Bulletin of Biological and Allied Sciences Research
***ISSN:* 2521-0092**
www.bbasr.org
DOI: https://doi.org/10.54112/bbasr.v2024i1.87
*Bull. Biol. All. Sci. Res., Volume, **9**: 87*
Original Research Article ***Open Access***

SMOG CRISIS IN LAHORE: EVALUATING AIR QUALITY TRENDS AND PUBLIC HEALTH IMPLICATIONS

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(Received, 13th August 2024, Revised 8th November 2024, Published 11th November 2024)

Abstract *Seasonal smog renders Lahore, Pakistan, an environment legally with low-quality air and poor health for frequent cases. The smog includes such air pollutants as particulate matter, including PM2.5, PM10, carbon monoxide (CO), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2), which worsens respiratory and cardiovascular diseases. Air pollution trends in pre-smog season and during smog season and the related public health consequences of this phenomenon are examined in this research. The study compared the values of air quality parameters, as well as health data on the whole population in Lahore, in the period before smog and the period of maximum smog intensity. The participants consisted of 500 persons, and data about the air quality indicators, including PM2.5, PM10, CO, NO_2, and SO_2, was obtained. Imagery indices, self-reported symptoms, hospitalization, and cardiovascular events were examined. Hypothesis testing analyzing the perception of air quality and confirmed behavioral change were concerned with a survey regarding the usage of masks, awareness of air quality alerts, and frequency of outdoor trips. The data were analyzed and compared using t-tests with a test of significance set at 0.05 for all the tests done in this research. The results of the present study reveal that air quality parameters such as PM2.5, PM10, CO, NO_2, and SO_2 had enhanced values during the smog-burst period as compared to the pre-smog condition. The PM2.5 concentrations were raised from 60.52 µg/m³ to 180.34 µg/m³, and those of PM10 from 85.24 µg/m³ to 230.14 µg/m³. Other effects included improvements and worsening health indicators for persons suffering various ailments during peak smog. Hospital admission per 1000 people rose from 20.42±5.83 to 45.79±10.10 respiratory symptoms rose from 3.23±1.17 to 7.84±1.90 and cardiovascular incidents rose from 1.19±0.41 to 3.52±1.27. The number of asthma, bronchitis, and COPD cases also rose during the peak smog period. Asthma increased from 12.52% to 28.74%, bronchitis from 10.10% to 22.30%, and COPD from 4.93% to 12.12%. Knowledge about air quality alerts and wearing a mask during the smog season also changed respectively. The result demonstrated that Lahore recorded the maximum AQI and pollutants compared to other big cities in Pakistan such as Karachi, Islamabad, and Faisalabad. The findings presented in the paper show an alarming increase in air pollution and adverse effects on human health particularly during the period of smog in Lahore. People's knowledge and changes in their behavior, including mask-wearing and reduced time spent outdoors, indicate that new and efficient preventive measures in public health and the environment should be developed to combat smog impacts on human health.*

[Citation: Malik, A., Islam, J., Zaib, G., Ashraf, M.H., Zahid, A., Rashid, A.R., *Zia, T.*, Ali, Q. (2024). Smog crisis in Lahore: evaluating air quality trends and public health implications. *Bull. Biol. All. Sci. Res.* **9***: 87. doi:* https://doi.org/10.54112/bbasr.v2024i1.87]
Keywords: *smog; pollution; people's health; respiratory diseases; heart attacks; strokes; PM2.5; environment*

Introduction

The second largest city of Pakistan, Lahore, has recently been engulfed by environmental pollution challenges such as smog. This type of smog is mainly found from October to December and has been caused by motor vehicle emissions, industries, crop burning in other provinces, and unfavorable meteorological conditions like temperature inversion and low wind speed. The air pollution index of the city is above hazardous and goes beyond the WHO safe limit for both PM 2.5 and PM 10 (Qu and Xia, 2024). This smog phenomenon is mostly characterized by a rise in particulate matter particularly PM2.5 which causes high health risks since they can enter the respiratory system (Mirza et al., 2022). During the smog season, the aerosol loading and other related pollutants in Lahore increase significantly also, such as PM2.5, PM1, CO, NO_2, and SO_2 (Arif et al., 2023; Jabeen et al., 2021). These pollutants have brief and long-term adverse impacts on health since they are related to respiratory and cardiovascular diseases and worsen

predefined preconditions, including asthma, chronic obstructive pulmonary disease (COPD), and bronchitis (Kausar et al., 2023; Khan et al., 2022). Based on the study, several adverse effects of long-term exposure to smog in Lahore are evident in public health. Literature reveals that air pollution elevates what was defined as high smog periods to increase hospital admissions due to respiratory and cardiovascular diseases as well as to enhance the rate of premature deaths (Riaz and Hamid, 2018). The above smog-related health ailments add to the current healthcare demands that exert more pressure on the dwindling health facilities in Lahore.

