Assessment of attributable proportion of particulate matter ($PM_{2.5}$ and PM_{10}) to different mortalities in Lahore city, Pakistan

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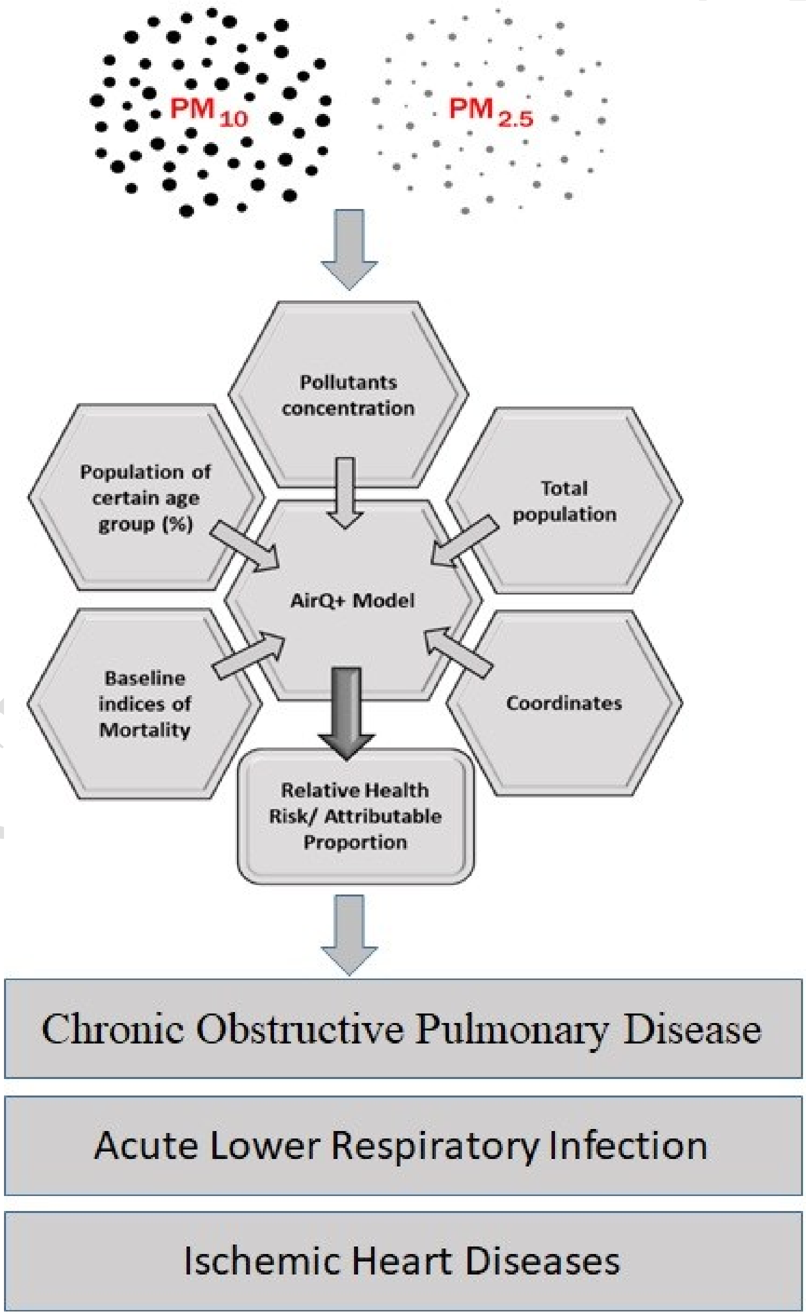
GRAPHICAL ABSTRACT



ABSTRACT

Urbanization causes a variety of environmental issues including air pollution. Particulate matter is one of the air pollutants that affects human health. Present study was conducted to evaluate the attributable proportion and relative risks caused by exposure of humans to particulate matter ($PM_{2.5}$ and PM_{10}). The health impacts of particulates among humans in terms of attributable proportion were modulated using AirQ+ software. Input data related to particulates' concentration, health and population were collected from the Environment Protection Department (EPD), Punjab Bureau of Statistics and Health Department of Punjab. Results showed that $PM_{2.5}$ with the annual average concentration of 55.9 ug/m^3 contributes 24.17% attributable-proportion (AP) to all-cause mortality in adults age 30+, and 31.41% AP to Chronic Obstructive Pulmonary Disease (COPD) in adults age 30+. Attributable proportion to stroke mortality in adults age 25+ was 33.4% (BI-150) and 34.09% (BI-630) was in children aged 0-5 years, contributing to acute lower respiratory infection (ALRI) mortality. Attributable proportion to ischemic heart diseases (IHD) in adults age 25+ was found 40.8%. It was also found that PM_{10} with an average concentration of 105 ug/m^3 contributes 31.11% AP to infant post-neonatal. There is need of proper mitigation measures for reduction of pollutants' concentration to decrease potential health impacts of air particulates.

