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By

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Abstract

The monthly trend of air pollution in Lahore exhibits a distinct seasonal pattern influenced by both climatic conditions and human activities. Winter months witness escalated pollution levels due to temperature inversion and increased heating system use, resulting in an unhealthy Air Quality Index (AQI) from November to January. Low wind speed and precipitation accelerate pollution levels during this period. The pre-monsoon and monsoon seasons show moderate AQI, with relief in July and August as precipitation helps clear pollutants. Post-monsoon, residual effects contribute to improved air quality in October, although risks persist due to crop residue burning. The AQI remains unhealthy for sensitive groups in February and October.

High-risk areas contributing to Lahore's air pollution encompass traffic congestion, industrial zones, burning of agricultural residue, residential areas, and construction sites. Vehicular emissions, particularly from old vehicles, significantly contribute to pollution. Industrial activities release pollutants like SO2 and CO, leading to enforcement efforts by EPA against polluting units. Crop burning and solid fuel use in residential areas further

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add to pollution, while construction activities generate dust. Meteorological effects vary pollution levels seasonally.

The Health Risk Assessment of Air Pollution in Lahore indicates significant implications for mortality across various age groups and health conditions. The adult mortality rate in Pakistan stands at 1830 per 100,000, with the Air Q+ Model predicting a 50% contribution of PM2.5 air pollution to adult mortality in Lahore. COPD poses a substantial challenge, with an age-standardized mortality rate of 138.2 per 100,000 for males and 41.3 per 100,000 for females, with a 44.11% role of PM2.5 in COPD mortality. Stroke mortality is rising, with a predicted doubling by 2020, and a 50% role of PM2.5 in stroke mortality in adults in Lahore. ALRI in children under 5 is a significant concern, with a mortality rate of 6.3 per 1000 and a 36.35% role of PM2.5 in child mortality due to ALRI in Lahore. IHD is a prevalent cause of mortality in adults aged 25-30, with a 50.08% role of PM2.5 air pollution in IHD-caused mortality. Respiratory diseases contribute significantly to adult mortalities in Pakistan, with a 25% role and a 58% role of PM2.5 in respiratory disease mortalities in Lahore.

Ongoing efforts involve EPA fines, inspections, and proposed emission control standards for industries, but challenges persist, including economic constraints for old industrial units and the difficulty of banning old vehicles. Crop residue burning remains despite EPA bans due to challenges for farmers.

Introduction

Lahore, a bustling metropolis in Pakistan, is grappling with a formidable air quality challenge that significantly impacts the health and well-being of its residents. The city's air pollution crisis has been exacerbated by rapid urbanization, industrial growth, and a surge in vehicular emissions, raising serious concerns about environmental sustainability. Exposure to air pollution in Lahore carries significant health consequences, manifesting in respiratory ailments like asthma, bronchitis, and infections due to elevated levels of particulate matter (PM) (World Health Organization [WHO], 2018). Prolonged exposure poses an augmented risk of cardiovascular diseases, including heart attacks and strokes (Brook et al., 2010). Children and individuals subjected to extended periods of air pollution may witness diminished lung function, resulting in persistent respiratory challenges (Gauderman et al., 2004). Moreover, certain carcinogenic air pollutants such as benzene and formaldehyde escalate the likelihood of developing lung cancer (International Agency for Research on Cancer [IARC], 2016). Research indicates a correlation between elevated air pollution levels and

premature mortality, underscoring the substantial health burden it imposes (Cohen et al., 2017).

The sources of pollution in Lahore are diverse, ranging from anthropogenic activities such as industrial processes, transportation, and agricultural practices to natural factors like wind-blown dust and occasional wildfires. Anthropogenic sources, in particular, contribute substantially to the emission of pollutants such as PM2.5, CO, and NO2, affecting the overall air quality [Sanchez-Triana et al., 2014]. Lahore exhibits distinct seasonal patterns in air pollution, with the winter season often witnessing a surge in pollutants. Factors such as temperature inversions, increased energy consumption, and agricultural activities contribute to heightened pollution levels during this period. The emergence of smog as a recurring "fifth season" further highlights the severity of the issue [Malik, 2017].

Modifications such as inflammation, heightened anxiety, and other psychological alterations, as well as disruptions in hormonal balance and oxidative stress, have been reported in studies [Furlong M.A., et al., 2020]. Additionally, there is evidence suggesting that air pollutants might be linked to changes in behavior among children, leading to alterations in physical activities, increased caloric intake, and shifts in eating habits [Wang Z., et al., 2021].

