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QUANTITATIVE ASSESSMENT OF AIR POLLUTION OVER HYDERABAD USING PRINCIPAL COMPONENT ANALYSIS: BEFORE, DURING AND AFTER THE COVID–19 LOCKDOWN

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Abstract:

The consequences of urban air pollution in underdeveloped countries were not fully addressed prior to, during, or following the COVID–19 lockdown. In this study, variations in air pollution concentrations of nine parameters were assessed before, during, and after the COVID-19 lockdown (March - June) over Hyderabad using the data obtained from the CPCB of six monitoring stations from 2018 to 2022 for the same period. By using a one-way analysis of variance (ANOVA), the fluctuations of the major air pollutants exhibit a significant difference ($p<0.0001$) in during when compared to before and after lockdowns. To demonstrate the interdependency of the air contaminants over the stations, a correlation study was done. Principal Component Analysis (PCA) applied to the entire data set in order to inter-compare the patterns of air pollution for each station. It is identified that the entire dataset of all the stations, reduced the parameters to two principal components that explains a variation between 66 – 74 %, 67- 76 % and 61-76% of the total variance for before, during and after COVID-19 lockdown periods respectively. The components that contribute significant variations with Positive (Negative) contributions in air quality for the said periods are principal component 1: $PM_{2.5}$, PM_{10}, SR, NO_x (RH); principal component 2: WS,O_3,CO (AT). The overall results indicate that the variation of the principal component 1 shows a declination during the lockdown except for the stations IDA Pashamylaram and ZooPark and principal component 2 shows specific seasonal characteristics within the data. The quantitative assessment of air pollutants using PCA analysis is indicating that the contribution of the pollutants to the air quality is increased after COVID–19 lockdown due to human activates.

Key words: Air Pollution; Particulate Matter; Principal Component Analysis

Introduction:

Air pollution is now recognized by the civil society, as the major global health risk factor. The health infirmity due to air pollution has a significant impact on heart and lung disease that affect millions of people, both children and adults. More than 90% of people on Earth today reside in locations where air quality is below WHO standards, according to the World Health Organisation (WHO 2016). Urban ambient air pollution is typically caused by human activities like driving, cooking, and the production of energy. These sources can be altered, and emissions can be controlled by altering activity levels or source intensities. Although the social isolation and decrease in human activity following the COVID-19 outbreak may have adverse consequences on economic growth, "social distance" following the COVID-19 outbreak may have a specific favourable side effect on air pollution levels. Most anthropogenic activity was shut down as a result of the tragic corona virus outbreak and the ensuing lockdown to stop the virus from spreading throughout the community. The immediate effect of the lockdown, imposed during COVID – 19, is a worldwide and national economic downturn, which could take years to recover to pre-lockdown levels. Positively, this lockout has helped the environment by improving the quality of the air across the globe.

Six pollutants are typically counted to determine the quality of the air: Ozone (O_3), Nitrogen dioxide (NO_2), sulphur dioxide (SO_2), fine particulate matter ($PM_{2.5}$, mass concentration of particles with diameters 2.5 m), and coarse particulate matter (PM_{10}, mass concentration of particles with diameters 10 m) (CO) (USEPA, 2018). The main contributors to primary air pollutants ($PM_{2.5}$, PM_{10}, NO_2, SO_2, and CO) include automobile emissions, biomass burning, natural forest fires, coal-fired power plants, and volcanoes. The secondary pollutant is ozone, created when nitrogen oxides and volatile organic compounds (VOCs) combine chemically in the presence of sunlight (NO_x). Existing research has shown that the concentration of these air pollutants, decreased during the lockdown periods as a result of decreased emissions from several sources, including traffic, industry and other sources. Studies from all across the world have evaluated the effects of changing emission sources on air quality (Jeff et. al., 2014; Kota et. al., 2018; Wang et.al., 2009;Chai et. al., 2014; Alizadeh-Choobariet.al., 2016; Wang et.al., 2018). Numerous studies conducted in India also found that the air quality was better when Lockdown was in effect (Garaga et. al., 2018; Mukherjee et. al., 2018; Urvashi et.al., 2020; Sigh et.al.,2020; Singh and Chauhan, 2020; Srama et.al., 2020;Bera et.al., 2020; Dhaka et.al., 2020;). Temporal and spatial variations of air pollutants were reported by (17-18). (Ajay kumar et.al., 2020; Vasudha and Rao, 2022). Polisetty et al., (2020) reported that during lockdown, the concentrations of PM2.5 and PM10 concentrations over Hyderabad were significantly decreased by 27% and 34% respectively.

