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Review

Impact of Air Pollution and Smog on Human Health in Pakistan: A Systematic Review †

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Abstract: Air pollution is a serious public health issue in Pakistan's metropolitan cities, including Lahore, Karachi, Faisalabad, Islamabad, and Rawalpindi. Pakistan's urban areas are vulnerable due to air pollution drivers such as industrial activities, vehicular emissions, burning processes, emissions from brick kilns, urbanization, and other human activities that have resulted in significant human health issues. The purpose of this study was to examine the impact of air pollutants and smog, as well as their causes and effects on human health. The PRISMA technique was used to assess the impact of environmental contaminants on human health. This study looked at air pollution sources and pollutants such as $PM_{2.5}$, PM_{10}, CO_2, CO, SO_x, and NO_x from waste combustion and agriculture. The population included people of all ages and sexes from both urban and rural areas of Pakistan. Data were retrieved and analyzed using SRDR+ software and Microsoft Excel spreadsheets. The data suggested that Karachi and Lahore had the highest levels of air pollution and disease prevalence, which were attributed to heavy industrial activity and traffic emissions. Smog was a serious concern in Lahore during winter, contributing to the spread of several diseases. Other cities, including Islamabad, Rawalpindi, Jhang, Sialkot, Faisalabad, and Kallar Kahar, were impacted by agricultural operations, industrial pollutants, brick kilns, and urbanization. Due to these drivers of air pollution, some diseases such as respiratory and cardiovascular diseases had notably higher incidences in these cities. Other diseases were connected with air pollution exposure, asthma, eye and throat problems, allergies, lung cancer, morbidities, and mortalities. To reduce air pollution's health effects, policies should focus on reducing emissions, supporting cleaner technologies, and increasing air quality monitoring.

Keywords: air pollution; smog; human health; cardiovascular diseases; respiratory disorders; morbidities and mortalities; air pollutants; Pakistan

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1. Introduction

A total of 92% of the Asia-Pacific population, or around 4 billion people, are exposed to levels of air pollution that pose a danger to health. Air pollution poses a significant health danger while also affecting economic growth, the environment, human health, and agricultural crop output. In 2015, 35% of all global fatalities caused by ambient (outdoor) air pollution occurred in East Asia and the Pacific; around 33% occurred in South Asia. The most harmful air pollutants are fine particulate matter (PM2.5), which includes black carbon, and tropospheric ozone. Air pollution is higher in urban and heavily industrialized regions with high population concentrations [1]. Air pollution is defined as a modification of the natural composition of the atmosphere by any chemical, physical, or biological factor in an indoor or outdoor environment [2].

Air pollution in Pakistan is predominantly caused by human activities. Air quality particularly refers to the concentrations of airborne pollutants such as carbon monoxide, nitrogen dioxide, ozone, particulate matter, and sulfur dioxide, all of which constitute serious hazards to human health [3]. The human activities that contaminate the air and pose risks to human health and the environment include burning fossil fuels, burning municipal waste, burning solid fuels, power generation, traffic emissions, industrial emissions, heating practices, and tobacco use [4]. These activities are causing environmental calamities with severe health consequences, including smog and air pollutants in smoke and fog. Heavy fog often contains dangerous industrial pollutants to generate smog, which has catastrophic effects on human health [5]. Smog is produced from the burning of fossil fuels, mostly made of carbon in the form of soot, tar, oil, and ash. There are different types of smog, each of which differs in composition, causes, effects, and geographical region. Pakistan suffers from photochemical smog, which results from complex photochemical processes involving NO2, NO, SO2, and volatile organic compounds, which act as precursors for ground-level ozone and fine particles [6]. Smog has substantial health consequences, including asthma, lung tissue damage, respiratory and tracheal infections, heart disease, and a variety of allergies [7].

Air pollution kills around 7 million people globally each year, with 4.2 million deaths caused by ambient air pollution, and the other ones caused by indoor smoke from unclean cooking stoves and fuels [8]. According to the World Health Organization (WHO), 90% of the people in countries with middle or low incomes experience high levels of pollution in the air, exceeding WHO guideline limits [9,10]. Some major air pollution drivers are vehicular emissions, urbanization, emissions from brick kilns, waste, and crop burning, which are having harmful effects not only on the environment by causing anthropogenic climate change but also on human health. According to a World Bank study result, transportation or vehicular emissions significantly contribute to air pollution and are one of Pakistan's most important dangers to public health. Vehicular emissions are primarily composed of CO, NOx, and Sox. CO is classified as a hazardous gas under the Clean Air Act (CAA) due to its harmful effects on the environment and human health. Exposure to these emissions can lead to health issues such as asthma, eye irritation, sleeplessness, coughing, and breathing difficulties [11]. Sulfur dioxide can cause acid rain and smog, while vehicle-produced nitrogen oxide can irritate the throat and eyes. Vehicular transportation accounts for up to 60% of all PAH emissions [12].

Punjab's overall population is around 73 million, with an annual growth rate of 2.64%. It is Pakistan's most densely inhabited province, with a population density of 358.5 persons per square kilometer. Additionally, around 31% of the population lives in urban areas, while the remaining live in rural regions [13]. Urbanization is increasing, leading to more industrial units and contributing to air pollution [14]. The quantum index of manufacturing (QIM) measures shifts in production levels over time. According to the Pakistan Bureau of Statistics, the QIM for large-scale manufacturing has a base year of 2005–2006

and a value of 100. By 2015–2016, this indicator had increased to around 131.9, representing a 31.9% growth in manufacturing production during that time. The values of 94% and 390% correspond to official QIM statistics, which indicate that these percentages were calculated using a different base year or technique. The shift from towns to industrialized cities is becoming a leading cause of air pollution. Large-scale manufacturing in Pakistan has increased from 94% to 390% between 2005–2006 and 2015–2016 [15]. A study in Karachi between 2020 and 2022 showed that the air pollutants released from industrial units were exceeding permissible levels, with PM2.5 levels exceeding 180 μg/m3, NO2 levels 12–50% above the 80 μg/m3 standard, and SO2 concentrations 30–50% over the 120 μg/m3 limit [16].

