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A Comprehensive Study: Seasonal Variation of BTEX in Ambient Air of Aligarh, Uttar Predesh, India

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Abstract

Volatile organic control of the air quality in the cities is becoming an issue especially when referring to BTEX- Benzene, Toluene, Ethylbenzene, and Xylene as a result of rapid growth of cities and high traffic and industrial engagements in ambient air of Aligarh. The current research paper determines the seasonal variability of the ambient BTEX concentration in Aligarh, an urban expanding province in western Uttar Pradesh, India. Passive diffusion and complementary active air samples were conducted in one-year period and BTEX levels were analyzed in summer and monsoon seasons and winter seasons. Meteorological parameters were also measured at the same time as the BTEX concentrations of the gas phase was determined by Gas chromatography with Flame Ionization Detection (GC-FID). The findings suggest that moderate concentrations of BTEX were the most popular finding at the presence of all the compounds, winter was the highest in both seasonal exceedances. The greatest rate of exceedance was 36 % of benzene followed by toluene (30 %), xylene (26 %), and ethylbenzene (18 %). It can be predicted seasonally with the colder months being of higher risk since the atmospheric mixing is less, and increased combustion emissions during colder months increase the health hazard. The study indicates that consistent air quality surveying is vital in tier-2 cities such as Aligarh and offers the much-needed fundamental information to make specific intervention actions and guidelines on environmental health of the Aligarh City.

Keywords*:* BTEX compounds, Volatile Organic Compounds (VOCs), ambient air quality, Seasonal variation, Aligarh

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Introduction

Air pollution in cities is one of the most important ecological issues on the planet, and India is one of the fastest growing countries in the world. Volatile organic compounds (VOCs) are among other air pollutants of great concern because of their susceptibility to affect the human health and the environment. A considerable upset of VOCs concentrations is BTEX group- Benzene, Toluene, Ethylbenzene and Xylene that are widely emitted through local vehicle emissions, industrial processes, petroleum products and fire. BTEX compounds not only represent an extreme risk in terms of toxicity but also, they have a premature role in secondary organic aerosols and ground-level ozone formation, which also contribute to air quality problems. Through the parameters of the meteorology, as well as the source of the emission and even seasonal changes, concentration of these compounds in the atmosphere may vary significantly. This is imperative to understand such variations in the assessment of population exposure and the air quality management strategies.

Aligarh is an expanding city in the state of Uttar Pradesh, which is typified by the rising levels of car traffic, small scale Industries as well as shift in land-legal rights. There is however, a limited amount of information on ambient levels of the BTEX compounds within this region most especially at various periods of seasons. Since the components of the BTEX mix (benzene, in particular) present numerous adverse health outcomes once exposed to it, such as carcinogenicity, respiratory discomfort, and neural complications, it is critical that their existence and temporal occurrence are researched to appear within the local air setting.

Background of the Study

The compounds BTEX have been characterized as leading to pollution of the urban air and they are often produced by anthropogenic sources like Traffic emissions, fuel storage facilities, refueling stations, and solvent application. Temperature, humidity, wind speed and atmospheric mixing are seasonal factors that may begin to affect the ambient concentrations of BTEX, by affecting the dispersion and rate of photochemical transformation. VOCs in India particularly in tier-2 cities such as Aligarh have not been studied in depth as specific on the size. Treatment on the same has mostly taken effect in major metros only. But secondary cities are evolving to be hotbeds of pollution controlled by unregulated urbanization, and the absence of complete air surveillance in these areas also puts a hole in the domain of research in environmental health. This study will be important as it will generate baseline information that can be utilized to come up with mitigation measures by local authority and other environmental agencies based on local patterns of pollution with the help of BTEX seasonal behavior in the ambient air of Aligarh.

Objectives of the Study

The present study is designed to fulfill the following objectives:

•To quantify the ambient levels of BTEX (Benzene, Toluene, Ethylbenzene, and Xylene) in various seasons (summer, monsoon and winter) at Aligarh, Uttar Pradesh.

•To evaluate the seasonal (time) trend and pattern of dispersion of compounds of BTEX in the urban air of Aligarh.