Numerous investigations have indicated a positive correlation between aerosol density and various air pollutants, encompassing particulate matter with a diameter of ≤10 μm (PM10), carbon monoxide (CO), nitrogen oxides (NOx), sulfur dioxide (SO2), Volatile Organic Compounds (VOCs), and PM2.5 [de Bont et al., 2019]. Particularly in densely populated regions, asthma is notably associated with air pollution, predominantly attributed to the presence of PM2.5, PM10, NO2, SO2, and O3 [Kathuria P. et al., 2016]. Children, due to their faster breathing rate and increased air intake compared to adults, are identified as being at a higher risk of experiencing morphological and functional effects during fetal development [Ghorbanian A., et al., 2020].

Addressing the health ramifications of air pollution in Lahore necessitates comprehensive policy interventions. Crucially, fortifying air quality regulations is imperative, emphasizing the reduction of key pollutants such as particulate matter, nitrogen dioxide, sulfur dioxide, and ozone (Pakistan Environmental Protection Agency [Pak-EPA], 2012). Encouraging the adoption of clean energy sources and technologies becomes pivotal to curtail emissions from industries, vehicles, and households (Malik & Mubarik, 2007). Strategic investment and promotion of efficient public transportation systems are essential to diminish reliance on individual

vehicles, consequently mitigating traffic-related emissions (Government of Punjab, Pakistan, 2020). Urban planning should prioritize the incorporation of green spaces and tree planting initiatives to augment air quality and amplify public health benefits (Qureshi et al., 2018). Implementing robust waste management systems is indispensable to mitigate the significant contribution of open burning of waste to air pollution (Khezri et al., 2016). Initiating public awareness campaigns is imperative to enlighten the public about the health risks associated with air pollution and advocate for individual actions to minimize exposure (Ahmad et al., 2018). Collaborative efforts with neighboring regions and countries are imperative to address cross-border pollution through mutually agreed initiatives and agreements (United Nations Environment Programme [UNEP], 2016).

Methodology

A comprehensive methodology was implemented to monitor ambient air quality through a mobile air quality monitoring station utilizing a Beta Attenuation Monitor (BAM) for PM2.5 monitoring in various locations across Lahore. Data collection, initiated in the past, involved allowing the BAM instrument to record real-time measurements, with continuous power supply to prevent data gaps. Real-time or periodic data transmission to a centralized database was established, incorporating alarms for immediate notification in case of equipment malfunction or abnormal readings. The collected data were analyzed to identify trends, patterns, and potential sources of pollution.

Periodic maintenance, following the manufacturer's recommended schedule, included cleaning components, checking seals, and replacing consumables. The methodology ensured compliance with local and national regulations governing air quality monitoring. Regular reports summarizing monitoring results were prepared and submitted. Stakeholder engagement was actively pursued, involving local communities and relevant stakeholders to share information and address concerns related to air quality. This comprehensive methodology in the past contributed valuable historical data for assessing and managing air quality in different locations in Lahore. Ongoing collaboration and updates further enhanced the effectiveness of these monitoring initiatives. Table-1 shows the methodology detail of the PM2.5 analyzer.

Annual average data of PM2.5 is used to model Health rRisk Assessment of PM2.5 through WHO AirQ+ Model. The PM2.5 contribution to different mortalities in Lahore has been modeled using AirQ+ Model.

Results and Discussion

The monthly trend of air pollution in Lahore is given in Figure-1. Lahore, like many urban areas, exhibits a distinctive seasonal pattern of air pollution, influenced by a combination of climatic conditions and human activities. During the winter months, from November to February, air pollution tends to increase due to temperature inversion and the heightened use of heating systems. The monthly trend shows an unhealthy Air Quality Index (AQI) during November, December, and January. Low wind speed and low precipitation also contribute towards elevated level of air pollution. Whenever wind direction is from Indian Punjab towards Lahore Pakistan, high level of air pollution is observed in Lahore. Solid fuel combustion for heating purposes, including the burning of wood and crop residues, contributes to elevated levels of particulate matter. The pre-monsoon season, spanning from March to June, sees rising temperatures and increased dust levels. Dry and hot conditions enhance the dispersion of pollutants, leading to higher concentrations in the air. The AQI remained moderately polluted from March to June and during September as well.

As the monsoon season sets in from July to September, Lahore experiences relief from high temperatures, and precipitation helps clear pollutants from the atmosphere. The AQI remained satisfactory during July and August, and moderately polluted during September. The monsoon's cleansing effect generally improves air quality, although localized factors such as water stagnation and increased humidity can contribute to the growth of pollutants. Post-monsoon, in October, the city may continue to benefit from improved air quality due to the residual effects of rainfall. However, the burning of crop residues in surrounding agricultural areas remains a potential source of localized pollution. AQI remained unhealthy for sensitive people during February and October.

It is crucial to recognize that these seasonal patterns are subject to variations based on numerous factors. Ongoing efforts to monitor and mitigate air pollution are essential throughout the year to safeguard the health and well-being of the population. Real-time air quality monitoring data provides valuable insights into the current levels of air pollution in Lahore, aiding in the formulation of effective strategies for pollution control.