Apart from affecting bodily well-being, air pollution has other social-economic consequences. Healthcare treatment, lost work days, school days, and loss of productivity which raises the economic impact for the local citizens (Ain et al., 2021). However, similar to the survey in Pakistan, the undoubtedly grave smog threat still has not received the proper attention from the public (Hussain et al., 2024), and behavior changes such as the use of masks and avoiding going outside during the smog has been observable but moderately low. Considering the smog problem in Lahore has reached its critical level, it is necessary to analyze the presented trends in the air quality change and study the consequences that hazardous conditions indicate for human health. The objectives of this research are to determine the overall trends of air quality in Lahore especially during the smog season and to assess the effects of poor quality air situation on human health in the area (Ashraf et al., 2022). Thus, it helps in raising awareness of the need for the development of effective policies and interventions aiming at reducing the impact of smog on the population.

Materials and methods

Study Design

This work was a cross-sectional descriptive study conducted to analyze the air quality trend during the smog season in Lahore and also to measure the impact on public health. The research centered on the given results of such indicators as air quality in the local population and an impact on the health of people with respiratory and cardiovascular diseases. For data collection, both EMPs and HAs were used and the study spanned for 1-year cross-cutting pre-smog period and peak smog season.

Target Population

The sample of this study comprised all the people living in Lahore, both adults aged between 18 and 65 years and children who frequently encounter the problem of smog. These subjects were recruited using residential area criteria and with daily exposure to different levels of air pollution more so in the time of the year when smog is frequent.

Sample Size

The sample size for this study was estimated by power analysis computing that this study will give a power of 80% plus and a confidence level of 95%. In this study, we hired 500 participants, and an equal number of participants were selected from both pre-smog and peak smog seasons. Specifically, the sample size was deemed sufficient for making comparisons utilizing indicators of APPs and relevant public health-related issues.

Inclusion Criteria

Participants were selected based on the following inclusion criteria: A minimum of three year's residency in Lahore and should be familiar with the environment and weather patterns that cause air pollution. Earning capacity between eighteen and sixty-five for both employed individuals in the working ages and the vulnerable elderly population affected by negative health effects of air pollution. Subjects' interest in actual surveys and measurements, together with voluntary consent on the procedures used in the present research and data gathering.

Exclusion Criteria

Individuals were excluded from the study if they met any of the following criteria: Historical chronic illnesses not associated with air pollution, ischemic heart diseases, or diseases that could confound the effects of smog exposure on health. Pregnant women were excluded because pregnant women might be at a higher risk due to exposure to high-level air pollution and may have different respiratory health conditions.

Demographics

To try and achieve gender and age diversity, as well as the geographical distribution of participants across Lahore, certain measures were taken when conducting the study. This was done to obtain a broad spectrum of possible exposure to smog, as this characteristic depends on location and the extent of urbanization. Dwellings were divided into high-exposure areas, moderate-exposure areas, and low-exposure areas using the data collected from the Environmental Protection Department of Lahore concerning the air quality index.

Data Collection Methods

Air Quality Indicators

Air quality data was collected from daily real-time monitoring of air at different locations in Lahore with the help of established air quality monitoring stations. The following air pollutants were measured during both the pre-smog and peak smog seasons: Particulate matter, fine particles with a diameter of less than 2.5 µm. PM10 is defined as particulate matter with ten microns or less in diameter. CO (Carbon Monoxide), NO_2 (Nitrogen Dioxide), SO_2 (Sulfur Dioxide), and O_3 (Ozone) These measurements were daily performed over a time frame of six months, and averages were obtained for each of the seasons.

Health Assessments

Data on health were obtained from structured questionnaires specially administered questions about respiratory complaints (Cough, difficulty in breathing, wheezing), cardiovascular complaints (Chest pains, palpitations), and hospitalizations.

Outcomes were measured through clinical examination and a set of standardized questionnaires that included questions about respiratory illnesses such as asthma, bronchitis, and chronic obstructive pulmonary disease (COPD). A respiratory symptoms score was also derived and a cardiovascular incidents score was also computed to measure the level of endangerment due to smog.

Public Awareness and Behavioral Changes

Regarding the level of awareness of air quality alerts as well as the behavior change about smog exposure (mask wearing and time spent outside), a survey was conducted among the participants. To capture the level and type of awareness by the population, questions were included which aimed at how they modify their lives when exposed to the smog crisis such as the exposure to AQI levels and time spent outside.