•To determine the effect of the meteorological conditions including temperature, humidity, and wind speed among others on the concentrations of BTEX.

Literature Review

Tiwari *et al.*, (2024) carried a long-term study aimed at the BTEX (Benzene, Toluene, Ethylbenzene and Toluene concentrations) in semi-arid urban areas of India. Their field study covered several seasons and was to not only consider the atmospheric dispersion of these substances but also the threats to the health of the people. The paper proved that during the winter, the levels of BTEX presence were poor due to low atmospheric mixing and decreased ventilation. The overt concentrations among the compounds were found in the benzene and the risk, which claimed the highest cancerous risk, was computed using the lifetime cancer risk values. The authors, along with others, have highlighted the risks of displaying long-lasting effects (chronic respiratory and neurological) due to the long-term exposure to these pollutants even at moderate levels. Their results were an indication to the fact that there was an urgent need to carry on continuous monitoring and regulatory measures in the growing urban areas which have insufficient infrastructure as far as pollution control mechanisms were concerned. Sahu, *et al.*, (2020) examined the seasonal variations and emission ratios of aromatic hydrocarbon, namely BTEX and the level of aromatic hydrocarbons in the semi-urban site in western India. The research showed that the meteorological conditions also significantly varied BTEX concentration with maximum concentrations experienced during winter. The authors of the study explained such seasonal variation by temperature inversions and shallow vertical mixing of the air which curtailed the dispersion of pollutants. The swg and dpg2 values estimated in the research paper assisted in determining some of the major contributors of BTEX including vehicle exhaust, industrial combustion, as well as, biomass burning. It was also pointed out in the paper that it is crucial to detect the features of emissions in smaller towns and peri-urban areas where the national surveillance programs of air quality does not typically operate. Garg and Gupta (2019) offered a complete exploration of the spatio-temporal dispersion of BTEX chemicals in the megacity that consumes the air most in the world since Delhi is the most polluted megacity, which is tracked in this study. Their study was involved in a health risk assessment and the presence of the ozone formation potential (OFP) of the individual BTEX components. It was identified that the maximum concentrations of BTEX were present in the area of high traffic and in the vicinity of fuel stations via the spatial analysis. Temporally, the winter and the post-monsoon seasons depicted high levels because of atmospheric stagnation. The risk analysis part of the project concluded that the benzene concentration was always above the recommended standards established by the international standards further causing an increased risk to getting cancer in the lifetime of the exposed population. Concerning the formation of ozone, the research established that toluene and xylene had the largest OFP values, which made them substantiate the challenge of the photochemical smog in Delhi. The authors advised the adoption of combined air quality management policies that addresses not only human health protection but also generation of secondary pollutants. Tripathi and Singh (2022) edited book on bioremediation, covered the novel technologies and bioremediation technologies to deal with the outcome of organic pollutants including BTEX mixtures. They observed the biochemical and microbial processes of the degradation of the aromatic hydrocarbons in the soils and in the water bodies. The volume enthusiastically highlighted the triumphant engagements in the use of microbial consortia, genetically modified organisms, and enzyme based systems in degrading BTEX pollutants in diverse environmental conditions using case studies. The book also gave the major issues that an implementation on large scale would elicit, which included site heterogeneity, bioavailability of contaminants, and regulatory bottlenecks. However, the authors also contended that bioremediation has very much potential to be a suitable alternative of physical and chemical remediation methods as well as cost effective and environmentally sustainable remediation technology especially in areas where resources are limited.

Research Methodology

This study uses systematic observational, analytical and environmental-monitoring based research methodology to study the seasonal change of BTEX (Benzene, Toluene, Ethylbenzene, and Xylene) concentrations in ambient air of Aligarh in Uttar Pradesh. It is intended to give quantitative and qualitative information on temporal trends of BTEX contamination and its dependence upon meteorological factors.

Aligarh's air quality has shown improvement over the last five years, with a notable decline in pollution levels.