Keywords: Air pollution, particulate matter, Chronic Obstructive Pulmonary Disease, relative risk, public health

1. Introduction

Urbanization has caused several issues including air pollution, soil pollution, land use change, pressure on infrastructure, solid waste generation, and human health problems (Gurjar *et al*. 2008, Liu *et al*. 2012, Ahmed *et al*. 2021a, Ahmed *et al*. 2021b, Shah *et al*. 2021). Exposure to air pollution has caused health issues worldwide. Developing countries have faced air pollution-related causalities due to higher levels of particulate pollution (WHO 2016). Particulate matter has been identified as a major issue due to its associated adverse health impacts. These issues are being faced regionally and globally due to anthropogenic activities. Attributable proportion of particulate matter to different mortalities were estimated in another district of Punjab by Nasir *et al*. (2022). Ambient particulate matter is attributed to the combustion of non-renewable fuels such as biomass. Automobiles in the megacity of Lahore are one of the major contributing factors for emissions of particulate matter in addition to contribution by industries present within the city and in the periphery (Hamid *et al*. 2019). Ambient air pollution in Lahore city becomes more significant from November to January, locally called "smog season". Contaminated air may cause respiratory and cardiovascular ailments which may even lead to death (Rovira *et al*. 2020; Aslam *et al*. 2022). Air pollution has a significant impact on the economy and health sector of a country (Anjum *et al*. 2021). According to WHO, 4.2 million deaths occur every year as a result of exposure to ambient (outdoor) air pollution (WHO 2022). Particulate matter is mixture made of small or mid-sized particles and liquid droplets. Source of particulate matter includes both natural and human activities. The particulate matters remain in air for long time periods and can affect human beings and plants (Aunan and Xiao 2004).

Different health issues including coronary, cardiovascular and pulmonary diseases have been reported in Lahore. These human health problems are linked to air pollution in urban areas of Lahore (Aziz and Bajwa 2007; Colbeck *et al.* 2010). Proportion of disease in the exposed population that can be attributed to the exposure is called Attributable Proportion (AP). It is expressed as percentage and sometimes called as Attributable Risk (AR). This proportion can be prevented by eliminating the risk factor (LaMorte 2018). Relative risk (RR) is the ratio of the probability of an event occurring with an exposure versus the probability of the event occurring without the exposure (Andrade 2015). Level of a particular disease that is usually present in a community is known as Baseline Incidence (BI). It is often considered as the diseases' expected level in community (CDC 2012).

There is a significant increase in pollution every year which impact human health seriously and the impacts of $PM_{2.5}$ are more significant as compared to PM_{10} (Samek 2016). If the concentration of $PM_{2.5}$ is higher than WHO limits, the relative risk becomes directly proportional as the concentration increases, resulting in financial losses (Hadei *et al*. 2017). An excess level of $PM_{2.5}$ causes reduced lung function and high risk of respiratory symptoms (Guaita *et al*. 2011). PM_{10} causes respiratory disease and ischemic heart disease admissions (Johnston *et al*. 2007). Samek (2016) found that long-term exposure to $PM_{2.5}$ was responsible for 458,000 premature deaths in 40 European countries. Long-term exposure to $PM_{2.5}$ resulted in 128 deaths per 100,000 population due to natural mortality during 2017-2018 in Iran. According to this study, 3797 people may have died because of IHD due to long term exposure to particulate matter while the valued number of attributable cases was 112.34 per hundred thousand population (Ansari and Ehrampoush 2019).

PM_{10} (course PM) deposits mostly in large conducting airways, while $PM_{2.5}$ (fine PM) deposits along the respiratory tract, mainly in alveoli and small airways. Because of the significant effects of PM, there are WHO guidelines (Dai et al., 2004). $PM_{2.5}$ is more harmful to health than any other particulate matter due to its small size and high penetration affecting the lungs directly. In Tehran from 2013 to 2016, long-term exposure to $PM_{2.5}$ caused 15,219 deaths and 474 deaths were attributed to COPD. Lung cancer caused 427 deaths during the study period of three years (Yarahmadi *et al*. 2018). Acute lower respiratory infections (ALRI) are also associated with $PM_{2.5}$ exposure and caused the deaths of 4.3 million children under 5 years of age. ALRI is also responsible for premature deaths, approximately 222 deaths per hundred thousand population per annum (JE 2020).

