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Identification of Dominant Air Pollutants Over Hyderabad Using Principal Component Analysis (PCA)

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ABSTRACT

The study aims to bring out the interdependence of the air pollutant components through Correlation and Principal Component Analysis (PCA) to identify the sources causing air pollution in Residential, Resident cum Industrial and Industrial areas of Hyderabad. For this purpose, daily data (from 1st January 2018 to 31st December 2020) of air pollutants recorded by Continuous Ambient Air Quality Monitoring Stations (CAAQMS) that includes 15 air pollution-causing components was collected from the Centre Pollution Control Board (CPCB) website. Data from Residential (Hyderabad Central University (HCU)), Residential and Industrial (ICRISAT-Patencheru), and purely Industrial (Pashmylaram) areas were analyzed and it was identified that 5 majorly contributed pollutants at HCU were due to residential activities however, 5 major pollutants at ICRISAT and Pashmylaram were due to vehicular traffic and industry emissions. The purpose of the study was to figure out the sources of air pollutants and their interdependency under different local conditions. The findings of the study may help the policymakers and authorities concerned to implement different strategies and take necessary steps to keep the pollution levels under control.

INTRODUCTION

The rapid increase in urbanization and industrialization has been observed in many Indian cities over the last two decades. Hyderabad, Telangana State is one of the fast-growing and most urbanized, and industrialized cities in the country. It is located on the bank of the Musi River, covering 650 sq km at an altitude of 542 m above sea level. In recent years the city experienced striking development in many areas, especially in information technology, pharmaceuticals, and other industries. Many World-class companies like Google, Amazon, etc., started their business which leads to a remarkable expansion of the city in all directions. In this process, several residential communities were developed, High range and multi-stored buildings had come up and resulted in an exponential increase in transport vehicles. This growth has a greater impact on air pollution, and it is well known that air pollution has adverse effects on human health and also on the environment.

In nature, the air is an essential element that does not have any potential defending barrier that can be isolated therefore, there is a need to analyze the impact of pollutants on Global, National, and Local-scale, thereby measures can be taken to control the pollution at all levels (Cichowicz &Wielgosiński 2015, Ménard et al. 2016, Vallero 2014).

World Health Organization (WHO) reported that the premature deaths of more than two million people each year are attributed to the effect of air pollution during the 21st century. According to the National Institutes of Health, industrial and photochemical smog are the two major forms of air pollution that can create health hazards.

Generally, pollutants found in urban areas are from short-range sources, which include vehicle exhaust, combustion, standby generators, construction, demolition, and kitchen exhaust (Cichowicz & Wielgosiński 2015, Gurney et al. 2012, Lelieveld et al. 2015, Nemitz et al. 2002). Airborne particulate matter is a complex mixture of organic and inorganic substances, that stay for more time in the atmosphere; as a result, they can easily bypass the filters of the nose and throat of human beings, causing a great impact on health that includes chronic bronchitis, breathing issues heart problems and asthma.

Many studies have proved that industrial and vehicular emissions are the two major contributors to atmospheric pollution (Ajay Kumar et al. 2020, Ravindra et al. 2016, Zhang et al. 2019, Zhao et al. 2019, Singh et al. 2020).

The air quality over Hyderabad gradually declined due to industrial and transport sectors (Guttikunda et al. 2014). The source contribution of Particulate matter over Hyderabad was quantified, using a chemical mass balance receptor model, and reported that more than 60 % of pollution was dominated by vehicular exhaust and road dust (Venkateswara et al. 2016). In this paper, an attempt was made to identify the dominant air pollutants in different areas of Hyderabad using PCA.

MATERIALS AND METHODS

Over the past two decades, Hyderabad city has evolved into an IT hub hosting several Global software companies and is famous for several Pharmaceutical industries and others. The extensive network of public transport includes state-owned road transport, Multi-Modal Transport System, elevated Mono Rail transit system apart from private cabs, and three-wheeler autos. The increased economic activity coupled with the migration of the population has resulted in the outward expansion of the city and made industrial estates an integral part of the city.