Air Quality Index (AQI) Trends:

- 2020: 197 AQI
- 2021: 128 AQI (-35% fall)
- 2022: 130 AQI (2% rise)
- 2023: 114 AQI (-12% fall)
- 2024: 108 AQI (-5% fall)
- 2025: 104 AQI (-4% fall)

The overall annual percentage change in AQI from 2020 to 2025 is an 11% decline, indicating improved air quality.

Most and Least Polluted Months:

- Most Polluted: November 2021 (227 AQI)
- Least Polluted: August 2024 (57 AQI)

Geographical Conditions: Aligarh is located in the Indo-Gangetic Plain, with a relatively flat terrain and an average elevation of 178 meters above sea level. The city experiences a humid subtropical climate, with hot summers and mild winters.

Current Weather Conditions:

- Humidity: 20-64%
- Wind Speed: 6-18 km/h
- UV Index: 0-7

Health Implications: Breathing the air in Aligarh is equivalent to smoking 1.1-2.1 cigarettes per day. It's essential to take precautions, especially for sensitive groups.

Study Area-The study is done in the city of Aligarh in the west of Uttar Pradesh, India, that is urbanizing, densely populated, with a vehicular population and the activities of the small-scale industries. Depending on these factors of traffic, location near industrial areas and residential-commercial mix, one or more sampling sites were selected strategically so that the data on air quality can be representative. Spatial context is noted and recorded in geographic coordinates of the locations and the usage of the land (characteristics).

Sampling Sites: Here are some commercial, traffic, and petrol pump stations in Aligarh:

Petrol Pump Stations

- Kumar Service Station: Located at GT Road, near Dhanipur, Aligarh.
- Sri Sudhir Filling Station: Ground Floor, Marris Road, Aligarh
- Vasundhra Filling Station: Autroli Road, Talashpur, Aligarh
- Shakun Galaxy Fuel Point: Chungi Bypass Road, Koel, Etah, Quarsi, Aligarh
- Ms Indian Oil: Khasra Maheshpur, Manjur Garhi, Aligarh
- Chawla Oil Company: Beedha, Nagargt Road, Ramghat Road, Vikram Colony, Aligarh (has two locations)
- City Energy Station: Ground Floor, Kol, Dhaurra Mafi, Quarsi Byepass Rd, Aligarh (near Lifestyle Mall)
- Jolly Motors: Khair Road, Bannadevi, Aligarh
- Khairwala Petroleum: Ground Floor, World Bank Colony, Bannadevi, Aligarh (open 24 hours)
- Raj Kumar Filling Point: Aligarh Nada Chauraha, Khair Bypass Road, Ashrafpur Jalal, Aligarh (open 24 hours)
- Indra Automobiles: Hathras Adda, Mahendra Nagar, Aligarh
- Sachdev Motors: Soot Mill, GT Road, Aligarh
- Kashish Filling Station: Ground Floor, Ogipur, Gabhana, Bannadevi, Aligarh
- Gangiri Filling Station: Ground Floor, Atrauli, Gangiri, Budhari Buzurg, Aligarh
- Somna Kissan Seva Kendra: Ground Floor, Somna Khiar Road, Somna, Pairi, Aligarh
- Gautam Indian Oil: Gata No 268, Birola, Khair, Tentigaon Road, Aligarh (open 24 hours)
- Pali Kissan Sewa Kendra: Ground Floor, Alampur, Badesara, Palimukimpur, Atrauli, Aligarh
- Dhruv Kissan Seva Kendra: Ground Floor, Badesara, Aligarh
- Maa Vaishno Filling Station: Ground Floor, Badhari Buzurg, Majhola, Atrauli, Aligarh
- Jugender Indianoil Ksk: Ground Floor, Aisi, Lodha, Kol, Akbarpur, Aligarh (open 24 hours).

Industrial Areas: Aligarh has several industrial locations, including-

- Sasni Gate: Location of Indian Diecasting Industries, a manufacturer of aluminum and zinc die-casting parts for the automotive industry.

Some prominent industries in Aligarh:

- Lock Industry: Aligarh is famous for its lock manufacturing, with companies like Johnson & Co. producing locks since 1870.
- Brass Hardware: Aligarh is known for its brass hardware and sculptures, with many manufacturers, exporters, and suppliers involved in the industry.
- Automotive Industry: Indian Diecasting Industries supplies aluminum and zinc die-casting parts to the automotive industry.
- Agricultural Product Processing: Aligarh is an agricultural trade center with industries involved in processing and manufacturing agricultural products.