High-Risk Areas of Air Pollution in Lahore and the role of EPA in control of Air Pollution

1. Traffic Congestion:

There are more 6.8 million registered vehicles in Lahore (as per 2022 data). Old vehicles play a major role in air pollution. There are 2.4 million 10-year-

old vehicles, 0.76 million 20-year-old, and 0.41 million 30-year-old vehicles in Lahore. High-traffic areas with dense vehicular movement contribute significantly to air pollution. Exhaust emissions from vehicles release pollutants like particulate matter (PM), nitrogen oxides (NOx), and volatile organic compounds (VOCs). Figure-3 shows a list of challans and fines imposed from March to December 2023 by EPA in Lahore. It is very difficult to control vehicular air pollution from old vehicles due to economic constraints. It is a big challenge for a developing country like to ban old vehicles. EPA Punjab has suggested EURO-V quality fuel and engine quality for new vehicles. The formation of new vehicular standards accordingly is under deliberation.

2. Industrial Zones:

Areas with a concentration of industrial activities are prone to higher levels of air pollution. Industrial emissions release pollutants such as sulfur dioxide (SO2), carbon monoxide (CO), and heavy metals. The industry is all around Lahore in different forms. The most worst and polluting industry in the form of Steel furnaces, re-rolling mills, textile dyings, etc is in the northern borders of Lahore. EPA has launched its day and night squads to control air pollution from these industries. There is a list of fines, FIRs, and sealings in this area. Most of the industries have installed air pollution control systems in this area. Two major industrial cities Sheikhupura and Gujranwala are also located in the northern side of Lahore. There is also a cluster of industries around the Rohi Nala on the eastern side of Lahore. Quaid-i-Azam Industrial Estate is located in the southern part of Lahore. Sundar Industrial Estate is located in the outer southwestern side of Lahore. There are many power plants in the outer southwestern side of Lahore. Table-3 shows a list of fines, sealing, and inspections against polluting units from March 2023 to December 2023 in Lahore.

Adoption of updated industrial emission control standards for different industrial processes is a key challenge for EPA due to economic constraints for old-designed industrial units. Work has been going for the adoption of new industry-specific standards from EPA Punjab.

3. Burning of Agricultural Residue:

During specific seasons, the burning of crop residue in the surrounding agricultural areas can lead to increased air pollution. Crop burning releases pollutants like PM, carbon dioxide (CO2), and other harmful gases. EPA Punjab has banned crop residue burning, but still, adoption of alternate ways is difficult for farmers making it difficult for farmers to avoid crop

residue burning. Figure-2 shows the crop residue burning in India and Pakistan. It can be seen that fire anomalies are greater in Indian Punjab.

4. Residential Areas:

Areas with a high density of residential buildings, especially those using solid fuels for heating and cooking, may experience elevated indoor and outdoor air pollution. Nevertheless, the use of even natural gas contributes to air pollution.

5. Construction Sites:

Construction activities generate dust and particulate matter, contributing to localized air pollution. Uncontrolled construction dust can contain various pollutants harmful to respiratory health. EPA Punjab has strictly bound contractors to shower water on construction sites to avoid fugitive dust.

6. Metrological Effects

Different seasons may influence the levels and types of pollutants in the air. Here are some general considerations for the seasonal impact of air pollution:

Winter:

Increased Particulate Matter (PM) Levels: Cold temperatures can lead to the accumulation of pollutants near the ground, especially in areas with temperature inversions. This can result in elevated levels of PM, including PM2.5 and PM10.

High Combustion Activities: Increased use of heating systems, both residential and industrial, can contribute to higher levels of pollutants such as sulfur dioxide (SO2) and nitrogen oxides (NOx). The Punjab government has been experimenting with artificial rain during winter to avoid air pollution. Moreover water showering and on roads is started to avoid fugitive dust in Lahore.

Summer:

Ozone Formation: Warmer temperatures and increased sunlight can lead to the formation of ground-level ozone, especially in areas with high levels of precursor pollutants (NOx and VOCs).

Agricultural Activities: In agricultural regions, the summer season may coincide with activities such as crop burning, contributing to higher levels of pollutants in the air.

Spring and Fall:

Allergens and Pollen: During the spring, the release of pollen and other allergens can exacerbate respiratory issues for susceptible individuals. Fall may also see increased pollen levels.

Transition Periods: Changes in weather patterns during spring and fall can result in varying pollution levels, depending on factors like wind patterns and temperature fluctuations.

Monsoon/Heavy Rainfall:

Dispersion and Cleansing: In regions with a monsoon season, heavy rainfall can help disperse and cleanse pollutants from the air. However, it may also lead to localized flooding and the release of contaminants from runoff.

Health Risk Assessment of Air Pollution

Mortality, all natural causes (adults age 30+ years)

According to the latest statistics, the adult mortality rate is around 1830 (1454 females and 2207 males) per 100000 in Pakistan. (Statistica, 2021). Around 36% population of Lahore is 30 plus (PAS, 2020). The Air Q+ Model predicts that there is 50% role of PM2.5 air pollution in adult mortality in Lahore as shown in Figure-3.