The present study primarily focuses on the assessment of air pollution over Hyderabad using Principal Component Analysis (PCA) for the period before, during and after the lockdown (March to June) over six monitoring stations from 2018 to 2022. The work is carried out:

(1) to study the spatio- temproral variation of air pollutants and meteorological parameters by analysing their significant differences during the study period using one-way ANOVA analysis; (2) to examine the relationship between the air pollutants for before, during and after the COVID -19 lockdown in the six stations, and the correlation between air pollutants and meteorological factors; (3) to provide overview of the interdependencies and to quantify the parameters that contribute significant variations in the air quality were studied using Principal Component Analysis (PCA).

Materials and Methods:

This study uses hourly data of air pollutants and meteorological parameters from 2018 to 2022 for the months of COVID – 19 lockdown (March to June) in six monitoring stations of Hyderabad from the website of the Central Pollution Control Board (CPCB). The six monitoring stations are Bollarum, Hyderabad Central University, ICRISAT, IDA Pashamylaram, Sanathnagar and Zoo Park. The locations of the six monitoring stations are shown in Table 1. These stations have wide variability in the nature of location, where the possible sources of air pollutants will show drastic changes in their characteristics. The data during the lockdown period (March to June) of all the study years was divided into three slots namely 1. Before: average of the years 2018 and 2019; 2. During: year 2020; 3. After: average of the years 2021 and 2022. To quantify the air pollutants and study their interrelation during the study period, the following methods were adopted:

One-way ANOVA test:

ANOVA was performed to determine whether or not there are significant differences in air pollutants across the study period and between monitoring sites.

Spearman's Correlation Analysis:

To give better understanding of the relationship between the air pollutants a correlation analysis is used for the study period across all the stations. The connection between air pollutants and meteorological conditions was also investigated.

Principal Component Analysis (PCA):

PCA is a dimensional reduction method that is often used to reduce the dimensionality of large data sets. In this study, PCA has been performed to determine the significant pollutant that is affecting pollution dispersion and the influences in air pollution trends for the study period and study areas.

Results and Discussions:

Overview of the air contaminants over Hyderabad

The average concentrations of the air pollutants over the study period from the six monitoring stations over Hyderabad are summarized in Table 2. The temporal and spatial variations of the air pollutants are depicted in Figure 1.The average mean concentrations of PM_{10}, NO_x and CO are showing a significant difference with the periods of before and after when compare with during, whereas $PM_{2.5}$ concentration is showing significant difference between during and after. The mean O_3 concentrations during did not alter significantly from before and after. According the results of one- way ANOVA, concentrations of all the pollutants showed significant differences with p-values < 0.05 across the periods. The lockdown has shown a significant decrease in the concentrations of air pollutants compared with before lockdown. After the lockdown the mean concentrations of air pollutants were showing the lower values when compared to during. This indicates that, even though the restrictions during lockdown were relaxed completely, the social activities such as usage of private vehicles were reduced when compared to before lockdown because most of the private sectors encouraged the employees to work from home.

The mean concentrations of the air pollutants over the six monitoring stations revealed notable spatial characteristics (Table 3): the concentration of the pollutants, except for O_3, was high in the city center areas Bollaram, Sanathnagar, Zoopark than IDA Pashamylaram, ICRISAT and HUC.

The concentrations of $PM_{2.5}$, PM_{10} were highest in the urban central areas followed by semi-residential and industrial areas. Because of the high population density, there is a concentrated consumption of fossil fuel, cooking, and vehicular emissions, resulting in greater concentrations of PM_{10} and $PM_{2.5}$. The concentration of NO_x is higher in Zoopark and IDA Pashamylaram, highlighting the significance of local vehicle exhausts emissions in these areas. Furthermore, wind speeds in the Zoopark, Bollaram and ICRISAT area are the lowest. This suggests that the ability for air pollution diffusion is lowest in this region. The concentrations of O_3 were slightly higher in the central areas like Zoopark, Sanathanagar. The concentration of CO, the principal pollutant emitted by industrial activity was higher in HCU, Sanathanagar and ICRISAT. These areas are influenced by many industrial and residential activities lead to produce high concentrations of CO. According the results of one- way ANOVA, concentrations of all the pollutants showed significant spatial differences between the monitoring stations with p-values < 0.05 across the periods.