Brick kiln manufacturing is a growing industry in developing countries, particularly Pakistan, with 20,000 brick kilns currently in operation. These kilns release pollutants like SO2, CO, NOx, and PM. Traditional brick kilns (TBKs) use rubber as fuel and are the most harmful [17]. They contribute to 11% of total suspended particulate matter in Peshawar. Brick kiln workers experience health problems, including respiratory problems, eye irritation, musculoskeletal issues, back pain, coughing, and other health issues [18]. Additionally, 77.33% of the workers experience lung function impairment, with 5% showing obstructive impairment and 95% showing restrictive impairment [19]. The increasing population in Pakistan has led to a surge in food demand, expanding the agricultural sector. The agricultural sector in Pakistan accounts for more than 35% of the country's GDP, with over 70% of the people employed in this industry [20]. However, the increasing population has led to intensified farming practices and crop burning, releasing harmful pollutants like PM, CO, NO_x, and SO_2. A study conducted in 2022, revealed that 49% of Pakistani farmers burn crop residues, causing adverse effects like coughing, eye irritation, headache, nausea, skin irritation, and respiratory allergies as mentioned in figure 1[21]. Different types of air pollutants come from different sources including So_x, NO_x, CO_2, CO, O_3, PAHs, $PM_{2.5}$, and PM. These air pollutants enter the human body through various routes, including inhalation, ingestion, and transplacental routes. Inhalation involves breathing in air pollutants, which can cause long-term damage. Ingestion involves consuming contaminated water and food, including heavy metals, which can cause chronic illnesses. Transplacental-route pollutants can reach the fetus, affecting its growth and development [22].

A study on Lahore smog from 2 to 5 November 2016 revealed that the highest-concentration pollutant was NOx, with other pollutants including SO_2, O_3, CO, VOC, $PM_{2.5}$, and PM_{10}. The air quality index (AQI) was six times higher than the baseline, indicating extremely poor air quality during smoggy days. Out of 700 patients, 20% reported dry eyes, with 13% reporting irritation and 80% having corneal diseases [23]. Since 2015, Pakistan has faced smog as a public health emergency, with cities like Faisalabad, Sargodha, Lahore, Multan, and Bahawalpur being majorly affected each year [24].

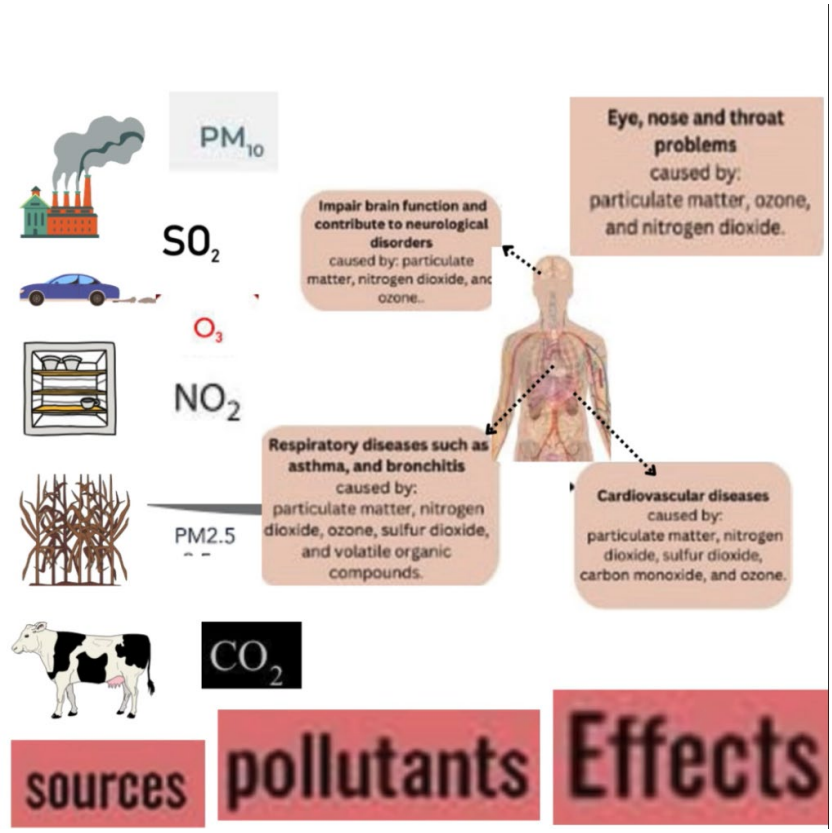

Figure 1. Schematic representation of sources (drivers) of air pollution and effects on human health in Pakistan [SOURCE: authors].

Smog negatively impacted 91% of the respondents in a survey included in a study, including laborers, shopkeepers, and farmers, with winter smog affecting 41% of the respondents. Laborers in construction or road work face job availability and efficiency issues, while office workers are most affected due to a lack of awareness and resources [25]. The air quality in Lahore remains hazardous, with PM2.5 levels in areas like Jalo and Batapur reaching up to 62 times higher than the WHO recommendation (5 μg/m³) and 20 times higher than the Punjab Air Quality Standard (PEQS). In 2022, $PM_{2.5}$ levels in the townships reached 192.7 μg/m³ during winter, exceeding permitted levels due to cold temperatures, wind speed, and rainfall. Health risk evaluations conducted between June 2021 and March 2024 revealed considerable health risks (respiratory issues, cardiovascular issues, allergies, asthma issues) for residents, with health hazard index values exceeding permitted levels [26].

This systematic review aimed to find the number of studies and their impact on people to understand air pollution and the effect of different drivers of air pollution on human health in Pakistan. This study examined the effects of air pollution and smog on human health within urban areas in Pakistan, with a focus on important pollution sources and their health effects. It aimed to give insights into effective mitigation strategies and policy development to reduce the health concerns associated with air pollution.

2. Materials and Methods

A systematic evaluation of the literature on environmental pollutants and their influence on human health was conducted using the PRISMA technique. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) provides guidelines for the reporting of systematic reviews evaluating the effectiveness of interventions [22].

2.1. Data Sources and Search Strategy

The following databases were searched: PubMed, Medline, Web of Science, Scopus, and Google Scholar. Using keywords and search strategies related to air pollution (such as "smog", "particulate matters", "Health Effects", and "Pakistan"), the databases were searched from 2000 to 2023. Particulate matter, $PM_{2.5}$, PM_{10}, CO_2, CO, So_x, NO_x, and pollutants from waste combustion and agriculture were regarded as the main sources of air pollution. The health outcomes considered were respiratory disorders, cardiovascular problems, ENT (ear, nose, and throat) issues, allergies, and mental health issues. This research study focused on all Pakistan areas and age groups. Abstracts were used to find the relevant literature, and the whole paper was then analyzed to extract data. To ensure that every reference was incorporated into this systematic review, the references list was examined. Only English articles were included. The time range for the searches was from November 2023 to January 2024.