Mortality due to COPD for adults (25+)

Pakistan, classified as a lower-middle-income nation confronts a substantial challenge in terms of chronic respiratory diseases, encompassing COPD and asthma. The age-standardized mortality rate attributed to chronic respiratory diseases is approximated at (89 per 100,000) 138.2 per 100,000 for males and 41.3 per 100,000 for females in Pakistan (Mendis, S. et al., 2014). The AirQ+ model pointed out 44.11 % role of PM2.5 in COPD mortality in Lahore as shown in Figure-4.

Mortality due to Stroke for adults (25-30)

Symptoms or indicators of focal (occasionally widespread) impairment of brain function manifest, and these symptoms may endure for more than one day or result in fatality with an apparently singular cause rooted in vascular issues (Kumar, 2016). According to the 2002 report from the World Health Organization, the overall mortality rate in Pakistan attributed to strokes was 78,512. By 2020, this figure is anticipated to double, primarily owing to the growing proportion of older individuals and prevailing smoking habits in developing countries like ours (WHO, 2018). Stroke related mortality is around 10-30% of all natural mortalities in Pakistan (Khealani, B et al.,

2008). Air Q+ model predicted around 50% role of PM2.5 in stroke mortality in adults in Lahore as shown in Figure-5.

Mortality due to ALRI for children age 0-5 years

There are 11.78% children under 5 in Pakistan (PBS, 2020). The mortality rate due to ALRI in children is 6.3/1000. Air Q+ model calculates that PM2.5 in Lahore has 36.35 %role in child mortality due to ALRI as shown in Figure-6.

Mortality due to IHD for adults (25-30)

There are 12.3% population of Pakistan in the age group of 25-30. IHD is 12.7% of total deaths in the world (Finegold, J et al., 2013). Air Q+ model calculates that there is 50.08% role of PM2.5 air pollution in IHD caused mortality in Lahore Pakistan as shown in Figure-7.

Mortality due to Respiratory (30+)

Around 36% population of Pakistan is over 30 (PBS, 2020). There is a 25% role of respiratory diseases in total adult mortalities in Pakistan (Sultana, T., et al., 2017). Air Q+ model finds out that there is a 58 % role Of PM2.5 in mortalities due to respiratory diseases as shown in Figure-8.

Conclusions:

The monthly trend of air pollution in Lahore, depicted in Figure-1, follows a distinctive seasonal pattern influenced by climatic conditions and human activities. Winter months experience heightened pollution due to temperature inversion and increased heating system use, resulting in an unhealthy Air Quality Index (AQI) during November to January. Low wind speed and precipitation exacerbate pollution levels. The pre-monsoon and monsoon seasons show moderate AQI, with relief in July and August as precipitation clears pollutants. Post-monsoon, residual effects contribute to improved air quality in October, but crop residue burning may still pose risks. The AQI remains unhealthy for sensitive groups in February and October.

High-risk areas contributing to Lahore's air pollution include traffic congestion, industrial zones, burning of agricultural residue, residential areas, and construction sites. Vehicular emissions, particularly from old vehicles, significantly contribute to pollution. Industrial activities release pollutants like SO2 and CO, with enforcement efforts by EPA against polluting units. Crop burning and solid fuel use in residential areas add to pollution. Construction activities generate dust, and meteorological effects vary pollution levels seasonally.

The Health Risk Assessment of Air Pollution in Lahore reveals significant implications for mortality across various age groups and health conditions. The adult mortality rate in Pakistan is reported at 1830 per 100,000, with the Air Q+ Model predicting a 50% contribution of PM2.5 air pollution to adult mortality in Lahore. For adults aged 25 and above, Chronic Obstructive Pulmonary Disease (COPD) presents a substantial challenge in Pakistan, with an age-standardized mortality rate of 138.2 per 100,000 for males and 41.3 per 100,000 for females. The AirQ+ model indicates a 44.11% role of PM2.5 in COPD mortality in Lahore. Stroke mortality, affecting adults aged 25-30, is on the rise in Pakistan, with a predicted doubling by 2020. The mortality rate attributed to strokes is around 10-30% of all natural mortalities in Pakistan. The Air Q+ model estimates a 50% role of PM2.5 in stroke mortality in adults in Lahore. In children aged 0-5 years, Acute Lower Respiratory Infection (ALRI) is a significant concern, with a mortality rate of 6.3 per 1000. The Air Q+ model calculates a 36.35% role of PM2.5 in child mortality due to ALRI in Lahore. For adults aged 25-30, Ischemic Heart Disease (IHD) is a prevalent cause of mortality, constituting 12.7% of total deaths globally. The Air Q+ model indicates a 50.08% role of PM2.5 air pollution in IHD-caused mortality in Lahore. Respiratory diseases contribute significantly to adult mortalities in Pakistan, with a 25% role. The Air Q+ model identifies a 58% role of PM2.5 in mortalities due to respiratory diseases in Lahore.

