F 4	F 1	F 2	F 3	F 4	F 1	F 2	F 3	F 4
PM_{10}	-0.06	0.49	0.42	0.39	-0.01	0.98	-0.05	0.17	-0.02	0.93	-0.06	0.03
$PM_{2.5}$	-0.14	0.90	0.30	0.17	-0.075	0.98	-0.19	0.29	-0.12	0.94	-0.27	0.04
NO_2	0.68	0.38	-0.22	0.09	0.99	-0.13	-0.01	0.48	0.59	0.10	0.07	0.65
SO_2	0.08	0.42	-0.27	0.13	0.01	0.31	0.04	0.58	0.17	0.16	0.72	-0.23
CO	0.54	-0.07	0.24	0.02	0.42	0.35	0.39	-0.05	0.35	0.40	0.13	0.09
O_3	-0.23	-0.86	-0.60	-0.17	-0.32	-0.17	0.07	0.01	-0.04	-0.02	0.44	0.04
NO	0.99	-0.12	0.19	-0.12	0.93	0.03	0.01	-0.15	1.03	-0.14	-0.03	-0.02
NOx	0.97	0.03	-0.12	0.02	0.98	0.01	-0.03	-0.02	0.96	-0.03	-0.17	0.23
NH_3	-0.07	-0.26	0.16	0.85	0.09	0.53	-0.04	-0.20	0.20	0.37	-0.91	-0.13
Benzene	0.01	0.98	0.19	-0.49	0.06	-0.26	0.98	-0.01	0.14	-0.30	0.23	0.14
Toluene	-0.08	0.18	0.65	-0.01	-0.22	0.29	0.71	0.18	-0.26	0.38	0.31	0.14
Eigen Value	4.49	1.97	1.48	1.06	4.71	2.011	1.45	1.03	3.49	2.09	1.91	1.28
Percentage Variance	40.81	17.88	13.49	9.6	42.84	18.28	13.22	9.37	31.79	19.06	17.35	11.68
Cumulative Percentage	40.81	58.69	72.18	81.82	42.84	61.13	74.34	83.72	31.79	50.85	68.21	79.89

Year 2018

	PM_{10}	$PM_{2.5}$	NO_2	SO_2	CO	O_3	NO	NOx	NH_3	Benzene	Toluene
PM_{10}	1.0	0.80	0.43	0.39	0.42	-0.39	0.24	0.26	0.52	0.51	0.35
	1.0	*0.00*	*0.03*	*0.06*	*0.04*	*0.05*	*0.24*	*0.21*	*0.01*	*0.01*	*0.08*
$PM_{2.5}$		1.0	0.54	0.41	0.18	-0.44	0.18	0.30	0.32	0.82	0.33
		1.0	*0.01*	*0.04*	*0.39*	*0.03*	*0.39*	*0.15*	*0.12*	*0.00*	*0.11*
NO_2			1.0	0.54	0.45	-0.17	0.73	0.90	0.15	0.53	-0.05
			1.0	*0.01*	*0.02*	*0.40*	*0.00*	*0.00*	*0.49*	*0.01*	*0.82*
SO_2				1.0	0.02	0.00	0.16	0.35	0.14	0.40	0.22
				1.0	*0.91*	*0.99*	*0.43*	*0.09*	*0.50*	*0.05*	*0.30*
CO					1.0	-0.32	0.56	0.48	0.09	0.12	0.18
					1.0	*0.12*	*0.00*	*0.01*	*0.68*	*0.56*	*0.40*
O_3						1.0	-0.40	-0.28	-0.22	-0.22	-0.48
						1.0	*0.05*	*0.18*	*0.28*	*0.29*	*0.01*
NO							1.0	0.92	0.120	0.21	0.09
							1.0	*0.00*	*0.58*	*0.32*	*0.67*
NOx								1.0	0.14	0.31	-0.09
								1.0	*0.50*	*0.14*	*0.68*
NH_3									1.0	-0.13	0.22
									1.0	*0.53*	*0.30*
Benzene										**1.0**	0.20
										1.0	*0.35*
Toluene											1.0
											1.0