The CPCB is operating 6 continuous ambient air quality monitoring stations (CAAQMS) [Bolaram; Sanathnagar; Zoo park; Hyderabad central university; ICRISAT; Pashamylaram] over Hyderabad. The details of the stations and their significance are mentioned in Table 1.

All the above CAAQM stations using sophisticated analyzers generate data instantly and facilitate online data dissemination of various parameters including Particulate Matter of size less than 10 microns and 2.5 microns (PM10, PM2.5), chemical pollutants (NOx, SO_2, CO, O_3 NH_3 VOCs) and meteorological parameters (Temperature, Relative Humidity, and Wind Speed). Our study includes air quality data taken from 3 stations out of the above six stations across Hyderabad. The aim behind choosing them was due to their proximity to the residential area (HCU) residential and Industrial area (ICRISAT) and Industrial area (Pashmylaram).

Data Analysis

The daily air quality data for three years from January 2018 to December 2020 amounting to 1905 days was taken from the CPCB website for the aforesaid stations. Significant outliers were removed from the data before the analysis. The details of pollutant components studied for the purpose are given in Table 2.

The pre-processed data of three stations (the residential area (HCU) residential and Industrial area (ICRISAT) and Industrial area (Pashmylaram), shown in Fig. 1 are correlated using Karl Pearson's Coefficient of correlation, and the results are reported in Table 3a, b and c respectively. From the correlation matrix, it is observed that most of the variables are moderate to highly correlated, they have been highlighted in bold.

Factor Analysis is a statistical technique used for dimension reduction of variables that are considered to be a linear combination of underlying factors. Initially, the data were tested for the suitability of factor analysis using KMO and Bartlett's Test. It was observed that KMO > 0.6 is a reasonable and acceptable value. Sig. <0.001for Bartlett's test indicates the correlation matrix is significantly different from the identity matrix which is consistent that the matrix is factorable.

Principal Component Analysis

The purpose of Principal component analysis is to account for the utmost portion of the variance with a minimum number of latest or composite variables called principal components. If X_1, X_2,……. X_k are variables required to represent the complete economy by removing overlapping the same can be accounted for by a small number p of the principal components. Replacing the initial k variables with p principal components the original data set consisting of n measurements of k variables thus reduces to an information set consisting of n measurements of p principal components. Algebraically principal components represent the linear combination of k variables X_1, X_2,……. X_k and a new coordinate system is obtained by rotating the original system with X_1, X_2,……. X_k is the new coordinate axes. The new axes represent the direction of maximum variability that gives rise to simple and precise covariances.

If $X^t=[X_1,X_2……X_k]$ stands for transformed covariance matrix, then $\lambda_1 \geq \lambda_2 \geq \ldots\ldots \geq \lambda_k \geq 0$ are its eigenvalues.

Table 1: Details of Continuous Ambient Air Quality Monitoring Stations.

S.No.	Name of the station	Significance of station	Latitude [ºN]	Longitude [ºE]
1	Bollaram Industrial Area, Hyderabad-TSPCB	Industrial Residential Rural and Other Area	17.54	78.34
2	Central University, Hyderabad-TSPCB	Downstream of industrial area and sensitive zone	17.45	78.34
3	ICRISAT Patancheru, Hyderabad-TSPCB	Industrial Residential Rural and Other Area	17.51	78.27
4	IDA Pashamylaram, Hyderabad-TSPCB	Industrial Residential Rural and Other Area	17.53	78.18
5	Zoo Park, Hyderabad-TSPCB	Industrial Residential Rural and Other Area	17.34	78.45
6	Sanathnagar, Hyderabad-TSPCB	Centre of the city and Balanagar IDA	17.45	78.44

The principal components are generated using the linear combinations

$$Y_1 = a_1^t X = a_{11}X_1 + a_{12}X_2 + \cdots \ldots \ldots + a_{1k}X_k$$

$$Y_2 = a_2^t X = a_{21}X_1 + a_{22}X_2 + \cdots \ldots \ldots + a_{2k}X_k$$

$$Y_k = a_k^t X = a_{k1}X_1 + a_{k2}X_2 + \cdots \ldots \ldots + a_{kk}X_k$$

Then $\mathrm{Var}(Y_i) = a_i^t \sum a_i$ for $i = 1, 2, \ldots. k$

and $Cov(Y_i, Y_j) = a_i^t \sum a_j$ for $i, j = 1, 2, \ldots. k$

The uncorrelated linear combinations of $Y_1, Y_2, \ldots Y_k$ generate principal components with the largest possible variances.

