RESEARCH PAPER

ASSESSMENT OF AIR POLLUTION AND ITS ASSOCIATION WITH POPULATION HEALTH: GEO-STATISTICAL EVIDENCE FROM PAKISTAN

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ABSTRACT. Human health is harmed by air pollution. The objective of this research was to show that air pollution in Pakistan is getting worse and is negatively impacting people's health. IQ Air and the Institute for Health Metrics and Evaluation provided the data for this descriptive research. Monthly data of $PM_{2.5}$ μg/m^3 from ten different localities across Pakistan are used to show spatial distribution through the geospatial technique of interpolation. The findings show that two third of the country has high $PM_{2.5}$ concentration, with Lahore as the most polluted city. In Pakistan, solid fuel use has decreased, leading to a decline in associated mortality and morbidity. However, there have been significant increases in $PM_{2.5}$ and ozone levels, resulting in a rise in the country's overall health burden caused by air pollution. Furthermore, the number of deaths attributed to air pollution has also increased since 1990. A total of 57% of chronic obstructive pulmonary disease, 40% of lower respiratory infections, 36% of ischemic stroke, 35% of ischemic heart diseases, 32% of lung cancer, 25% of diabetes, and 20% of neonatal outcomes are directly attributed to air pollution in Pakistan. The main contributors to air pollution are population growth, growing motorization, and unsustainable energy usage. The main challenges due to air pollution control and monitoring in Pakistan include a lack of awareness, poor policy creation and implementation, the use of improper fuel, rising energy demands, and an absence of pollution monitoring stations in most cities. Therefore, there is a need for a robust air pollution monitoring system, increased public awareness, and the implementation of clean and sustainable policies to regulate this environmental health issue.

KEYWORDS: air pollution, health effects, interpolation, Pakistan, $PM_{2.5}$

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INTRODUCTION

An important environmental health problem around the world is air pollution, both outdoors and indoors. In developing countries, urban centers have poor air quality due to population growth, degradation of vegetation cover, broad industrialization and urbanization (Colbeck et al. 2010; Tabinda et al. 2020). With 207.9 million inhabitants Pakistan has the fifth-highest population in the world. Pakistan is bordered by the most populated countries of China and India as well. The average $PM_{2.5}$ concentration in Pakistan in 2022 was 14.2 times higher than the annual air quality guideline value recommended by the World Health Organization (WHO). In 2019, Pakistan recorded a $PM_{2.5}$ reading of 65.81 μg/m^3, placing it in the 'unhealthy' ratings category. This category typically includes readings between 55.5 to 150.4 μg/m^3. Similarly, neighboring countries like India and Afghanistan also exhibited high $PM_{2.5}$ concentrations, with readings of 68.78 μg/m^3 and 55.14 μg/m^3 respectively (IQAir 2023). Similar to Pakistan, where only 49.1 percent of the population consumes clean fuel such as natural gas for cooking, the remaining half of the population uses alternative fuels such as wood, dung, agricultural waste etc. that contribute to indoor air pollution (WHO 2018). The combined health effects of ambient and household air pollution are significant in Pakistan. According to the World Health Organization (WHO), ambient and household air pollution are responsible for around 113 deaths per 100,000 people in Pakistan (WHO 2021a).

Population growth, unmonitored industrialization, and rapid urbanization are the key driving forces for environmental problems such as noise and air pollution, drinking water scarcity, poor sanitation and waste management, especially in urban areas of Pakistan (Mir et al. 2016). Anjum et al. (2021) stated in their recent review that major air pollutants including NO_x, O_3 and SO_2 have been increasing in Pakistan for two decades. But

the country's air quality monitoring system hasn't kept up with the problem. There are numerous causes of air pollution in Pakistan, some are constant throughout the year, such as automobiles, factories, and brick kilns, while others are seasonal or occasional, such as stubble burning during winters and openly burning waste in the streets. In addition, poorly maintained construction sites and dust storms also add silt, dust and silica, which ultimately make the concentration of $PM_{2.5}$ and PM_{10} in the air. Large-scale loss of trees is also one of the main reasons for high pollution. On the other hand, exposure to smoke inside, from smoking or using solid fuels for cooking is the main contributor to household air pollution and may have negative effects on health. Despite the fact that there is research on the effects of air pollution on health in Pakistan, most of them are based on the case studies of big urban centres such as Karachi, Lahore, Peshawar, Quetta, Rawalpindi and Islamabad (Anjum et al. 2021).

Contamination caused by toxic gases, dust, fumes, smoke or any other substance in the atmosphere may vary in quantities and duration. It is injurious to human health referred to as air pollution. The human respiratory system is mainly exposed to air pollution, hence breathing in these pollutants causes inflammation, oxidative stress, immunosuppression, and mutagenicity in cells throughout our body impacting the lungs, heart, and brain among other organs and eventually leading to disease (Kampa and Castanas 2008; WHO 2021a). According to the World Health Organization (WHO), indoor and outdoor air pollution causes seven million premature deaths due to stroke, heart disease, chronic obstructive pulmonary disease, lung cancer and acute respiratory infections (WHO 2021a). Outdoor or ambient air pollution includes mainly particulate matter (PM_{10} and $PM_{2.5}$), Carbon Mono oxide CO, Nitrogen dioxide NO_2, and ground ozone O3. However, there are two categories of indoor air pollution: combustion sources (CO, PM_{10}, and $PM_{2.5}$) and non-combustion sources (Volatile organic compound VOCs, Lead, Radon, mould, bacterial growth etc.) (WHO 2021b). The major outdoor pollution sources include residential energy for cooking and heating, combustion of fossil fuel, vehicles, power generation, agriculture/waste burning, and industrial smoke and forest fires. Although air pollution affects developed and developing counties equally, low and middle-income countries show a maximum health burden. The reason includes widespread industrialization, unmonitored environmental planning, urbanization and high population growth, especially in urban areas (Mannucci and Franchini 2017). Nine out of ten people worldwide breathe air that exceeds WHO guideline limits, according to recent reports from the WHO.