2.2. Inclusion and Exclusion Criteria

Full-text peer-reviewed journal articles, systematic review reports from federal or state governments, and reports from international authority bodies (e.g., the WHO, World Bank, FAO, NEQS, PAK-EPA, EPA) were all included in this systematic review. The focus of this study was on the effects of air pollution on human health and to examine the direct health consequences of smog. The population of interest consisted of people living in Pakistan's urban and rural areas, regardless of their age or sex.

Research or methods that had not been published as complete papers or those that were not related to climate change or human health systems were excluded. Additionally, this study did not include public health initiatives. The exclusion criteria also included no human involvement and experiments using animals.

2.3. Data Extraction and Quality Evaluation

Data on smog, particles, air pollutants, human exposure, and health concerns were taken from all possibly relevant publications for Pakistan's four provinces. The restrictions found were also documented. SRDR+ Software 2019 (Systematic Review Data Repository) was used for developing questionnaires and extraction. The data were extracted and screened and then exported to Microsoft Excel sheets (Microsoft Corporation, Redmond, WA, USA) with sections for every element of relevant data. The tables were utilized in the final text. The extracted data included geographical regions of Pakistan, sample size, study design (where applicable), government or organization authoring report (where applicable), measurements, health impacts, quantitative data of health issues (e.g., respiratory, cardiovascular, ENT, allergies), and details of pollutants and composition of smog ($PM_{2.5}$, PM_{10}, O_3, CO, So_x, NO_x, VOCs, and CO_2). The scope was wide, spanning various potential exposures and health consequences, and the data were synthesized descriptively. This study's findings are presented in tables with brief descriptive descriptions, and systematic reviews were divided to include quantitatively synthesized data.

2.4. Data Analysis

Depending on the studies identified, we aimed to provide a statistical synthesis of groups of articles based on (i) the impact of climate change on pollution in the environment (agricultural waste products, solid waste, and motor vehicle emission levels); (ii) smog and air pollutants; (iii) air pollution, smog, and health issues (respiratory disorders; heart disease; allergies; ear, nose, and throat; and mental health problems) faced by vulnerable groups and all people in Pakistan.

2.5. Role of Funder

The funder did not participate in this study's design; data collection, interpretation, or analysis; or report writing.

3. Results

A total of 45 articles were found eligible that analyzed the impact of air pollution on human health in Pakistan (Figure 2). The identified studies were conducted in several cities across Pakistan, with most of them conducted in Lahore, Karachi, Rawalpindi, and Islamabad. Some studies were executed in Kallar Kahar, Sialkot, Bahawalpur, Faisalabad, Jhang, Makland, and the Karakoram Hindu Kush Himalayan Region (Figure 3). Detailed information on the distribution of the studies is presented in Table 1.

This review concentrated on air pollution and smog's effect on human health. $PM_{2.5}$, PM_{10}, So_x, NO_x, and O_3 were the most often investigated air pollutants, while other meteorological indicators were included as the most frequently researched when temperatures were higher than optimum. These pollutants and other temperature variations cause specific cardiovascular diseases and respiratory illnesses including respiratory infections, asthma, lung cancer, allergies, and eye and throat problems; these pollutants also affect mental and physical health (Figure 4). A total of 45 studies that were examined showed the relationship between air pollution and human health and concluded that it had a significant association with asthma, cardiovascular disease, respiratory problems, morbidities, and mortalities. The correlations between human illnesses and air pollution vary depending on the kind of air pollutant, age group, and sex.

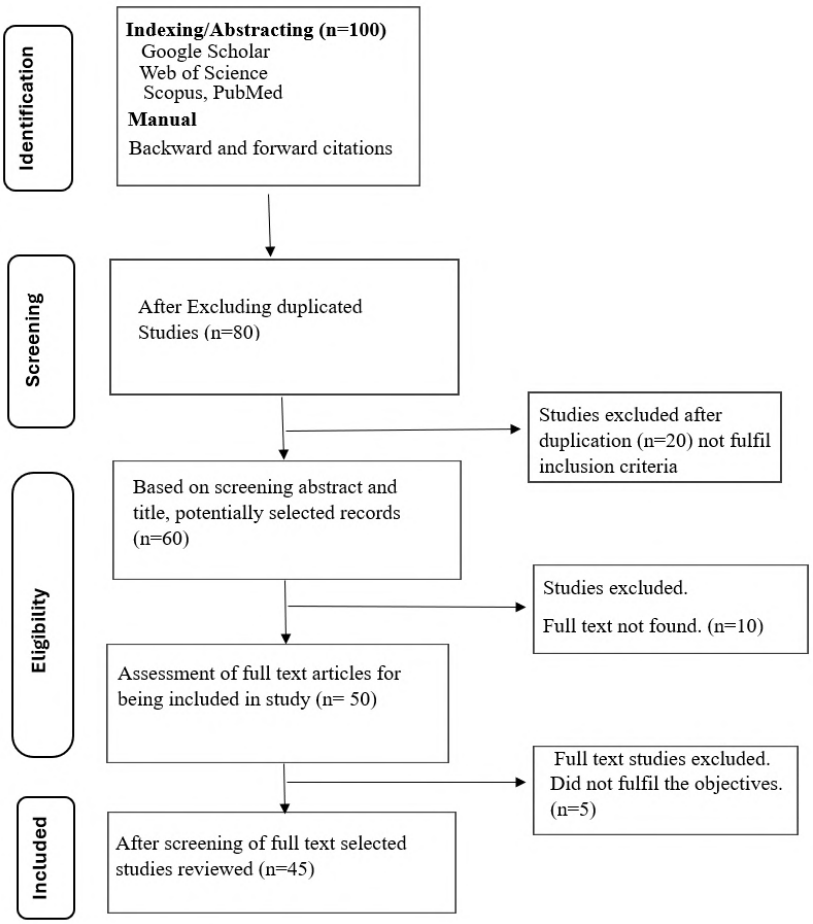

Figure 2. Flowchart of inclusion and exclusion of articles.

Figure 5 shows the publication years of the articles on the effect of air pollution on human health in Pakistan. The majority of articles were from 2021–2023, which show growing concern and interest in research to understand the effects of air pollution on human health. However, the research began in the early 2000s, which indicates the early recognition of this issue. However, current research studies show a gradual increase in concern about this issue (Figure 5). The progress in research has been triggered by factors such as extreme climatic events, global warming, increasing seasonal variability, increasing climate-induced disasters, crop failure, and outbreaks of diseases. A significant number of studies took place in 2021 due to public awareness as well as the national and international initiatives taken to tackle air pollution and its consequences mainly on human health.