These findings underscore the critical need for air quality management strategies to mitigate the adverse health impacts of air pollution in Lahore. Effective measures targeting PM2.5 reduction can significantly contribute to reducing mortality across various age groups and health conditions.

Efforts to control pollution involve EPA fines, inspections, and proposed emission control standards for industries. Challenges include economic constraints for old industrial units and difficulty in banning old vehicles. Crop residue burning remains despite EPA bans due to challenges for farmers. Seasonal impacts on air pollution include increased PM levels in winter, ozone formation in summer, allergens in spring, and cleansing during monsoons. Continuous monitoring and mitigation efforts are crucial for addressing Lahore's air quality challenges throughout the year.

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Table-1: PM2.5 Analyzer for continuous Monitoring

Pollutant	Instrument	Range	Method	Detection Limit
$PM_{2.5}$	BAM Analyzer	0~5 mg m-3	Gravimetric Method/Beta attenuation Method	-



Table-2: The age structure of motor vehicles in Lahore

TOTAL MOTOR VEHICLE REGISTERED IN LAHORE				
CATEGORY	TOTAL	10-YEAR OLD	20-YEAR OLD	30-EAR OLD
AMBULANCE	3,116	826	140	45
BUS	58,173	39,247	19,886	9,903
CRANE	3,261	388	30	8
DOUBLE CABIN	7,302	2,618	1,136	59
MOTOR CAR	1,541,583	669,981	209,377	97,793
MOTOR CYCLE	4,752,508	1,485,618	422,187	239,390
PICKUP	74,217	32,823	21,207	15,454
RICKSHAW	222,938	96,589	29,464	12,316
TAXI CAB	27,674	15,979	15,049	3,468
TRACTOR	60,685	34,684	18,036	13,636
TRUCK	98,126	67,677	30,584	19,095
TOTAL	6,849,583	2,446,430	767,096	411,167

Table-3: Anti-Smog campaign in Lahore

INDUSTRIAL UNITS (Only Lahore)	
Units Visited	7055
Hearing Notice Issued	951
EPO Issued	40
Units Sealed	1081
FIR Lodged	513
Fine Imposed *(in Rs.)*	109,360,000
Fine Imposed (*In Rs. Millions)*	109.36
VEHICULAR CHALLANING (Only Lahore)	
Vehicles Checked	18041
Vehicles Challaned	7219
Impounded	817
Fine Imposed	8,272,300

Table-4: AirQ+ data presenting attributable proportion (AP) and relative risk (RR), including baseline incidence (BI)

Pollutant	Annual Average (µg/m3)	Mortality Type	Target Population (%)	BI per 100000	AP (%)	RR	Population at Risk
PM2.5	96	All (natural) cause (adults age 30+ years)	36 %	1830	50.36	1.08	5032440
PM2.5	96	COPD for adults (25+)	48%	89	44.11	2.4	6709920
PM2.5	96	Stroke for adults (25-30)	12.3%	136	50.08	1.79	1719417
PM2.5	96	ALRI for children age 0-5 years	11.78%	630	36.35	1.57	1646726
PM2.5	96	IHD for adults (25-30)	12.3%	86	50.08	2.27	1719417
PM2.5	96	Respiratory (30+)	36%	457	58	2.38	5032440

