Review

Impact of Indoor Air Pollution in Pakistan—Causes and Management

Ayesha Kausar [1,2,3,*], Ishaq Ahmad [1,2,3], Tianle Zhu [4] and Hassan Shahzad [3]

[1] NPU-NCP Joint International Research Center on Advanced Nanomaterials and Defects Engineering, Northwestern Polytechnical University, Xi'an 710072, China
[2] UNESCO-UNISA Africa Chair in Nanosciences/Nanotechnology, iThemba LABS, Somerset West 7129, South Africa
[3] NPU-NCP Joint International Research Center on Advanced Nanomaterials and Defects Engineering, National Centre for Physics, Islamabad 44000, Pakistan
[4] School of Space and Environment, Beihang University, Beijing 100191, China
[*] Correspondence: dr.ayeshakausar@yahoo.com

Abstract: This state-of-the-art review is designed to provide a factual analysis of indoor air pollution in Pakistan. Primarily, the main sources of indoor air pollution and related air pollutants were analyzed. Key sources of indoor air pollution include household energy sources (biomass, wood, coal, tobacco, and low temperatures) producing particulate matter (PM), dust particles, smoke, COx, noxious gases, bioaerosols, airborne microflora, and flame retardants. According to the literature, rural regions of Pakistan using biomass indoor fuels have a high indoor PM concentration in the range of 4000–9000 $\mu g/m^3$. In rural/urban regions, indoor smoking also leads to high $PM_{2.5}$ levels of ~1800 $\mu g/m^3$, which can cause pulmonary infections. In hospitals, PM concentrations were detected up to 1000 $\mu g/m^3$, causing repeated infections in patients. Indoor ingestion of dust containing polychlorinated biphenyl concentrations was observed at high levels (~8.79–34.39 ng/g) in cities; this can cause serious health effects such as cancer risks and a loss of working productivity. Moreover, indoor microflora and bacteria (~10,000–15,000 cfu m^{-3}) in urban/rural regions cause respiratory/cancer risks. In this context, indoor air quality (IAQ) monitoring and management strategies have been somewhat developed; however, their implementation in Pakistan's rural/urban indoor environments is still needed. Various challenges were identified for monitoring/regulating IAQ. There is a firm need for industry–academia–research cooperation and for the involvement of government/agencies to support indoor air pollution control/management and for intervention strategies.

Keywords: indoor air pollution; Pakistan; pollutants; particulate matter; health hazards; IAQ; monitoring

1. Introduction

Indoor air pollution has become a global challenge due to increasing health hazards and socio-economic risks [1]. In developing countries such as Pakistan, the lack of an appropriate analysis of indoor air quality (IAQ) management and protection strategies has caused health and economic risks. Indoor activities such as cooking, heating, cleaning, smoking, use of building materials, as well as the infiltration of outdoor air continuously increase the indoor air pollution level [2]. The choice of household fuel (biomass, wood, coal, charcoal, crop residue, animal dung, etc.) can contribute to >80% of indoor pollution. In recent decades, concentrations of major indoor air pollutants (particulate matter (PM), gaseous pollutants, dust, smoke, and bioaerosols) have been continuously increasing in Pakistan [3,4]. Consequently, rising indoor pollutant concentrations have resulted in numerous diseases including respiratory, asthmatic, allergic, cardiovascular, carcinogenic, and other health issues [5,6]. According to the World Health Organization (WHO), indoor air pollution has increased the annual disease burden and mortality rate in Pakistan [7]. For

example, safe $PM_{2.5}$ and PM_{10} concentrations levels are 25 μg/m^3 and 50 μg/m^3, respectively (as per WHO). The safe concentration level for ozone is ~150–200 μg/m^3. Similarly, WHO provides safe indoor levels for various other indoor pollutants. Subsequently, the implementation of IAQ management policies, monitoring devices, and sustainable WHO solutions are key challenges for improving IAQ in Pakistan [8–10]. In this context, IAQ sensing systems [11–13], filtration/adsorption media [14–16], UV photocatalysts [17], and advanced techniques need to be adopted in Pakistan.