Year 2019

	PM_{10}	$PM_{2.5}$	NO_2	SO_2	CO	O_3	NO	NOx	NH_3	Benzene	Toluene
PM_{10}	1.0	0.79	0.23	0.37	0.64	-0.22	0.35	0.32	0.40	0.24	0.51
	1.0	*0.00*	*0.36*	*0.13*	*0.01*	*0.38*	*0.15*	*0.19*	*0.10*	*0.33*	*0.03*
$PM_{2.5}$		1.0	0.16	0.26	0.45	-0.17	0.18	0.19	0.54	0.10	0.44
		1.0	*0.52*	*0.30*	*0.06*	*0.49*	*0.46*	*0.44*	*0.02*	*0.69*	*0.07*
NO_2			1.0	0.25	0.56	-0.29	0.79	0.85	0.12	0.37	0.17
			1.0	*0.32*	*0.01*	*0.25*	*0.00*	*0.00*	*0.63*	*0.13*	*0.49*
SO_2				1.0	0.15	0.17	-0.03	0.00	0.04	0.19	0.31
				1.0	*0.54*	*0.49*	*0.88*	*0.99*	*0.0.87*	*0.44*	*0.21*
CO					1.0	-0.38	0.73	0.71	0.51	0.63	0.48
					1.0	*0.12*	*0.00*	*0.00*	*0.03*	*0.01*	*0.04*
O_3						1.0	-0.34	-0.38	-0.41	-0.09	-0.07
						1.0	*0.16*	*0.11*	*0.09*	*0.72*	*0.79*
NO							1.0	0.99	0.35	0.35	0.13
							1.0	*0.00*	*0.15*	*0.16*	*0.61*
NOx								1.0	0.37	0.33	0.09
								1.0	*0.13*	*0.19*	*0.71*
NH_3									1.0	0.13	0.19
									1.0	*0.61*	*0.46*
Benzene										1.0	0.71
										1.0	*0.00*
Toluene											1.0
											1.0

Year 2020

	PM_{10}	$PM_{2.5}$	NO_2	SO_2	CO	O_3	NO	NOx	NH_3	Benzene	Toluene
PM_{10}	1.0	0.83	0.36	0.19	0.46	0.02	0.16	0.26	0.34	-0.17	0.344
	1.0	*0.00*	*0.10*	*0.41*	*0.04*	*0.92*	*0.50*	*0.25*	*0.13*	*0.44*	*0.13*
$PM_{2.5}$		1.0	0.25	0.00	0.42	-0.12	0.06	0.20	0.50	-0.28	0.29
		1.0	*0.27*	*0.98*	*0.06*	*0.61*	*0.79*	*0.38*	*0.02*	*0.21*	*0.19*
NO_2			1.0	0.13	0.47	0.09	0.63	0.78	0.02	0.09	0.12
			1.0	*0.56*	*0.03*	*0.69*	*0.00*	*0.00*	*0.92*	*0.71*	*0.59*
SO_2				1.0	0.43	0.17	0.18	0.06	-0.49	0.049	0.100
				1.0	*0.05*	*0.45*	*0.43*	*0.78*	*0.02*	*0.83*	*0.67*
CO					1.0	0.036	0.42	0.47	0.10	-0.18	-0.02
					1.0	*0.87*	*0.06*	*0.03*	*0.67*	*0.42*	*0.92*
O_3						1.0	-0.04	-0.09	-0.40	-0.01	0.26
						1.0	*0.86*	*0.71*	*0.07*	*0.97*	*0.24*
NO							1.0	0.95	0.27	0.08	-0.17
							1.0	*0.00*	*0.24*	*0.71*	*0.46*
NOx								1.0	0.36	0.07	-0.13
								1.0	*0.11*	*0.76*	*0.58*
NH_3									1.0	-0.29	-0.24
									1.0	*0.20*	*0.29*
Benzene										1.0	0.35
										1.0	*0.12*
Toluene											1.0
											1.0

TABLE 2

Average concentration of various pollutants and meteorological parameters during the study period

Pollutants	2018	2019	2020
PM_{10}	218.1184	244.7247	158.1334
$PM_{2.5}$	116.3639	109.0914	78.60111
NO_2	48.47059	46.23059	35.18471
SO_2	13.8363	14.23185	13.06407
CO	1.449444	1.359167	1.115
O_3	34.99972	33.06083	33.81444
NO	37.22676	31.56568	24.51081
NOx	61.13	52.26571	41.81314
NH_3	41.47692	36.77385	33.09808
Benzene	4.1357	4.113889	5.931905
Toluene	38.54327	32.08389	36.30286
AT	23.64667	25.24364	26.47542
BP	952.0652	958.3552	953.9789
SR	142.9557	126.0517	137.5128
RH	60.11909	57.18571	59.76724
WD	168.1213	181.0258	189.3893
WS	1.465	1.332593	1.138929

TABLE 5

Change in meteorological parameters during the years 2019 and 2020 as compared to the year 2018

Year	AT (in ºC)	BP (mmHg)	SR (W/mt2)	RH (%)	WD (degree)	WS (m/s)
2019	+1.59	+6.29	-16.90	- 2.93	+12.90	-0.13
2020	+2.83	+1.91	-5.44	- 0.35	+21.27	-0.33

TABLE 6

Change in meteorological parameters during the 2020 as compared to the year 2019

Year	AT (in ºC)	BP (mmHg)	SR (W/mt2)	RH (%)	WD (degree)	WS (m/s)
2020	+1.23	-4.38	+11.46	+2.58	+8.36	-0.19

TABLE 3
Percentage relative change in the concentration of various pollutants during the year 2019 and 2020 as compared to the year 2018