Data Analysis

Descriptive quantitative analysis was done using SPSS software with a version of 26. Quantitative data of air quality and health outcomes were summarized using descriptive statistics: mean with standard deviation. The results are presented in tables 1-5, and analysis of the data included the use of paired t-tests for comparing pre-smog and specially defined peak smog season values and were regarded significant if corresponding p-values were <0.05. Bivariate regression analysis was used to examine possible correlations existing between air quality prognosis and state of health, controlled by age, sex, and chronic diseases.

Ethical Considerations

The study was cleared by the Institutional Review Board (IRB) of the University of Lahore. Participants' consent was sought before they were recruited into the study, to explain to them the objectives and activities of the study, and possible consequences. Participants' anonymity was promised throughout data collection and analysis to ensure participant confidentiality and anonymity.

Results

For the concentration of PM2.5 (Table 1), there was a significant difference (60.52 µg/m³±15.24) at the onset of the smog season compared to the mean value during the period of intensive smog (180.34 µg/m³±25.71, p=0.000). The same results were obtained for the rates of PM10 which increased from 85.24 µg/m³ ±18.71 to 230.14 µg/m³ ±35.39, p-value=0.001). CO from (0.57 mg/m³ to 2.19 mg/m³ p= 0.015, NO_2 from (25.45 ppb to 55.90 ppb, p=0.011, and SO_2 from (10.34 ppb to 28.43 ppb, p=0.006 showed other pollutants which have also raised significantly during peak smog period. Specifically, the mean reducing gas concentration was higher during smog season it decreased in the range of O_3 40.70±10.15) pre smog season to 25.22±7.51) during peak smog season p-value=0.017. A critical rise was noted in hospitals during the smog season which stood at 45.79/1000 as against 20.42/1000 during the pre-smog season, p-value=0.037 (Table 2). Also, the respiratory symptoms score improved significantly from 3.23±1.17 to 7.84±1.90 during the peak smog period, p-value=<0.05). Other cardiovascular events also increased from 1.19±0.41 to 3.52±1.27, p-value=0.025). The ascertainment of asthma increased from 12.52% ±3.23 to 28.74% ±5.46, p=0.021. Likewise, bronchitis rose from 10.10% ±2.73) to 22.30% ±4.17, p<0.05) while the prevalence of COPD rose from 4.93% ±1.47 to 12.12% ±3.35, p< 0.05 (Table 3).

Concerning awareness of air quality alerts, there is a boost during the smog season from 78.67% to 45.33%, with smog season p-value= 0.006. Masks were also worn more, 60.44% during the smog season and 15.22% before the season, p-value=0.017 (Table 4). Participants also cut down their outdoor activities from 3.45±1.57 hours before the smog season to 1.23±0.74 before the peak smog season, p=0.010. Lahore had the highest overall AQI (230.02±25.01), higher than other cities such as Karachi (165.01±20.14), Islamabad (140.44±18.15) and Faisalabad (190.15±22.26). So Lahore recorded the highest average concentration of PM2.5 at 180.37µg/m³, PM10 at 230.19µg/m³, CO at 2.12mg/m³ NO_2 at 55.91ppb and SO_2 at 28.44ppb than the other cities of the study (Table 5).

Concisely, the study shows a general trend emanating from the peak smog season in Lahore which is a deterioration of air quality and consequently negative impacts on health, particularly respiratory and cardiovascular diseases. Results of self-organized population response were identified, including the growth in face mask usage and decrease in time spent outdoors, indicating that the population is gradually adjusting to increased danger levels related to smog. However, the information obtained also revealed that the air quality of Lahore is still lower than that of other large cities in Pakistan, which proves that the smog problem is still rather acute.

Table 1. Air Quality Indicators Before and During Peak Smog Season

Indicator	Pre-Smog Season (n=500)	Peak Smog Season (n=500)	p-Value
PM2.5 (µg/m³)	60.52±15.24	180.34±25.71	0.000
PM10 (µg/m³)	85.24±18.71	230.14±35.39	0.001
CO (mg/m³)	0.57±0.23	2.19±0.54	0.015
NO_2 (ppb)	25.45±6.32	55.90±10.83	0.011
SO_2 (ppb)	10.34±3.27	28.43±5.77	0.006
O_3 (ppb)	40.70±10.15	25.22±7.51	0.017

Table 2. Health Outcomes Associated with Smog Exposure (Sample Population)

