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Factor Analysis of Air Pollutants over Hyderabad - A Case Study

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Abstract

Pollution levels in Metros of India are raising to alarm levels in last decades. This issue needs to be addressed immediately because it is hazardous to people's health.The present work is focused to highlight the major air pollutants in various areas of Hyderabad using publicly available data at Kaggle.com. By consolidating more air pollutants into fewer factors, this study's key objective is to reduce the complexity of air pollution. This helps to understand the inter dependency of air pollutants. Ten air pollution-causing components of five different locations including residential and industrial areas in Hyderabad were identified and analyzed using Factor Analysis. There was an attempt made to find out the contribution of various air pollutant components to air pollution using standard Karl Pearson's coefficient of correlation and factor analysis using the Varimax method. The results of the analysis showed similar air pollutant components resulting in factors depending on the nature of the location. Residential cum industrial areas, ICRISAT and ZOO park had $PM_{2.5}$, PM_{10}, NOx, CO grouped into Factor 1 as major contribution to AQI, VOCs were the second major contributors followed by NH_3, SO_2, O_3. However, in the residential area HCU ten air pollutants resulted into only two factors, first factor being CO, SO_2, O_3 and VOCs as contributors generated due to residential communities and $PM_{2.5}$, PM_{10}, NOx, NH_3 as factor two. Bollaram has $PM_{2.5}$, PM_{10}, CO, O_3 as factor one as major pollution is contributed due to traffic and industries and Pashamylaram has NOx, SO_2 and VOCs as factor one due to the presence of pharmaceutical industries in the vicinity

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Introduction

Hyderabad, being a fast-growing metropolitan city has various IT establishments, pharmaceuticals and manufacturing industries. The growth triggered a huge influx of population and thereby resulted in the exponential growth of high-rise buildings and vehicles. In addition, this of the growth enhanced the pollution levels of the city and air pollution in particular. This abnormal rise in air pollutant levels adversely affects the city habitants'health. There is an immediate need to address this issue to save the environment and humanity.

In nature, air does not have barriers to remain isolated therefore, there is a need to analyze the impact of pollutants on global, national, and local-scale, so that measures can be taken to control the pollution.[1,2] According to the report of the World Health Organization (WHO) 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 types of air pollution that can create health hazards.[25]

Urban environments typically have short-range sources of pollution, such as combustion, backup generators, constructions, demolition, and kitchen exhaust.[1,3,4,5] A complex mixture of organic and inorganic materials called airborne particulate matter (APM) can readily pass through human nose and throat filters, having a significant negative impact on health conditions such as chronic bronchitis, breathing difficulties, heart concerns, and asthma. Many studies have shown that industrial and emissions of vehicles majorly contributed to the atmospheric pollution.[6,7,8,9]

The air quality over Hyderabad has gradually declined due to the activities of the industrial and transport sectors.[10] 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.[11]

A statistical technique called factor analysis is employed to reduce the dimensions of the underlying components by linearly combining them into variables.In this paper, an attempt was made to highlight the major air pollutant contributors at different locations, including residential and industrial areas in Hyderabad by grouping them into factors.

Literature Survey

A simple statistical method-based Air Quality Index (AQI) has been proposed by[12,13] to address using Principal Component Analysis (PCA) employing the SPSS 10.0 software, the New Air Quality Index (NAQI) was created. Utilizing concentration of each pollutant's hourly average, the NAQI and AQI have been calculated. Indices thus calulated were also used to rate the seasons according to their air pollution levels. In proportional terms, a higher index value denotes greater pollution. The indices were also used to rate the seasons according to their air pollution levels. In proportional terms, a higher index value denotes greater pollution. Additionally, the index can be used to compare the amounts of daily and seasonal pollution at various sites.

The source of pollution caused by heavy metal was determined in the Zlatibor ecosystem in Serbia. Enrichment factor analysis and multivariate statistics were utilized by[14] to calculate the source contribution to the pollution of areas far from industries. The seven heavy metals Cu, Cr, Cd, Ni, Mn, Zn and Pb quantified by atomic absorption spectrometry in samples of top soil and moss. The outcomes of two statistical methods of multivariate analysis on the mosses, enrichment factor analysis, cluster analysis and principal component analysis identified the distinction between human-caused and lithologic originsof the heavy metals. In order to determine how human activities affected the amount of metal in moss, enrichment factors were examined.