Correlation Analysis:

Spearman's correlation coefficients were calculated for three study periods among the air pollutants over the stations (Table 4). For the study period i.e., before, during and after lockdown, $PM_{2.5}$ was highly correlated with PM_{10} and NO_x with p value < 0.01. O_3 was weakly correlated negatively with $PM_{2.5}$ before and after lockdown. During lockdown O_3 was weakly correlated positively with $PM_{2.5}$. The correlations among the five air pollutants showed spatial variations. For instance, the correlation between $PM_{2.5}$ and PM_{10} was high in the during lockdown period.

Spearman's correlation coefficients between the air pollutants and the meterorological parameters were also calculated by taking the average of the parameters across all the six monitoring stations (Table 5). Overall, the mean concentrations of Particulate Matter i.e, $PM_{2.5}$ and PM_{10} showed significant negative correlations with Ambient Temperature (AT), Relative Humidity (RH) and Wind Speed (WS). The results of the correlation analysis indicate a significant spatial variation. That is, various causes of air pollution have different consequences in different areas.

Principal Component Analysis (PCA):

PCA was applied to the data recorded at each one of the stations under three different time slots i.e., before, during and after lockdown months (March to June) between 2018 to 2022. The results of PCA are summarized in Table 6 along with the most significant PC contributions (PC coefficients >0.6) are presented. A variable's contribution to a PC can be positive or negative, depending on the sign of the related PC coefficient. The PCA for the entire dataset was reduced to two PCs for the stations over the study period except for IDA Pashamylaram it is three PCs for during and after lockdown and for Zoo Park it is three PCs during lockdown. The cumulative variance across all the stations for before, during and after lockdown is showing a variation in the order 66 – 74 %, 67- 76 % and 61-76%.

The first component for before lockdown period is accounted to 38.23 – 49.97%; during lockdown period is accounted to 32.04 to 44.17% and after lockdown period is accounted to 32.79 – 47.08% variations over all the stations. PC-1 consists of positive contribution of air quality parameters associated with traffic originated emissions ($PM_{2.5}$,PM_{10},NO_x) and industrial originated emissions (CO), along with SR, and negative contributions of RH and AT across the study period. The second PC is characterized mostly by positive correlation with O3 and WS, as well as negative contributions of AT. Furthermore, the percentage of the overall data variations explained by these PCs is higher for before lockdown, when compare to during and after lockdown. This indicates that the data variations expressed by this PC can be attributed mainly to local traffic and industrial source for the major pollution in Hyderabad.

Conclusions:

In this study, air pollutants and meteorological data was taken from six monitoring stations of Hyderabad city between 2018 to 2022 for the lockdown months of March to June were analysed. Inorder to understand the impact COVID-19 lockdown on air pollution in Hyderabad, the data was divided in to three slots namely before, during and after the lockdown. One-way ANOVA test was used to understand the spatial and temporal variations of the concentrations. The results of the test gave a significant difference of spatial and temporal variations of the concentrations for the study period. The correlation analysis between the air pollutants suggest that PM2.5,PM10 and NOx contribute the most to undesirable pollution levels in the study areas. This indicates a significant spatial variation, which means that different sources of air pollution produce different effects in different regions. The PCA of the entire data set was reduced the parameters to two principal components of the study periods and cumulative variance across all the stations for before, during and after lockdown is showing a variation in the order 66 – 74 %, 67- 76 % and 61-76%. The percentage of the overall data variations explained by these PCs is higher for before lockdown, when compare to during and after lockdown. This indicates that the data variations expressed by these PCs can be attributed mainly to local traffic and industrial source for the major pollution in Hyderabad.