Sampling Design and Duration

Air sampling is conducted over a one-year period to capture the seasonal variation across three primary seasons:

•Summer (April–June)
•Monsoon (July–September)
•Winter (December–February)

The procedure of sampling is done on the days of the month selected most of the time and there is a clear interval of time between sampling. Sampling days are selected in order to eliminate the unusual pollution events (e.g., festivals, fires) that would distort data.

Sampling Methodology

In the experiment, the BTEX compounds are collected by using the passive diffusion samplers, e.g., activated charcoal tubes or thermal desorption tubes. Such samplers are most suitable in long term monitoring of the ambient air because they operate even without any external power sources. During some situations, the active sampling would also be used to supplement the passive sampling. This comes in form of low-volume air samplers, which sample ambient air by passing it through adsorbent cartridges at a given period to trap BTEX compounds to be analyzed effectively. The samples are analyzed weekly or bi-weekly per season depending on the resources and the laboratory capacity to achieve a steady time cover Gaillard *et al*. (2010).

Analytical Techniques

After collection, samples are subjected to chemical analysis using standardized techniques:

•Extraction: Solvent extraction or thermal desorption methods are used in the extraction of the adsorbed BTEX compounds.

•Quantification: BTEX is determined in concentrations by means of Gas Chromatography (GC) with Flame Ionization Detector (FID) or Mass Spectrometry (GC-MS) which is more accurate and enables identification of the compounds.

•Calibration: BTEX standard solutions are used to calibrate data following the principle of accuracy and reproducibility of data.

•Quality Control: BTEX standard solutions are used to calibrate data following the principle of accuracy and reproducibility of data.

Data Analysis and Interpretation

To assess the seasonal variation, distribution of pollutants, and meteorological effect, the statistical analysis of the number of data on the concentration of BTEX (Benzene, Toluene, Ethylbenzene, and Xylene) was performed. Data was analyzed with descriptive statistics, frequency of pollutants concentration in categorically defined groups and seasonal exceedance of levels of standard limits. Analysis of each BTEX compound was determined by the descriptive parameters mean, range and standard deviation. The level of the concentration was then segregated into certain brackets (e.g. low, moderate, high) according to the spread between the samples and frequency distributions were prepared accordingly that indicated the percentage of the samples belonging to each bracket. It was supposed to identify the frequency in which the BTEX compounds were over the safe levels and time with high pollution of the environment.

Table 1: Frequency Distribution of Benzene Concentrations (μg/m³)

Benzene Level	Concentration Range	Frequency	Percentage (%)
Low	0 – 5	32	32%
Moderate	5.1 – 10	40	40%
High	10.1 – 15	20	20%
Very High	> 15	8	8%
Total		**100**	**100%**

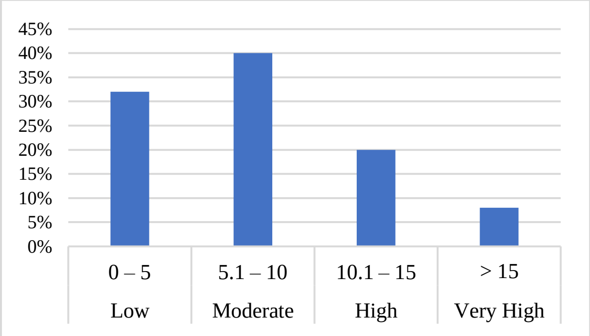

Figure 1: represents the percentage of Distribution of Benzene Concentrations ($\mu g/m^3$)

Examination of benzene concentrations which were distributed in the ambient air depicts that the extent of exposure varied over the sampling time. Analysis of 100 samples showed a proportion of 32 percent for low concentrations of benzene between 0 and 5 0, 6, that is, ambient air at these moments was relatively clean as far as benzene is concerned. Most of the samples, that is, 40% of them, had the concentration lying in the medium category of 5.1-10 mg/m3. This range of concentrations occurred most often meaning that pollution by benzene tends to be at such levels that may potentially cause chronic health effects in the long run. The samples with the higher concentration of benzene, which ranged between 10.1-15 0g/m 3 were 20%. This represented the times when the pollutants could have been present in high levels as a result of factors that included vehicles clusters, industrial discharges or adverse weather conditions. Also, very high benzene values of more than 15 2g/m 3 increased to 8 percent of the samples, which gives concerns of risk of exposure in the short term and about non-compliance with the standards of the national/international air quality of countries.