A diverse range of methods were used in the articles. Surveys and questionnaires were the most often used methods for investigating the perception of individuals regarding air pollution and its association with human health. National and international reports played a crucial role in gathering data as they provided detailed assessments of air quality, health impacts, and policy recommendations at various levels (Figure 6). A diverse range of population groups was analyzed, majorly focusing on women, men, children, and older adults, and they also included people with pre-existing health conditions. The consideration of diverse groups vulnerable to air pollution aided in finding meaningful conclusions about the impacts of air pollution on human health in Pakistan.

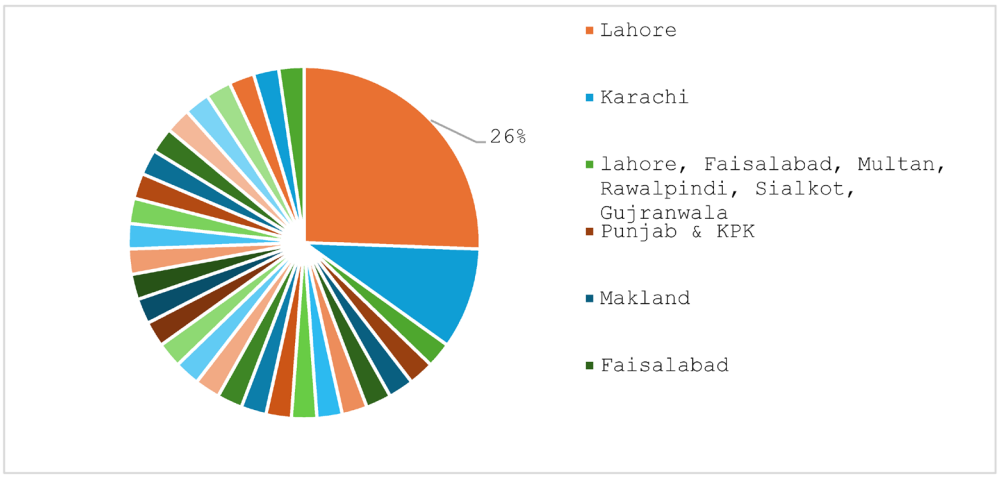

Figure 3. Geographically distribution of selected studies in Pakistan.

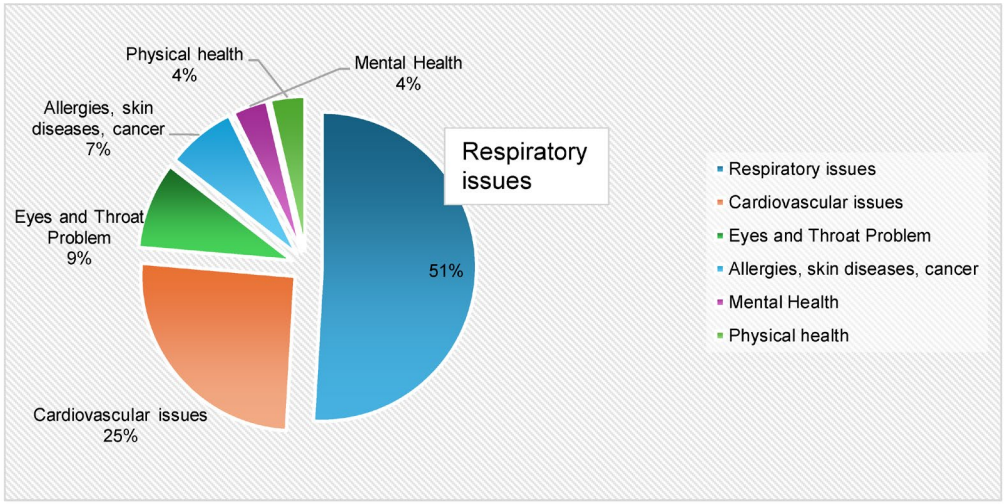

Figure 4. Disease types due to air pollution in selected studies.

Air pollution is driven by different sources including industrial emissions, vehicular emissions, brick kilns, crop burning, smog, aerosols, waste burning, household combustion devices, and meteorological drivers. Common pollutants such as $PM_{2.5}$, PM_{10}, CO, SO_2, NO_2, and ozone were frequently examined in these studies, with studies finding significant associations between these pollutants and a variety of health outcomes, including respiratory and cardiovascular issues, emphasizing the urgent need for effective air quality management and public health interventions in Pakistan.

Regarding the geographic distribution of the articles, most studies were from Lahore. This depicts the relatively alarming situation in Lahore as compared to other cities because air pollution is worse there due to Lahore being the hub of major industrial and agricultural activities. Articles focusing on Karachi as a study area were the second most numerous (n = 12). Karachi, being the "city of lights", has faced severe air pollution, which has led to various disease outbreaks. The major industrial cities, Islamabad, Peshawar, and Faisalabad, each had three studies that focused on air pollution and its impact on human health. Studies from other cities were also available; the majority were from the provinces of Punjab, Sindh, and KPK. These parts of the country face intense air pollution affecting the quality of life and health of human beings. The detailed findings of several studies on the impacts of air pollution on health in Pakistan are given in Table 1. The table summarizes the primary pollutants studied, their sources, and the related health consequences reported by the researchers.