Year	PM_{10}	$PM_{2.5}$	NO_2	SO_2	CO	O_3	NO	NOx	NH_3	Benzene	Toluene
2019	+12.20	-6.25	-4.62	+2.86	-6.23	-5.54	-15.21	-14.50	-11.34	-0.53	-16.76
2020	-27.50	-32.45	-27.41	-5.58	-23.07	-3.39	-34.16	-31.60	-20.20	+43.43	-5.81

TABLE 4
Percentage relative change in the concentration of various pollutants during the year 2020 compared to the year 2019

Year	PM_{10}	$PM_{2.5}$	NO_2	SO_2	CO	O_3	NO	NOx	NH_3	Benzene	Toluene
2020	-35.38	-27.95	-23.89	-8.21	-17.96	+2.28	-22.35	-20.00	-9.99	+44.19	+13.15

III. Result And Discussion

The average concentration of all pollutants shows decreasing trend in the year 2020 when compared to 2018 except the volatile organic compound, benzene (Table 3). However, when the average concentration of pollutants for the year 2020 is compared with that of the year 2019, it is observed that except ozone, benzene and toluene the average concentration of all other pollutants decreases (Table 4).

Variation in concentration of particulate matters (PM_{10} and $PM_{2.5}$)

Close analysis of Fig. 2(a) shows that the concentration of PM_{10} have increased in 2019 at all monitoring stations in comparison to the year 2018. However, it shows a decreasing trend in 2020 at all monitoring stations when compared to the year 2018 and 2019. This decrease may be due to various lockdowns implemented due to COVID 19 pandemic. The concentration of pollutant $PM_{2.5}$ at all monitoring stations shows almost similar trend in the year 2019 as was in the year 2018 except at two stations Alipur and Anand Vihar. For the year 2020, at all monitoring stations the average concentration is reduced when compared to 2018 and 2019. The percentage relative change in overall average concentration of PM_{10} and $PM_{2.5}$ are +12.20 and -6.25 respectively in 2019 when compared to 2018. This increase in PM_{10} concentration may be due to tremendous increase in vehicular traffic, which is the main source of PM_{10} in ambient air. However, percentage relative change in the average concentration of both the parameters decreases substantially in the year 2020 when compared with the year 2018 as well as 2019. The main reason of these reduction in average concentration in 2020 may be due to massive decrease in vehicular traffic, halting of industries and stopping of all construction related work[32], sealing of borders of the city during various complete lockdowns and restricted unlocks implemented due to Covid-19 pandemic in the year 2020. The decline in $PM_{2.5}$ concentration is also due to less movement of people to keep "social distancing" to control the spread of CORONA virus[33]. In general the process of open crop residue burning in the northwestern states of India is thought to be significantly responsible for some of the extreme air pollution episodes during the post-monsoon period in Delhi[34].

Variation in concentration of trace gases

Oxides of Nitrogen and Ammonia

The variation in the concentration of NO_2, NO, NOx and NH_3 have been shown in Fig. 2(c), 2(g), 2(h) and 2(i) respectively for each monitoring stations and for the three consecutive years 2018, 2019 and 2020. It is observed that the maximum concentration of NO_2, NO and NOx have been observed from the monitoring station at Anand Vihar for all the three years. As it is generated by combustion process so the reason for high concentration of these pollutants may be the high population density of Anand Vihar resulting in high vehicular movement so high combustion. However the highest average concentration of NH_3 has been noted from the monitoring station at ITO in 2018. A decrease of 4.62% for NO_2, 15.21% for NO, 14.50% for NOx and 11.34% for NH_3 have been observed in the year 2019 when compared to 2018. Similarly, the average concentration of NO_2 is reduced by 27.41%, whereas NO, NOx and NH_3 recorded a substantive decrease of 34.16%, 31.60% and 20.20% respectively in 2020 when compared to 2018. The percentage decrease of the oxides of nitrogen and ammonia was found as 23.89% for NO_2, 22.35% for NO, 20.00% for NOx and 9.99% for NH_3, respectively in 2020 as compared to 2019.

The activities like biomass burning, domestic emission, vehicular emission, combustion process etc. are main source of generation of oxides of nitrogen and ammonia. In 2020, due to COVID 19 pandemic, above activities were restricted or limited, this may be the reason for decrease in level of oxides of nitrogen[35] pointed that strict lockdown reduces the tropospheric column of NO_2 also.

The decrease in the concentration of NH_3 can be due to the formation of secondary aerosols like ammonium sulphate and ammonium nitrate with an increase in the rate of photochemical reactions[36-39].