In this novel, state-of-the art, and comprehensive review, the current situation of IAQ in Pakistan was analyzed using multiple occurrences of indoor air pollution around the major cities and rural regions of Pakistan. Key sources of indoor air pollution, primary pollutants, and health effects were surveyed. Consequently, the necessity of IAQ assessment, control, and monitoring technologies was analyzed. The involvement of academic/research institutes, government organizations, and stakeholders for long-term planned studies on indoor air pollution was found to be crucial. In this context, linking indoor air control/management to appropriate policy interventions (as per WHO standards) is also indispensable.

Recent strategies need to be focused for eradicating essential indoor pollutants and for IAQ control and monitoring in Pakistan. Using advanced materials in these technologies can offer a promising way to improve IAQ. In this context, various nanomaterials, membranes, nanoporous materials, nanohybrids, and polymeric nanocomposites can be designed and employed to reduce indoor pollution. The future of IAQ control/monitoring in Pakistan depends on using advanced nanomaterial-based sensing, filtration/adsorption, and photocatalysts to remove indoor pollutants. Subsequently, key pollutants, health effects, and control methods need to be analyzed in Pakistan. In this context, there are some reports in the previous literature that have studied indoor pollution in Pakistan but not in an updated form which depicts the current state. Among related studies, a minireview was undertaken by Colbeck et al. [18] in 2010. However, the article was published more than a decade ago, and contains analyses of few research reports, probably due to the limited available data at that time. Poor IAQ in Pakistan was attributed to wood-based fuel and indoor smoking, and few directions were proposed for improving the situation. However, the implementation of legislation on tobacco smoking in public places and the adoption of safe fuel were suggested. As compared to previous studies, our review presents a recent sketch of the state of IAQ in Pakistan with comprehensive coverage of the literature, knowledge, and the needs of policy implementations to remove indoor air pollution. However, as compared to past decades, there has not been much improvement in IAQ in Pakistan, especially in rural areas. There is still a need for safe indoor fuel choices, stoves producing less smoke, house designs with separate kitchens, and public awareness regarding smoking.

To the best of our knowledge, such a specific recent review on indoor pollution in Pakistan, with a well-arranged outline and an in-depth interpretation of recent publications, has not been seen in the literature before. The novelty of this review depends upon innovative topic selection and arrangement to form a framework and on the inclusion of all possible relevant studies of the indoor pollution situation in Pakistan. Moreover, the included literature is comprehensively discussed to depict the situation of indoor pollution. On this review topic, some previous research reports have been observed, nevertheless, the reported literature is not in a compiled and updated form that portrays the current state of IAQ in Pakistan. For this particular review, the literature was obtained from various databases such as Scopus, Science Direct, Web of Science, etc., because limited studies have been carried out regarding indoor air pollution in Pakistan. It is not possible for researchers to make future developments regarding IAQ management in Pakistan without access to prior knowledge of the recent literature. Accordingly, the relevant literature published between 2016 and 2023 in the Scopus database is shown in Figure 1.
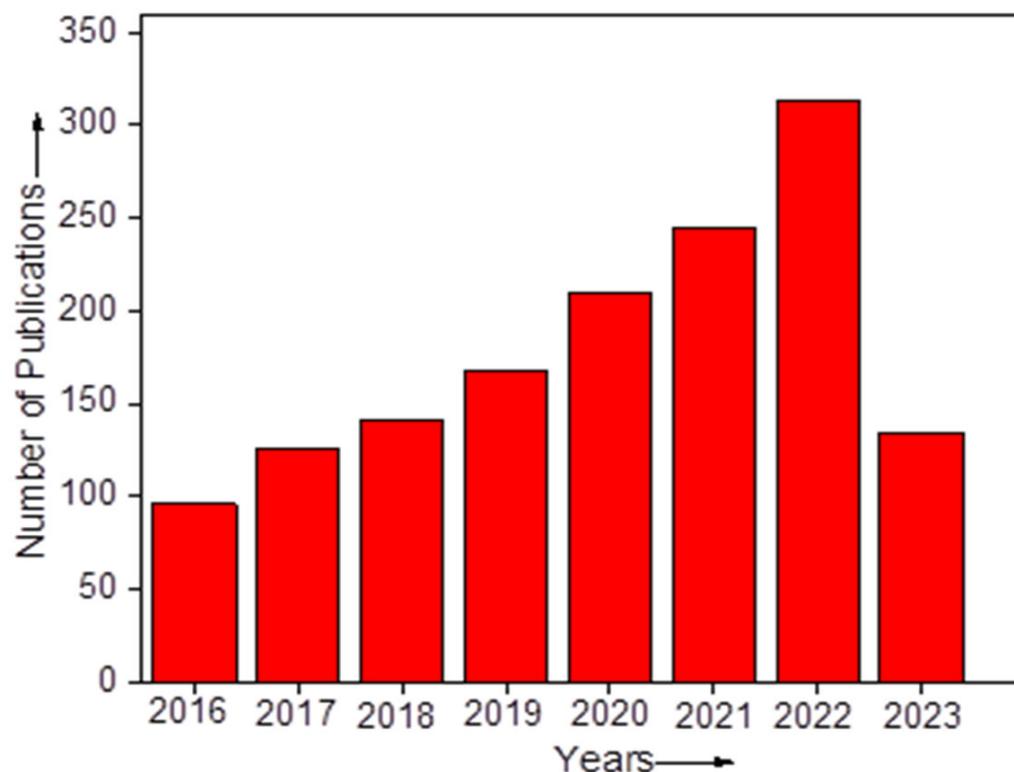
Figure 1. Trend in yearly publications on indoor air pollution in Pakistan.