There are diverse models used for air eminence and health impact valuation. GEOS-Chem runs estimates of global yearly mean concentration of $PM_{2.5}$ and other contaminants (Lee *et al*. 2017). The objective of present study was to estimate the health impacts of ambient particulate matter in Lahore city. AirQ+ was used to estimate the relative risk of particulate matter to different mortalities in different age groups in the study area. No such research work has been done in the mega city of Lahore. The study is useful for policymakers and urban planners for environmental and health risk management in urban areas, particularly of developing countries such as Pakistan.

2. Materials and methods

2.1 Description of Study Area

The present study was conducted in Lahore city, which is one of the major cities of Pakistan with a population of 13,541,764 and the annual growth rate of 3.41% (World Population Review, 2022). The study area is shown below in the figure 1. The city is in the north-eastern Pakistan's Punjab territory. Lahore lies between 74°10′ and 74°39′ E longitude and 31°15′ and 31°43′ N latitude. It has an area of 1,772 km^2 (GoP 2000). Lahore is located on River Ravi bank and it is bounded by Sheikhupura district (North and West), Indian border (East) and Kasur district (South). Chemical, pharmaceutical, manufacturing and automobiles industries are located in Lahore. There is high vehicular and industrial load, causing different environmental issues including air pollution (Stone *et la*. 2010).

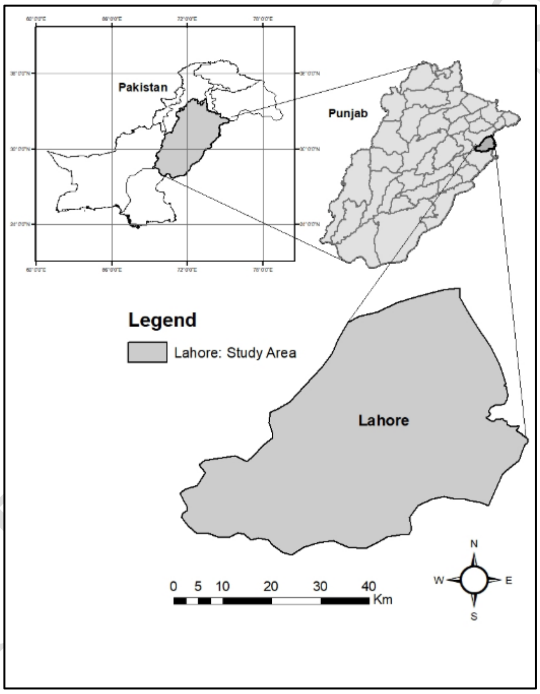


Figure 1. Map showing study area (Lahore-Pakistan)

2.2 AirQ+ Model and Input Data

AirQ+ software was used for the estimation the attributable proportion of $PM_{2.5}$ and PM_{10} to different mortalities which include chronic obstructive pulmonary disease, acute lower respiratory infection mortality, ischemic heart disease, post-neonatal, respiratory mortality, all-cause mortality and stroke mortality. Average annual concentrations of $PM_{2.5}$ and PM_{10} were used as input data in the software. Data was collected with the cooperation of Environmental Protection Department (EPD) and Pak Green Enviro-Engineering Laboratories. Equipment used in the study had model number DPM-6000, based on the US-EPA method, the beta attenuation method, having a detection limit of less than 1 μg/m^3 (Gobeli *et al*. 2008). Health and population data was collected from the Punjab Bureau of Statistics and Health Department.

Air quality data was correlated to epidemiological variables such as attributable proportion (AP), relative risk (RR), baseline incidence (BI), and proportion mortality per 100,000 people. The relative risk is the likelihood of sickness as a result of acquaintance to a contaminant. The RR and BI values were obtained from the WHO-developed AirQ+ statistics files (Rendón *et al*. 2015). Annual data of $PM_{2.5}$ and PM_{10} concentrations for the year 2019-20 were collected for impacts estimation. The wind speed and direction are not taken into account by the AirQ+ model. Figure 2 shows the inputs needed to analyze the health impact of the AirQ+ model (Mirzaei *et al*. 2021). Microsoft Excel was used to process the data, and the results were presented by looking at the central cure-lines of AirQ+ output graphs.