Sulphur dioxide, carbon monoxide and ozone

The average concentration of SO_2 have been found to increase in the year 2020 for many of the monitoring stations like ITO, JLN Stadium, Major Dhyan Chand National stadium, Mandir Marg, Okhla Phase 2, Patparganj, Srifort. and Vivek Vihar (Fig.2(d)). The monitoring station at Vivek Vihar recorded maximum concentration of pollutants SO_2 in the year 2020. The main source of SO_2 are burning of fossil fuel like coal, oil, and natural gas. Despite of lockdowns called in 2020, the concentration of SO_2 is found to increase for many monitoring stations. The reason may be that after lock down suddenly activities were increased due to opening of many industries. The average concentration of SO_2 is found to increase by 2.86% in 2019 when compared to 2018. However, it decreased by 5.58 % in 2020 when compared to 2018 (Table 3). The overall average concentration of SO_2 have been found to be decreased by 8.21% in 2020 when compared to 2019.

The average concentration of CO was found to be maximum from the station located at Anand Vihar for all the three consecutive years. Its main source is incomplete combustion and Anand Vihar is worse affected by it. The concentration is found to decrease over time. The percentage decrease of 6.23% and 23.07% have been observed in 2019 and 2020 respectively when compared with 2018. Substantive decrease of 17.96% have been noted in the year 2020 when compared to 2019.

The concentration of ozone was observed to be maximum for the monitoring station located at Srifort. The average concentration is observed to fall by 5.54% in 2019 and 3.39% in 2020 when compared to 2018. However, the concentration increases by 2.28% in 2020 when compared to 2019. The reason for sudden rise in the level of O_3 may be the increase in the intensity of solar radiation, which helped to the continuous rise of ozone and the decrease in the concentration of NO in the year 2020 due to various lockdowns called in lieu of pandemic as NO helps in the breakdown of O_3 to O_2[39].

Variation in concentration of volatile organic compounds

The concentration of benzene was recorded as maximum in the year 2020 from the monitoring station located at RK Puram and from monitoring station at Alipur in 2018. Overall average decrease of 0.53% for benzene and 16.76% for toluene have been observed in 2019 when compared to 2018. However, the concentration of benzene increases by 43.43% and that of toluene decreases by 5.81% in 2020 when compared to 2018. The average overall concentration of benzene as well as toluene is found to significantly increase by 44.19% and 13.15% respectively in the year 2020 when compared to 2019. The reason may be the attributed to the sudden increase in vehicular movement[40] and reopening of industries after lockdowns were called off.

Impact of meteorological parameters

Time varying[41] meteorological parameters analyzed in this study are Air Temperature (AT), Barometric Pressure (BP), Solar radiation (SR), Relative humidity (RH), Wind direction (WD) and Wind speed (WS) over the period of three years.

Air temperature affects the dispersion of pollutants in the atmosphere. Fig. 2(l) shows the annual average air temperature for the three consecutive years 2018, 2019 and 2020. It is observed that for many stations, AT has increased in 2020 as compared to 2018 and 2019. The maximum AT recorded in 2018 is 28.94ºC from the monitoring station IHBAS, in 2019 the maximum AT goes to 27.21ºC, which is recorded from monitoring station Patparganj. In 2020 the maximum AT recorded is 28.33ºC, which is from the monitoring station Anand Vihar. The average annual temperature during 2019 and 2020 have been increased by 1.59 ºC and 2.83 ºC respectively as compared to annual average air temperature in 2018 (Table 4). Also the average annual AT of 2020 is increased by 1.23 ºC when compared with 2019 (Table 5). Therefore, a slight decrease in concentration of pollutant in 2020 may be due to increase in average annual air temperature.

The increase in the wind speed is favorable for the dispersion of pollutants[39]. Wind speed decreased in the year 2019 and 2020 by 0.13 m/s and 0.33 m/s respectively when compared to 2018. It also decreased in 2020 by 0.19 m/s when compared to 2019.

High humidity increase the rate of harmful chemicals in the ambient air and dust mites inside our homes resulting in the accumulation of pollutants. The accumulation rates of $PM_{2.5}$ are favoured by very dry (< 45%), dry (45% – 60 %), and low (60 % - 70%) relative humidity in the ambient air, whereas the other pollutants PM_{10}, SO_2 and NO_2 accumulations are peaked at 45 ± 5 % relative humidity[42]. The relation between $PM_{2.5}$ concentration and the RH to the visibility have been identified as, the visibility decreases quickly as $PM_{2.5}$ concentration increases at clean condition and decreases slowly when $PM_{2.5}$ concentration exceeds 100 µg/m^3. However, When RH exceeds 40%, atmospheric visibility tends to display an inversely proportional and exponential relationship with RH under polluted and clean conditions respectively. During the study period the annual average RH have been found to 60.12 % in 2018, 57.19% in 2019 and 59.77% in 2020. So, the RH remained favourable for the accumulation of $PM_{2.5}$ throughout the study period[28]. To comment on the visibility more study need to be done and seasonal variation in the RH should also be analyzed. In the absence of those study, this study may be used to have an idea about the accumulation of pollutants.

