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Original Research

Health Risk Assessment via AirQ+ Modelling in Faisalabad and Adaptive Management Framework

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Abstract

The study was conducted in a major industrial city in Pakistan (Faisalabad) with a population of 3.2 million. Air quality data was monitored for a whole year using United States Environmental Protection Agency certified instruments, while the World Health Organization (WHO) recommended AirQ+ model was used to assess the human health risks of air pollutants. The annual mean concentration of NO_2 (13.6 μg/m^3) was within the permissible limits of Punjab Environmental Quality Standards (PEQS) (40 μg/m^3), but the annual mean concentration of $PM_{2.5}$ was above both standard limits (106.1 μg/m^3). As per the model, contribution of PM_{10} and $PM_{2.5}$ to newborn mortality was 39.7% and 43.9%. Precisely, Acute Lower Respiratory Infections (ALRI) in children under 5 years of age group was significantly high due to $PM_{2.5}$ i.e., 44.6%. Overall, $PM_{2.5}$ was found to be significantly affecting the mortality rates, including causing a high number of deaths due to natural causes, ALRI in children under 5, Chronic Obstructive Pulmonary Disease (COPD) in those aged 30 or older, and stroke. Based on the findings of the study, it is strongly recommended that comprehensive measures and interventions be implemented to effectively reduce the elevated levels of $PM_{2.5}$ in Faisalabad to mitigate the adverse health effects, particularly the increased mortality rates and respiratory illnesses observed in vulnerable populations such as children under 5 and individuals aged 30 or older.

Keywords: AirQ+, air pollution, exposure, mortality, health risk assessment

Introduction

The degraded air quality is one of the leading causes of poor human and animal health worldwide [1, 2]. According to the World Health Organization (WHO), exposure to ambient air pollution is responsible for 4.2 million premature deaths worldwide every year [3]. This situation is getting worse in developing countries where industrialization, urbanization and population growth are increasing dramatically [4-6]. Air pollution contributes to millions of deaths each year and is associated with various health conditions such as heart disease, stroke, lower respiratory infections, lung cancer, diabetes, and chronic obstructive pulmonary

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disease (COPD) [1]. The Institute for Health Metrics and Evaluation (IHME) estimates that air pollution contributes to 11.65% of deaths worldwide. Almost all of the global population (99%) breathes air that exceeds the WHO guideline limits for pollutants, with low- and middle-income countries experiencing the highest exposures [7].

In recent times, comprehensive air pollutant characterization and source apportionment modelling has greatly enhanced our understanding to assess and evaluate pollution-related health effects [8]. This advancement has been crucial in addressing the question of "what sources contribute the most to the formation of air pollution" and developing effective policies to alleviate the health burden of poor air quality [9]. Air pollution continues to be a major concern for both the environment and human health. It is estimated that globally, 6.7 million premature deaths each year are attributable to fine particulate matter ($PM_{2.5}$) and ozone (O_3) exposure, with the majority occurring in regions that exceed the current World Health Organization air quality standards. Even, Group of Twenty (G20) countries, which include the world's largest economies, play a significant role in air pollution-related premature deaths. Ambient pollution exposure in G20 countries is responsible for over 3.0 million premature deaths annually. To tackle this issue, policy-makers have implemented regionally, nationally, and locally focused policies. However, understanding the sources that contribute most to air pollution formation has remained a challenge [9].

Source apportionment techniques have been instrumental in identifying the origins of air pollution in urban areas. By quantitatively assessing the different sources of air pollution, these techniques support the design of accurate air quality plans and the implementation of effective mitigation strategies. The European Air Quality Directive emphasizes the importance of source apportionment in assessing air pollution origins and recommends its application in estimating source contributions to particulate matter (PM). The Forum for Air quality Modelling (FAIRMODE), a joint initiative of the European Environment Agency (EEA) and the European Commission Joint Research Centre (JRC), has developed a European guide to provide an overview and recommendations for applying air quality models to estimate source contributions to PM and guide the selection of effective mitigation strategies and measures for air quality plans [10]. New tools are being developed while several extensive studies have been conducted around the globe [7]. This includes health risk assessment studies by using AirQ+ tool, developed by the WHO [11-15]. To this end, fine particulate matter ($PM_{2.5}$), coarse particulate matter (PM_{10}), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), and ozone (O_3) are recognized as key pollutants deteriorating human health [16]. Their specific toxicity mechanisms can cause respiratory disorders, cardiovascular diseases, immune system disturbance, and cancer of different body organs [17]. In general, an elevated level of PM_{10} is harmful to human health because it carries several toxic elements and compounds [18]. The exposure of PM_{10} in both short- and long-terms is linked with increased morbidity and mortality [19]. Exposure to high NO_2 and SO_2 concentrations in ambient air may aggravate asthma, chronic bronchitis, pulmonary and systemic inflammation, which could also amplify viral infections [20, 21].