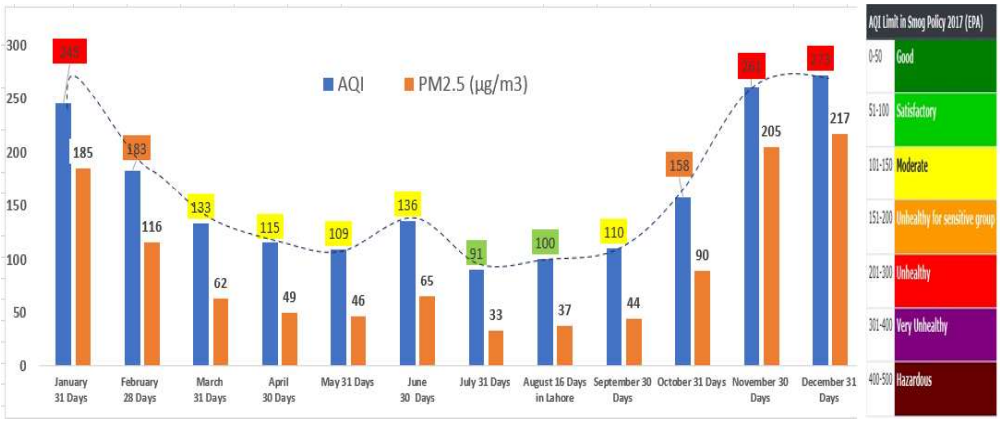


Figure-1: Monthly trend of PM2.5 in Lahore

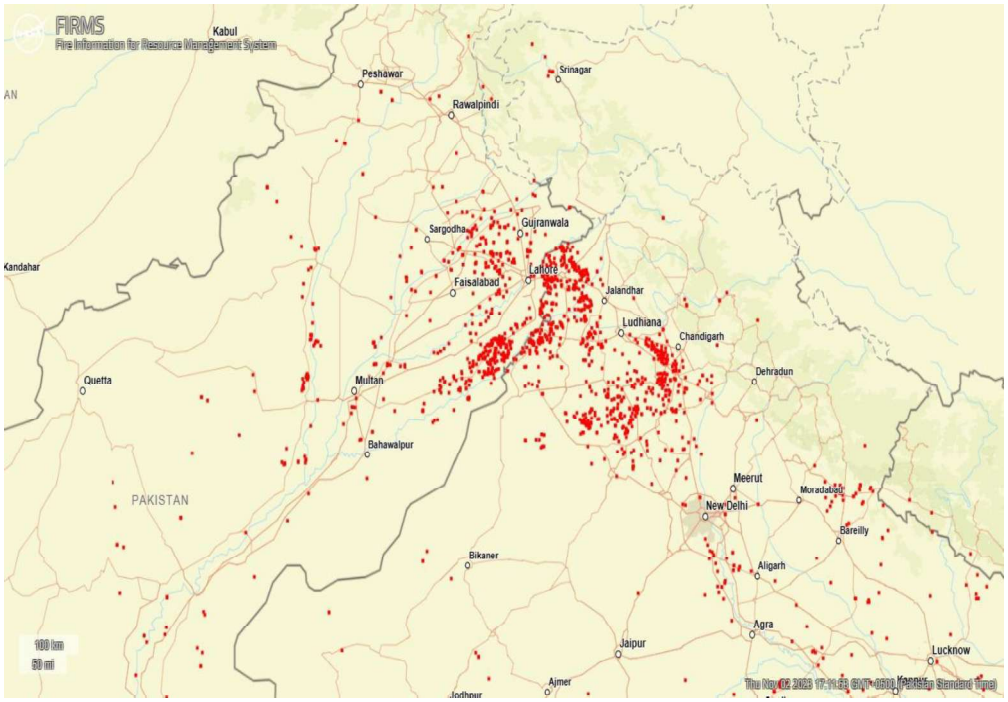


Figure-2: Fire anomalies in India and Pakistan on 25th October, 2023 (Taken from https://firms.modaps.eosdis.nasa.gov/map/)