RESULTS AND DISCUSSION

Principal Component Analysis using the Varimax method is applied for data reduction. The rotated component matrix of the 3 stations is consolidated in Table 4 and the resulting factors are summarized in Table 5.

From Table 5 three factors are extracted from 15 pollutant components at HCU, however, four factors each were extracted at other stations (ICRISAT and Pashmylaram). Eigenvalues at HCU amount to 68.4% of the variability whereas at ICRISAT and Pashmylaram amount to 74.049% and 67.486% respectively. The cumulative percentage of variation is well preserved by rotation, however; the spread of variation is distributed evenly over the components.

The air pollution at HCU rose due to its proximity to the IT corridor. The major variability of 29.487% at HCU is contributed by Volatile organic compounds (VOCs), the most

Table 2: Details of air pollutants.

Air Pollutants	Abbreviation	Units of Measurements
Particulate Matter 2.5	PM 2.5	$\mu g.m^{-3}$
Particulate Matter 10	PM 10	$\mu g.m^{-3}$
Nitric Oxide	NOx	$\mu g.m^{-3}$
Ammonia	NH_3	$\mu g.m^{-3}$
Sulfur Dioxide	SO_2	$\mu g.m^{-3}$
Carbon Monoxide	CO	$\mu g.m^{-3}$
Ozone	O_3	$\mu g.m^{-3}$
Benzene	Benzene	$\mu g.m^{-3}$
Toluene	Toluene	$\mu g.m^{-3}$
Relative Humidity	RH	%
Wind Speed	WS	Meter/sec [$m.s^{-1}$]
Wind Direction	WD	Degree [°]
Solar Radiation	SR	Watt/Meter^2 [W/m^{-2}]
Ambient Temperature	AT	°C
Xylene	Xylene	$\mu g.m^{-3}$

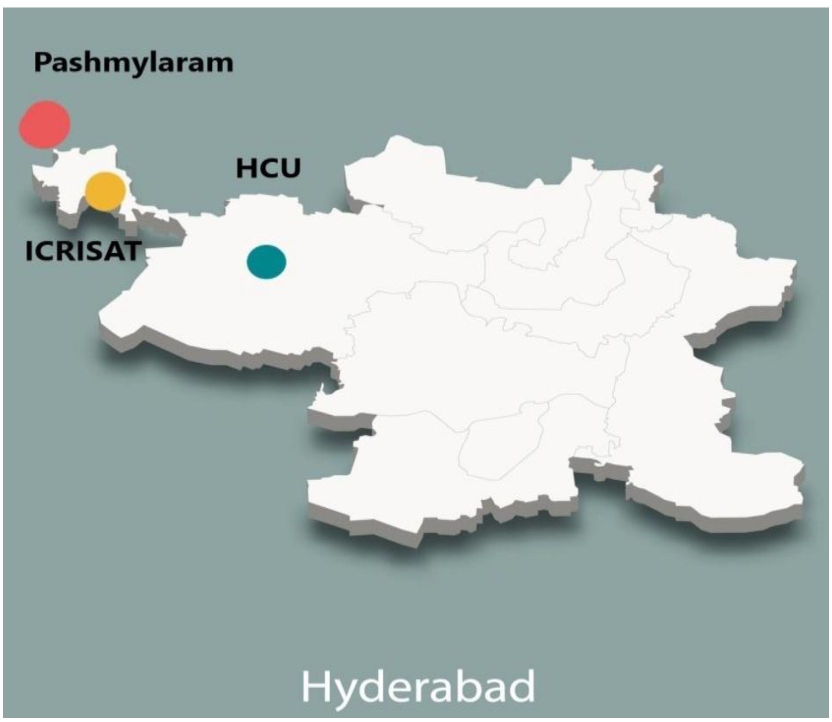

Fig.1: Selected CAAQMS stations based on their proximity to Residential, Residential & Industrial, and Industrial areas.