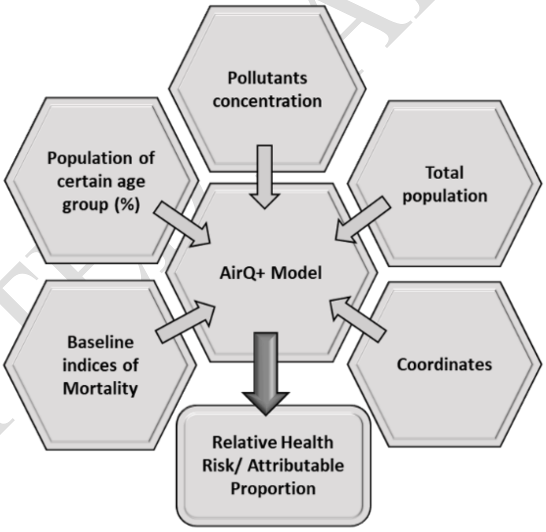


Figure 2. Input data required for the AirQ+ model (Mehmood *et al.* 2019)

All designs made by AirQ+ are based on epidemiological research' methodology and concentration response functions. The software's concentration-response functions are based on a rigorous examination of all known studies and their meta-analysis (Samek 2016).

3. Results and Discussion

PM_{10} and $PM_{2.5}$ concentrations were significantly higher than WHO recommendations for ambient air quality. Table 1 displays a comparison of pollutant concentrations with local and international regulations i.e., Punjab Environmental Quality Standards (PEQS) and WHO guidelines.

Table 1. Pollutant concentration comparison with standards

Pollutant	**Annual Average Conc. (µg/m^3)**	**WHO Standards (µg/m^3)**	**PEQS (µg/m^3)**
$PM_{2.5}$	55.99	10	15
PM_{10}	105.00	20	120

Present study showed diverse health effects caused by $PM_{2.5}$. Table 2 shows results obtained from AirQ+ software against the concentration of $PM_{2.5}$ and PM_{10} for attributable proportion to baseline incidence of different mortalities like "All causes mortality (adults age 30+ years), Chronic obstructive pulmonary disease mortality (adults age 30+ years), Stroke mortality (adults age 25+ years), acute lower respiratory infection mortality (children age 0-5 years), ischemic heart disease mortality (adults age 25+) and post-neonatal infant mortality".

Table 2. AirQ+ data showing Attributable Proportion and Relative Risk

Pollutant	**Annual Av. Conc. (µg/m^3)**	**Mortality**	***BI per 100,000**	**Attributable Proportion (%)**	**Relative Risk**
$PM_{2.5}$	55.99	All causes (adults age 30+ years)	270	24.17	1.310
$PM_{2.5}$	55.99	COPD mortality (adults age 30+ years)	89	31.41	1.458
$PM_{2.5}$	55.99	Stroke mortality (adults age 25+ years)	150	33.40	1.500
$PM_{2.5}$	55.99	ALRI mortality (children age 0-5 years)	630	34.09	1.510
$PM_{2.5}$	55.99	IHD mortality (adults age 25+)	95.25	40.80	1.680
PM_{10}	105.00	Post-neonatal infant mortality	4400	31.11	1.450

*Baseline Incidence derived from National and International Data (Majeed *et al*. 2019; Khealani *et al*. 2008; Finegold *et al*. 2013; Khan *et al*. 1990), and WHO Reports.

3.1 Attributable proportion of $PM_{2.5}$ in COPD mortality (adults age 30+)

Attributable proportion of $PM_{2.5}$ at the annual concentration of 55.9 µg/m^3, in COPD mortality, was 31.4% at the baseline incidence of 89/100,000 population in the study area, as shown in Fig. 3. The number of cases was quite higher than in the study conducted by De Marco *et al*. 2018, in which AP mortality was reported due to exposure to $PM_{2.5}$ in the years 2015 and 2016 in Rome, Italy. The results of present study are in line with the findings of De Marco *et al*. (2018). The impacts of ambient pollutants were higher in Lahore city because the $PM_{2.5}$ concentration was three times higher in Lahore than that of Rome city.