The deteriorating ambient air quality of the major cities of Pakistan is raising serious health concerns among local societies. Faisalabad is one of those cities which has been severely affected due to industrialization and urbanization; it is also known as industrial hub in Pakistan with a population of more than 3.2 million [22, 23]. Several small- and large-scale industries are located in the city vicinity whose operation continuously deteriorate the city's air quality. In this study, total non-accidental, cardiovascular and respiratory mortalities were modelled against standard air quality parameters (e.g., PM_{10}, O_3, NO_2 and SO_2) between 2018 and 2019. For modelling, AirQ+ (v2.2.3) was used, which is developed by WHO to estimate human health outcomes linked to air pollution in a particular area within specific time interval [24-26]. Previously, the model was used to calculate health and ecological constraints in Islamabad, Pakistan [27]; nevertheless, extent of contamination in Faisalabad is at least 20-times higher which signifies the study's importance for an industrially polluted city.

Experimental

Study Area and Exposure Assessment

Faisalabad is an industrial hub in Pakistan, and also the third most populous city with 3.2 million inhabitants as per the 2017 census (Government of Pakistan, 2017). It is located north eastern side of the Punjab (31°25'4.8"N, 73°4'44.4"E) with a total area of 1,230 km^2 (Fig. 1) [28]. The energy requirements of the city are exceptionally high due to extensive urbanization and industrialization. Briefly, there are eight heavily trafficked intercity highways; while major industries include marble factories, flourmills, chemical and soap factories, textile units, engineering complexes, hosiery, carpet and rugs, nawar and lace, printing and publishing, pharmaceutical products, and food processing units [29]. Further, there are at least 12,000 household industries, which include nearly 60,000 power loom factories [30]. The intensive industrial operation has already ranked the city 3rd according to air quality pollution index scale globally.

The city climate is characterized as hot and dry (arid) with an annual mean rainfall of 350 mm, of which approximately 70% falls during the monsoon season (July-September) [22]. The climate is divided into four distinct seasons; hot and rainy summer