2. Indoor Air Pollution

The indoor environmental conditions in residential buildings, educational, and work places directly affect human health [19]. According to the WHO, indoor air pollution may affect ~4–5 million people per year worldwide [20]. Most of rural and urban humans spend 90% of their time indoors [21]. Human activities, construction materials, and outdoor air have been major sources of indoor pollution [22–24]. The resulting indoor pollutants have been identified as PM, noxious gases, bacteria, fungi, insects, etc. [25–27]. The major indoor toxic gases involve the oxides of carbon (COx) (carbon monoxide (CO) and carbon dioxide (CO_2)) [28], oxides of nitrogen (NOx) (nitric oxide (NO) and nitrogen dioxide (NO_2)) [29,30], oxides of sulfur (SOx) (sulfur dioxide (SO_2)) [31], PM [32–34], radon [35,36], volatile organic matter (VOC) [37], carbonaceous aerosols/biological aerosols/microorganisms (bacteria, viruses, fungi) [38–40], and pesticides [41]. Common human health effects observed due to indoor pollutants comprise respiratory diseases, allergic diseases, lung cancer, nervous system malfunctioning, kidney cancer, and cardiovascular diseases [42]. The succeeding sections of this review cover various sources as well as pollutants in indoor environments in the rural/urban regions of Pakistan.

3. Sources and Key Indoor Air Pollutants in Pakistan

This section of the review analyzes the key indoor air pollutants and their sources in Pakistan. This points towards the current indoor pollution situation in the rural/urban areas of Pakistan and also the desired steps to improve the IAQ levels (Figure 2).

Figure 2. Steps to move forward from indoor air pollution to accomplishment of safe indoor air quality.

3.1. Indoor Particulate Matter and Dust Ingestion

Among indoor pollutants, PM has been considered as the most abundant contaminant [43–45]. Here, $PM_{2.5}$ and PM_{10} were identified as important indoor air pollutants [46–48]. According to a study on the indoor environment of Lahore city, a rise in $PM_{2.5}$ concentration in the outdoor air improved the indoor pollution [49]. The study was conducted between the period of 2019 and 2020. To realize the current situation of air pollution in Lahore, the $PM_{2.5}$ concentration data were obtained as well as evaluated (WHO standard $PM_{2.5}$ concentrations ~25 µg/m^3). The industrial growth, traffic, and seasonal changes were the main contributing factors to indoor pollution [50,51]. During winter and post-monsoon season in Lahore, the high PM concentrations have been observed due to the excessive burning of plant residues [52]. The needs of monitoring indoor/outdoor air quality using IAQ equipment and policy implementation have been analyzed in Pakistan.