Concentration Mean	Number of days	%person *days	RR	B+[c]	N+[c]
55.99	365	100%	1.458029	12.95	1,120.25

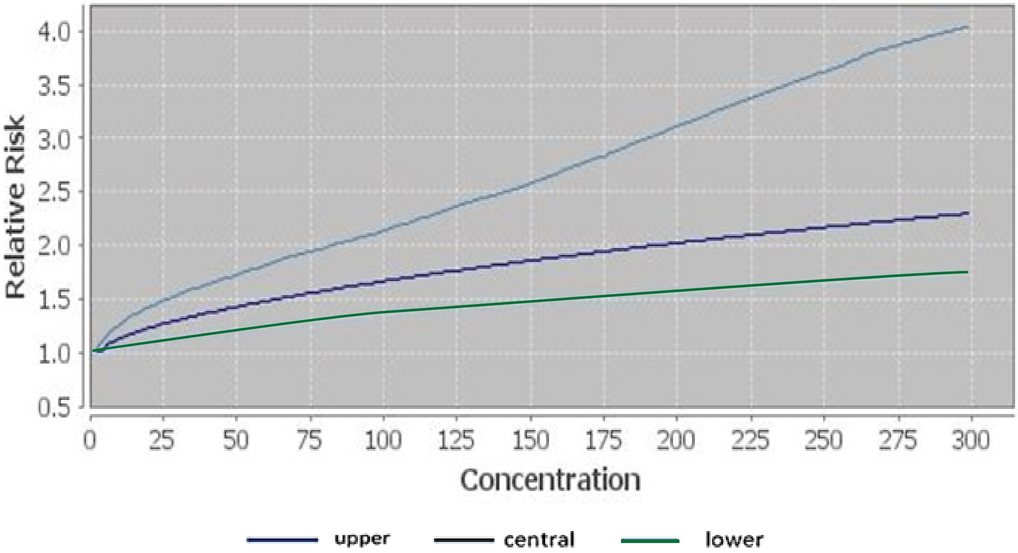


Figure 3. Relative Risk of $PM_{2.5}$ in COPD mortality (adults age 30+)

3.2 Attributable Proportion of $PM_{2.5}$ in Stroke Mortality (adults age 25+)

Figure 4 shows that AP is 33.4% and the relative risk is 1.50, when the average concentration of $PM_{2.5}$ was 55.9µg/m^3 in the ambient air of Lahore city and concentration of pollutant increased four to five-fold in the smog season due to due to climatic changes. High exposure to air pollution can result in adverse stroke mortality. Studies showed that the chemical nature of $PM_{2.5}$ is more significant as compared to the mass of particulate matter, responsible for mortality (Franklin *et al*. 2008). Present study found the attributable proportion of $PM_{2.5}$ in adults age 25+ for the stroke mortality having a baseline incidence of 150 deaths per one hundred thousand population. Results of present study are in agreement with Hadei *et al*. (2020), according to which the AP was 14.8% when the ambient concentration of $PM_{2.5}$ was 25 µg/m^3.

Concentration Mean	Number of days	%person *days	RR	B+[c]	N+[c]
55.99	365	100%	1.501821	50.12	2,677.68

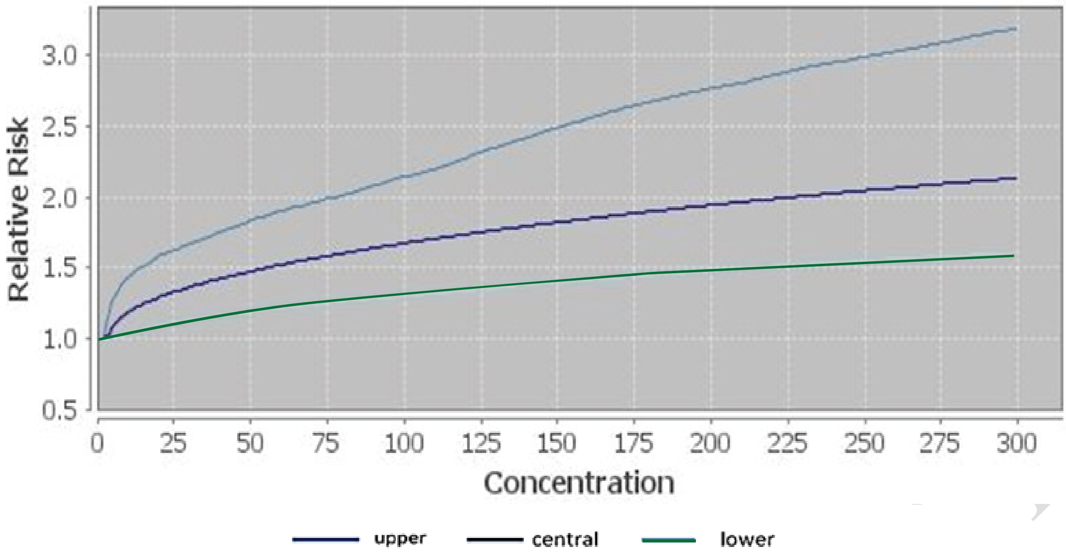


Figure 4. Relative Risk of $PM_{2.5}$ in stroke mortality (adults age 25+ years)