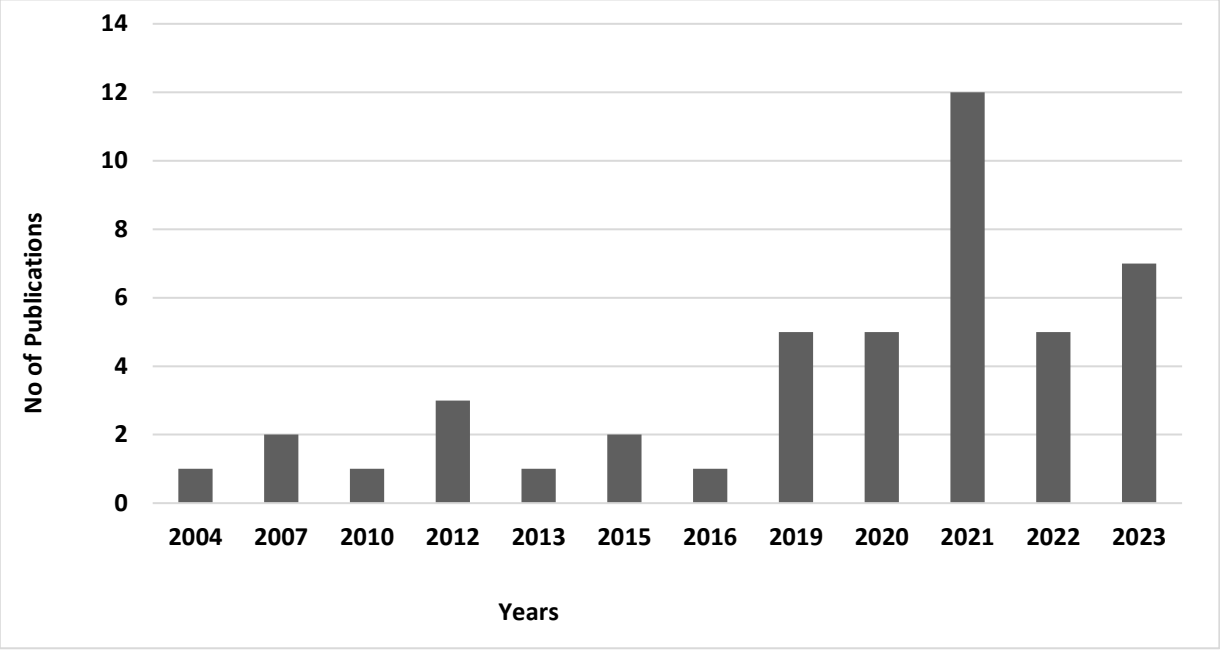

Figure 5. Annual distribution of the selected studies in Pakistan.

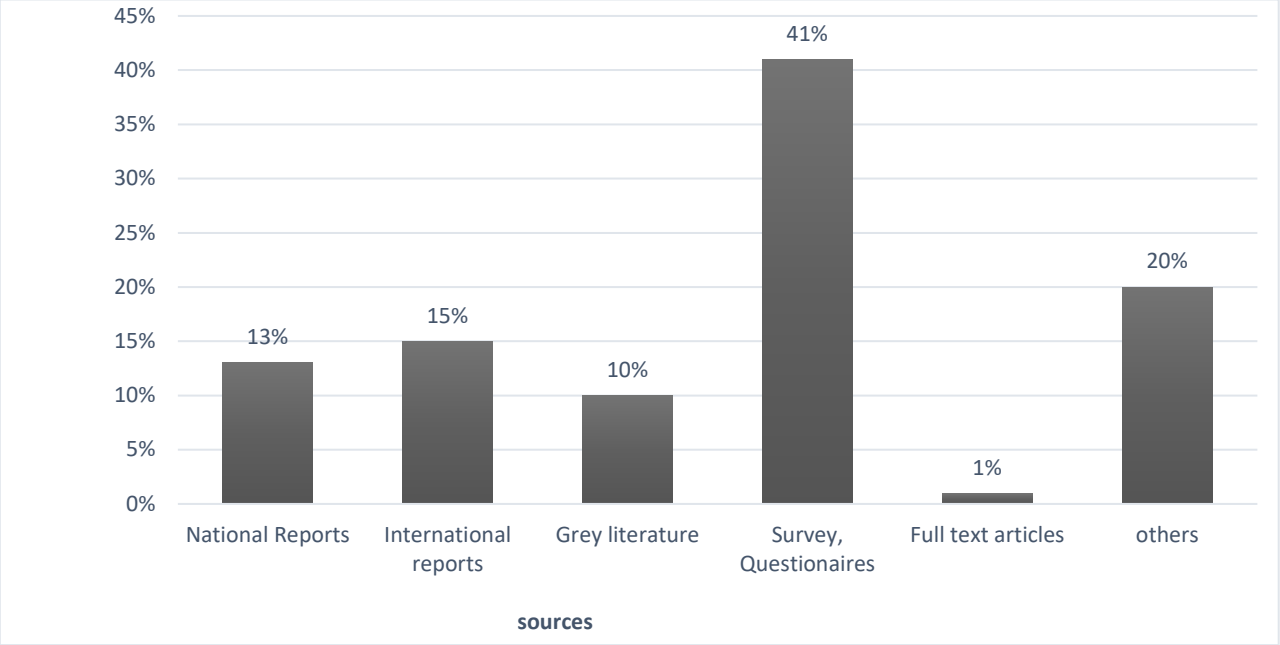

Figure 6. Sources describing air pollution drivers.

Table 1. Analysis of studies on air quality and associated health impacts.

Sr. no	Reference, City and Journal	Study Characteristics	Primary Outcomes	Outcome Source	Population Group	Exposure Addressed	Exposure Gases
1.	Javeria et al., 2023 Rawalpindi, Environmental Monitoring and Assessment [25]	Ecological study	Respiratory issues	National reports Others	Children	Air pollution/pollutants	NO_x
2.	Lu et al., 2019 Karachi Environmental Pollution [26]	Others	Cardiovascular issues	National reports Surveys Questionnaires	Men Women Older people People with pre-existing health conditions (e.g., diabetes, heart disease, lung diseases, asthma)	Air pollution/pollutants Fossil fuel burning	$PM_{2.5}$ PM_{10} O_3 Heavy metals
3.	Mehmood et al., 2021 Lahore, Faisalabad, Multan, Rawalpindi, Sialkot, Gujranwala, Environmental Science and Pollution Research [27]	Ecological study	Respiratory issues	International reports (WHO, UNEP, World Bank, WWF, FAO, NEQS, PAK-EPA, EPA) Grey literature Surveys Questionnaires	People with pre-existing health conditions (e.g., diabetes, heart disease, lung diseases, asthma)	Air pollution/pollutants Aerosols Fossil fuel burning	$PM_{2.5}$ PM_{10} CO So_2 No_2 O_3
4.	Moyebi et al., 2023 Karachi, Science of Total Environment [28]	Cross-sectional study	Cardiovascular issues	Full-text articles National reports International reports (WHO, UNEP World Bank, WWF, FAO, NEQS, PAK-EPA, EPA) Grey literature	Men Women Children Elderly people People with pre-existing health conditions (e.g., diabetes, heart disease, lung diseases, asthma)	Air pollution/pollutants Vehicle Emissions Fossil fuel burning	$PM_{2.5}$ Heavy metals
5.	Hussain et al., 2023 Karakoram Hindukush Himalaya region *Chemosphere* [29]	Cross-sectional study	Respiratory issues	Others	Children	Air pollution/pollutants Vehicle emissions Meteorological drivers	PM2.5 PM_{10} CO SO Ozone