Subsequently, the literature reports have shown an abundant generation of $PM_{2.5}$ and PM_{10} in indoor environments in Pakistan [53]. Nafees et al. [54] investigated the rise in indoor $PM_{2.5}$ levels in the restaurants/cafés/clubs in Karachi. According to indoor monitoring results, the $PM_{2.5}$ level was observed in the range of 25–390 µg/m^3. The increasing indoor pollutant levels were attributed to indoor hospitality, smoking, and public gatherings. Using biomass fuels in kitchens mainly contributed to indoor pollution in rural and semi-urban areas in Pakistan [55,56]. The rising PM_{10} and $PM_{2.5}$ concentrations in kitchens and associated living rooms have been investigated [57]. Accordingly, the indoor biomass smoke has increased the health risks [58]. Colbeck et al. [59] evaluated indoor pollution due to PM_{10}, $PM_{2.5}$, and PM_1 in rural areas of Pakistan.. The kitchens using biomass fuel had PM_{10}, $PM_{2.5}$, and PM_1 concentrations of 3.80, 4.36, and 4.11, respectively. The mass concentrations of particles (PM_{10}, $PM_{2.5}$, PM_1) were monitored using the GRIMM aerosol spectrometer Model 1.108 and Model 1.101 (Grimm Aerosol Technik GmbH, Ainring, Germany) devices. The GRIMM monitors showed a sensitivity of ~ 1 particle/liter with a reproducibility of ±2%. The high PM concentration levels were observed in the range of 4000–8555 µg/m^3. The other sources for rising PM levels were identified in the form of cleaning and smoking in the kitchenette and living areas [60]. Junaid et al. [61] discovered higher indoor PM concentrations in rural/urban areas, as compared with the WHO standards for PM_{10} (50 µg/m^3) and $PM_{2.5}$ (25 µg/m^3) levels. The >50% population

fulfil their energy needs by the indoor conventional biomass burning. The rising indoor PM levels also revealed high respiratory and mortality rates in Pakistan [62]. In the same way as Pakistan, the indoor air pollution has been examined for other developing South Asian countries (having similar indoor conditions) such as Nepal, Bangladesh, Bhutan, etc. [63].

A few of the latest studies have better analyzed the situation of indoor pollution in Pakistan [7,17,64]. Asghar et al. [65] studied PM as a major source of air pollution in Haripur city, Pakistan. The Youngteng yt-hpc 3000a handle particulate counter was used to measure the $PM_{2.5}$ and PM_{10} concentrations. The sensors installed in these devices automatically detected the PM levels and displayed readings on the device screen. The permissible limits for the $PM_{2.5}$ and PM_{10} were ~35 $\mu g/m^3$ and 150 $\mu g/m^3$, respectively (as per standards of the Environmental Protection Agency Pakistan). The $PM_{2.5}$ hourly mean concentrations increased in the range of 23.7–126.0 $\mu g/m^3$, whereas the PM_{10} concentrations rose from 39.0 to 166.3 $\mu g/m^3$. The outside traffic in Haripur caused high indoor concentrations of $PM_{2.5}$ and PM_{10}. Furthermore, the high PM levels led to respiratory infections in the population. Aslam et al. [66] measured the $PM_{2.5}$, PM_{10}, CO, NO_2, SO_2, and O_3 concentrations in different places in Lahore city. The industrial and vehicle emissions in the outside environment were found to improve the indoor pollution and led to epidemiological and asthma problems. A total of 64% of asthma patients were reported in Lahore hospitals, which mainly included females involved in indoor activities. Jiao et al. [67] studied the PM_1, $PM_{2.5}$, and PM_{10} concentrations in residents near brick kilns in specific locations in Northern Pakistan. The high PM_1, $PM_{2.5}$, and PM_{10} concentrations were studied as 3377, 2305, and 3567.67 $\mu g/m^3$, respectively. The PM levels were found to be higher than the Pakistan National Environmental Quality Standards, which caused serious health risks such as respiratory diseases and asthma problems [68].

In the developing countries, dust is an important factor contributing to the indoor air pollution. The major sources for dust include the outside traffic/human activities, indoor electronics, building materials used, as well as pest control actions [69–71]. The indoor furniture, sofas, carpets, etc., contribute to >80% of indoor dust [72]. Ali and co-workers [73] investigated the indoor dust as the major source of organic contaminants in rural areas. The flame retardants/pesticides such as polybrominated diphenyl ether, polychlorinated biphenyl, tri-(2-butoxyethyl)phosphate, and triphenyl phosphate were detected in the indoor dust. For adults and toddlers, the dust ingestion levels were found to be high, ~0.65 and 15.2 ng/kg bw/day, respectively [74]. Khalid et al. [75] found polychlorinated biphenyls as the main organic pollutants in the indoor dust of Lahore, Faisalabad, and Bahawalnagar. The concentrations of polychlorinated biphenyl were observed as about 34.39 ng/g, 9.94 ng/g, and 8.79 ng/g for Lahore, Faisalabad, and Bahawalnagar, respectively. Hence, the dust ingestion caused health effects such as skin damage, liver/gastrointestinal diseases, immune/nervous system ailments, and cancer risks [76,77].