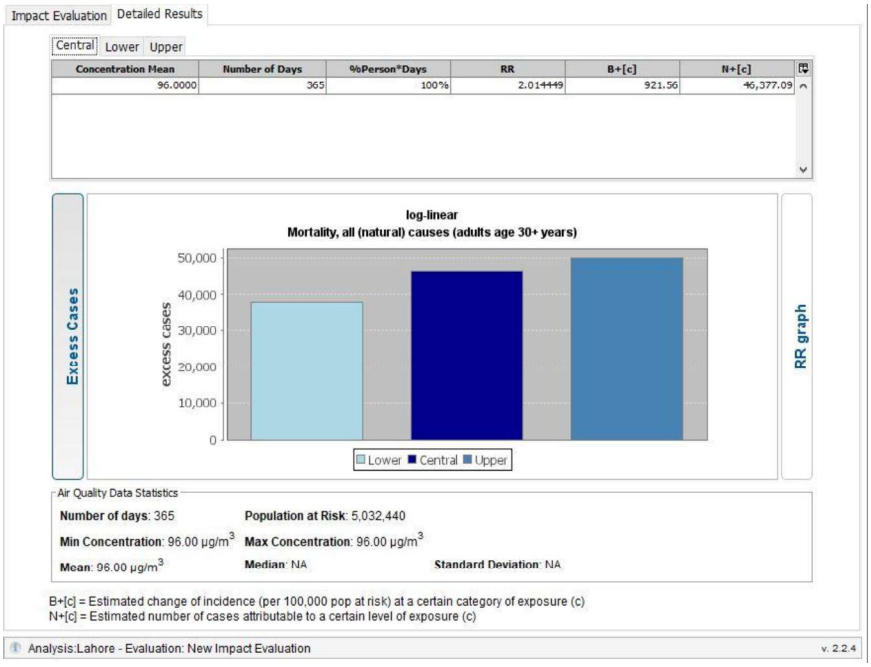


Figure-3: Estimated mortality due to all natural causes in adults 30 plus

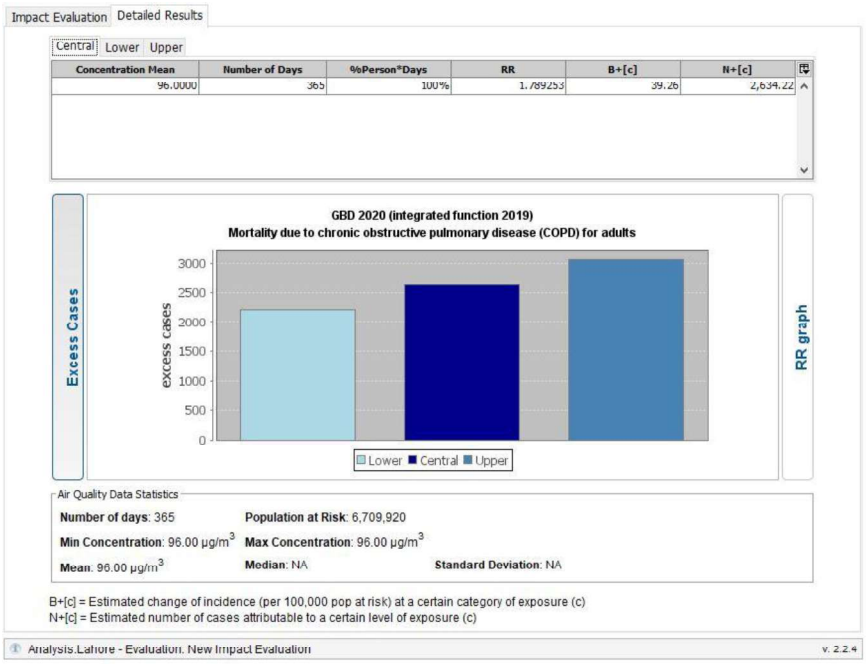


Figure-4: Mortality due to COPD for adults

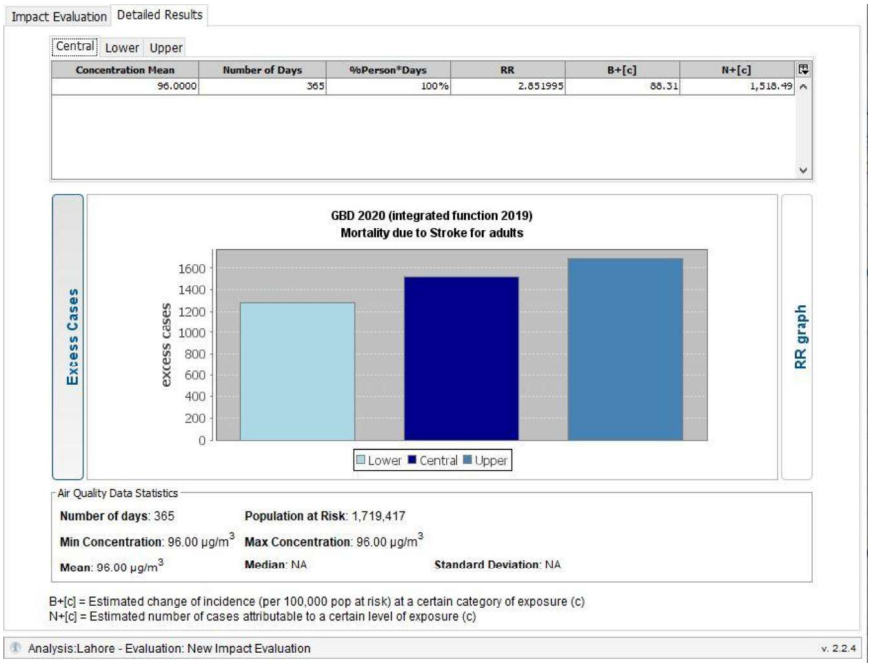


Figure-5: Mortality due to Stroke for adults