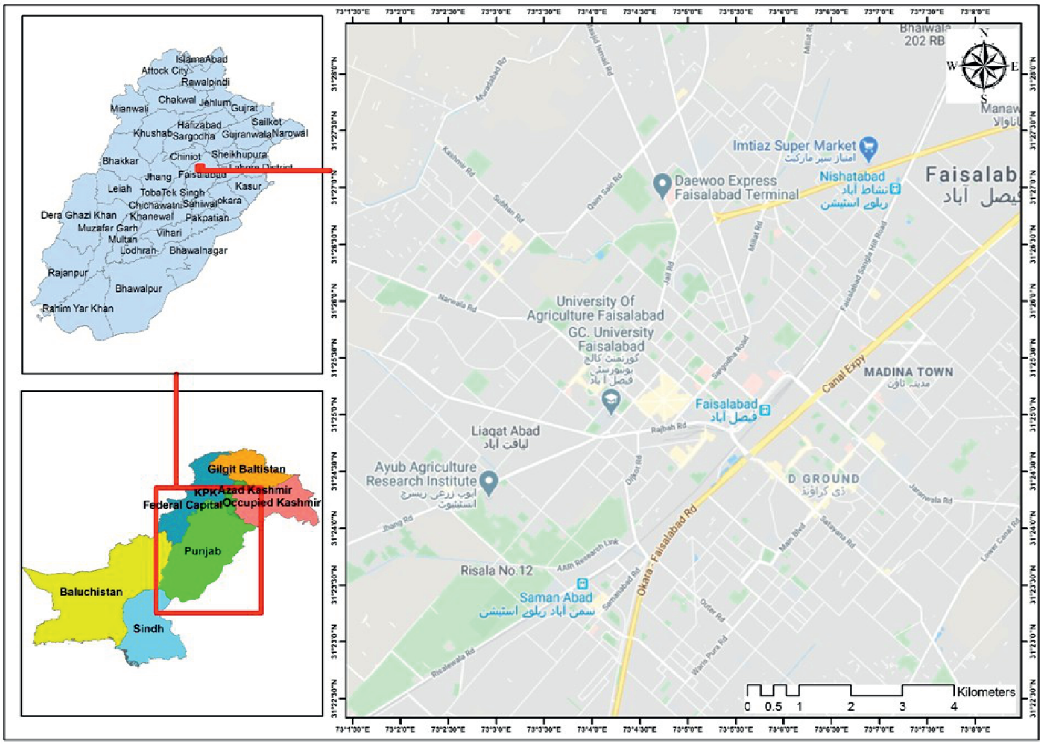

Fig. 1. Study Area.

(June-August) followed by autumn (September-November), cold and dry winter (December-February) and a mild spring (March- May). Mean maximum and minimum temperatures in summer ranges between 40ºC and 27ºC and during winter from 21ºC to 6ºC, respectively. The predominant wind directions are mostly from the southwest. The average humidity during winter and summer ranges from 67 to 85% and 57 to 78%, respectively. Average humidity during rainy season (monsoon) ranges from 60 to 88% [22].

The ambient air quality monitoring data of different criteria pollutants (i.e., PM_{10}, NO_2, SO_2 and O_3) was collected from fixed air quality monitoring stations on hourly basis for the period of 12 months. The data of population demographics (age groups: <5years, 15-30 years, and >60 years), and mortality data was collected from Bureau of Statistics and from the hospitals of the city. Detail of the instruments used during the ambient air quality monitoring in Faisalabad, Pakistan is given in Table 1.

Air Q+ Modelling

For health effects attributed to pollution by criteria pollutants, the AirQ+ 1.0 software package was used. WHO European Centre for Environment and Health (WHO/E 2016) recommended AirQ+ as a reliable tool for estimation of cardiovascular, respiratory and total non-accidental mortality caused by human exposure to air pollution. The model establishes relationship between baseline incidence rates (BI) and population exposure to specific pollutants based on concentration–response functions [31].

Table 1. Detail of air quality monitoring instruments.

S.NO	Pollutant Type	Instrument	Range	Method	Finding Limit
1	NO/NO_2 /NOx	Horiba (Model APNA-370)	0~1 (ppm)	Chemiluminescence (ISO7996)	0.5 ppb
2	O_3 (Ozone)	-(APOA-370)	0~1(ppm)	UV photometry	0.5 ppb
3	SO_2 (Sulfur dioxide)	-(APSA-370)	0~0.5 (ppm)	U.V. fluorescence (ISO10498)	1ppb
4	CO (Carbon monoxide)	-(APMA-370)	0~50 (ppm)	Non-dispersive infrared ray method (ISO4224)	0.1ppm
5	PM (2.5 & 10)	Particulate Matter sampler	0~5 (mg m^{-3})	Gravimetric/Beta attenuation	2 (µg m^{-3})

Results and Discussion

Mortalities Attributed to Criteria Pollutants

Infant mortality due to PM$_{10}$ in developing countries is a major public health concern. In Pakistan, population of new borns constitutes 2.8% of the total population whereas mortality rate is 4.9% [32]. In this study, we found that PM$_{10}$ was a significant factor contributing to 39.7% of the total newborn mortalities, i.e., 1946 of 4900 deaths. This is equivalent to an estimated 1743 attributable cases out of the population of 89,600 newborns. These observations are consistent with findings from other developing countries such as India, where a significant association between exposure to PM$_{10}$ and increased infant mortality rates were recorded [33]. Similarly, another study found that PM$_{10}$ exposure during pregnancy was associated with higher risk of infant mortality in South Korea [34]. A study conducted in Italy proposed that reducing PM$_{10}$ concentration to 20% could reduce short-term deaths by above 30%. Further details are provided in Fig. 2 and Table 2.