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Table 1. Details monitoring stations in Hyderabad

S.No.	Name of the station	Significance of the station	Latitude (^{0}N)	Longitude (^{0}E)
1	Bollaram	Industrial, Residential Rural and other area	17.54	78.34
2	Hyderabad Central University (HCU)	Downstream of Industrial area adn sensitive zone	17.45	78.32
3	ICRISAT Patnacheru	Industrial, Residential Rural and other area	17.51	78.27
4	IDA Pahsmylaram	Industrial, Residential Rural and other area	17.53	78.43
5	Zoo Park	Industrial, Residential Rural and other area	17.34	78.45
6	Sanathnagar	Centre of the City and Balanagar IDA	17.45	78.47

Table 2. Mean concentrations of air pollutants for the study period during 2018 to 2022

Study Period	$PM_{2.5}$ µg/m^3	PM_{10} µg/m^3	NO_x µg/m^3	CO µg/m^3	O_3 µg/m^3
Before	42.47±12.64	99.05±26.30	0.75±0.32	46.21±13..92	30.01±2.18
During	42.41±11.29	112.35±26.77	0.62±0.19	39.93±16.40	31.74±2.35
After	32.07±10.79	75.09±24.84	0.47±0.20	28.97±11.01	27.48±4.2

Table 3. Mean concentrations of air pollutants in the six monitoring stations during 2018 to 2022

Stations	$PM_{2.5}$ µg/m^3	PM_{10} µg/m^3	NO_x µg/m^3	CO µg/m^3	O_3 µg/m^3
Bollaram	40.11 ± 12.11	101.08 ± 31.71	0.49 ± 0.16	31.67 ± 10.80	29.27 ± 3.98
HCU	31.43 ± 10.75	88.93 ± 28.73	0.57 ± 0.30	52.82 ± 20.61	28.76 ± 3.06
ICRISAT	34.74 ± 10.33	92.20 ± 29.66	0.49 ± 0.11	40.13 ± 17.00	29.06 ± 4.44
IDA Pashamylaram	37.92 ± 11.18	92.50 ± 30.86	0.73 ± 0.33	30.61 ± 09.24	30.03 ± 3.00
Sanath nagar	43.74 ± 11.73	NA	0.62 ± 0.18	40.01 ± 08.57	30.87 ± 2.19
Zoo park	48.35 ± 11.93	105.60 ± 26.07	0.77 ± 0.34	34.44 ± 12.00	30.87 3.53

*NA – data not available

Table 4. Correlation of pollutants in six monitoring stations based on study periods during 2018-20222

BEFORE												
	Bollaram				HCU				ICRISAT			
Pollutants	PM10	NOx	CO	O3	PM10	NOx	CO	O3	PM10	NOx	CO	O3
PM2.5	.846**	.795**	.396**	-0.194	.809**	.275**	0.130	-0.154	.816**	.572**	-.225*	-.394**
PM10	1.000	.632**	0.190	0.209	1.000	0.119	0.150	0.020	1.000	.475**	-.274**	-0.038
NOx		1.000	.217*	-.285**		1.000	.207*	-0.163		1.000	-.524**	-.421**
CO			1.000	-.261*			1.000	-0.009			1.000	.245*
O3				1.000				1.000				1.000
	IDA Pashamylaram				Sanathnagar				Zoopark			
Pollutants	PM10	NOx	CO	O3	PM10	NOx	CO	O3	PM10	NOx	CO	O3
PM2.5	.823**	0.116	-0.132	-.263*		.528**	-.332**	-.306**	.866**	.449**	-.230*	-.430**
PM10	1.000	0.121	-.257*	0.096					1.000	.419**	-0.140	-.245*
NOx		1.000	0.080	.250*		1.000	-0.198	-0.174		1.000	-.548**	-.583**
CO			1.000	0.110			1.000	.628**			1.000	.521**
O3				1.000				1.000				1.000
DURING												

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	Bollaram				HCU				ICRISAT			
Pollutants	PM10	NOx	CO	O3	PM10	NOx	CO	O3	PM10	NOx	CO	O3
PM2.5	.844**	.512**	-0.149	.300**	.852**	.591**	-0.162	.278*	.846**	.524**	-.299**	.427**
PM10	1.000	.425**	-0.026	.424**	1.000	.455**	-0.106	.412**	1.000	.423**	-.291**	.374**
NOx		1.000	-.353**	0.067		1.000	-0.137	.281**		1.000	-.212*	0.146
CO			1.000	.654**			1.000	.359**			1.000	-.408**
O3				1.000				1.000				1.000