From November 2003 to November 2004, areas in a Kolkata metropolitan area that were both residential (Kasba) and industrial (Cossipore) were observed for ambient PM10 levels by.[15] These locations were chosen for their level of anthropogenic activity. An inductively coupled plasma atomic emission spectrometer was used to identify the metal components of atmospheric PM10 deposited on glass fibre filter paper (ICP-AES). Seven dangerous trace elements like Cr, Zn, Pb, Cd, Ni, Mn, and Fe were found in the measured PM10 concentrations. To evaluate impact of air masses on wind speed, temperature, rainfall, relative humidity etc., a concurrent meteorology study was conducted. Major contributors of the PM10 have been identified using factor analysis.

In order to understand how the self perceives danger from environmental dangers, psychologists[16] established the psychological components of ecological risk perception. Factor analysis was used to create a 20-item measure with three subscales using 159 university students' responses on the scale of 26-items of perceived dangers in environment that was an adaption of the Environmental Appraisal Inventory (EAI).[17] The subscales, which were the first to be built on the EAI, reflected natural, technical, and human hazards. The psychometric characteristics of the tools and cultural variations in hazard identification are explored.

The correlation between indoor and outdoor (I/O) airborne contaminants, as well as the identification of the most likely season-specific source of contamination (winter, summer, rainy). I/O ratios were determined while concurrent measurements of air pollutants by[18] were being made. Average ratios of winter with summer and winter with monsoon were computed to look at how the seasons affect both interior and outdoor air quality. To learn more about how outdoor concentrations of air pollution affect indoor concentrations, regression analysis was used. Using principal-component analysis, the kinds of sources for these pollutants that are most likely to exist have been found. Some actions are also suggested in light of this study's findings.

Materials and Methods

Daily data of ten major air pollutant components (Particulate matter, CO, O_3, NOX, NH_3, SO_2, Benzene, Toluene, Xylene) was downloaded from the Kaggle website (https://www.kaggle.com/docs/datasets) for the period of 30 months (January 2018 to June 2020). Table 1 gives the significance of the localities under the study.

Significant outliers were removed from the data before the analysis. The details of pollutant components studied for the purpose are given in Table-2

Table 1: Details of localities under the study

S. No	Name	Significance of locality
1	Bollaram Industrial Area, Hyderabad	Industrial Area
2	Central University, Hyderabad	Residential Area
3	ICRISAT Patancheru, Hyderabad	Industrial cum Residential
4	IDA Pashamylaram, Hyderabad	Industrial Area
5	Zoo Park, Hyderabad	Industrial cum Residential

Table 2: Details of the air pollutants

Air Pollutants	Abbreviation	Units of Measurements
Particulate Matter 2.5	$PM_{2.5}$	micro gram/meter^3
Particulate Matter 10	PM_{10}	micro gram/meter^3
Nitric Oxide	NOx	micro gram/meter^3
Ammonia	NH_3	micro gram/meter^3
Sulfur dioxide	SO_2	micro gram/meter^3
Carbon monoxide	CO	milli gram/meter^3
Ozone	O_3	micro gram/meter^3
Benzene	Benzene	micro gram/meter^3
Toluene	Toluene	micro gram/meter^3
Xylene	Xylene	micro gram/meter^3

Karl Pearson's correlation coefficient was used to correlate the pre-processed data from the five places, and the results are shown in Tables 3 a through e, respectively. The majority of the variables, which have been bolded for emphasis, are found to be moderate to highly correlated according to the correlation matrix.

Table 3 a: Correlation matrix of air pollutants at Bollaram

	PM2.5	PM 10	NOx	NH3	CO	SO2	O3	Benzene	Toluene	Xylene
PM 2.5	1	.843**	.339**	-.114**	.616**	-.110**	.410**	.142**	.161**	.227**
PM 10		1	.473**	.033	.590**	.043	.432**	.258**	.262**	.344**
NOx			1	.228**	.415**	.362**	.361**	.233**	.188**	.317**
NH3				1	-.024	.414**	-.063	.451**	.360**	.129**
CO					1	-.048	.399**	.136**	.092**	.340**
SO2						1	.162**	.245**	.197**	.085*
O3							1	.019	-.101**	.223**
Benzene								1	.740**	.415**
Toluene									1	.443**
Xylene										1