Air pollution can have both immediate and long-term negative impacts on a person's health (Saldiva et al. 1994). This is especially true for the elderly, children, and those who already have cardiovascular and respiratory problems (Lee et al. 2014). These problems varied from slight upper respiratory irritation to chronic respiratory and heart disease, lung cancer, acute respiratory infections in children and chronic bronchitis in adults, provoking pre-existing heart and lung disease, or asthmatic attacks (Kampa and Castanas 2008). In a study, Fiordelisi et al. (2017) stated that PM_{10} with a diameter <10 μm reaches the lung and $PM_{2.5}$ with a diameter <2.5 μm penetrates deeper into the lung, and exposure to these pollutants increases the rate of cardiovascular deaths. Similarly, indoor air pollution is equally injurious to human health. The main indoor air pollution source is the use of biomass fuels such as coal, wood, animal dung, crop residues and their incomplete combustion. This incomplete combustion produces suspended particulate matter, carbon monoxide, formaldehyde, nitrogen dioxide, polycyclic aromatic hydrocarbons, etc. in the indoor air. There is several evidence that exposure to such pollutants can raise the risk of developing disorders including respiratory infections (e.g., pneumonia, tuberculosis and chronic obstructive pulmonary disease (COPD), lung cancer, and asthma), low birth weight, cataracts, and cardiovascular events (Kim et al. 2011).

There are several studies focusing health impacts of air pollution in Pakistan. Khwaja et al. (2012) proved that extremely elevated concentrations of $PM_{2.5}$ are associated with significantly raised rates of cardiovascular disease in Karachi. In another study based in Lahore, Sughis et al. (2012) found that 8–12-year-old children, who are exposed to (traffic-related) air pollution were associated with higher systolic and diastolic blood pressure. Similarly in a self-reported study students of Malakand Division Pakistan, reported that exposure to air pollution significantly affected their physical health, behaviour, and psychology (Ullah et al. 2021). Khan and Lohano (2018) analyzed that children in households using polluting fuels are 1.5 times more likely to have symptoms of acute respiratory infection (ARI) than children in households using cleaner fuels in Pakistan. Likewise, another study relates indoor air pollution to childhood pneumonia (Naz and Ghimire 2020). In addition, there are several reviews available explaining the health effects of air pollution on human health in Pakistan (Ilyas et al. 2010; Colbeck et al. 2010; Anjum et al. 2021). But almost all of these studies focus on the big cities, and none of them gives an updated and comprehensive insight into the overall health impacts of air pollution in Pakistan. Thus, this descriptive research article aims to present the geo-statistical evidence of air pollution through spatial distribution of $PM_{2.5}$ and cumulative health effects of different air pollutants since 1990 in Pakistan.

STUDY AREA

The Islamic Republic of Pakistan is a country situated in South Asia. Pakistan's total population is almost 220.9 million making it the fifth most populated country in the world (UNODC 2022). It is situated at 30.3753° N, and 69.3451° E covering an area of 881,913 square kilometers (Riaz et al. 2021). In terms of relative location, Pakistan is bounded by Afghanistan to the north and northeast, by China to the northeast and by India to the east and southeast. The Arabian Sea makes its southern border (Burki et al. 2021). Baluchistan, Khyber Pakhtunkhwa (KPK), Punjab and Sindh are the four main provinces of Pakistan. However, Azad Jammu, Kashmir (AJK) and Gilgit Baltistan are regarded as autonomous regions (Fig. 1). Geographically, Pakistan is a part of the Indo-Gangetic Plain, with mountains and plateaus making up three-fifths of its total land area and a level plain making up remaining two fifths. Pakistan's climate, which is predominantly dry and continental in origin, is marked by hot summers and chilly to frigid winters. Pakistan lies at the edge of the monsoonal system. Precipitation received varies greatly throughout the country (Burki et al. 2021). The degradation of all environmental components (air, water, and land) is frighteningly escalating and continues to be a serious concern in Pakistan due to growing industrial and agricultural operations, energy demands, urbanization, traffic density, and population expansion (Khwaja et al. 2012). These degraded environmental problems cause serious health issues in Pakistan (Khan et al. 2014).