Table 3a: Correlation matrix of air pollutants at HCU.

	PM 2.5	PM 10	NOx	NH_3	SO_2	CO	O_3	Ben-zene	Tolu-ene	RH	WS	WD	SR	AT	Xy-lene
PM 2.5	1	**.911****	**.683****	**.513****	.493**	**.536****	**.538****	**.553****	.477**	-.328**	-.428**	-.361**	.138**	-.132**	.451**
PM 10		1	**.721****	**.516****	**.550****	**.557****	**.623****	**.607****	**.566****	**-.561****	-.362**	-.321**	.316**	.083**	**.517****
NOx			1	**.584****	**.513****	**.575****	.390**	**.676****	**.630****	-.433**	-.440**	-.372**	.201**	-.021	**.630****
NH_3				1	.226**	.235**	.305**	.375**	.336**	-.301**	-.197**	-.352**	.074*	-.056	.337**
SO_2					1	.287**	.404**	**.526****	**.525****	-.446**	-.240**	-.173**	.171**	-.020	.387**
CO							1	**.580****	**.518****	**-.659****	-.080**	-.092**	.403**	.348**	**.549****
O_3								1	**.941****	-.481**	-.228**	-.043	.211**	.101**	**.899****
Ben-zene									1	-.486**	-.238**	-.066*	.227**	.131**	**.838****
RH										1	.062*	.111**	**-.654****	**-.573****	-.433**
WS											1	.383**	-.059	.254**	-.128**
WD												1	-.033	.121**	-.027
SR													1	**.538****	.228**
AT														1	.192**
Xy-lene															1

common pollutant found in urban residential areas (Marńet al. 2010). VOCs are derived from benzene and a sub-group of this family of compounds. The significance of VOCs is in lower solar radiation (SR) and also they are precursors of ozone O_3 which is justifiable by the highest variability of ozone O_3 than that of ICRISAT and Pashmylaram. The variability of $PM_{2.5}$, PM_{10}, NOx, and NH_3 is 21.313% can be attributed to vehicular pollution.

PM 2.5, PM 10, NOx, NH_3, and CO contribute to 33.587% of the variance at ICRISAT. Pollution generated

Table 3b: Correlation matrix of air pollutants at ICRISAT.

	PM 2.5	PM 10	NOx	NH_3	SO_2	CO	O_3	Benzene	Tolu-ene	RH	WS	WD	SR	AT	Xylene
PM 2.5	1	**.923****	**.770****	**.671****	.396**	**.792****	.255**	.295**	.304**	-.292**	**-.522****	**-.666****	-.034	-.231**	.239**
PM 10		1	**.787****	**.676****	.489**	**.781****	.340**	.314**	.309**	**-.512****	-.465**	**-.595****	.155**	-.107**	.270**
NOx			1	**.617****	.385**	**.806****	.154**	.359**	.393**	-.292**	**-.519****	**-.559****	.032	-.262**	.382**
NH_3				1	.297**	**.660****	.231**	.295**	.287**	-.353**	-.476**	**-.553****	.048	-.259**	.264**
SO_2					1	.273**	.326**	-.049	-.073*	-.356**	.158**	-.207**	.096**	.003	-.001
CO						1	.265**	.363**	.383**	-.351**	**-.561****	**-.598****	.019	-.397**	.439**
O_3							1	.140**	.099**	**-.537****	-.089**	-.271**	.359**	.026	.138**
Benzene								1	**.849****	-.075*	-.461**	-.311**	.099**	-.139**	**.549****
Toluene									1	-.063*	-.478**	-.321**	.088**	-.243**	**.533****
RH										1	.201**	.291**	**-.650****	-.050	-.034
WS											1	**.584****	-.126**	.253**	-.353**
WD												1	-.015	.303**	-.149**
SR													1	.245**	.042
AT														1	-.131**
Xylene															1