3.3 Attributable Proportion of $PM_{2.5}$ in All-cause mortality

Present research work showed that AP was 270% and relative risk was 1.31 at the ambient $PM_{2.5}$ concentration of 55.99 μg/m^3, as shown in figure-5. Impacts were estimated in adults with age 30+ years. This incidence rate is closer to a study conducted in Islamabad, Pakistan in which all-cause mortality due to $PM_{2.5}$ was estimated (Mehmood *et al*. 2019). A study conducted in Iran showed that exposure to PM2.5 caused 6710 deaths during 2017-18 and the relative risk was 1.062. Long-term exposure caused 128 deaths per 100,000 population. Results of this research work are in agreement with the study conducted by Ansari and Ehrampoush (2019). Research studies have been done to study all-cause mortality resulting from $PM_{2.5}$ due to its adverse health effects, which shows agreement with present study (Jiménez *et al*. 2009; Hart *et al*. 2015). Pope *et al.* (2002) showed mortality hazard due to fine particualtes ($PM_{2.5}$) exposure at 10 μg/m^3 elevation, with all-cause mortality at 1.06 and cardiovascular mortality 1.34 in the adult population.

Concentration Mean	Number of days	%person *days	RR	B+[c]	N+[c]
55.99	365	100%	1.318702	181.26	7,262.68

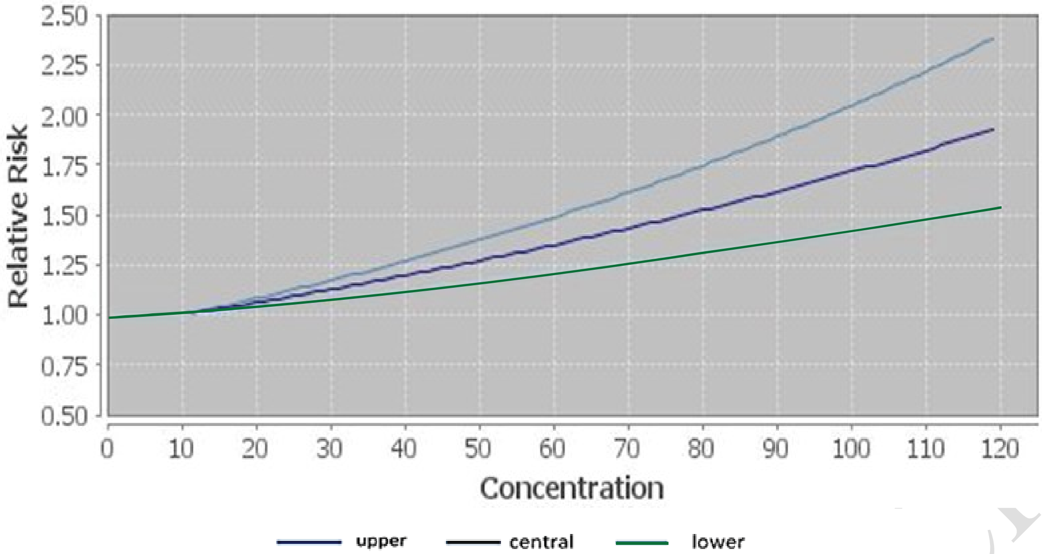


Figure 5. Relative Risk of $PM_{2.5}$ in All-cause mortality

3.4 Attributable Proportion of $PM_{2.5}$ in Ischemic Heart Disease

Ischemic heart disease (IHD) is most often attributed to $PM_{2.5}$ exposure. Present study analyzed the effect of $PM_{2.5}$ on adults aged 25+ years when the average concentration of $PM_{2.5}$ was 55.99 µg/m^3 and BI was 95.2 per 100,000 population. The results showed that the attributable proportion was 40.8% and the relative risk was 1.68 which is the highest AP of $PM_{2.5}$ to IHD mortality in present research study. A study conducted in Iran estimated the health effects due to $PM_{2.5}$ in 25 major cities and results indicated that long-term exposure caused more deaths as compared to short-term exposure (Hadei *et al*. 2020). $PM_{2.5}$ was calculated during the COVID pandemic, the average concentration of $PM_{2.5}$ was very less compared to the year 2021-2022 during smog season in Lahore city, the level was up to 500µg/m^3 which indicates severe IHD illness during that smog season may occur as short term impact (Rodríguez-Urrego and Rodríguez-Urrego 2020).