Table 3 b: Correlation matrix of air pollutants at HCU

	PM 2.5	PM 10	NOx	NH3	CO	SO2	O3	Benzene	Toluene	Xylene
PM 2.5	1	.902**	.688**	.550**	.498**	.513**	.494**	.524**	.462**	.461**
PM 10		1	.709**	.521**	.503**	.600**	.581**	.583**	.552**	.508**
NOx			1	.579**	.522**	.553**	.344**	.658**	.619**	.608**
NH3				1	.193**	.258**	.281**	.354**	.307**	.324**
CO					1	.301**	.506**	.576**	.524**	.545**
SO2						1	.402**	.564**	.570**	.443**
O3							1	.575**	.513**	.559**
Benzene								1	.944**	.898**
Toluene									1	.835**
Xylene										1

Table 3 c: Correlation matrix of air pollutants at ICRISAT

	PM 2.5	PM 10	NOx	NH3	CO	SO2	O3	Benzene	Toluene	Xylene
PM 2.5	1	.907**	.748**	.316**	.780**	.313**	.158**	.041	.230**	.226**
PM 10		1	.769**	.320**	.774**	.410**	.252**	.094**	.284**	.290**
NOx			1	.251**	.816**	.290**	.065	.202**	.433**	.366**
NH3				1	.317**	.159**	.160**	.174**	.097**	.110**
CO					1	.213**	.195**	.171**	.370**	.369**
SO2						1	.260**	-.042	-.113**	.013
O3							1	.023	.071*	.101**
Benzene								1	.382**	.252**
Toluene									1	.615**
Xylene										1

Table 3 d: Correlation matrix of air pollutants at Pashmylaram

	PM 2.5	PM 10	NOx	NH3	CO	SO2	O3	Benzene	Toluene	Xylene
PM 2.5	1	.923**	.379**	.110**	.361**	.513**	.405**	.535**	.505**	.297**
PM 10		1	.405**	.149**	.333**	.541**	.343**	.557**	.542**	.403**
NOx			1	.141**	.162**	.330**	.114**	.328**	.364**	.335**
NH3				1	.247**	.091**	.002	-.043	.009	.064
CO					1	.163**	.374**	.061	.073*	.030
SO2						1	.235**	.612**	.632**	.437**
O3							1	.046	.010	-.132**
Benzene								1	.944**	.647**
Toluene									1	.715**
Xylene										1

Table 3 e: Correlation matrix of air pollutants at Zoo Park

	PM 2.5	PM 10	NOx	NH3	CO	SO2	O3	Benzene	Toluene	Xylene
PM 2.5	1	.930**	.715**	.394**	.695**	.309**	.212**	.414**	.317**	.200**
PM 10		1	.748**	.432**	.723**	.472**	.280**	.481**	.383**	.244**
NOx			1	.486**	.700**	.439**	.172**	.402**	.371**	.184**
NH3				1	.538**	.516**	.298**	.258**	.281**	.226**
CO					1	.574**	.195**	.366**	.320**	.228**
SO2						1	.244**	.371**	.377**	.314**
O3							1	.247**	.230**	.134**
Benzene								1	.915**	.768**
Toluene									1	.738**
Xylene										1

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

KMO and Bartlett's Test were initially used to assess the data's suitability for factor analysis. It was discovered that a KMO value of >0.5 is suitable and acceptable. According to Bartlett's test, the correlation matrix is considerably distinct from the identity matrix, which is consistent with the matrix's factorability (Sig. 0.001 for Bartlett's test).

In factor analysis, we assume that the variable is generated from a factor. Suppose there are p variables and m < p factors represented by $f_1, f_2, \ldots, f_m$. Then for a variable y_i , i=1,2,…p , the model is

$$y_1 - \mu_1 = \lambda_{11} f_1 + \lambda_{12} f_2 + \cdots \ldots . + \lambda_{1m} f_m + \varepsilon_1$$

$$y_2 - \mu_2 = \lambda_{21} f_1 + \lambda_{22} f_2 + \cdots \ldots . + \lambda_{2m} f_m + \varepsilon_2$$

$$y_p - \mu_p = \lambda_{p1} f_1 + \lambda_{p2} f_2 + \cdots \ldots . + \lambda_{pm} f_m + \varepsilon_p$$

The factor loading λ_{ij} indicates the importance of factor j to variable i. Although the factors are unknown, they are also considered random variables, and in the model we have E(fi) = 0, Var(fi) = 1, Cov(fi ,fj) = 0 So the factors are assumed to be independent. The model also assumes $E(\varepsilon_i) = 0$, $Var(\varepsilon_i) = \psi i$ In other words, the error terms differ for each variable and it is assumed that Cov(εi ,fj) = 0 and Cov(εi ,εj) = 0. Hence variance of each variable y_i, i=1,2,…p

$$Var(y_i) = \lambda_{i1}^2 + \lambda_{i2}^2 + \cdots \ldots \ldots + \lambda_{im}^2 + \psi i$$

Results and Discussions

For data reduction, factor analysis using the Varimax approach was used. Table-4 compiles the five stations' rotated factor matrix.