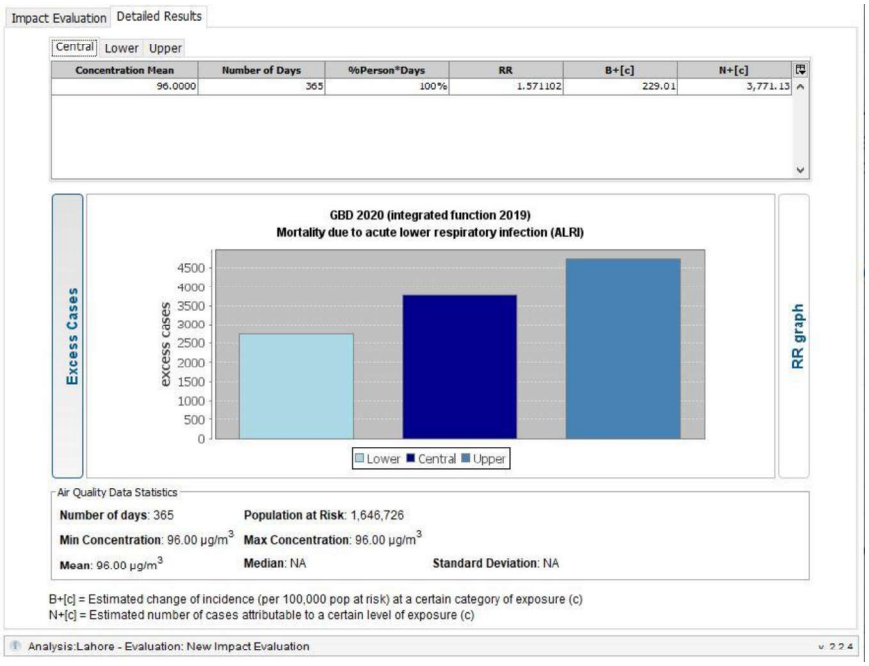


Figure-6: Mortality due to ALRI for children under 5

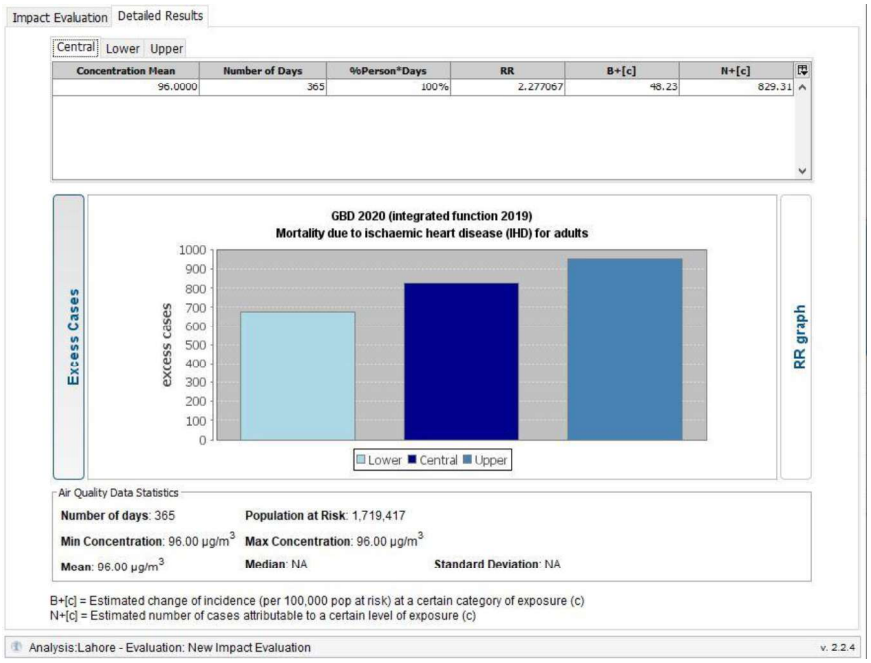


Figure-7: Mortality due to IHD for adults

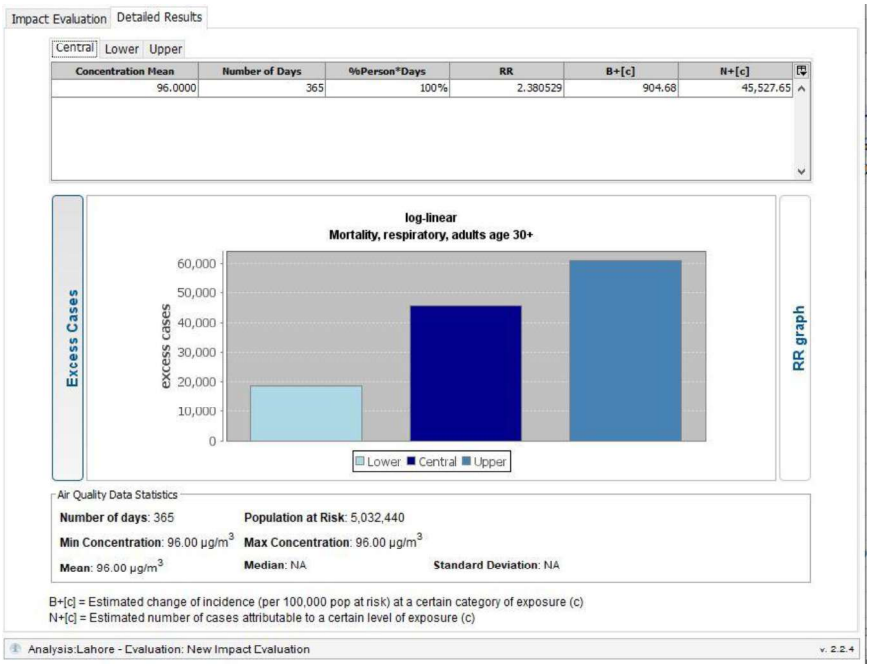


Figure-8: Mortality due to respiratory illness for adults 30 plus