by vehicular traffic and industry emissions is the major contributor. Also being a residential area the second highest contributor to atmospheric pollution is VOCs amounting to 16.874% of the total variance. These large amounts of VOCs prohibit atmospheric ozone to decompose and the presence of a large amount of ozone contributes to 14.708% of the variance. It was observed that SO_2 has contributed 8.881% variance to the pollution. According to a report released by Telangana Pollution Control Board in 2019 (CBCP 2019). ICRISAT is housing many steel industries whose major air pollutants are Sulphur dioxide and Nitrogen oxides.

Pashmylaram is a hub of chemical and pharmaceutical industries. Major chemical pollutants released in the air are in the form of smog with air-borne particulate matter and Sulphur dioxide (Naidu et al., 2021). It is evident from particulate matter PM 2.5, PM 10, and So_2 contributed to 23.163% of the total variance. Air pollutants generated by pharmaceutical industries predominantly constitute VOCs consisting of sulfur dioxide, nitrogen oxide, etc. (Yaqub et al. 2012). It can be noted that the contribution of NH_3 and NOx is 9.328% to the variability.

Fig. 2 illustrates the box and whisker plot of various pollutants under the study at three different stations. It was observed from 2(b) and 2(h) of Box and whisker plots of NOx and Ambient temperature (AT) that the higher the AT in ICRISAT and HCU lower is the NOx. This indicates that the concentrations of NOx have a strong negative correlation with ambient temperature. A similar observation was made by Chen et al. (2010). Fig.2 (c), (b), and (e) are Box and whiskers plots of NH_3, CO, and NOx. Lower boxes of NH_3 at ICRISAT support lower production of CO and NOx, and higher boxes of NH_3 at HCU and Pashmylaram support higher production of CO and NOx. Industrial and traffic emissions are also important ammonia sources in urban areas (Ianniello 2010, Pandolfi 2012, Phan 2013). It was recently proved that Ammonia in the air plays a primary role in the formation of CO, SO_2, and NOx (Behera & Sharma 2010, Updyke et al. 2012).

The destruction of atmospheric O_3 is done by the action of solar radiation (SR) on NOx to break it down to Nitrogen monoxide (NO) and atomic oxygen (O), This atomic oxygen synthesizes with molecular oxygen(O_2) to form tropospheric ozone (O_3), which in turn reacts with NO to form new NO_2 and O_2, maintaining the concentrations of reagents and products in equilibrium (Yurdakul et al. 2013). Box and whisker plots corresponding to SR and O_3 are in agreement with the results of the aforesaid paper.

CONCLUSIONS

Interdependency of the air pollutants was very well brought

Table 3c: Correlation matrix of air pollutants at Pashmylaram.

	PM 2.5	PM 10	NOx	NH_3	SO_2	CO	O_3	Benzene	Toluene	RH	WS	WD	SR	AT	Xylene
PM 2.5	1	**.929****	.398**	.147**	**.502****	.458**	.458**	.303**	.339**	-.342**	**-.553****	-.433**	-.116**	-.181**	.171**
PM 10		1	.424**	.177**	**.502****	.434**	.409**	.337**	.401**	-.473**	**-.509****	-.365**	.028	-.042	.234**
NOx			1	.088**	.330**	.219**	.139**	.113**	.159**	-.217**	-.162**	-.085**	-.111**	-.371**	.158**
NH_3				1	.115**	.314**	.202**	.019	.141**	-.365**	.031	-.173**	.072*	.318**	.156**
SO_2					1	.140**	.259**	.297**	.346**	-.256**	-.270**	-.315**	-.020	-.172**	.256**
CO						1	.437**	-.042	.008	-.385**	-.291**	-.230**	.027	.136**	-.043
O_3							1	-.056	.067*	**-.683****	-.187**	-.387**	.219**	.250**	.083**
Benzene								1	**.733****	.017	-.205**	-.334**	-.024	-.048	.452**
Toluene									1	-.173**	-.238**	-.417**	.096**	.152**	**.616****
RH										1	.089**	.297**	**-.543****	**-.543****	-.199**
WS											1	.192**	.088**	.179**	-.105**
WD												1	-.064*	-.229**	-.322**
SR													1	**.586****	.105**
AT														1	.214**
Xylene															1

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

Table 4: Rotated Component Matrix of 3 Stations.