	IDA Pashamylaram				Sanathnagar				Zoopark			
Pollutants	PM10	NOx	CO	O3	PM10	NOx	CO	O3	PM10	NOx	CO	O3
PM2.5	.791**	.378**	-.406**	0.205		.237*	0.077	0.005	.835**	.285*	.386**	.323**
PM10	1.000	.444**	-.521**	.386**					1.000	.295*	.452**	.416**
NOx		1.000	-.462**	.311**		1.000	.233*	.459**		1.000	0.067	-0.035
CO			1.000	-0.115			1.000	.664**			1.000	.767**
O3				1.000				1.000				1.000

AFTER

	Bollaram				HCU				ICRISAT			
Pollutants	PM10	NOx	CO	O3	PM10	NOx	CO	O3	PM10	NOx	CO	O3
PM2.5	.754**	.523**	.241*	0.094	.748**	0.083	.330**	0.034	.764**	.526**	.287**	-0.137
PM10	1.000	.627**	-0.089	.486**	1.000	-0.149	.405**	0.015	1.000	.538**	-0.062	0.065
NOx		1.000	-0.048	.274**		1.000	0.119	0.197		1.000	-0.116	-.226*
CO			1.000	-0.117			1.000	0.140			1.000	0.129
O3				1.000				1.000				1.000

	IDA Pashamylaram				Sanathnagar				Zoopark			
Pollutants	PM10	NOx	CO	O3	PM10	NOx	CO	O3	PM10	NOx	CO	O3
PM2.5	.778**	.435**	-0.003	0.132		.374**	0.062	-0.081	.557**	.466**	.406**	-0.221
PM10	1.000	.228*	-0.056	.249*					1.000	.514**	.259*	-.399**
NOx		1.00	.278*	.226*		1.00	-	-		1.00	.282*	-

	0	*		0	.503**	.588**	0	*	.478**
CO		1.000	.637**		1.000	.751**		1.000	-.557**
O3			1.000			1.000			1.000

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 5. Correlations between air pollutants and meteorological parameters of the study periods during 2018-2022

Observation	Pollutants	AT	RH	WS	SR
BEFORE	PM2.5	-.370	-.174	-.296	.301
	PM10	-.446	-.212	-.157	.208
	NOx	-.412	.022	.141	.737
	CO	.158	.244	.060	-.419
	O3	-.301	.208	.472	-.111
DURING	PM2.5	-.277	-.083	-.270	.449
	PM10	-.461	-.083	-.057	.250
	NOx	-.239	-.097	.052	.589
	CO	-.046	-.309	.048	-.057
	O3	-.394	-.229	.087	-.196
AFTER	PM2.5	-.169	-.061	-.134	.185
	PM10	-.302	.050	-.129	.193
	NOx	.084	-.057	-.024	.331
	CO	-.290	.311	.230	-.119
	O3	-.367	.065	.280	.296

Table 6. Loadings after varimax rotation for six stations for the study periods between the years 2018-2022

Stations		PC1			PC2			PC3		
		Before	During	After	Before	During	After	Before	During	After
HCU	(+)	PM2.5,PM10,SR,Nox,CO	PM2.5,PM10,SR,Nox	PM2.5,PM10,CO	WS, O3	WS,CO,O3	WS, O3			
	(-)					AT	AT			
	% of Total Variance	49.9	39.9	37.3	23.6	36.7	24.4			
ICRISAT	(+)	PM2.5,PM10,SR,Nox	PM2.5,PM10,SR,Nox	PM2.5,PM10,SR Nox,CO		WS,O3	AT			
	(-)	RH	RH	RH		AT	WS			
	% of Total Variance	49.97	44.17	47.08	23.64	32.74	18.8			
Bollaram	(+)	PM2.5,PM10,SR,Nox,CO	RH,WS,O3	PM2.5,PM10,CO	WS, O3	PM2.5, PM10, Nox	AT,RH		CO	WS
	(-)	AT	AT		RH					
	% of Total Variance	40.44	32.04	32.79	26.3	30.371	24.1		13.115	13.473