							(O3) Heavy metals Aerosols
6.	Ali et al., 2019 Islamabad, Lahore, Peshawar *The Science of the Total Environment* [30]	Qualitative study (interviews/questionnaires)	Respiratory issues	Grey literature Surveys Questionnaires	Others	Air Pollution/Pollutants Smog Aerosols Waste Burning Vehicle Emissions Fossil Fuels Burning Ozone Crop Burning	$PM_{2.5}$ PM_{10} CO SO_2 NO_2 Ozone (O_3)
7.	Aslam et al., 2023 Lahore, *Environmental Science and Pollution Research* [31]	Cross-sectional study	Respiratory issues Allergies	Surveys Questionnaires	Children Elderly people	Air Pollution/Pollutants Coal Waste Burning Vehicle Emissions Fossil Fuels Burning Ozone Meteorological Drivers	PM2.5 PM10 SO_2 NO_2 Ozone (O_3)
8.	Mehmood et al., 2021 Lahore, Karachi, Peshawar, Islamabad, *Chemosphere* [32]	Ecological study	Respiratory issues	International reports (WHO, UNEP, World Bank, WWF, FAO, NEQS, PAK-EPA, EPA)	Children Older people People with pre-existing health conditions (e.g., diabetes, heart disease, lung diseases, asthma)	Air pollution/pollutants Vehicle emissions	$PM_{2.5}$ NO_2
9.	Bukhari et al., 2021 Lahore *Iranian Journal of Allergy, Asthma, and Immunology* [33]	Cross-sectional study	Respiratory issues	Surveys Questionnaires	People with pre-existing health conditions (e.g., diabetes, heart disease, lung diseases, asthma)	Air pollution/pollutants Aerosols Vehicle emissions Environmental Pollutants Fossil fuel burning	$PM_{2.5}$ PM_{10} Aerosols
10.	Kamal et al., 2015 Rawalpindi,	Cross-sectional study	Cardiovascular issues	Others	Men	Vehicle emissions PAHs	$PM_{2.5}$ PM_{10} CO

	Environmental science and pollution research international [11]						SO_2 NO_2 Ozone (O_3)
11.	Ilyas et al., 2009 Quetta, *Clean technologies environmental policy* [18]	Cross-sectional study	Respiratory issues	Surveys Questionnaires	Men Women Children Older people People with pre-existing health conditions (e.g., diabetes, heart disease, lung diseases, asthma) Others	Air pollution/pollutants	$PM_{2.5}$ SO_2 NO_2 Ozone (O_3) Heavy metals
12.	Gull et al., 2013, Jhang, *Academic Journal of Interdisciplinary Studies* [34]	Cross-sectional study	Respiratory issues	Surveys Questionnaires	Women Men	Air pollution/pollutants	$PM_{2.5}$ PM_{10} CO SO_2 NO_2 others
13.	Aziz et al., 2007 Lahore, Sahiwal, and Multan *Environmental monitoring and assessment* [35]	Ecological study	Cardiovascular issues	Surveys Questionnaires	Others	Air pollution/pollutants Vehicle emissions Meteorological drivers	$PM_{2.5}$ PM_{10} SO_2 NO_2
14.	Sughis et al., 2012 Lahore, *BMC Public Health* [36]	Cross-sectional study	Cardiovascular issues	Surveys	Children	Air pollution/pollutants	$PM2.5$ PM_{10}
15.	Asghar et al., 2020 Lahore, *Environmental Science and Pollution Research* [37]	Ecological study	Respiratory issues Others	Others	Women Men Children Older people Pregnant women People with pre-existing	Waste burning Fossil fuel burning	CO_2

					health conditions (e.g., diabetes, heart disease, lung diseases, asthma)		
16.	Ali et., 2021 Islamabad, *International Journal of Environmental Science and Technology* [38]	Ecological study	Respiratory issues	Others	Others	Air pollution/pollutants Smog Vehicle emissions	$PM_{2.5}$
17.	Majid et al., 2012, Karachi, Lahore, Rawalpindi *Health* [39]	Ecological study	Cardiovascular issues	International reports (WHO, UNEP, World Bank, WWF, FAO, NEQS, PAK-EPA, EPA) Grey literature Surveys Questionnaires	Children Older people People with pre-existing health conditions (e.g., diabetes, heart disease, lung diseases, asthma)	Air pollution/pollutants Coal Waste burning Vehicle emissions Fossil fuel burning	$PM_{2.5}$ PM_{10} CO SO_2 NO_2 Heavy metals
18.	Nasir et al., 2021 Peshawar, *Environment, Development and Sustainability* [40]	Cross-sectional study	Physical health Others	Surveys Questionnaires	Children	Air pollution/pollutants	$PM_{2.5}$ PM_{10} NO_2 Ozone (O_3) Heavy metals
19.	Arif et al., 2023 Lahore, *Journal of Natural Science and Technology* [41]	Ecological study	Cardiovascular issues Respiratory issues	International reports (WHO, UNEP, World Bank, WWF, FAO, NEQS, PAK-EPA, EPA) Surveys Questionnaires	Women Men Children Older people	Air pollution/pollutants Smog	$PM_{2.5}$ PM_{10} CO SO_2 NO_2 Ozone (O_3) others
20.	Hamid et al., 2022 Lahore and Pattoki, *Environmental Science and pollution research* [16]	Cross-sectional study	Respiratory issues	Surveys Questionnaires	Men Women Children	Air pollution/pollutants Coal Waste burning Vehicle emissions	$PM_{2.5}$ PM_{10} CO SO_2

						Fossil fuel burning Ozone	NO_2 Heavy metals Aerosols
21.	Rabbani et al., 2022 Karachi, *Journal of Occupational and Environmental Medicine* [42]	Cross-sectional study	Respiratory issues	Others	Men Women	Air pollution/pollutants Coal Waste burning Incineration Vehicle emissions	$PM_{2..5}$ CO
22.	Raza et al., 2022 Punjab, *Journal of Occupational and Environmental Medicine* [43]	Cross-sectional study	Respiratory issues	Surveys Questionnaires	Men Women	Air Pollution/Pollutants Smog Aerosols Waste Burning Climate Change Crop Burning	$PM_{2.5}$ PM_{10} CO_2 CO NO_2 NO SO_X Ozone (O_3) Aerosols
23.	Yousaf et al., 2021 Lahore, *Brazilian Journal of Biology* [44]	Ecological study	Respiratory issues	National reports Grey literature	Men Women	Air pollution/pollutants Smog Aerosols Vehicle emissions Fossil fuel burning Ozone Crop burning Metrological drivers	$PM_{2.5}$ PM_{10} SO_2 NOx Ozone (O_3)
24.	Ullah et al., 2021 Makland, *Environmental Monitoring and Assessment* [45]	Cross-sectional study	Respiratory issues	Surveys Questionnaires	Others	Air pollution/pollutants	$PM_{2.5}$ PM_{10} SO_2 NO_2 Ozone (O_3)