Raising pressure usually means clear skies, diminishing readings make cloudy weather more likely, while a rapid falling barometer can indicate an approaching storm[44]. Low pressure periods in winter time are the reason for elevated air pollution concentration from local sources[45]. The annual average barometric pressure (BP) in 2018 was recorded as 952.09mmHg, which rises in 2019 and average is recorded as

958.36 mmHg. However, in 2020 the annual average BP becomes 953.98mmHg.

Identification of possible sources of pollution

Discussion of results from Correlation and p-value analysis

Form Fig. 3, it is clear that in the year 2018, the p-value is less than or equal to 0.05 for the pollutants pairs (PM_{10}, $PM_{2.5}$), (PM_{10}, NO_2), (PM_{10}, CO), (PM_{10}, O_3), (PM_{10}, NH_3), (PM_{10}, Benzene), ($PM_{2.5}$, CO), ($PM_{2.5}$, SO_2), ($PM_{2.5}$, O_3), ($PM_{2.5}$, Benzene), (NO_2, SO_2), (NO_2, CO), (NO_2, NO), (NO_2, NOx), (NO_2, Benzene), (SO_2, NOx), (SO_2, Benzene), (CO, NO), (O_3, NO), (O_3, Toluene) and (NO, NOx). In the year 2019, the pollutants pair having significant correlation coefficient are (PM_{10}, $PM_{2.5}$), (PM_{10}, CO), (PM_{10}, Toluene), ($PM_{2.5}$, CO), ($PM_{2.5}$, NH_3), (NO_2, CO), (NO_2, NO), (NO_2, NOx), (CO, NO), (CO, NOx), (CO, NH_3), (CO, Benzene), (CO, Toluene), (NO, NOx) and (Benzene, Toluene). However, the pollutant pairs (PM_{10}, $PM_{2.5}$), (PM_{10}, CO), ($PM_{2.5}$, NH_3), (NO_2, CO), (NO_2, NO), (NO_2, NOx), (SO_2, CO), (SO_2, NH_3), (CO, NOx) and (NO, NOx) have significant p-value in 2020. There is good association between PM_{10} and $PM_{2.5}$ as the concentration of both the pollutants mainly depends on transport/ vehicular emission, biomass burning, industrial emission, dust from road side and construction activities, which are common source for their generation. Also, PM_{10} as well as $PM_{2.5}$ correlates significantly with CO for all consecutive three years, which may be due to some common sources of their generation which is incomplete combustion. The pollutant NO_2 also correlates significantly with CO, which is expected because CO influences the oxidation of NO to NO_2. CO has a life span of about four months in the atmospheric environment and it reacts with hydroxyl radical as shown below:

$$CO_{(g)} + HO^{\bullet}_{(g)} \rightarrow CO_{2(g)} + H_{(g)} \quad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

$$O_{2(g)} + H_{(g)}\ M \rightarrow HOO^{\bullet}_{(g)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ (3)$$

$$HOO^{\bullet}_{(g)} + NO_{(g)} \rightarrow HO^{\bullet}_{(g)} + NO_{2(g)} \quad \ldots\ldots\ (4)$$

The atomic hydrogen (*H*) produced in reaction (2) combines with oxygen molecule in the presence of a third body (*M*) like N_2 to form hydroperoxly radical[46].

However, for the remaining pollutant pairs the p-value is greater than 0.05, which suggests that the correlation between them is not significant.

Discussion of results from Principal Component Analysis and Factor Analysis

Form Table 1, it is clear that in 2018, the first four factors represented the maximum the variances with cumulative variance of 81.82%. Factor 1(F 1) represented a variance of 40.81% with significant factor loadings for NO and NOx. Factor 2 (F 2) showed a 17.88% variance with significant factor loading for $PM_{2.5}$ and Benzene. Factor 3 (F 3) represented variance of 13.49% with considerable loadings for Toluene. However factor 4 (F 4) showed a variance of 9.64% with significant factor loadings for NH_3.The source of NH_3 can be the agricultural waste burning and rural residential sources in the vicinity of the city[39].

In 2019, the first four factors represented the maximum the variances with cumulative variance of 83.72%. F 1 represented a variance of 42.84% with significant factor loadings for NO_2, NO and NOx. F 2 showed 18.28% variance with significant factor loading for PM_{10} and $PM_{2.5}$. F 3 represented variance of 13.22% with considerable loadings for Benzene and Toluene. F 1, F2 and F3 shows that vehicular emission may be the major source of PM, NO, NO_2 and NOx. However, F 4 showed a variance of 9.37% with significant factor loadings for SO_2. The vehicular emission can be the primary source of these emissions. The main source of these may be the thermal power plant.