The role of PM$_{2.5}$ in the mortality due to all-natural causes was 43.9%. Specifically, mortality rate for Acute Lower Respiratory Infections (ALRI) in children under 5 was 6.7% (6,720 per 100,000), with PM$_{2.5}$ responsible for 44.6% of cases. The mortality rate for Chronic Obstructive Pulmonary Disease (COPD) in the 30+ age group was 0.09% (89 per 100,000), with PM$_{2.5}$ causing 40.8% of cases. The stroke mortality rate in the 25+ age group was 0.15% (150 per 100000), with PM$_{2.5}$ causing 41.0% of cases. Previously, American Heart Association's research found that an average increase in PM$_{2.5}$ exposure is responsible for a 10% increase in all-cause mortality [35]. In Europe too, a study found a clear link between exposure to PM$_{2.5}$ and mortality [36], and compliance with the WHO guidelines on air quality could increase life expectancy by 660 days at the age of 30 [37]. A study conducted in Iran found that exposure to ambient PM$_{2.5}$ contributes to different types of diseases in the human body, with deaths from ischemic heart disease accounting for most of the mortality attributable to long-term exposure to PM$_{2.5}$. Almost all the population was exposed to high level of PM$_{2.5}$ concentration which is above WHO guidelines.

Overall, annual mean level of PM in 34 countries was found highest in Pakistan (207 to 171 μg/m^3) in a study conducted by World Bank from 2009 to 2011. The annual mean PM$_{2.5}$ concentration of four capital cities (Quetta, Peshwar, Lahore, Islamabad) of Pakistan ranges from 63.3 μg/m^3 to 118.3 μg/m^3 which is well above WHO (10 μg/m^3) guidelines and National Environmental Quality Standards (NEQS) (25 μg/m^3). Many Indian cities are also among the most polluted cities in the world, with recorded PM$_{10}$ and PM$_{2.5}$ concentrations of 106.38 μg/m3 and 58.59 μg/m^3, respectively.

In Faisalabad, mortality due to NO$_2$ was computed to be 1.4% of total population i.e., attributable cases were 343.2 out of 3,203,846 population. The annual mean concentration was identified to be 13.6 μg/m^3, which is within the WHO and PEQS guidelines, i.e., 40 μg/m^3. A recent study conducted in European countries found an association between daily mean NO$_2$ concentrations and daily natural-cause mortality [38]. The studies across the globe shows that in many cities, population is exposed to high level of PM$_{2.5}$ concentration while NO$_2$ level are within the permissible limits of WHO guidelines in most of the parts of the world.

Evaluation of the Exposure and Projection of Related Mortality

The current level of 139.4 μg/m^3 of PM$_{10}$ is liable of infants' mortalities (n = 1750). With 10% reduction in PM$_{10}$, infant mortalities could be reduced to 1601 and

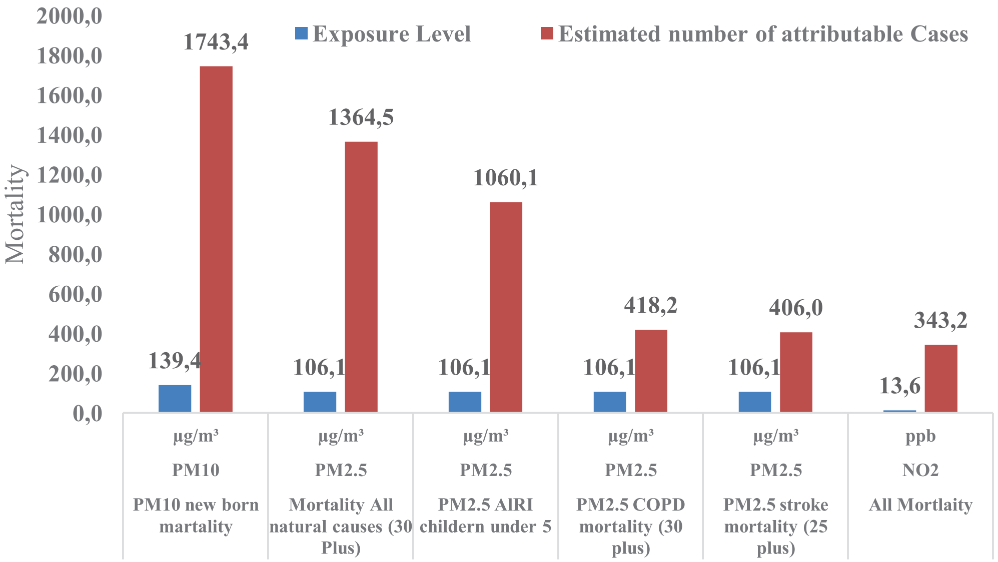

Fig. 2. Health risk assessment of PM$_{10}$, PM$_{2.5}$ and NO$_2$ in different age groups.