3.2. Indoor Smoke, COx, VOC, and Pollutants from Household Energy Sources, Tobacco, and Building Materials

Around three billion of the world's population in developing countries depend on biomass to meet their household energy needs [78–80]. Relative to the developed countries, the indoor air pollution levels have been found to be quite high in developing countries [81]. Using biomass fuel, wood, coal, crop residues, animal dung, etc., produced high amounts of COx, CO, and VOC in the indoor air [82]. Due to indoor pollution, the increasing risks of chronic respiratory and cardiac diseases were observed in the developing countries [83]. Pakistan is a predominantly rural country having an average family size of five to seven members [84]. As per an estimate, about 90% of the rural and 50% of the urban population rely on biomass fuels in Pakistan [85–87]. However, this consumption was decreased for the population with improved income and economic conditions [88]. Hence, the biomass households were mostly found among the low-income population in developing countries

(Figure 3). In urban areas, clean and efficient indoor energy sources such as liquified petroleum gas and electricity were used.
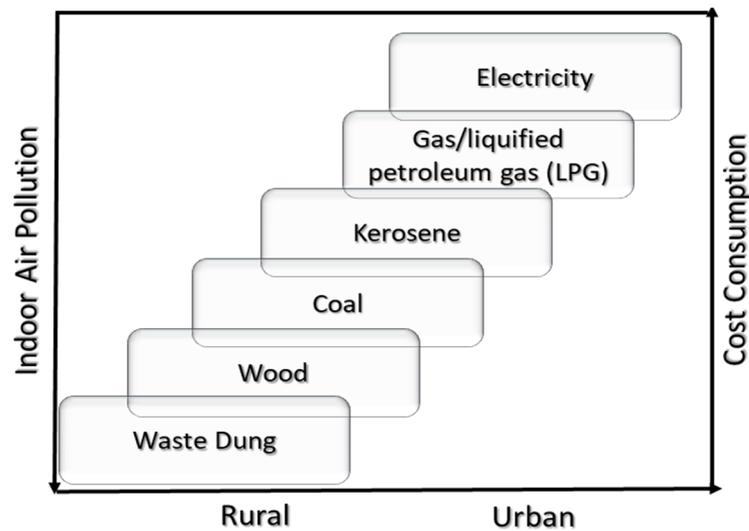
Figure 3. Sources of fuel used from rural to urban areas vs. indoor air pollution and cost consumption in Pakistan.

Biomass fuel is consumed in almost all provinces of Pakistan including Punjab, Sindh, Baluchistan, and Khyber Pakhtunkhwa. The wood as a fuel was used for households in the rural regions of Baluchistan, whereas the rural regions in Panjab utilized crop residues [89]. Similar indoor fuels were consumed in the rural regions of Khyber Pakhtunkhwa. In Sindh rural regions, wood, coal, crop residues, animal dung, and agricultural waste were employed to fulfil the indoor energy needs [90]. Here, the biomass consumption was observed as lower than that of Baluchistan due to urbanization [91–93]. Ahmed et al. [94] performed a comparative analysis on the fuel types used in the South Asian countries (Pakistan, India, and Bangladesh). Figure 4 shows indoor cooking fuels used in Pakistan, India, and Bangladesh. The statistical relationship between the indoor cooking fuel and women's health has been studied [95]. The choice of an appropriate cooking fuel was the top concern to maintain the human health [96].
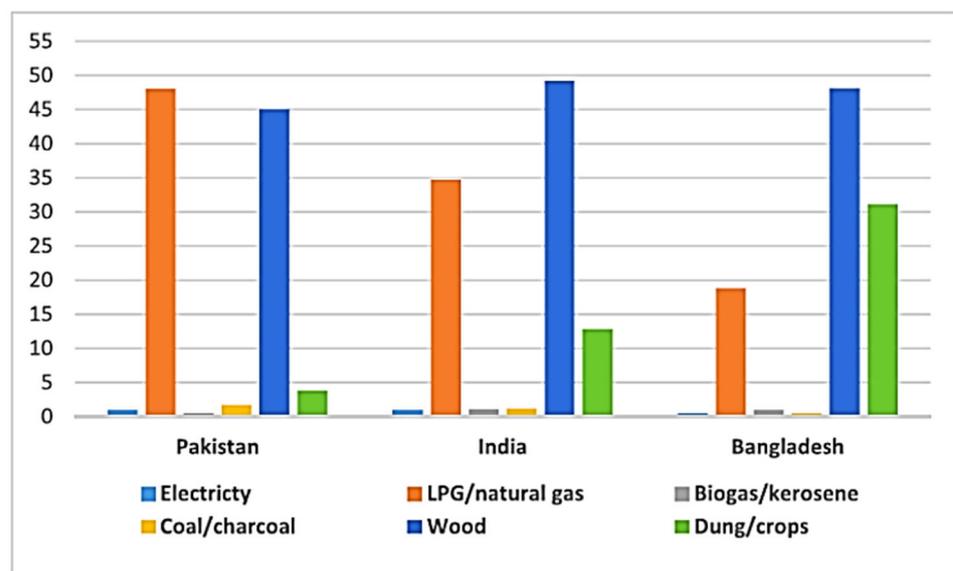
Figure 4. Type of indoor cooking fuel used [94]. Reproduced with permission from Elsevier.