25.	Raza et al., 2021 Lahore, Tehsil Pattoki, *Journal of health & pollution* [21]	Cross-sectional study	Respiratory issues	Questionnaires	Men	Air pollution/pollutants	$PM_{2.5}$ PM_{10} SO_2 NO_2 others
26.	Majeed et al., 2023 Lahore *Pakistan Journal of Medical & Health Sciences* [46]	Ecological study	Respiratory issues	Others	Children	Air pollution/pollutants Smog Coal Waste burning Vehicle emissions Crop burning	$PM_{2.5}$ PM_{10} CO SO_2 NO_2 Ozone (O_3)
27.	Khan et., 2022 Punjab, KPK *Environmental Science and Pollution Research* [47]	Cross-sectional study	Respiratory issues	Surveys Questionnaires	Others	Air pollution/pollutants Waste burning Fossil fuel burning	$PM_{2.5}$ $PM1_0$ CO NO_2 NO_x Ozone (O_3)
28.	Kamal et al., 2015 Lahore, *Chemosphere* [48]	Cross-sectional study	Cardiovascular issues	Surveys Questionnaires	Men	Vehicle emissions PAHs	Others
29.	Aziz et al., 2007 Lahore, *Environmental monitoring and assessment* [49]	Cross-sectional study Ecological study	Respiratory issues	National reports Grey literature Surveys	Others	Vehicle emissions	CO
30.	Anjum et al., 2021 Karachi, Lahore, Peshawar, Islamabad, Faisalabad, *Journal of Hazardous Materials* [50]	Ecological study	Cardiovascular issues	National reports International reports (WHO, UNEP, World Bank, WWF, FAO, NEQS, PAK-EPA, EPA) Grey literature	Men Children Elderly people Pregnant women People with pre-existing health conditions (e.g., diabetes, heart disease, lung diseases, asthma)	Air pollution/pollutants Smog Coal Waste Burning Incineration Vehicle Emissions Climate Change	$PM_{2.5}$ PM_{10} CO SO_2 NO_2 Ozone (O_3)

						Environmental Pollutants Fossil Fuel Burning Ozone Wildfires Crop burning PAHs	Heavy metals
31.	Moyebi et al., 2023 Karachi, *Environmental Monitoring Assessment* [51]	Ecological study	Cardiovascular issues	Others	Men Women Children Elderly people People with pre-existing health conditions (e.g., diabetes, heart disease, lung diseases, asthma)	Air pollution/pollutants Smog Aerosols Coal Waste Burning Incineration Vehicle Emissions Environmental Pollutants Fossil Fuel Burning Ozone Meteorological drivers PAHs	$PM_{2.5}$ PM_{10} CO SO_2 NO_2 NO Ozone (O_3)
32.	Jabeen et al., 2021 Lahore, *Atmosphere* [23]	Cross-sectional study	Eye and throat problems	Surveys Questionnaires	Women Men Older people People with pre-existing health conditions (e.g., diabetes, heart disease, lung diseases, asthma)	Air pollution/pollutants Smog	$PM_{2.5}$ PM_{10} SO_2 NO_2 Ozone (O_3)
33.	Naveed et al., 2023 Lahore and Islamabad *International Journal of Environmental Science and technology* [52]	Cross-sectional study	Mental Health	Others	Children	Air pollution/pollutants	$PM_{2.5}$ CO SO_2 NO_2

34.	Ashraf et al., 2019 Lahore, *Atmospheric Environment* [53]	Cross-sectional study	Cardiovascular issues	Others	Men Women Children Elderly people People's lung diseases, asthma)	Air pollution/pollutants Smog Meteorological drivers	PM_{10} SO_2 NO_x Ozone (O_3)
35.	Mehmood et al., 2021 Faisalabad, *Environmental science and pollution research* [15]	Cross-sectional study	Respiratory issues	Full-text articles International reports (WHO, UNEP, World Bank, WWF, FAO, NEQS, PAK-EPA, EPA) Surveys Questionnaires	People with pre-existing health conditions (e.g., diabetes, heart disease, lung diseases, asthma)	Air pollution/pollutants	$PM_{2.5}$ PM_{10} CO SO_2 NO_2 Ozone (O_3) Heavy metals
36.	Majeed et al., 2023 Lahore, Pakistan *Pakistan Journal of Medical & Health* [54]	Cross-sectional study	Mental Health	Surveys Questionnaires	Men Women	Air pollution/pollutants Smog	$PM_{2.5}$ PM_{10} CO SO_2 NO_2 Ozone (O_3)
37.	Barbar et al., 2021 Karachi, *The Journal of Climate Change and Health* [55]	Others	Cardiovascular issues Respiratory issues Allergies Physical health	National reports International reports (WHO, UNEP, World Bank, WWF, FAO, NEQS, PAK-EPA, EPA) Surveys Questionnaires	Men Women Children	Air pollution/pollutants Environmental pollutants	$PM_{2.5}$
38.	Hassan et al., 2020 Karachi, *Journal of Environmental Science, Computer Science, Engineering & Technology* [56]	Ecological study	Cardiovascular issues Eye and throat problems Physical health	Questionnaires Other	Men Women Children Older people Pregnant women People with pre-existing	Vehicle emissions	CO_2 CO SO_2 NO_2

					health conditions (e.g., diabetes, heart disease, lung diseases, asthma)		
39.	Ali et al., 2024 Faisalabad, *Pakistan Journal of life and social sciences* [57]}	Cross-sectional study	Respiratory issues Eye and throat problems Mental health Physical health	Surveys Questionnaires	Men Women	Air pollution/pollutants	$PM_{2.5}$ PM_{10} CO NO_2 Ozone (O_3)
40.	Ajmal et al., 2016 Dera Ghazi Khan, *Journal of Environment and Earth Science* [4]	Cross-sectional study	Respiratory issues Allergies Eye and throat problems Cancer Skin diseases	Surveys Questionnaires	Men Women	Air pollution/pollutants Waste Burning Vehicle Emissions Fossil fuel burning	$PM_{2.5}$ PM_{10} CO SO_2 NO_2 Ozone (O_3)
41.	Akbar, 2018 Lahore *Editorial Board* [6]	Qualitative study (interviews/questionnaires)	Cardiovascular issues Respiratory issues Eye and throat problems	Full-text articles National reports International reports (WHO, UNEP, World Bank, WWF, FAO, NEQS, PAK-EPA, EPA)	Older people People with pre-existing health conditions (e.g., diabetes, heart disease, lung diseases, asthma)	Air pollution/pollutants Smog Coal Waste Burning Vehicle Emissions Fossil fuel burning Ozone Crop burning Meteorological drivers	$PM_{2.5}$ PM_{10} CO SO_2 NO_2 Ozone (O_3) Heavy metals Aerosols others
42.	Nasir et al., 2022 Kallar kahar, *Atmosphere* [26]	Ecological study	Respiratory issues Cancer	Others	People with pre-existing health conditions (e.g., diabetes, heart disease, lung diseases, asthma)	Air pollution/pollutants	$PM_{2.5}$