Table 2. Health risk assessment of different air pollutants.

Mortalities Attributed to these Parameters	Parameters	Exposure Level	WHO Guidelines (µg/m^3)	PEQS (µg/m^3)	Percentage role of pollutant in mortality			Population in the respective age group	Mortality per 100000 in the respective age group	Total Cases/ Total Population in the same age group due to disease	Total Cases per 100000 due to disease in same age group	Estimated number of attributable Cases per 100000 in the respective age group due to pollutant	Estimated number of attributable Cases in total Population in the respective age group due to pollutant
					BC 95% CI (%)	Lower (%)	Upper (%)						
PM_{10} new born mortality	PM_{10}	139.4	20	120	39.7	22.5	58.2	89600	4900	4390	4900	1945.8	1743.4
Mortality All-natural causes 30 Plus Long Term	$PM_{2.5}$	106.1	10	15	43.9	31.4	53.5	1152000	270	2304	270.0	118.4	1364.5
$PM_{2.5}$ ALRI children under 5	$PM_{2.5}$	106.1	10	15	44.6	35.0	53.2	376960	6720	2375	630.0	281.2	1060.1
$PM_{2.5}$ COPD 30 plus mortality	$PM_{2.5}$	106.1	10	15	40.8	27.2	54.4	1152000	270	1025	89.0	36.3	418.2
$PM_{2.5}$ stroke mortality 25 plus	$PM_{2.5}$	106.1	10	15	41.0	23.8	54.0	1536000	150	2304	150.0	61.0	944.0
All Mortality	NO_2	13.6	40	40	1.4	0.7	2.2	3203846	750	24029	750.0	10.7	343.2

50% reduction in PM_{10} may result in only 918 mortalities (Fig. 2a). Similarly, exposure level of 106.1 µg/m^3 of PM2.5 was computed to cause 406 mortalities for 25-29 age group. If $PM_{2.5}$ level reduces 10% and 50%, mortalities could be reduced to 386 and 275 respectively (Fig. 2b). For 25 plus age group, 454 mortalities caused by $PM_{2.5}$ at 106.1 µg/m3 level.

The number mortalities decrease to 329 and 297 with the reduction of $PM_{2.5}$ to 10% and 50% (Fig. 3c). As far as all-natural causes in 30 plus age group and ALRI under 5-year age group mortalities are concerned, it resulted in 1363 and 1060 mortalities at level of 106.1 µg/m^3, respectively ($PM_{2.5}$). However, mortalities would reduce to 1250 and 882 for 10% reduction as well as for 50% reduction, the mortalities would be 710 and 622 as projected in Fig. 3(d, e). At level of 13.6 µg/m^3 ($PM_{2.5}$), $PM_{2.5}$ is responsible of 345 mortalities due to all-natural causes. If its concentration reduces to 10% and 50% ($PM_{2.5}$) the mortalities could be 215 and 7 (Fig. 3f). Overall, the study confirmed that the current level of PM_{10} and $PM_{2.5}$ pollutants in the air have caused a significant number of infant mortalities, ALRI in under 5-years age group and stroke mortality in 25 plus age group.

Implications

Health risk assessment via AirQ+ modeling has significant implications in quantifying the health effects of air pollution exposure and evaluating the potential impacts of changes in air pollution levels. The AirQ+ software tool allows for the calculation of health risks associated with short-term and long-term exposures to air pollutants [3]. By utilizing risk estimates from