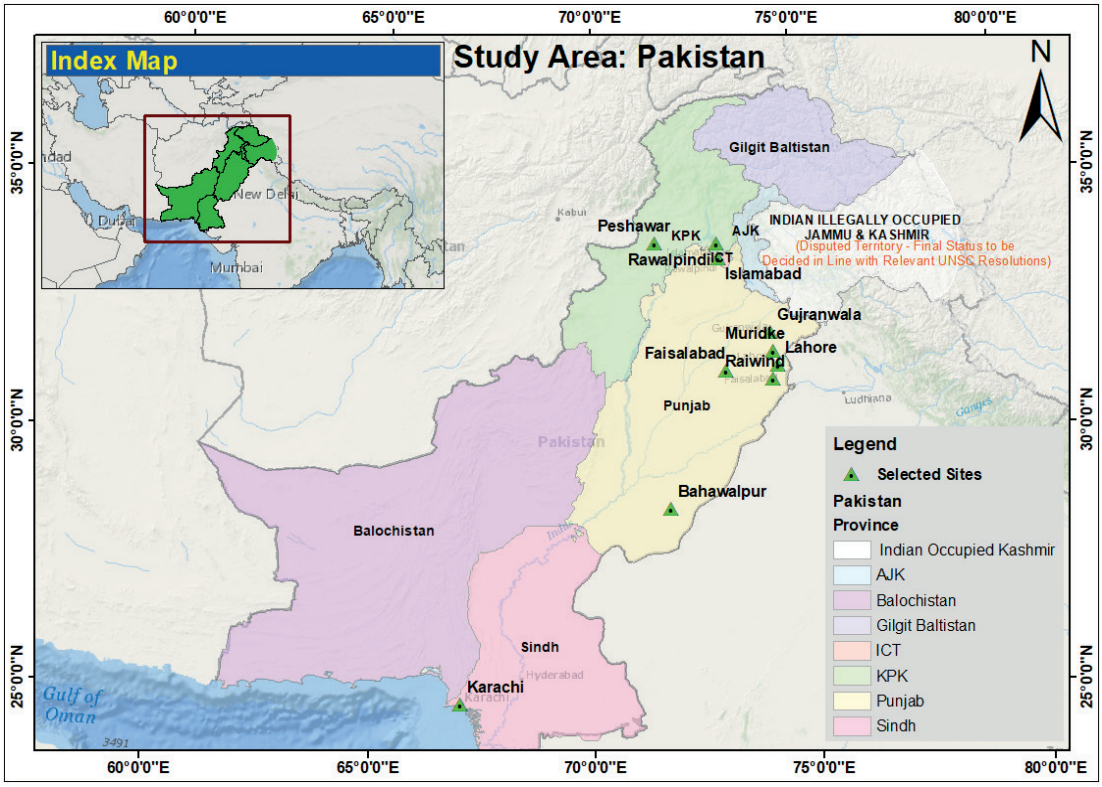

Fig. 1. Map of Pakistan showing the Provinces and Selected sites for IDW of $PM_{2.5}$

MATERIALS AND METHODS

For this study, air quality data about $PM_{2.5}$ µg/m^3 was taken from the online data resource of IQAir[1]. This data is available for each month of 2020 for ten different cities across Pakistan. On the other side, health impact statistics are taken from the Global Burden of Disease Study published in 2019 by the Institute for Health Metrics and Evaluation (IHME)[2]. Health data is presented in total deaths attributed to air pollution, disability-adjusted life-years (DALYs) attributed to each type of air pollution (ozone, solid fuel and $PM_{2.5}$), cause-specific mortality and morbidity, and age-standardize rates. DALYs can be defined as the sum of the years of life lost from early deaths plus the years lived with a disability, such as paralysis from a stroke related to air pollution exposure. However, the age-standardized rates are the total number of deaths or DALYs per 100,000 people, calculated based on a standard distribution of the population across age categories. Higher air pollution-attributable and age-standardized rates of disease reflect directly a combination of higher air pollution intensities and/or sicker populations (IHME 2021). The methodology of this study is shown in Fig. 2. As the study is based on secondary sources of data, hence no primary data has been collected for this descriptive research.

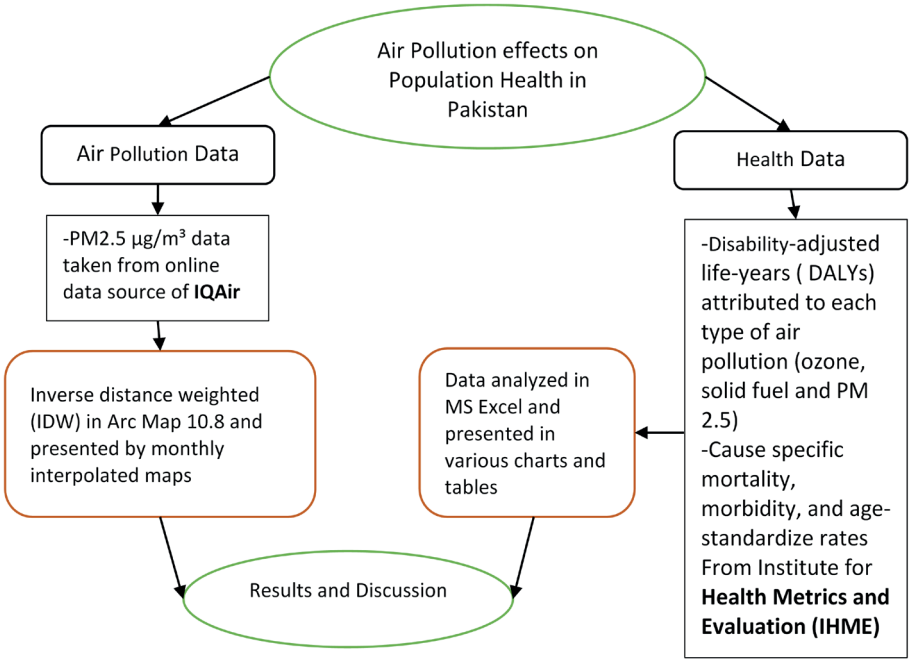

Fig. 2. Methodology Flowchart

[1]https://www.iqair.com
[2]http://www.healthdata.org

Chronic obstructive pulmonary disease (COPD) is the only disease for which the health burden of ozone is estimated. Neonatal deaths and DALYs are estimated only for $PM_{2.5}$, household air pollution, or the two combined (air pollution). Neonatal outcomes include complications from being born too small (low birth weight) or too early (pre-term) and lower respiratory infections. Facts and numbers about air pollution and health are also taken from the websites of the WHO, the Pakistan Environmental Protection Agency (EPA) and various published articles in addition to these two main sources (IHME 2021).