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IDA Pashamylaram	(+)	PM2.5,PM10, CO(0.62)	PM2.5,PM10,SR,Nox(0.61)	PM2.5,PM10,SR Nox	WS, O3	WS,O3	WS, O3			
	(-)		RH(0.69)	RH(0.63)	SR,AT(0.64)	AT	AT			
	% of Total Variance	41.8	38.6	41.1	28.7	29.9	35.1			
Sanathnagar	(+)	PM2.5,SR, Nox	PM2.5,SR	PM2.5,SR, Nox	WS, O3	WS,O3	WS, CO,O3			
	(-)	RH	RH		AT	AT	AT			
	% of Total Variance	38.23	40.11	42.25	31.12	27.03	29.04			
Zoopark	(+)	PM2.5,PM10,SR,Nox	PM2.5,PM10,SR,Nox	PM2.5,PM10,WS,SR	AT,RH	WS,CO,O3	RH,NOX,CO	WS		
	(-)				O3	AT	AT			
	% of Total Variance	40.3	42.19	40.79	20.6	29.39	32.78	13.33		

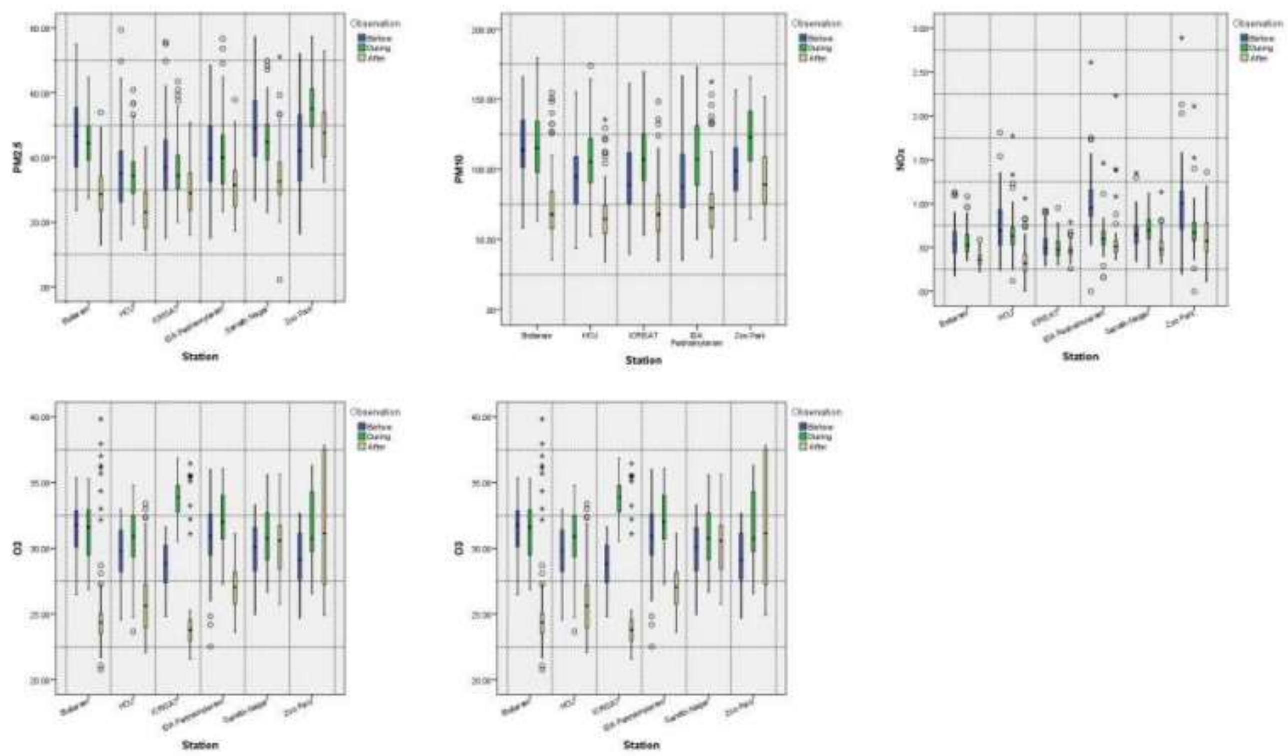

Figure 1. Spatio-temporal variation of air pollutants over Hyderabad for the study periods during 2018-2022; the whiskers above and below indicate the 90th and 10th percentiles, the upper and lower bounds of the boxes represent the 75th and 25th percentiles and the lines inside the boxes represent mean values.