In 2020 also, the first four factors represented the maximum the variances with cumulative variance of 79.89%. F 1 represented a variance of 31.79% with significant factor loadings for NO and NOx. These pollutants may be transported from agricultural waste burning in nearby areas[47, 48]. The factor, F 2 showed a 19.06% variance with significant factor loading for PM_{10} and $PM_{2.5}$. The main source of PM may be the burning of fossil fuel in the vehicles[49, 50]. F 3 represented variance of 17.35% with considerable loadings for SO_2. F 1, F 2 and F 3 shows that vehicular emission may be the major source of PM, NO, NO_2 and NOx. However, F 4 showed a variance of 11.68% with significant factor loadings for NO_2. The vehicular emission can be the primary source of these emissions. The main source of these may be the thermal power plant[51].

IV. CONCLUSION

The comparison of air quality data for three consecutive years 2018, 2019 and 2020 showed that there was a reasonable reduction in the concentration of almost all pollutants in year 2020 except for ozone and benzene. In 2020 the decrease in concentration may be observed due to various restrictions imposed during lockdown called due to COVID- 19 pandemic. However, after the lockdown is called off, the environment is overburden as all works started(including industries, Construction work, traffic movement etc.) and offices were opened and all are accelerating to recover the loss caused due to lockdown leading to the raise in the level of pollutants in the city.

The pattern of meteorological parameters over the years also explains certain variations in the concentration of major pollutants. The principal component analysis, factor analysis and Pearson's correlation identify the vehicular emission as primary source of air pollution in mega city, Delhi. The present study helps to locate and understand the possible sources and mechanism of air pollution over time. This may help in planning and framing appropriate policies to reduce the air pollution in the city.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

V. ACKNOWLEDGEMENT

Authors are thankful to anonymous reviewer for providing valuable suggestions, which leads to the improvement over the previous version of the paper.

VI. REFERENCES

K. V. Hamilton Ron, T. Johan, and J. Watt (2009). The effect of air pollution on cultural heraitage, Springer-Verlag, Boston, MA, USA.

R. C. Abernethy R. W. Allen, I. G. McKendry, and M. Brauer (2013). A land use regression model for ultrafine particles in vancouver, Canada. Environmental Science Technology, 47 (10) 5217-5225.

D. Nunez-Alonso, L. V. Perez-Arribas, Saia Manzoor and Jorge O. Caceres (2019). Statistical Tools for Air Pollution Assessment: Multivariate and Spatial Analysis in the Madrid Region, Journal of Analytical Methods in Chemistry, DOI: https://doi.org/10.1155/2019/9753927.

P. Pant, S. K. Guttikunda, R. E. Peltier (2016). Exposure to particulate matter in India: A synthesis of findings and future directions. Environ Res. 147: 480-96.

K. Balakrishnan, A. Cohen, K. R. Smith (2014). Addressing the burden of diseases attributable to air pollution in India: the need to integrate across household and ambient air pollution exposures. Environ Health Perspect, 122(1): A6.

E.Saikawa, Q. Wu, M.Zhong, A.Avramov, K. Ram, E. A. Stone, C. E. Stockwell, T.Jayarathne, A. K. Panday, and R. J. Yokelson (2020) Garbage burning in South Asia: How important is it to Regional Air Quality? *Environmental Science & Technology 54* (16), 9928-9938.

Melanie S. Hammer, Aaron van Donkelaar, Chi Li, Alexei Lyapustin, Andrew M. Sayer, N. Christina Hsu, Robert C. Levy, Michael J. Garay, Olga V. Kalashnikova, Ralph A. Kahn, Michael Brauer, Joshua S. Apte, Daven K. Henze, Li Zhang, Qiang Zhang, Bonne Ford, Jeffrey R. Pierce, and Randall V. Martin (2020). Global Estimates and Long-Term Trends of Fine Particulate Matter Concentrations (1998–2018), *Environmental Science & Technology 54* (13), 7879-7890DOI: 10.1021/acs.est.0c01764

D.W. Dockery, C. A. Pope III, X. Xu, J. D. Ware, J. H. Fay, B. G. Ferris, F. E. Speizer (1994). An association between air pollution and mortality in six U. S. Cities, N. Engl. J. Med., 329, 1753-1759.

J. Schwartz (1996). Air pollution and hospital admissions for respiratory disease. Epidemiology. Jan. 7(1):20-8.

A. J. Cohen, M. Brauer, R. Burnett (2017). Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: an analysis of data from the Global Burden of Diseases Study 2015. Lancet, 389, 1907 – 1918.

Weeberb J. Requia, Qian Di, Rachel Silvern, James T. Kelly, PetrosKoutrakis, Loretta J. Mickley, Melissa P. Sulprizio, HereshAmini, Liuhua Shi, and Joel Schwartz (2020). An Ensemble Learning Approach for Estimating High Spatiotemporal Resolution of Ground-Level Ozone in the Contiguous United States, *Environmental Science & Technology*, *54* (18), 11037-11047 DOI: 10.1021/acs.est.0c01791

WHO (2000). Air quality guidelines for Europe. Copenhagen, World Health Organization Regional Office for Europe (WHO Regional Publications, European Series, No. 91).