The main technique used to show the spatial distribution of $PM_{2.5}$ is interpolation. The distance between the observed sample sites and the site at which the prediction must be made is used to calculate the interpolation weights in inverse distance weighted (IDW) models (Wong et al. 2004). Hence, IDW from the Geo-statistical Interpolation Tool of Arc Map was used to predict the spatial distribution pattern of $PM_{2.5}$ concentrations across Pakistan. The weights are calculated through the following equation:

$$\hat{v} = \frac{\sum_{i=1}^{n} \frac{1}{d_i^p} v_i}{\sum_{i=1}^{n} \frac{1}{d_i^p}}$$

where $\hat{v}$ is the interpolated value at the target location
n is the number of sample points (known values) used in the interpolation
v_i is the value of the i^{th} sample
$1/d_i^p$ is the weight assigned to the i^{th} sample point, which is inversely proportional to its distance from the target location.

This technique is based on the idea that adjacent will share more characteristics than distant ones. It provides an air pollution probability distribution in Pakistan that is more precise. Hence, IDW uses point data of $PM_{2.5}$ in numeric values and resulted in a raster buffered image according to to strengthen the points and values across the country. For this reason, interpolated maps of air pollution are generated by using Arc Map 10.8 software developed by ESRI to analyze and evaluate geospatial, spatial-statistical and remotely sensed data. The trend of air pollutants and the deaths, DALYs, and age-standardized rates attributed to air pollution are shown with the help of charts and graphs. Microsoft Excel is used to chart the health effects of air pollution in Pakistan.

RESULTS

Spatial Interpolation of $PM_{2.5}$ µg/m³ over Pakistan

Fig. 3 shows the interpolated maps of $PM_{2.5}$ µg/m³ concentration from high values (red) to low values (blue) over Pakistan during 2020. This interpolation is based on a total of ten cities around the country including Lahore, Bahawalpur, Faisalabad, Gujranwala, Muridke, Raiwind, Karachi, Rawalpindi, Islamabad, and Peshawar (Fig. 1). The interpolation of each month shows the different distributions. During January, $PM_{2.5}$ values are higher around Peshawar, Faisalabad and Lahore and lower values spread out from Rawalpindi and Karachi. The map of February also depicts almost similar distribution to January but with high values (dark colour) distributed widely in the central parts of Pakistan.

March and April show red contours around Peshawar and Bahawalpur, with relatively low values at the rest of the sample sites. During May and June, southern Punjab, western KPK and most of the Baluchistan province show comparatively higher values than other parts of the country. July, August and September show high values toward the northwestern part of the country generally around Peshawar. October pinpoint red contours only around Peshawar and Lahore, and blue contours around Islamabad and nearly the whole south of the country. Interpolation maps of November and December show a high concentration of $PM_{2.5}$ in most of the parts, except the north and south of the country (Fig. 4).

Fig. 3 shows the average annual interpolation of $PM_{2.5}$ in Pakistan, which clearly shows higher values > 60 in almost

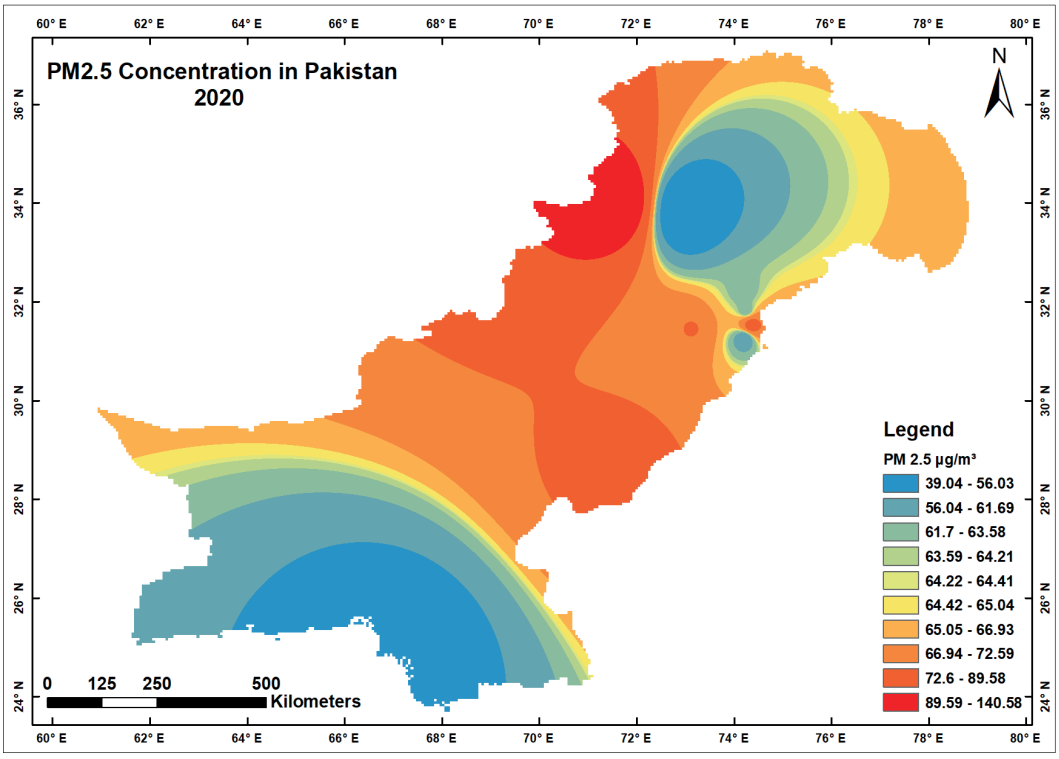

Fig. 3. Interpolated Map of Pakistan showing average PM2.5 concentration (2020)

two third areas of the country. Blue zones can only be seen in the extreme south and north of the country.

In comparison to these maps, the actual values of $PM_{2.5}$ concerning WHO air quality standards are shown in Table 1. According to these values, major cities like Peshawar, Lahore, Bahawalpur, Faisalabad, and Gujranwala showed high values of $PM_{2.5}$ µg/m^3 concentration making them unhealthy and sometimes very unhealthy according to the WHO air quality standards; however, Karachi, Rawalpindi and Islamabad show comparatively low concentration and moderate air quality. Besides this, a higher concentration of these pollutants is persistent between November to February.