Nasir et al. [97] suggested that the household solid fuel was responsible for the indoor pollution, due to COx and VOC production in large amounts. According to this study, poverty played an important role in selecting an inappropriate fuel and causing indoor pollution [98]. Therefore, the increasing need for sustainable intervention strategies has been analyzed for reducing the indoor pollution [99]. Khan et al. [100] surveyed cross-sectional data from Pakistan (rural regions) for employing wood, crop residues, charcoal, coal, kerosene, and animal dung. Due to unhealthy indoor fuel producing excessive amounts of CO_2 and CO, acute ailments and respiratory infections were observed in children (under five years) [101]. Consequently, using cleaner household fuels has been found essential in these areas [102]. Naz et al. [103] reported the household fuel and cooking activities as major causes of respiratory diseases and deaths in young children. In this context, avoiding the inappropriate indoor fuel and changes in the housing/kitchen designs have been suggested. Fatmi et al. [104] studied the production of indoor noxious gases due to the biomass fuel burning. Using biomass directly influenced the women's and children's health. Accordingly, the small and close houses with non-ventilated kitchens led to high levels of indoor smoke and pollutants, which increased the negative health effects [105]. High indoor PM levels were observed in the range of 200–5000 μg/m^3, due to biomass fuel burning. Moreover, a high carbon monoxide concentration was found of ~29.4 ppm, which caused serious health effects. Shams et al. [106] measured the CO concentration in gas-fired kitchens of 54 bungalows and 25 apartments. The 8 hourly CO concentrations were found in the range of 2.13–5.29 ppm, which was higher than the WHO standards. Therefore, the CO level monitoring in the gas-fired kitchens was found essential.

Since 2009, biogas was used as an indoor fuel in rural areas of Pakistan to minimize the serious indoor health effects [107]. Recently, a study by Yasmin et al. [108] mentioned the adoption/non-adoption of biogas in the rural areas of Punjab. The multinomial logit regression was used to analyze the adoption behavior (Figure 5 and Table 1). According to the Pakistan Bureau of Statistics, nearly 52–67% population live in the rural areas. Formerly, domestic biomass or animal dung were used in these areas causing serious health issues [109]. Afterwards, the biogas utilization was enhanced in the rural areas due to high average education and awareness of people, improved kitchen designs, as well as building concrete houses.

Table 1. Details of study of districts according to Pakistan Bureau of Statistics (2020) [108].