Table 4: Rotated Factor Matrix of 5 Stations

	Bollaram Factor			HCU Factor		ICRISAT Factor			Pashmylaram Factor			Zoo Park Factor		
	1	2	3	1	2	1	2	3	1	2	3	1	2	3
PM 2.5	.859	.140	-.191	.316	.858	.921	.024	.167	.553	.703	.114	.905	.150	.030
PM 10	.858	.251	-.002	.419	.821	.898	.085	.283	.617	.627	.169	.892	.205	.184
NOx	.561	.118	.563	.487	.700	.876	.270	.049	.478	.153	.382	.850	.165	.152
NH3	-.159	.462	.609	.051	.784	.237	.161	.508	-.037	.025	.902	.440	.089	.633
CO	.792	.109	-.044	.633	.251	.856	.255	.148	-.007	.652	.412	.826	.118	.271
SO2	-.021	.078	.875	.495	.451	.344	-.276	.580	.690	.324	.000	.418	.254	.632
O3	.671	-.230	.300	.615	.304	-.013	.096	.825	-.083	.849	-.147	-.027	.087	.792
Benzene	.081	.864	.196	.922	.255	-.040	.688	.157	.919	.095	-.107	.276	.917	.109
Toluene	.036	.904	.078	.904	.201	.257	.829	-.072	.943	.048	-.033	.196	.916	.147
Xylene	.377	.572	.056	.892	.223	.255	.738	.019	.809	-.172	.134	.055	.893	.117
% of Variance	30.44	22.71	16.3	40.02	30.3	34.62	19.62	14.37	37.88	20.02	12.23	35.06	26.62	16.06
Cumulative %	30.44	53.15	69.45	40.02	70.32	34.62	53.24	67.61	37.88	57.9	70.13	35.06	61.68	77.74

From Table-4 three factors are extracted from ten pollutant components at Bollaram, ICRISAT, Pashmylaram and Zoo Park but two factors were extracted at HCU as it is purely residential area with greenery resulting low pollution levels. Cumulative variability contributed by 10 pollutant components at Bollaram was 69.45%, at HCU was 70.32%, at ICRISAT was 67.61%, at Pashmylaram and at Zoo Park amounted to 70.13% and 77.74% of the total variability respectively. Rotation effectively preserves the cumulative percentage of variation, and the spread of variation is evenly distributed among the factors.The resulted factors are summarized in Table-5.

Table 5: Summary of resulted factors

	Bollaram	HCU	ICRISAT	Pashmylaram	Zoo Park
1	$PM_{2.5}$, PM_{10}, CO,O_3	CO, SO_2, O_3, Benzene, Toluene, Xylene	$PM_{2.5}$, PM_{10}, NOx, CO	NOx, SO_2, Benzene, Toluene, Xylene	$PM_{2.5}$, PM_{10}, NOx, CO
2	Benzene, Toluene, Xylene	$PM_{2.5}$, PM_{10}, NOx, NH_{3a}	Benzene, , Toluene Xylene	$PM_{2.5}$, PM_{10}, CO,O_3	Benzene, Toluene, Xylene
3	NH_3, NOx, SO_2		NH_3, SO_2, O_3	NH_3	NH_3, SO_2, O_3

According to a report released by Telangana Pollution Control Board in 2019[19], Bollaram houses 26 Bulk Drug & Pharmaceutical Industries, out of the 17 industries are categorized as high pollution causing. Traffic contributes 25% of the urban ambient particulate matter pollution, and industrial activities contribute 15%.[20] The contribution of variability by $PM_{2.5}$, PM_{10}, CO and O_3 is 30.44% of the total indicating that industries and traffic are the major contributors to air pollution in Bollaram. Volatile organic compounds (VOCs) are generally derived from benzene and a sub-group of this family of compounds. VOCs are the second-highest contributors amounting to 22.71% of the total variability due to the presence of pharmaceutical industries,[21] It was observed that NH_3, NOx and SO_2 have contributed 16.3% variance to the pollution contributed by vehicles.[10]

The air pollution at HCU rose due to its proximity to the IT corridor. As there is increase in the high-rise gated communities and vehicular traffic. The major variability of 40.02% at HCU is contributed by VOCs, CO, SO_2 and O_3. As most of the domestic heating systems release VOCs, they are the most common pollutant found in urban residential areas.[22] Variability of $PM_{2.5}$, PM_{10}, NOx and NH_3 is 30.3% of the total due to construction activity and vehicular pollution.