Use of Solid Fuel in Pakistan

Fig. 5 compares the population-weighted ozone concentration, population-weighted $PM_{2.5}$µg/m^3, and people utilizing solid fuel since 1990. Analyzing the historic data from 1990 to 2019, it is revealed that the proportion of the population using solid fossil fuels decreased from 0.83 in 1990 to 0.53 in 2019. Though $PM_{2.5}$ reached its maximum of 70.9µg/m^3 in 2014 followed by a slight decrease, ozone remained persistently increased since 1990. However, collectively the population-weighted $PM_{2.5}$ µg/m^3 and ozone concentration showed an increasing trend.

Health Impacts of Air Pollution in Pakistan (1990-2019)

Deaths Attributed to Air Pollution

Fig. 6 shows the number of deaths attributed to each pollutant such as $PM_{2.5}$, ozone and solid fuel between 1990 and 2019. It can be observed that the total number of deaths attributed to $PM_{2.5}$ increased exponentially since 1990; however, deaths due to ground ozone remained constant at a low number with a slight increase. On the other hand, for thirty years, the total number of deaths due to fossil fuels decreased.

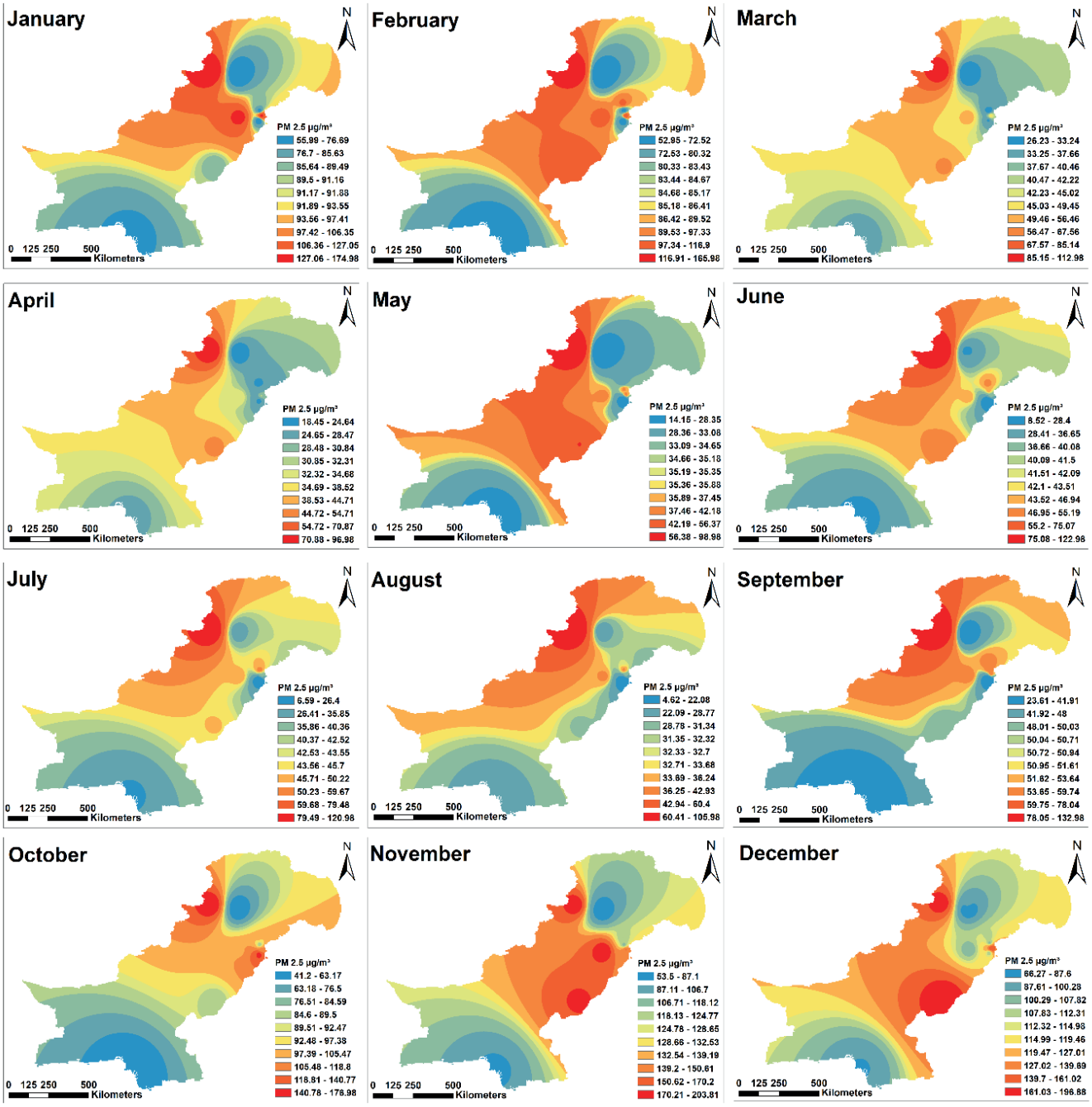

Fig. 4. Map Showing Monthly Spatial Distribution of Pm2.5 µg/m^3 in Pakistan for 2020

Table 1. $PM_{2.5}$ µg/m^3 Concentration in Major Cities of Pakistan during 2020 (Source: IQ Air 2020).