Rotated Component Matrix											
	HCU			ICRISAT				Pashmylaram			
	Component			Component				Component			
	1	2	3	1	2	3	4	1	2	3	4
PM 2.5	0.453	**0.745**	0.083	**0.891**	0.143	0.06	0.205	**0.886**	0.243	-0.121	0.139
PM 10	0.503	**0.678**	0.322	**0.824**	0.179	0.276	0.307	**0.828**	0.302	-0.008	0.202
NOx	0.601	**0.629**	0.087	**0.803**	0.298	0.04	0.215	0.325	0.112	-0.373	**0.654**
NH3	0.216	**0.613**	0.099	**0.767**	0.146	0.135	0.067	0.034	0.076	0.326	**0.65**
SO_2	**0.468**	0.377	0.157	0.337	-0.098	0.199	**0.794**	**0.463**	0.382	-0.146	0.293
CO	**0.637**	0.208	0.188	**0.849**	0.286	0.075	0.078	**0.619**	-0.205	0.206	0.268
O_3	0.5	0.218	0.579	0.193	0.087	**0.646**	0.229	**0.617**	-0.097	0.471	0.194
Benzene	**0.934**	0.157	0.151	0.2	**0.878**	0.081	-0.117	0.126	**0.838**	-0.114	-0.083
Toluene	**0.891**	0.128	0.156	0.238	**0.855**	0.04	-0.175	0.16	**0.89**	0.086	0.042
RH	-0.36	-0.206	**-0.815**	-0.319	0.056	**-0.844**	-0.086	-0.438	-0.033	**-0.694**	-0.395
WS	-0.124	**-0.641**	0.169	**-0.621**	-0.344	-0.139	0.513	**-0.703**	-0.157	0.159	0.297
WD	0.125	**-0.771**	-0.022	**-0.787**	-0.076	-0.136	0.185	-0.419	**-0.452**	-0.282	0.011
SR	0.086	0.092	**0.822**	-0.095	0.076	**0.882**	-0.104	-0.031	0.055	**0.748**	-0.015
AT	0.071	-0.273	**0.824**	**-0.47**	-0.043	0.327	0.292	-0.12	0.1	**0.909**	-0.006
Xylene	**0.917**	0.079	0.143	0.162	**0.795**	-0.012	0.104	-0.019	**0.764**	0.158	0.202

Table 5: Summary of resulted factors.

	HCU		ICRISAT		Pashmylaram	
Factors	Components	% of Variance			Components	% of Variance
1	SO_2, CO, Benzene, Toluene, Xylene	29.487	PM 2.5, PM 10, NOx, NH_3, CO, WS, WD, AT	33.587	PM 2.5, PM 10, SO_2, CO, O_3, WS	23.163
2	PM 2.5, PM 10, NOx, NH_3, WS, WD	21.313	Benzene, Toluene, Xylene	16.874	Benzene, Toluene, Xylene, WD	17.912
3	O_3, RH, SR, AT	17.602	O_3, RH, SR	14.708	RH, SR, AT	17.084
4			SO_2	8.881	NH_3, NOx	9.328
		68.402		74.049		67.486

out in the correlation matrix and was grouped into various factors using PCA. The weightage of each group was carefully examined, and the major contributors were identified in the three different areas of Hyderabad. It was observed that VOCs were the dominant contributors in residential areas and particulate matter was significant in the areas where industries are located. Causes of various pollutants were well deciphered from the Box and whiskers plot emphasizing the role of meteorological parameters in pollution.