Health Outcome	Pre-Smog Season (n=500)	Peak Smog Season (n=500)	p-Value
Hospital Admissions (per 1000)	20.42±5.83	45.79±10.10	0.037
Respiratory Symptoms Score	3.23±1.17	7.84±1.90	0.001
Cardiovascular Incidents	1.19±0.41	3.52±1.27	0.025

Table 3. Prevalence of Respiratory Conditions (Asthma, Bronchitis, COPD)

Condition	Pre-Smog Season (n=500)	Peak Smog Season (n=500)	p-Value
Asthma (%)	12.52 ± 3.23	28.74± 5.46	0.021
Bronchitis (%)	10.10 ± 2.73	22.30 ± 4.17	0.026
COPD (%)	4.93 ± 1.47	12.12 ± 3.35	0.014

Table 4. Public Awareness and Behavioral Changes

Survey Metric	Pre-Smog Awareness (n=500)	During Smog Awareness (n=500)	p-Value
Knowledge of Air Quality Alerts (%)	45.33 ± 12.51	78.67 ± 15.90	0.006
Use of Masks (%)	15.22 ± 4.61	60.44 ± 11.82	0.017
Time Spent Outdoors (hours/day)	3.45 ± 1.57	1.23 ± 0.74	0.010

Table 5. Air Quality Index (AQI) of Lahore vs. Other Major Cities in Pakistan

City	AQI (Overall)	PM2.5 (µg/m³)	PM10 (µg/m³)	CO (mg/m³)	NO_2 (ppb)	SO_2 (ppb)
Lahore	230.02±25.01	180.37±25.73	230.19±35.35	2.12±0.57	55.91±10.83	28.44±5.73
Karachi	165.01±20.14	120.53±20.37	150.20±28.54	1.57±0.41	40.23±9.74	15.67±4.33
Islamabad	140.44±18.15	95.73±15.44	110.37±22.13	1.07±0.33	30.42±8.15	12.44±3.56
Faisalabad	190.15±22.26	150.84±23.68	190.72±32.43	1.87±0.54	50.52±10.27	20.14±4.63
Peshawar	175.59±21.14	130.25±19.82	160.57±29.72	1.63±0.47	42.31±9.59	18.75±4.17
Gilgit	60.27±10.19	30.57 ± 8.24	45.23 ± 12.57	0.44±0.19	8.52 ± 2.73	3.24 ± 1.17
Quetta	150.16±20.02	100.81±18.43	125.64±24.94	1.26±0.37	25.39±7.51	12.54±3.87

Discussion

The current problems of smog in Lahore, implying a twofold increase in air pollution during the season of its activity, can be referred to as a public health issue of great concern. These observations stress the sharp increase in the levels of hazardous air emissions including PM2.5, PM10, CO, NO_2, and SO_2 which has been linked with respiratory and cardiovascular morbidity of the residents. These outcomes support the findings found in prior research, for example, (Awez et al., 2024; Khan et al., 2022), identify that the degree of air pollution in the urban settlements of South Asia is increasing especially in Lahore that is known to have turn into one of the most polluted urban centers in the region. Our study also reveals that during the peak smog season, PM2.5 and PM10 counts were more than three times higher than before the smog season, this conclusion is in line with other studies that have revealed seasonal fluctuation in air pollutants in Lahore (Malhi et al., 2023). There is a significant increase in PM2.5 in particular which several research works elaborated that these fine particulate matters are dangerous because they will reach deep into the lungs and several health hazards are associated with them such as respiratory diseases, cardiovascular incidents, and premature mortality (Jabeen et al., 2021).

This hampers the public health needs more especially since the concentrations of CO, NO_2, and SO_2 rise during the peak smog period. These pollutants are mainly emitted by vehicles, industries, and biomass burning which increase during the colder months when the smog season is considered (Nawaz et al., 2023). Recent prior research has established that there is a positive association between elevated emissions of NO_2 and CO with the prevalence of asthma, bronchitis, and cardiovascular illnesses (Abdul-Rahman et al., 2024). Concerns about the increased levels of NO_2 and SO_2 during the increased smog period are supported by our study findings with p-values of (0.011) and (0.006) for NO_2 and SO_2 respectively; the results underlining the need for increased regulatory measures in checking vehicular and industrial emissions during this period. Our findings show that exposure to smog harms public health, and hospital admissions, respiratory symptoms, and cardiovascular events all rose over the period analyzed. The increase in the number of patients admitted to the hospitals (Trend test = 0.037) during the smog period is in line with previous smog-vulnerable cities reporting shocking high rates of emergency department visits and admission for pulmonary and cardiovascular conditions during episodes of high air pollution (Miller, 2022). Respiratory symptoms seem to have risen (p-value=0.001) and so did cardiovascular incidents (p-value=0.025) which is particularly worrying given the effect it has on the health system and the population's health.