Cities	2020 mean	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Lahore	79.2	138	107.3	47	31.4	38.9	39.9	39.7	30.8	56	109.9	151.3	161
Bahawalpur	78.7	86.7	112.8	57.8	46.6	56.5	49.8	46	31	48.8	85.5	177.2	196.9
Faisalabad	73.2	146.3	108.2	54.7	34.6	39.2	45.7	50	38.3	56.7	103.9	203.9	101.5
Gujranwala	62.1	86.6	104.4	35.6	22.4	30.7	49.8	46.6	32.4	57	98.6	118	110
Muridke	61.6	70.4	63.7	27.8	27.7	38.4	45.5	55.5	37.4	57.7	84.8	114.8	105.1
Raiwind	56.6	62	60.8	32.3	23.1	18.5	7.9	5.9	4.1	23	152.7	145.3	107.6
Karachi	43.8	70.9	60	35.4	26.9	24.1	25.6	24.6	24.6	29.7	41.2	80.9	86
Rawalpindi	42.4	55.9	55.5	26.2	18.4	14.1	24	29.2	22.8	35	51.1	82.9	93.7
Islamabad	39	63.5	52.9	26.7	22.4	18.8	29.8	33.2	27.2	32	42.4	53.3	66.1
Peshawar	140.6	175	166	113	97	99	123	121	106	133	177	193	185

WHO target | Good | Moderate | Unhealthy sensitive | Unhealthy | Very unhealthy | Hazardous

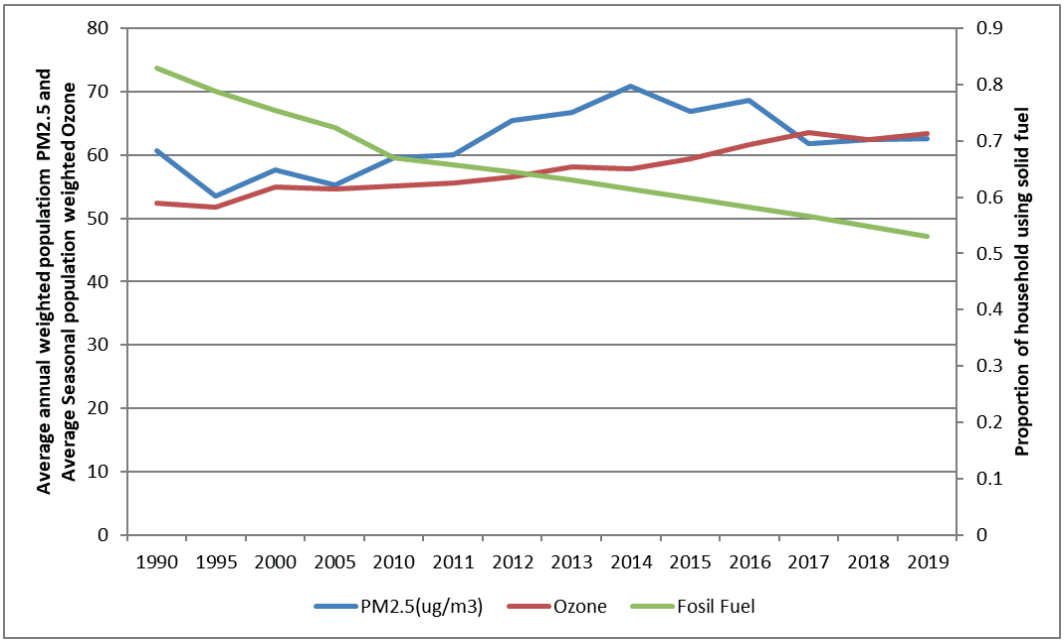

Fig. 5. The trend in the Proportion of the Population Using Solid Fuels, Average Annual Population-Weighted $PM_{2.5}$ (ug/m^3) and Average seasonal population-weighted Ozone in Pakistan (1990 to 2019)

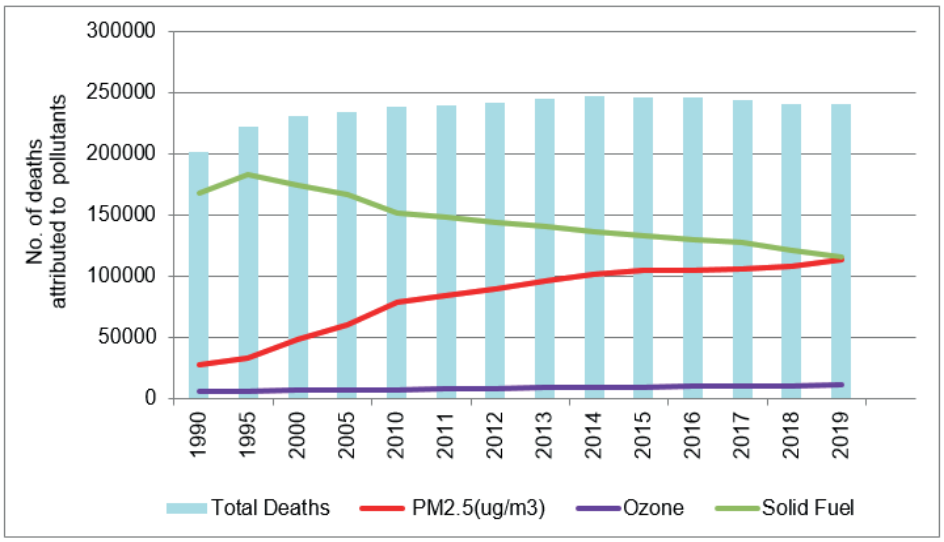

Fig. 6. The trend in the number of deaths attributed to major Pollutants in Pakistan (1990-2019)

Age Standardized DALYS attributed to Air Pollutants

Age-standardized DALYs/100,000 persons in Pakistan are shown in Fig. 7. The cumulative DALYs attributed to air pollution show a decreasing trend, but DALYs attributed to $PM_{2.5}$ increased since 1990. DALYs attributed to solid fuel decreased sharply, however, DALYs attributed to ozone remained constant as low as <500 DALYs/100,000 persons.