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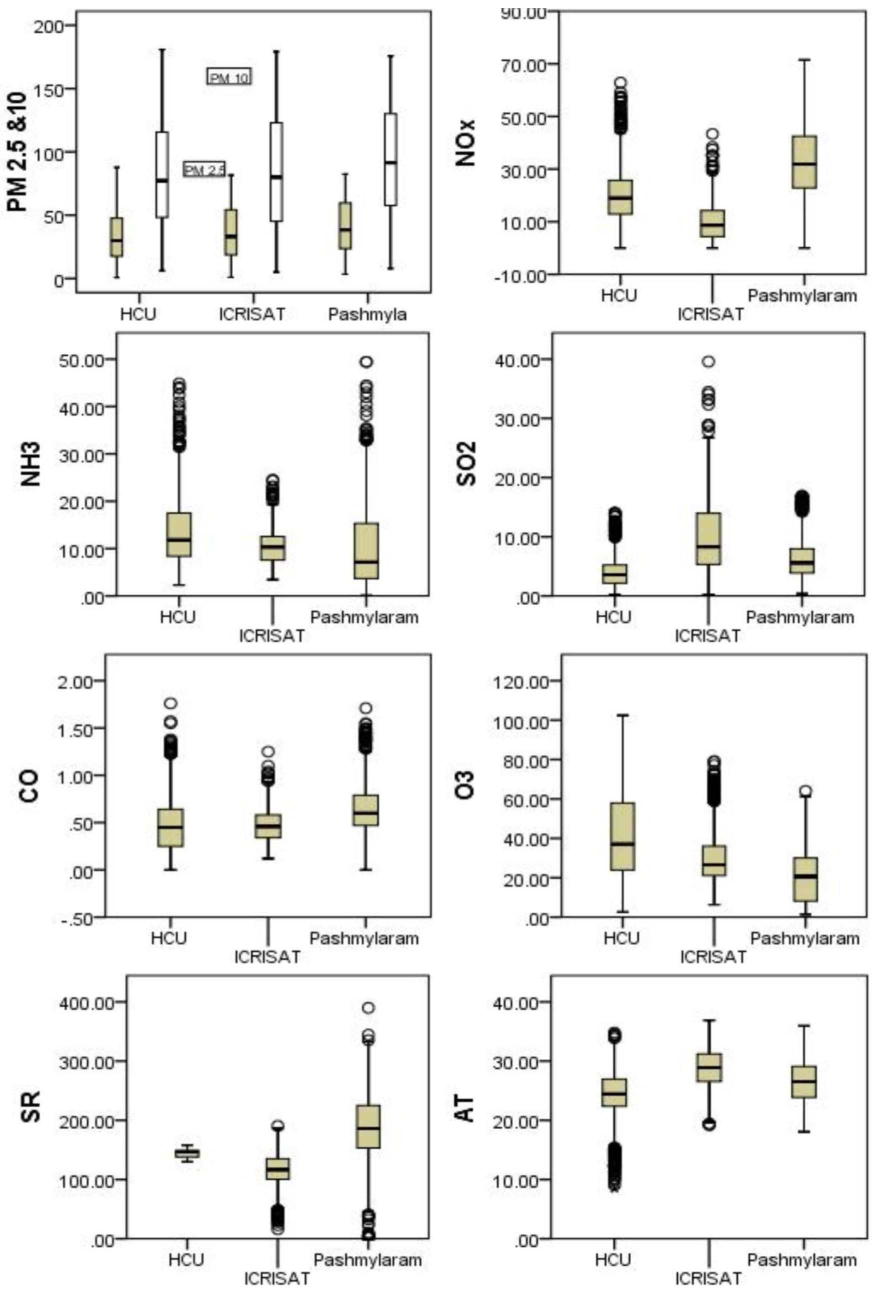

Fig. 2: Box and whisker plots of PM 2.5 & PM 10, NOx, NH_3, SO_2, CO, and O_3 at HCU, ICRISAT, and Pashmylaram in Hyderabad.

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