There is a negative trend towards the respiratory conditions in BC during the time of peak smog to mention that the cases of asthma, bronchitis, and COPD have increased. Specifically, smog has been associated with asthma owing to the worsening effects of particulate matter on the respiratory system. Epidemiological investigation has identified increased air pollution in exacerbation of asthma and chronic obstructive pulmonary diseases (COPD)

(Manisalidis et al., 2020). As our results highlight that the proportion of patients having asthma (p-value=0.021) bronchitis (p-value=0.026) and COPD (p-value=0.014) all rise substantially during the smog season, such pollution does pose a serious threat to public health especially if people are exposed to severe pollution for long periods. This study also compared public knowledge and attitudes concerning the smog season and behavior during the smog season. An understanding of air alerts, concerning (p=0.006) and mask usage (p=0.017) suggests a rising awareness of the threat jeopardized by air pollution and the population's effort to prevent the adverse effects (Jabeen et al., 2021). It is vivacious to see such behavioral changes bearing in mind they are a result of coping with the harsh environment. However, the daily contact duration has decreased out-of-door stay (p-value=0.010) indicating drastic changes in people's lives as they factor in measures of avoiding contact. A similar situation has been noted in other contaminated air areas when people limit themselves to outdoor activity during the period of enhanced air pollution to decrease adverse health effects (Awez et al., 2024; Nawaz et al., 2023)(Rasool et al., 2021; Zaman et al., 2022). These are the reasons long-term measures that are a thousand times more appropriate in this context include safe modes of transport, more rigorous emission standards for vehicles, and the promotion of health awareness programs to cope with the two evils that are smog and its consequences on citizens of Lahore.

Compared to other large cities in Pakistan, the findings shown above reveal startling results for air quality. The current study for this index showed that Lahore had the highest Index (230.02±25.01) and concentration of PM2.5 (180.37µg/m^3), PM10 (230.19µg/m^3), Carbon monoxide, (2.12 mg/m^3), Nitrogen dioxide, (55.91ppb) and Sulfur dioxide (28.44ppb) respectively. This means that Lahore has a higher concentration of smog than the rest of the other cities in Pakistan thus a call for the government to urgently address on causes of air pollution in the city (Majeed et al., 2024). Comparison with other big conurbations with lower AQI indicators showed that air quality differs between regions and requires the development of local measures to improve it. Therefore, this study strengthens the knowledge of the extreme public health effects of smog in Lahore. The increase in the level of the bad air quality index during this period has been linked with the deterioration health of respiratory and cardiovascular illness. People have become more conscious and are changing their behaviors about the impacts of air pollution, but still, there is a need for better and sustainable approaches for handling the Effects of Air pollution. Some of the changes might be more stringent standards for emissions, enhanced modern human transport systems, and public health crusades that seek to have people avoid exposure to airborne pollutants. It becomes important to resolve the smog crisis in Lahore not only for the people's health and their lives but also to help the city become sustainable and ultimately build capable of addressing other environmental issues in the future.

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Declarations

Acknowledgments

On behalf of all the individuals and institutions that we have benefited from while conducting this research, we say thank you. On behalf of our team, we are grateful to the Environmental Protection Agency of Lahore for sharing the air quality data that was useful in this research work. We are equally grateful to all the people of Lahore who agreed to be used in drawing the health perception surveys for this research. Dr. Qurban Ali deserves appreciation for the suggestions that he provided from the aspect of environmental health in the development of the study proposal and model. We also acknowledge the administrative cooperation of the University of Lahore in the data collection and analysis section.

Authors' Contribution

MHA, AQ Study definition, data collection, analysis, and interpretation. **AM** Wrote up data analysis, outcomes, literature review and assisted with discussion section preparation. **ARR** Participated in survey design, fieldwork, data analysis, and methodology writing. **JI** Analyzed air quality data and made paper comments. **AZ** Helped explain health survey findings, especially health repercussions data. Additionally, she revised the manuscript. Helped collect data for public health surveys and proofread the manuscript. **GZ** Participation in environmental data collecting, notably air quality, and paper analysis and review.

Conflict of Interest

The authors of this research have no conflict of interest in the publication of this research. The execution of this research was entirely non-partisan, and the authors declare no conflict of interest that may have influenced the contents of this manuscript.

Funding

We are grateful to the Lahore Environmental Health and Safety Fund for providing support in accruing and processing the environmental information.

Consent for Publication

Not applicable