Concentration Mean	Number of days	%person *days	RR	B+[c]	N+[c]
55.99	365	100%	1.689297	38.76	2,070.91

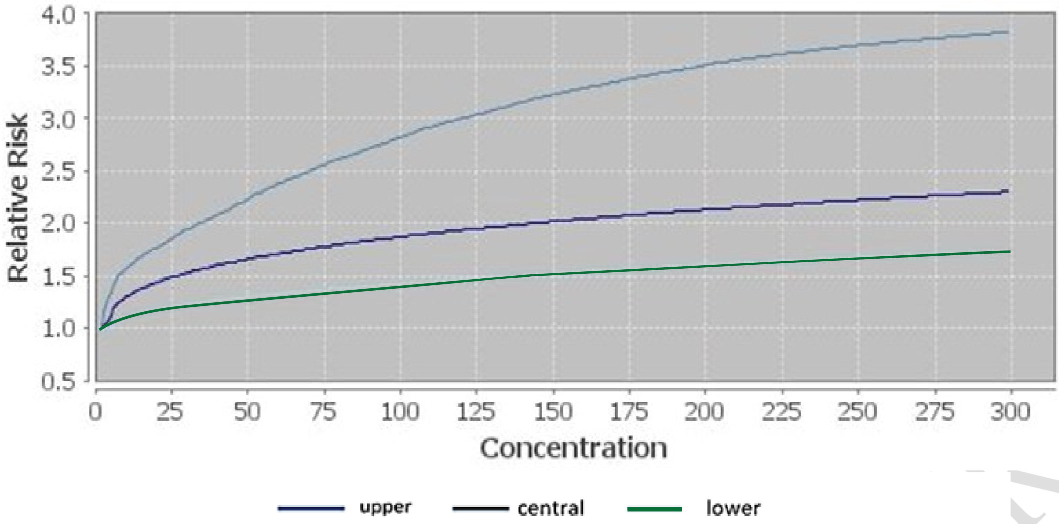


Figure 6. Relative Risk of $PM_{2.5}$ in Ischemic Heart Disease (adults age 25+ years)

3.5 Attributable Proportion of $PM_{2.5}$ in ALRI mortality

Attributable Proportion to ALRI mortality was also estimated in children under five years of age, at 59 µg/m^3 concentration of ambient $PM_{2.5}$. Modulated attributable proportion was 34.11% and baseline incidence was 630. Results indicated that ambient $PM_{2.5}$ is significantly affecting the children's health. Present research is in line with the study conducted in Delhi, India which reported an excess number of cases of 3471 due to long term exposure to $PM_{2.5}$ in children aged 0-5 years during 2013-2018 (Afghan & Patidar 2020).

Concentration Mean	Number of days	%person *days	RR	B+[c]	N+[c]
55.99	365	100%	1.517750	214.91	2,822.52

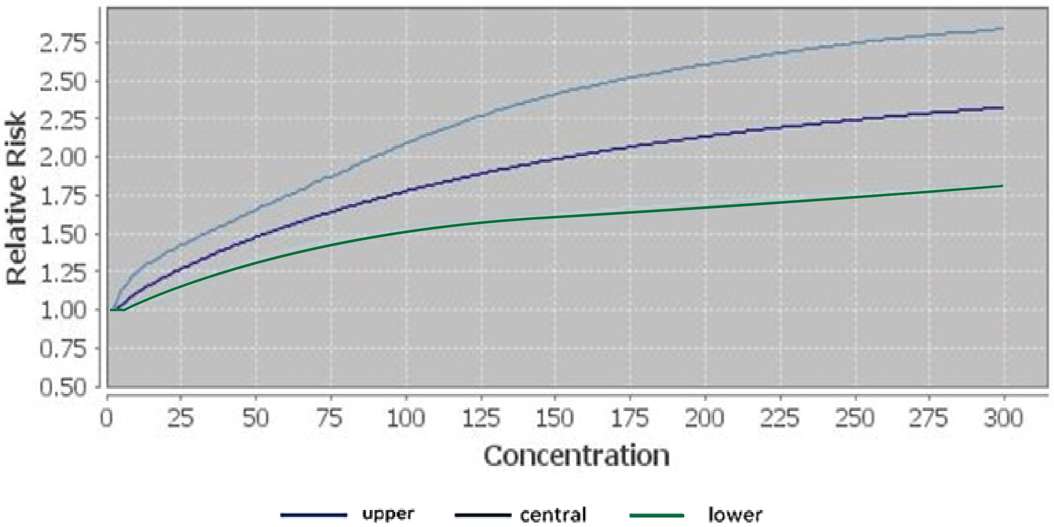


Figure 7. Relative Risk of $PM_{2.5}$ in ALRI mortality (0–5-year age)