Miller et al., (1982). Pulmonary dosimetry of nitrogen dioxide in animals and man. In., Schneider, T. & Grant, L., ed. Air pollution by nitrogen oxide. Proceedings of the US-Duch International Symposium, Maastricht, Netherland. Amsterdam, Elsevier, 377-386 (Studies in Environmental Science, No. 21)

W. S. Linn, D. A. Shamoo, T. G. Venet, R. M. Bailey, L. H. Wightman, J. D. Hackney (1984). Comparative effects of sulfur dioxide exposures at 5 degrees C and 22 degrees C in exercising asthmatics. Am Rev Respir Dis. Feb;129 (2) :234-9. PMID: 6696323.

Climate and clean air coalition, www.ccacoalition.org

S. Abdullah, A. A Mansor, N. N. L. M Napi, W. N. W Mansor, A. N Ahmed, M. Ismail, Z. T. A.Ramly (2020). Air quality status during 2020 Malaysia Movement Control Order (MCO) due to 2019 novel coronavirus (2019-nCoV) pandemic. Sci Total Environ. 729:139022.

G. Dantas, B. Siciliano, B. B. Franca, C. M. da Silva and G.Arbilla (2020). The impact of COVID-19 partial lockdown on the air quality of the city of Rio de Janeiro, Brazil. Science of the Total Environment, 729, 139085.

S. Zangari, D. T. Hill, A. T. Charette and J. E. Mirowsky (2020). Air quality changes in New York City during the COVID-19 pandemic. Science of the Total Environment, 742, 140496.

K. Binaku, M. Schmeling (2017). Multivariate statistical analyses of air pollutants and meteorology in Chicago during summers 2010-2012. Air QualAtmos *Health* **10,** 1227–1236.

M.Marć, M.Bielawska,V. Simeonov,J. Namieśnik,B.Zabiegała (2016). The effect of anthropogenic activity on BTEX, NO2, SO2, and CO concentrations in urban air of the spa city of Sopot and medium-industrialized city of Tczew located in North Poland, Environmental Research, 147, 513-524.

P. Pavón-Domínguez, F.J. Jiménez-Hornero,E. Gutiérrez de Ravé (2014). Proposal for estimating ground-level ozone concentrations at urban areas based on multivariate statistical methods, Atmospheric Environment, 90, 59-70.

P. Patel (2019). Tackling Delhi's Air Pollution Problem, ACS Central Science 5, 3-6 (DOI: 10.1021/acscentsci.9b0009),

Census, 2011, https://census2011.co.in.

CPCB (2016). Analysis of Air Pollution in Delhi. Published by ENVIS center CPCB.

Mahato, Susanta & Pal, Swades & Ghosh, Krishna. (2020). Effect of lockdown amid COVID-19 pandemic on air quality of the megacity Delhi, India. Science of The Total Environment. 730. 139086. 10.1016/j.scitotenv.2020.139086.

Central Pollution Control Board of India (https://app.cpcbccr.com/ccr/#/caaqm-dashboard-all/caaqm-landing/data).

The Gazette of India (2009, Nov. 18). National Ambient Air Quality Standards (NAAQS), CPCB.

H. Hotelling (1933). Analysis of a complex of statistical variables into principal components. Journal of Educational Psychology, 24, 417-41.

M.Rebelo,E.F. Da Silva, and F. Rocha (2015). Characterization of Portuguese thermo-mineral waters to be applied in peloids maturation. Environmental Earth Sciences, 73, 2843-2862.

Xinwei Lu, Lijun Wang, Loretta Y. Li, Kai Lei, Li Huang, Dan Kang, (2010). Multivariate statistical analysis of heavy metals in street dust of Baoji, NW China, Journal of Hazardous Materials, Volume 173, Issues 1–3, Pages 744-749, https://doi.org/10.1016/j.jhazmat.2009.09.001.

H. Guo, T. Wang, P.K.K. Louie (2004). Source apportionment of ambient non-methane hydrocarbons in Hong Kong: Application of a principal component analysis/absolute principal component scores (PCA/APCS) receptor model, Environmental Pollution, Volume 129, Issue 3, Pages 489-498, https://doi.org/10.1016/j.envpol.2003.11.006.

Chdcovid19, 2020. http://chdcovid19.in/index.php/page/office-ordersCichowicz

AkshanshaChauhana , Ramesh P. Singh (2020). Decline in PM2.5 concentrations over major cities around the world associated with COVID-19, Environmental Research, Volume 187, 109634.

Santosh H. Kulkarni, Sachin D. Ghude, Chinmay Jena, Rama K. Karumuri, Baerbel Sinha, V. Sinha, Rajesh Kumar, V. K. Soni, and ManojKhare (2020). How Much Does Large-Scale Crop Residue Burning Affect the Air Quality in Delhi? *Environmental Science & Technology* **2020** *54* (8), 4790-4799DOI: 10.1021/acs.est.0c00329

Sarvan Kumar (2020). Effect of meteorological parameters on spread of COVID-19 in India and air quality during lockdown, Science of The Total Environment, Volume 745, 141021

A.D. Bhanarkar, S.K. Goyal, R. Sivacoumar, C.V. Chalapati Rao (2005). Assessment of contribution of SO2 and NO2 from different sources in Jamshedpur region, India, Atmospheric Environment, Volume 39, Issue 40, Pages 7745-7760, https://doi.org/10.1016/j.atmosenv.2005.07.070.