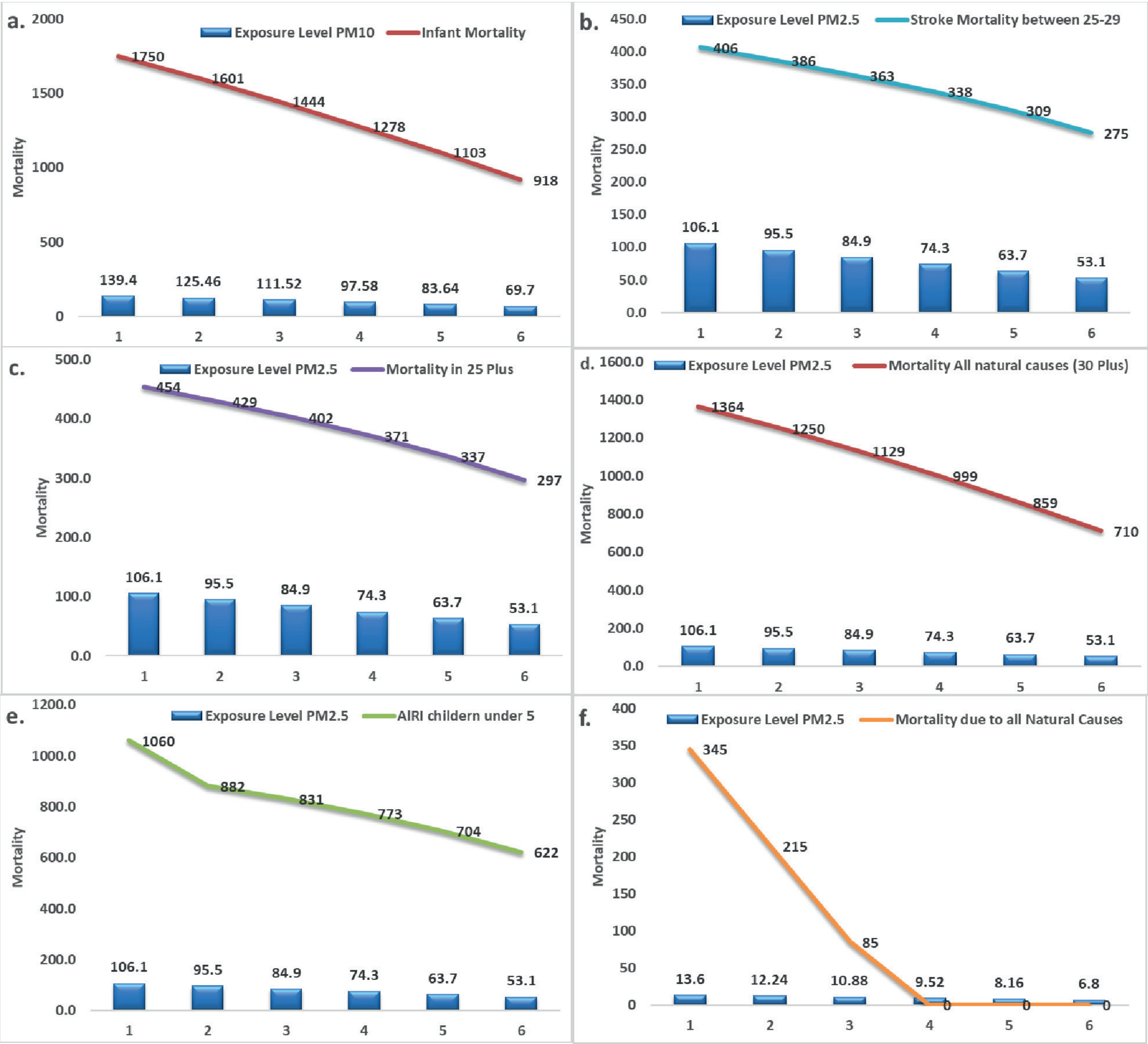

Fig. 3. a) Decline in health risk with a. infant mortality due to PM_{10}, b). stroke mortality between 25-29 due to $PM_{2.5}$, c) mortality in 25 plus due to $PM_{2.5}$, d). mortality all-natural causes in 30 plus due to $PM_{2.5}$, (e). ALRI children under 5 due to $PM_{2.5}$, (f). mortality (all natural causes) due to $PM_{2.5}$.

time-series and cohort studies, AirQ+ can estimate the effects of air pollution on various health outcomes, including mortality, respiratory diseases, and other health conditions [39]. The implications of Health risk assessment via AirQ+ modeling are as follows:

Quantification of Health Effects

AirQ+ allows for the quantification of health effects attributed to the air pollutants. It also provides estimates of the reduction in life expectancy and the attributable burden of disease, enabling policymakers and researchers to understand the magnitude of the health risks posed by air pollution [40].

Comparative Analysis

The modeling capabilities of AirQ+ enable comparisons between different scenarios of air pollution levels. It helps answer questions such as how much of a particular health effect is attributable to selected air pollutants and how health effects would change if air pollution levels were altered in the future. This comparative analysis is crucial for guiding policy decisions and interventions aimed at reducing air pollution and minimizing its health impacts [40].