Variables		Unit	Districts		
			Faisalabad	Sargodha	Jhang
Population	Total	Millions	5.4	2.6	2.8
	Male	Percentage	50.7	51.5	52.0
	Female	Percentage	49.9	48.5	48.0
	Urban	Percentage	47.7	28.1	23.4
	Rural	Percentage	52.3	71.9	76.6
Average household size	Persons living in one house	Number of persons	7.2	6.5	6.5
House type	Pacca (cemented)	Percentage	69.8	77.75	37.5
	Kacha (mud)	Percentage	30.17	22.24	62.5
Mode of cooking	Gas	Percentage of housing units	26.7	9.0	5.1
	Other	Percentage of housing units	73.3	91.0	94.9
Number of animals	Buffaloes and cows	Thousands	2421	1495	1890

Variables		Unit	Districts		
			Faisalabad	Sargodha	Jhang
Financial institutions	Commercial banks	Number of branches	36	53	31
	Microfinance institutions	Number of banks	2	2	3
Economic growth	Average annual growth	Percentage	2.5	1.97	2.16
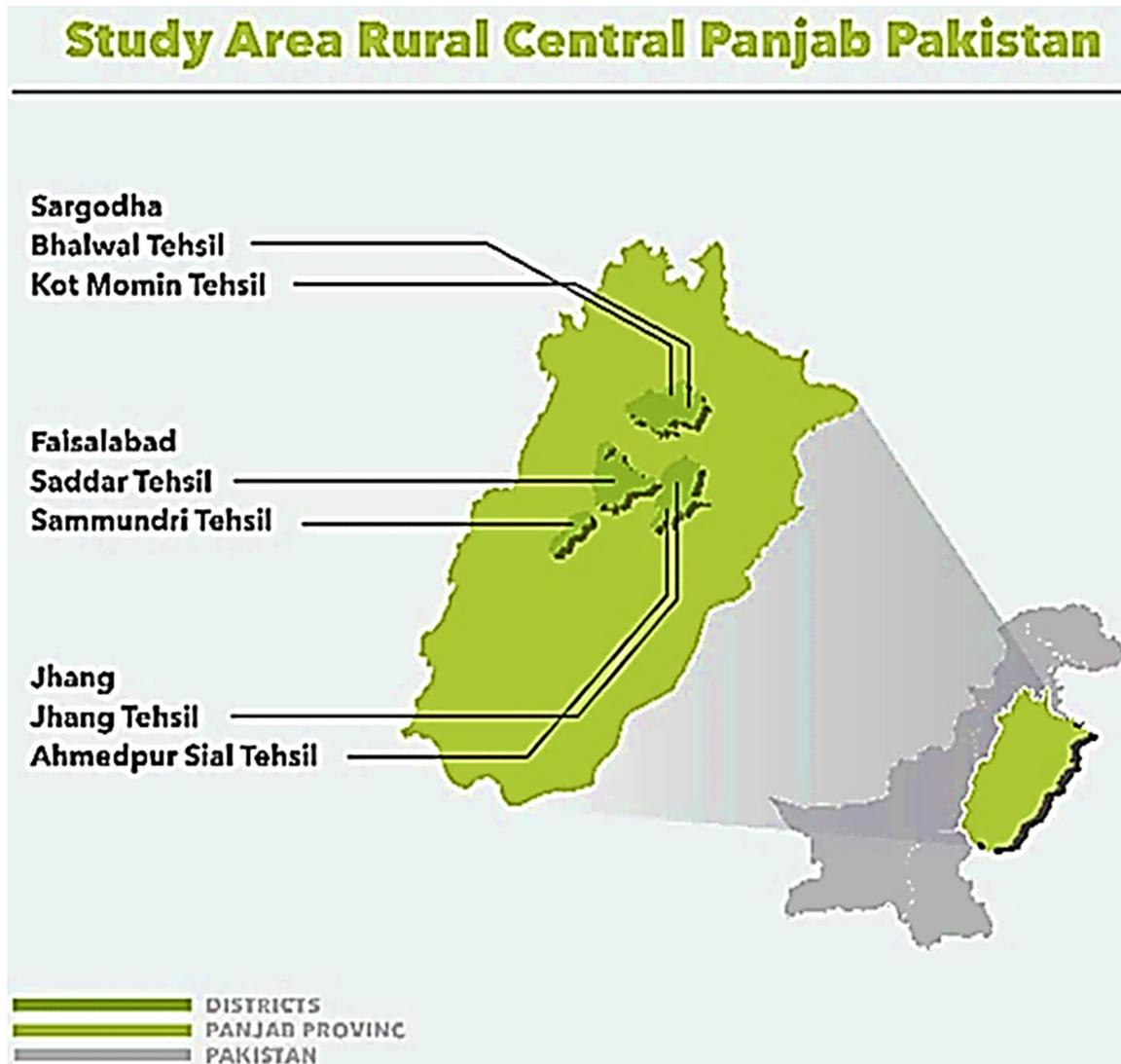
Figure 5. Study area of rural central Punjab in Pakistan [108]. Reproduced with permission from Springer.