Cause-Specific Deaths

Fig. 8 shows the estimates of State of Global Air 2020, during 2019 in terms of case-specific deaths in Pakistan. COPD shows the highest burden with 57% of total deaths it causes during 2019. Similarly, among other respiratory diseases, lower respiratory infections (LRI) 40 % and Lung cancer 32% of total deaths can be attributed to air pollution. Besides this, ischemic heart disease and ischemic stroke constitute 36 and 35 per cent of their total deaths respectively. Almost 25% of diabetes deaths and 20% of neonatal outcomes deaths are also because of air pollution.

Cause-specific Burden of Diseases

Similar to mortality, morbidity due to air pollution can be measured by the cause-specific burden of diseases. Fig. 9 shows the cause of a specific burden of various diseases due to air pollution in Pakistan. Among these diseases, 53% of total COPD, 40% of LRI and 32% of lung cancer can be attributed to air pollution. Ischemic heart disease and ischemic stroke also show a high burden of 38 and 39 percent respectively. Diabetes and neonatal outcomes disease burden are < 25 per cent.

DISCUSSION

This research gives an overview of Pakistan's potential health outcomes related to air pollution. In 2019, Pakistan became the second most polluted country in the world. According to IDW, the majority of cities in Punjab and KPK have air quality levels that are about a year over the recommended limit which must not be more than 5 µg/m3 (WHO 2021c). Results also revealed that the northern and southern parts of the country show comparatively low concentrations of $PM_{2.5}$. In terms of seasonal variations, $PM_{2.5}$ concentration is more persistent between winters i.e., November to February. Time trends show that the proportion of the population using solid fuel decreased but the average annual weighted PM of 2.5 and average seasonal proportion weighted ozone kept on increasing since 1990. As a result, the mortality and morbidity attributed to solid fuel declined in comparison to $PM_{2.5}$ and ozone which increased massively causing the overall

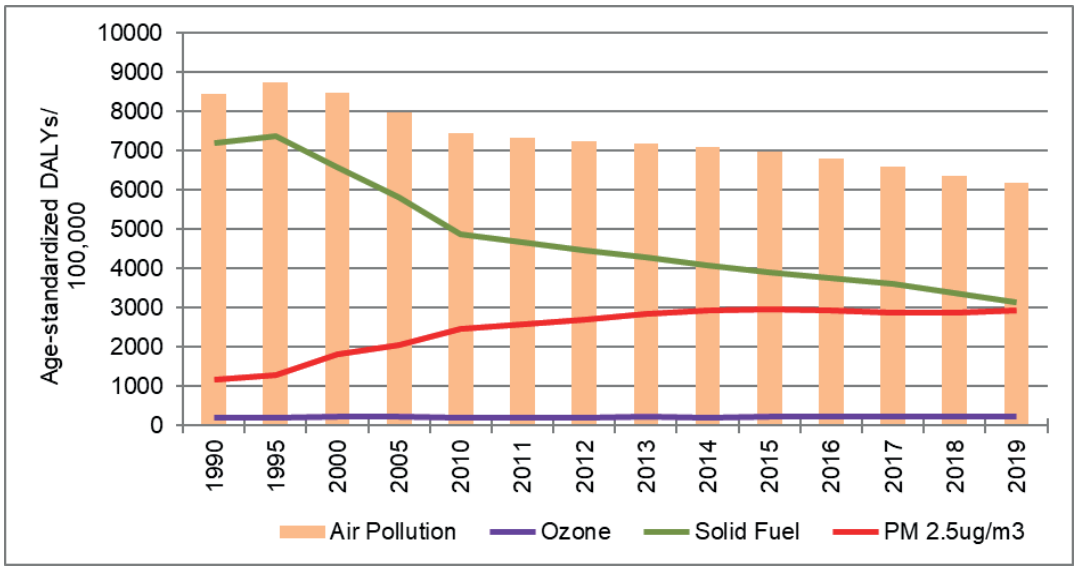

Fig. 7. The trend in Age-Standardized DALYs/100,000 attributed to major Pollutants in Pakistan (1990-2019)

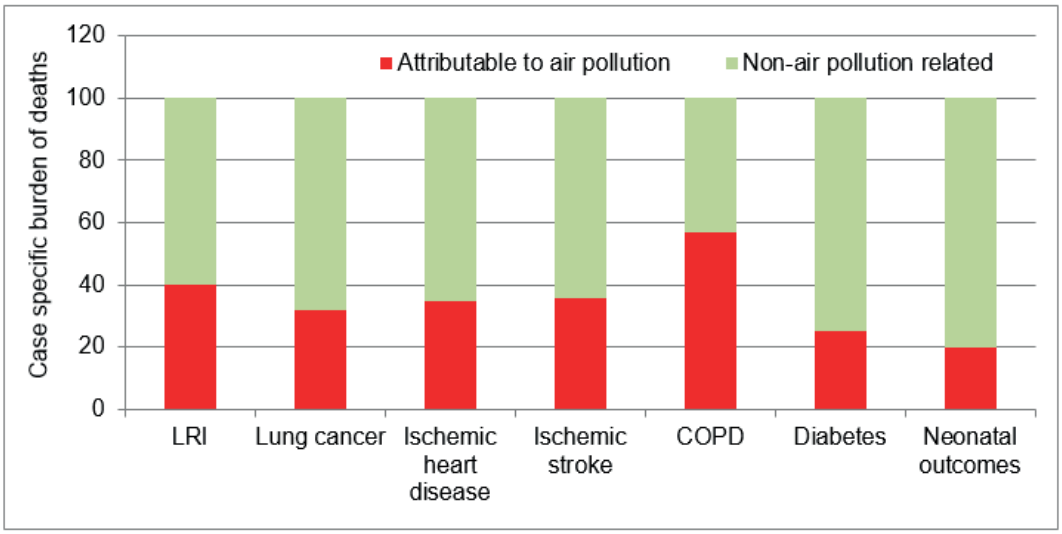

Fig. 8. Cause-specific Burden of Deaths in Pakistan (2019)