Population-Specific Assessments

AirQ+ allows for the assessment of health risks in specific population groups, considering their vulnerability to air pollution. For example, it can estimate the impact on children's health, adults aged over 18 years, or other subpopulations by evaluating the risks associated with various health outcomes such as respiratory diseases, cardiovascular conditions, and mortality [39].

Informing Policy and Interventions

The results obtained through Health risk assessment via AirQ+ modeling provide valuable evidence for policymakers, health authorities, and environmental agencies. The information can guide the development and implementation of air pollution control measures, intervention strategies, and policy interventions to improve air quality and protect public health [39, 40].

Adaptive Management Framework

Based on the findings of this study, we suggest adaptive management framework for air pollution control in Pakistan as follows:

1. Establish a Comprehensive Policy Framework:
   - Develop and implement a comprehensive national air quality policy that addresses the specific challenges related to air pollution faced by local communities.
   - Set ambitious air quality targets in alignment with international standards and guidelines.
   - Create an institutional framework with clear responsibilities and coordination mechanisms involving federal and provincial environmental protection agencies (EPAs) to ensure effective policy implementation.
2. Strengthen Monitoring and Data Analysis:
   - Enhance air quality monitoring infrastructure across major urban centers and industrial areas.
   - Invest in advanced monitoring technologies, including remote sensing and satellite-based monitoring systems, to improve data accuracy and coverage.
   - Establish real-time data dissemination platforms to provide timely information to policymakers, researchers, and the public.
3. Identify and Prioritize Pollution Sources:
   - Conduct a comprehensive assessment of major pollution sources, including industrial emissions, vehicular pollution, and household emissions.
   - Prioritize pollution sources based on their contribution to air pollution and potential for control measures.
   - Use data-driven approaches, such as source apportionment studies, to identify the most significant emission sources and their geographical distribution.
4. Implement Effective Control Measures:
   - Develop and enforce stringent emission standards for industries, power plants, and vehicles.
   - Promote the adoption of cleaner technologies, such as the use of low-sulfur fuels, catalytic converters, and particulate matter filters.
   - Encourage the transition to renewable energy sources and promote energy efficiency measures to reduce emissions from the power sector.
   - Implement measures to control open burning, waste management practices, and indoor air pollution from biomass burning and solid fuel use.
5. Strengthen Regulatory and Enforcement Mechanisms:
   - Enhance the capacity of regulatory agencies to monitor and enforce compliance with air quality standards.
   - Establish penalties and incentives to encourage industries, transport operators, and individuals to adopt cleaner practices.
   - Improve inter-agency coordination and collaboration to ensure effective enforcement of air pollution control measures.
6. Promote Public Awareness and Participation:
   - Launch public awareness campaigns to educate the population about the health risks associated with air pollution and the importance of individual actions.
   - Engage local communities, NGOs, and civil society organizations in air pollution monitoring, reporting, and advocacy.
   - Foster public participation in decision-making processes related to air pollution control through public consultations and stakeholder engagement.

7. Foster Research and Innovation:

- Support research and development initiatives to explore innovative solutions for air pollution control, including new technologies, policies, and behavioral change approaches.
- Encourage collaborations between academic institutions, research organizations, and industry to address specific air pollution challenges in Pakistan.
- Establish a knowledge-sharing platform to disseminate research findings, best practices, and lessons learned to support evidence-based decision-making.

Conclusions

The study focuses on the impact of air pollution on human health in Faisalabad, Pakistan. The annual mean concentration of $PM_{2.5}$ in Faisalabad was found to be well beyond the permissible limits of WHO guidelines and PEQS. Mortality and morbidity data were collected, and the WHO recommended Air Q+ model was used to determine the human health risks of monitored air pollutants. The study found that PM2.5 is responsible for a significant percentage of mortalities due to all-natural causes, ALRI in children under 5 years of age, COPD, and stroke in 30 plus age groups. The health risk of NO_2 is negligible due to its low annual mean concentration (13.6 $\mu g/m^3$) as compared to WHO guidelines and and PEQS standards, i.e. 40 $\mu g/m^3$. The study estimates a possible decrease in mortality associated with different levels of pollutant reduction, highlighting the need for abatement strategies. Finally, the study concludes that reducing air pollution levels would lead to a decrease in mortalities, creating a foundation for raising awareness of the issue and developing abatement strategies.

Conflict of Interest

The authors declare no conflict of interest.

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