Table 2: Frequency Distribution of Toluene Concentrations ($\mu g/m^3$)

Toluene Level	Concentration Range	Frequency	Percentage (%)
Low	0 – 10	28	28%
Moderate	10.1 – 20	46	46%
High	20.1 – 30	18	18%
Very High	> 30	8	8%
Total		**100**	**100%**

The frequency and strength of toluene in ambient air can be seen in the distributive mass of this pollutant throughout the hours of monitoring. Of the 100 samples measured, 28 percent of the collected samples had concentrations of toluene that were low with values of 0 to 10 ug/m 3 and this means that the air was relatively free of pollution at such times. The proportion of the data that was attributed to moderate concentration range (10.1 to 20 mg/m 3) was 46 percent. This implies that practically half of the monitored period is encountered with toluene levels, which, although not extremely high, can cause long-term effects of exposure, particularly in urban population centers. The percentage of samples found to have high level of toluene concentration of 20.1 to 30 ug/m3 was also 18%. This indicates occasional spikes in pollution which are probably induced by an additional amount of automotive exhaust, solvent usage, or other industrial processes. Also, 8 percent of the samples had extremely high concentrations of over 30 0g/m 3. These cases could be an indication of the high level of pollution that can be a short-term risk to human health especially when ventilation is bad or the weather is not favorable.

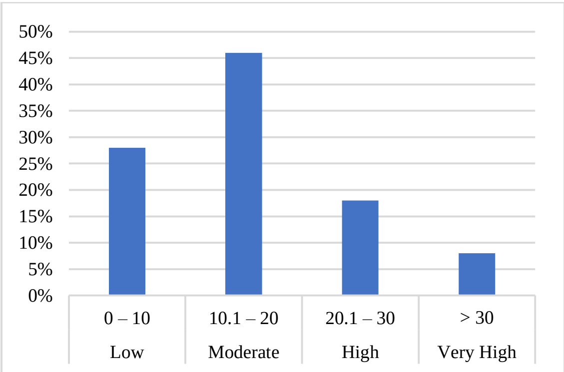

Figure 2: represents the percentage of Distribution of Toluene Concentrations ($\mu g/m^3$)

Table 3: Frequency Distribution of Xylene Concentrations ($\mu g/m^3$)

Xylene Level	Concentration Range	Frequency	Percentage (%)
Low	0 – 8	30	30%
Moderate	8.1 – 16	42	42%
High	16.1 – 24	20	20%
Very High	> 24	8	8%
Total		**100**	**100%**

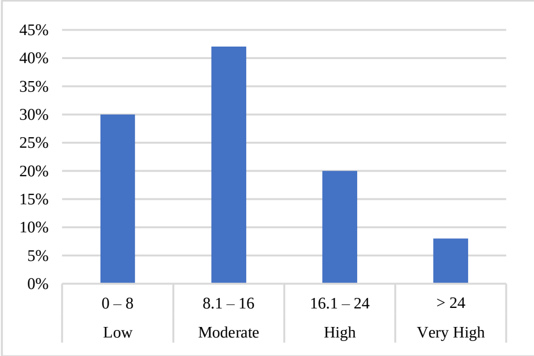

Figure 3: represents the percentage of Distribution of Xylene Concentrations ($\mu g/m^3$)