3.6 Attributable Proportion of PM_{10} in Post Neonatal Mortality

Present study also evaluated the effect of PM_{10} exposure on neonates. Average annual concentration recorded during the study period was 105 µg/m^3 while the RR value was 1.45 and the attributable proportion (AP) was 31.11%. The baseline incidence rate of mortality is 4400 per 100,000 population. The central cure-line has been considered in figure 8 to estimate the relative risk/ attributable proportion to post neonatal mortality. A study conducted in Nigeria revealed that infant mortality has been a major public worry although the mortality rate had reduced from 90 deaths per thousand live births to 48 deaths in 2012. During the five-year duration, 6,285 deaths occurred in children under 5 years of age (Ezeh *et al*. 2015). Habeebullah (2014) showed that higher PM level than the standards caused negative health impacts in children and vulnerable people. Native plant species should be planted in green belt along roads to mitigate air pollution in the megacity, as recommended by Irshad *et al*. 2020 and Sen *et al*. 2017.

Concentration Mean	Number of days	%person *days	RR	B+[c]	N+[c]
105	365	100%	1.451499	1,524.18	0.47

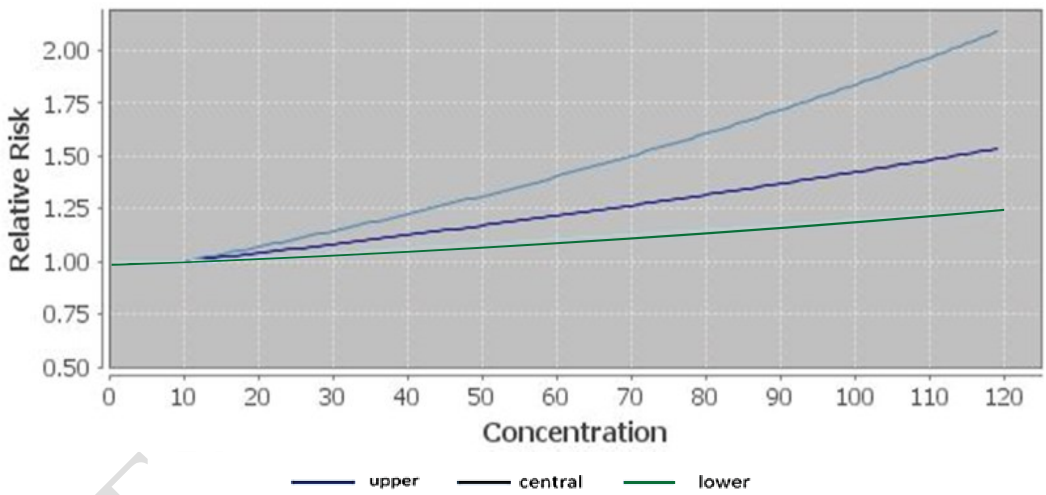


Figure 8. Relative Risk PM_{10} in Post Neonatal mortality

4. Conclusion

Higher concentration of air pollutants especially particulate matter adversely affects human health and significantly contributes to baseline incidence of different disease mortality. The purpose of the study was to evaluate the effects of air pollution on population in Lahore and it was found that concentrations of the pollutants $PM_{2.5}$ and PM_{10} under consideration were higher than the WHO and PEQS for ambient air quality. Particulate matter concentration is four times higher than WHO standards resulting in an increased mortality rate and the highest numbers of attributable cases were recorded due to $PM_{2.5}$. With the annual average concentration of 55.9 ug/m^3, attributable-proportions of 24.17% and 31.41% were found to all-cause mortality in adults (age 30+) and to Chronic Obstructive Pulmonary Disease (COPD) in adults age 30+, respectively. Similarly, attributable proportions of 33.4% and 34.09% were found to stroke mortality in adults (age 25+) and in children aged 0-5 years, contributing to acute lower respiratory infection (ALRI) mortality. Attributable proportion to ischemic heart diseases (IHD) in adults age 25+ was found 40.8%. It was also found that PM_{10} with an average concentration of 105 ug/m^3 contributes 31.11% AP to infant post-neonatal. Situation becomes more damaging during smog episodes in the city. There is need of concrete steps to mitigate the increasing concentration of pollutants by implementing pollution control measures. Policy regarding ambient air pollution should be implemented. Proper mitigation measures should be implemented for reduction of concentration of air pollutants to decrease their potential health impacts. Future work should be on identification and quantification of chemical species of the ambient air particles for a better understanding of their health effects.

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