Olivier, A.F. Bouwman, K.W. Van der Hoek, J.J.M. Berdowski (1998). Global air emission inventories for anthropogenic sources of NOx, NH3 and N2O in 1990, Environmental Pollution, Volume 102, Issue 1, Supplement 1,Pages 135-148, https://doi.org/10.1016/S0269-7491(98)80026-2.

EPA (2020). https://www.epa.gov/so2-pollution/sulphur-dioxide-basics.

SumanMor, Sahil Kumar, Tanbir Singh, SushilDogra, Vivek Pandey, KhaiwalRavindra, (2021). Impact of COVID-19 lockdown on air quality in Chandigarh, India: Understanding the emission sources during controlled anthropogenic activities, Chemosphere, Volume 263, 127978, https://doi.org/10.1016/j.chemosphere.2020.127978.

Bruno, P., Caselli, M., de Gennaro, G. *et al.*(2006). High spatial resolution monitoring of benzene and toluene in the Urban Area of Taranto (Italy). *J AtmosChem* **54,** 177–187. https://doi.org/10.1007/s10874-006-9030-1

AlaaMhawish, Tirthankar Banerjee, MeytarSorek-Hamer, Muhammad Bilal, Alexei I. Lyapustin, Robert Chatfield, and David M. Broday (2020). Estimation of High-Resolution PM2.5 over the Indo-Gangetic Plain by Fusion of Satellite Data, Meteorology, and Land Use Variables, *Environmental Science & Technology*, *54* (13), 7891-7900 DOI: 10.1021/acs.est.0c01769

Lou, C., Liu, H., Li, Y. *et al.* (2017). Relationships of relative humidity with $PM_{2.5}$ and PM_{10} in the Yangtze River Delta, China. *Environ Monit Assess* **189,** 582. https://doi.org/10.1007/s10661-017-6281-z.

Xiaoyan Wang, Renhe Zhang and Wei Yu (2019). The effect of $PM_{2.5}$ concentrations and relative humidity on atmospheric visibility in Beijing. Journal of Geophysical Research: Atmospheres, 124(4) https://doi.org/10.1029/2018JD029269

https:// allthestuff.com/barometric-pressure-future-weather/How Barometric Pressure Determines Whether It Rains or Shines (allthestuff.com)

Zanobetti A, Peters A. (2015). Disentangling interactions between atmospheric pollution and weather. *J Epidemiol Community Health*. 69(7):613-615. doi:10.1136/jech-2014-203939

P. Njoku, f. C. Ibe, J. Alinoor, A. Opara (2016). Signal variability of carbon monoxide in the ambient environment of Imo state, Nigeria, Int. Letters Nat. Sci. 53, 42-52.

KhaiwalRavindra, Tanbir Singh, Vivek Pandey, SumanMor (2020). Air pollution trend in Chandigarh city situated in

Indo-Gangetic Plains: Understanding seasonality and impact of mitigation strategies, Science of The Total Environment, Volume 729, 138717, https://doi.org/10.1016/j.scitotenv.2020.138717.

H Sembhi and M Wooster and T Zhang and S Sharma and N Singh and S Agarwal and H Boesch and S Gupta and A Misra and S N Tripathi and S Mor and R Khaiwal (2020). Post-monsoon air quality degradation across Northern India: assessing the impact of policy-related shifts in timing and amount of crop residue burnt, Environmental Research Letters, Volume 15, No. 10, 104067, https://doi.org/10.1088/1748-9326/aba714.

BirnurBuzcu, Matthew P. Fraser (2006). Source identification and apportionment of volatile organic compounds in Houston, TX, Atmospheric Environment, Volume 40, Issue 13, Pages 2385-2400, https://doi.org/10.1016/j.atmosenv.2005.12.020.

Milena B. Fernandes, Leila S.R. Brickus, J.C. Moreira, J.N. Cardoso (2002). Atmospheric BTX and polyaromatic hydrocarbons in Rio de Janeiro, Brazil, Chemosphere, Volume 47, Issue 4, Pages 417-425, https://doi.org/10.1016/S0045-6535(01)00319-8.

Ming Wang, Min Shao, Si-Hua Lu, Yu-Dong Yang, Wen-Tai Chen (2013). Evidence of coal combustion contribution to ambient VOCs during winter in Beijing, Chinese Chemical Letters, Volume 24, Issue 9, Pages 829-832, https://doi.org/10.1016/j.cclet.2013.05.029.