The frequency of xylene concentration distribution in the ambient air points to the moderate to sometimes high concentration of this volatile organic compound during the sampling period. The 100 samples that were examined showed that 30 percent had low levels of xylene that ranged between 0 and 8 ug/m 3 which means that the air was rather cleaner at the time the monitoring was made. Most of the samples were observed with less than 16 ug/m3 with 42 percent falling between the 8.1 to 16 ug/m3. This is an indication that xylene was widely occurring in the environment at a level that might not be of immediate health implications but serving effects in the protracted exposure to the element and especially affecting the sensitive populations. 20 percent of the samples had high level of xylene that varied between 16.1 and 24 n(micro)g/m 3. Such high concentrations are correlated with local pollution events which were probably caused by traffic congestion, fuel evaporation, heavy industry, or atmospheric stagnation. Also, very high concentrations of xylene in the range of up to 24 2l-g/m 3 were observed in 8 percent of the samples and this may cause acute exposure effects with long-term exposure.

Table 4: Seasonal Exceedance of BTEX Compounds over CPCB/WHO Standards

Compound	Summer	Monsoon	Winter	Total Exceedance Frequency	Percentage (%)
Benzene	12	6	18	36	36%
Toluene	10	8	12	30	30%
Ethylbenzene	5	4	9	18	18%
Xylene	9	6	11	26	26%

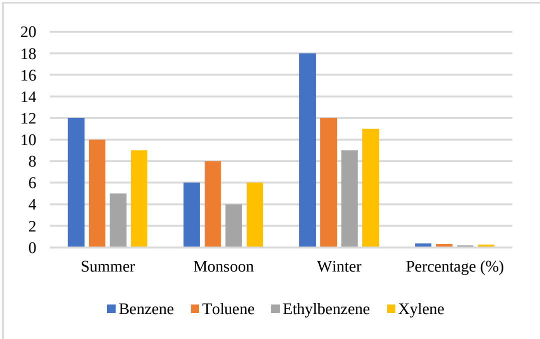

Figure 4: represents the percentage of Seasonal Exceedance of BTEX Compounds over CPCB/WHO Standards

Table 4 indicates seasonal exceedance frequencies of BTEX (Benzene, Toluene, Ethylbenzene and Xylene) as exceeding the permissible limits specified in the CPCB or the WHO guidelines. The statistics show that benzene was the substances with the greatest exceedance rate as 36 samples (36 percent) passed the acceptable limits. Markedly, winter and summer were associated with the highest number of exceedances (18 and 12, respectively), which shows that the colder and drier weather could be related to the buildup of benzene in the atmosphere since it is dispersed less and more activities can be linked to combustion. In 30% (or 30 samples) toluene was found to be above the standard with comparative distribution among the seasonal data namely 10 in summer, 8 in monsoon and 12 in winter. This implies that seasonal difference is present; however, toluene may be produced by invariable resources such as road traffic and solvents, which can occur throughout the year. In ethylbenzene, the exceedance was low with 18 samples (18 percent) exceeding the guideline values. Its seasonal trend is consistent with reduced exceedances during monsoon (4), probably because in this season the humidity and rainfall are higher and may contribute to the disappearance of pollutants. Nevertheless, it continued to be more than the limits in the summer (5) and winter (9) hinting at its occasional evacuation into the traffic and industrial sources. Xylene was above normal levels in 26, that is 26 percent of samples taken (26)

Conclusion

The current study offers a thorough evaluation of seasonal variation in the levels of BTEX in the air environment of Aligarh, Uttar Pradesh, by a parametric environmental monitoring method that is testified to be an effective one. This data shows the clear indication that the levels of BTEX are also highly different depending upon the seasons with the highest concentration and frequencies of exceedances being recorded during winter. Benzene turned into the most essential pollutant by prevalence and health danger, with standard safety flexibilities being violated persistently both nationally and internationally. Many exceedances were also displayed in toluene, xylene and ethylbenzene especially at high traffic and industrial sites. The seasonal exceedance analysis highlights the importance of the impacts of meteorological variables temperature, relative humidity and atmospheric stability levels on dispersion and accumulation of BTEX. The described cases of pollution, especially seasonal episodes in winter, emphasize the necessity of urgently attempts in policies and tougher regulation of the pollution control especially in booming cities. The research also creates a missing data niche in the environmental monitoring of the tier-2 cities and provides the basis of datasets to support the next-generation air quality assessment, risk analysis, and sustainable city development in the region.

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