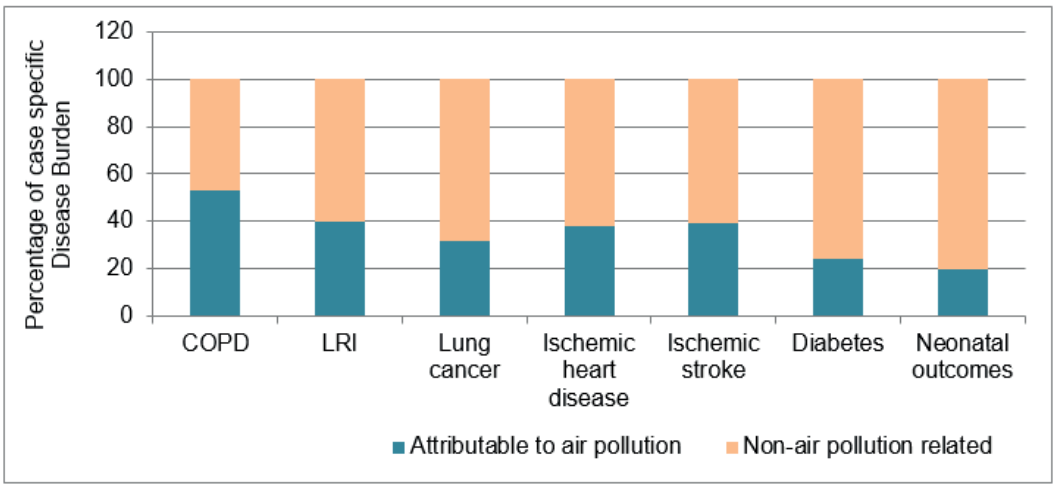

Fig. 9. Percentage of Case-Specific Burden of Diseases and Air Pollution

increase in health burden due to air pollution in Pakistan. COPD has the highest mortality and morbidity burden attributed to air pollution. LRI, lung cancer, ischemic heart diseases, ischemic stroke, diabetes and neonatal outcomes are also the main health problems relatable to air pollution in this country.

The ecosystem, biodiversity, human communities, animal habitations, forests, lands, and oceans are continually threatened by Pakistan's low adaptive capacity as a result of its high poverty rate, limited financial resources, lack of physical resources, and continual extreme climatic events such as varying temperatures, continuous flooding, melting glaciers, a saturation of lakes, earthquakes, hurricanes, storms, avalanches, droughts, scarcity of water, pest diseases, human healthcare issues, and seasonal and lifestyle changes (Hussain et al. 2019). The levels of $PM_{2.5}$ in all of Pakistan's major cities are above the legal limit. There are no facilities for continuous monitoring in the country. Lack of emission inventories, political will, and awareness are the greatest challenges (Anjum et al. 2021). Pakistan is the most urbanized country in the region, and it is undergoing fast motorization and increased energy demand, which is the cause of this terrible scenario. The main health effects of air pollution are associated, mainly, with increased premature mortality and learning disabilities (Sánchez-Triana et al. 2014). The uncontrolled urban population, increasing the number of vehicles, industries, and poor implementation of air quality standards have made the problem of air pollution even worst (Ali et al. 2017). Air pollution, particularly in large urban centres, harms the populations' health and quality of life, and contributes to environmental degradation (Sánchez-Triana et al. 2014). Pakistan's rapid growth in motor vehicle activity in cities has brought in its wake a range of serious socioeconomic, environmental, health, and welfare impacts (Ilyas 2007). The main challenges relating to air pollution control and monitoring in Pakistan include lack of awareness, failure of policy making and implementation, use of improper fuel, increasing energy demands and a smaller number of pollution monitoring stations. The establishment of a better monitoring system, developing of emission inventories and benchmarks, raising awareness and promoting sustainable policies and practices are all urgently needed to address these challenges (Anjum et al. 2021).

This research article has a few restrictions. Air pollution data of $PM_{2.5}$ is only available for the year 2020, which can represent results, that deviated from normal years due to the Covid-19 pandemic and the suspension of most of the transport and industrial activity in Pakistan. In addition, there was no data available on any site from the Baluchistan province. There is a lack of air pollution monitoring stations across Pakistan; hence no real-time data is used for this research. Despite these limitations, this research provides a spatial overview of air pollution across the country. Moreover, it provides evidence of the intense effects of air pollution causing different diseases in Pakistan. The research's findings can serve as a foundation for future studies that examine the relationship between numerous other social, economic, and environmental determinants of health as well as their regional differences across the country.

CONCLUSION

This descriptive research article is unique as it provides strong pieces of evidence of air pollution and its association with population health in terms of various disease burdens in Pakistan. The evidence relating to air pollution and its association with health outcomes has been presented in this research a clear picture of how bad the situation is in Pakistan. Air pollutants especially $PM_{2.5}$ and ozone are on the rise causing various health issues, particularly respiratory diseases. Thus, the current air pollution condition is not suitable for health in Pakistan, hence needed a strong monitoring system and implementation of clean and sustainable policies to regulate this environmental health issue. Government should initiate rapid action not only to minimise ambient air pollution but also to sensitize and aware public to adopt preventive measures. Furthermore, to support the nation's sustainable aims, this issue needs to be explored on a more scientific basis. This study also provides valuable facts and figures that provide the foundation for further scientific research linking each air pollutant with different diseases in Pakistan.

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