4. Discussion

This study reviewed scientific evidence on how air pollution affects human health. Forty-five studies conducted in several areas of Pakistan met the inclusion criteria and were included in this review. Half of them adopted a cross-sectional study design, while the others adopted a qualitative and ecological study design. The air pollutants examined were NO_x, So_x, $PM_{2.5}$, PM_{10}, O_3, CO, CO_2, heavy metals, and overall air quality. This line of research has documented the adverse effects of air pollution on inflammation as well as the development and progression of chronic illnesses such as asthma, respiratory and cardiovascular diseases, and certain types of cancer [6,25,26,31,33]. Pakistan's air quality remains poor because of traffic, the country's main source of pollution. Punjab is Pakistan's second largest province, in which transportation accounts for 43% of air pollution emissions, while industrial sites for 25%, and agricultural sites for 20%. Pakistan is also affected by seasonal air quality challenges such as crop burning and winter weather patterns causing temperature inversion, which promotes air stagnation and keeps air pollution closer to ground level [19,30]. Environmental health experts at the University of Punjab found a decrease in lung capacity of 40% due to haze occurrence, which mostly affected people with tuberculosis, asthma, and cardiovascular diseases. In Pakistan, the rising rate of air pollution and smog causes multidimensional damage to public health, resulting in a wide range of diseases and having negative health effects. The high concentrations of pollutants in the air cause respiratory problems, cardiovascular problems, eye and throat issues, skin allergies, as well as mental health disorders [56,57]. So_x, NO_x, O_3, CO_2, CO, $PM_{2.5}$, and PM_{10} are the primary sources of air pollutants that are produced from the transportation sector, which include vehicular emissions from automobiles as well as industrial operations such as power plants and refineries. These pollutants raise the level of diseases and contribute to the formation of ground-level ozone and other hazardous substances [26,27,29]. According to a wide range of research conducted between 2000 and 2023, respiratory problems are the most common health concern in Pakistan. These diseases range from cough and asthma to chronic obstructive pulmonary disease (COPD) and have a considerable influence on the population. Those who live near industrial sectors as well as commuting office workers and school children are especially prone to air pollution [11,18,29,31]. After respiratory disease, cardiovascular disorders are the second most common health outcome due to polluted air, which causes illnesses such as heart disease and hypertension, posing a serious risk to public health. Furthermore, studies emphasize the prevalence of eye and throat disorders because of air pollution exposure that causes irritation and inflammation. Skin diseases and allergies are also among the health disorders, indicating the widespread impact of air pollution on dermatological health and immune system functioning [31,57].

Air pollution is a significantly worse problem in Karachi and Lahore as compared to other cities in Pakistan because of being major industrial hubs, with larger numbers of manufacturing operations, high population growth, and heavy traffic. They release major pollutants such as So_x, NO_x, $PM_{2.5}$, PM_{10}, and VOCs [21,44,52,55]. These pollutants lead to the development of fine particulate matter that affects human health in different ways and causes respiratory diseases such as asthma, COPD, and cardiovascular problems. The larger numbers of industries and port operations in Karachi contribute to significant pollution emissions, resulting in continuous haze and poor air quality. Similarly, Lahore is known for intense smog during the winter season, which raises concerns regarding substantial air pollution. The city location, the high levels of industrial activities, and high traffic congestion lead to high pollution levels and rank it as one of Pakistan's most polluted cities. Smog has serious health effects: considerable increases in hospital admissions for respiratory and cardiovascular diseases during smog events. According to studies,

higher exposure to air pollution at these times is related to higher mortality and morbidity rates. However, Rawalpindi and Islamabad are not industrialized cities like Lahore and Karachi but still suffer from severe air pollution caused by vehicular emissions and other human activities [34,50,58]. The high population density and increased vehicular emissions in these twin cities have resulted in higher levels of PM and NO_x. People residing in these cities are directly exposed to transportation routes and construction sites, which cause poor air quality. The health effects in Rawalpindi and Islamabad are the same as those seen in Karachi and Lahore, with a higher rate of cardiovascular and respiratory diseases. Continuous exposure to these air pollutants results in more frequent hospitalization and higher healthcare expenses. Kallar Kahar, Faisalabad, and Jhang all have considerable air pollution although they are less urbanized than other cities [18,29,34,50,55]. These areas are polluted mostly by agricultural practices and vehicle emissions. Faisalabad, which is famous for its textile industry, is polluted by manufacturing emissions, which release significant amounts of particles and chemicals into the atmosphere. Even though Jhang and Kallar Kahar are more rural, they nonetheless suffer from pollution caused by agricultural burning and local industrial operations [34,58]. These regions' health repercussions include respiratory disorders, cardiovascular disorders, and other pollution-related health concerns, which are comparable to those faced in more urbanized areas. The studies' findings show the urgent need to address the high levels of air pollution in Pakistani cities such as Karachi, Lahore, Rawalpindi, Islamabad, Kallar Kahar, Faisalabad, and Jhang, as well as the accompanying health consequences. The prevalence of respiratory and cardiovascular disorders highlights the serious public health threat caused by air pollution. Implementing comprehensive regulations and supporting cleaner technology can help to reduce health hazards and enhance the quality of life of the citizens in these cities. Collaboration among government agencies, companies, and the public is crucial for combating air pollution and protecting public health in Pakistan.

5. Conclusions

This systematic review focused on the major issues of air pollution and smog in Pakistan, as well as their major effects on public health. By analyzing the current research and using both qualitative and quantitative data, this study provides an entirely new perspective on the unique issues confronting Pakistan, an area that has received relatively little attention in this context. The findings emphasize the need for comprehensive legislative reforms, tighter environmental legislation, and more public awareness to confront the rising air quality issue. This study contributes to a better knowledge of the impacts of air pollution in Pakistan, providing the framework for future research and public health initiatives.

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Recommendations: Based on the analyzed literature, some general recommendations emerge, including strict air quality standards, the use of cleaner, renewable energy sources, improved transportation systems, investment in green spaces, effective emission control measures in the industrial sector, increased public awareness about air pollutants, collaboration and research on pollution sources and impacts, and advocating for policies prioritizing environmental protection and human health. These recommendations aim to reduce harmful impacts on the environment.

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