$PM_{2.5}$, PM_{10}, NOx and CO are the highest contributors amounting to 34.62% of the variance at ICRISAT. Pollution generated 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 19.62% of the total variance due to motor vehicles with internal combustion engines.[22,24] These large amounts of VOCs prohibit atmospheric ozone to decompose and hence a large amount of O_3 along with NH_3 and SO_2 contributes to 14.37% of the variance.

Pashmylaram is a hub of chemical and pharmaceutical industries. Air pollutants generated by pharmaceutical industries predominantly constitute VOCs along with sulphur dioxide, nitrogen oxide, etc.[21] and it was observed that VOCs, NOx and SO_2 contribute to 37.88% of the total variation. Major chemical pollutants released in the air are in the form of smog with air-borne particulate matter.[23] It is evident from particulate matter $PM_{2.5}$, PM_{10} along with CO and O_3 contributing to 20.02% of the total variance. It can be noted that the contribution of NH_3 is 12.23% to the total variability as major sources of NH_3 emissions in urban areas are due to industrial processes and vehicular emissions.[26]

35.06% of the total variability is contributed by the air pollutants $PM_{2.5}$, PM_{10}, NOx and CO at Zoo Park. This huge contribution can be attributed to Zoo Park being Industrial cum Residential area. Due to the dense population, VOCs are the second-highest contributors to the total variance, accounting for 26.62% of it. These emissions are caused by a variety of indoor sources, such as building materials, consumer products (fragrances, air fresheners), occupant activities (cleaning), and smoking.[27] NH_3, SO_2 and O_3 contribute 16.06% of the total variability. The percentage of variance is depicted in Figure-1 indicates the dominance of different air pollutants at different localities. This figure helps to understand the number of factors and their percentage of contribution to air pollution at different locations. In addition, it also gives information of the air pollutants making up these factors, thereby one can understand the type of the pollutants affecting the individual residing in that locality. It was observed from Figure 1, that Zoo Park and ICRISAT which are industrial cum residential areas have same pollutants grouped into factors.

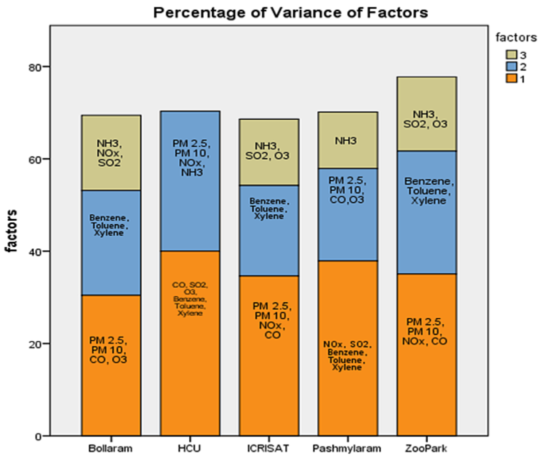

Fig. 1: Percentage of Variance of Factors

Conclusions

It is clear from the current study that factor analysis was successful in simplifying the complexity of air pollution by effectively combining the 10 main air pollutants into fewer variables. According to the locality's characteristics, it was seen that the same set of variables was grouped into factors (factors consisting of similar variables are highlighted in bold in Table 5). Industrial cum Residential areas are found to have the same pollutants grouped into 3 factors. However, the residential area had two factors indicating a low level of air pollution. In both industrial and residential regions that are dominated by the chemical industry, VOCs are determined to be a factor one contributor.

The interdependency between air pollutants was very well brought in the form of factors which helps to reduce the overall pollution by reducing any one component in that factor. The authorities concerned can focus on economical and feasible measures to reduce air pollution. This study also helps to identify the major air pollutant contributors and hence implement appropriate measures depending on the locality to reduce the pollution levels and thereby improve the health of an individual.

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