In addition to fuel smoke, indoor smoking activities have caused harms to health as well as environmental issues [110]. Tobacco smoke (a secondhand smoke) caused major indoor pollution [111]. Naeem et al. [112] explored the indoor pollution due to tobacco smoke which caused hostile health effects in Lahore. The indoor smoking produced CO_2 emissions as well as other airborne pollutants. The studies were conducted on 208 individuals, out of which 90% were non-smokers, while 9.1% were active smokers. A total of 38% of indoor inhabitants claimed headaches, whereas 15–23% individuals suffered from coughing/sneezing and eye irritation due to indoor air pollutants' exposure.

Hence, tobacco smoke directly influenced the public health. Zaidi et al. [113] reported that secondhand smoke caused a noteworthy public health threat. A portable air quality monitoring device was used; the TSI SidePak AM510 Personal Aerosol Monitor (TSI, St Paul, MN, USA) with an air drawing pump. The aerosol monitor was fitted with the 2.5 μm impactor for measuring the PM concentrations, using the mass-Median aerodynamic diameter of ≤2.5 μg. The data were collected from 39 indoor restaurants, bars, and cafes. The high concentration of $PM_{2.5}$ ≤2.5 microns diameter was observed in tobacco smoke in Pakistan. The high level of $PM_{2.5}$ ~1745 μg/m^3 was obtained from smoking places, whereas the non-smoking zones had lower $PM_{2.5}$ levels (~101 μg/m^3). Moreover, the secondhand smoke caused cardiovascular and respiratory health risks [114,115].

The comparative analysis of the air quality of Pakistan and south-east Asian countries (India, Nepal, Sri Lanka, Bangladesh, and Bhutan) was performed [116]. The assessment was performed for CO, NO_2, SO_2, O_3, Pb, PM_{10}, and $PM_{2.5}$ pollutants. The WHO standards were considered for comparison. The air quality level of Pakistan was found higher than the WHO standards. As compared to Sri Lanka, Bangladesh, and Bhutan, the Pakistan air quality level was observed lower and needed improvement. Consequently, the implementation of IAQ policies for public health monitoring was observed indispensable in Pakistan. Table 2 depicts the comparative data of air quality in Pakistan as well as South Asian countries.

Table 2. Comparison of the air quality of Pakistan and South Asian countries [116]. Sustainable Development Policy Institute (open access).

Parameters (Time Average)	Pakistan	Air Quality Level for South Asia Countries (μg/m^3)					WHO Standard
		India	Nepal	Sri Lanka	Bangladesh	Bhutan	
Carbon Monoxide (CO) (8 h)	5	2	10,000	10,000	10	2000	Not Applicable
Nitrogen Dioxide (NO_2) (24 h)	80	80	80	100	Not given	Not given	Not Applicable
Sulphur Dioxide (SO_2) (24 h)	120	80	70	80	365	80	125
Ozone (O_3) (1 h)	130	180	Not given	200	235	Not given	150–200
Lead (Pb) (Annual)	1	0.50	0.5	Not given	0.5	Not given	0.5–1
Particulate Matter (PM10) (24 h)	150	100	120	100	150	100	50
Particulate Matter ($PM_{2.5}$) (24 h)	35	60	Not given	50	65	Not given	25

The air quality data trends of Pakistan, India, Nepal, Bangladesh, Bhutan, and Sri Lanka were analyzed. According to a careful analysis, the poor indoor air quality led to environmental, health, and sustainability issues in the South Asia countries [117]. In Pakistan, the mean annual exposure to $PM_{2.5}$ was 58.3 μg/m^3 (1990), which steadily increased to 60.34 μg/m^3 in 2017. The mean annual exposure to $PM_{2.5}$ in India was higher (81.3 μg/m^3) in 1990, which was further increased (90.9 μg/m^3) in 2017. Moreover, Nepal's exposure to $PM_{2.5}$ was highest among all countries (~99.7 μg/m^3) in 2017 (Figure 6). Hence, it can be concluded that the pollution exposure situation in Pakistan was worse than Bhutan and Sri Lanka, however, it was a little better than India and Bangladesh. However, the IAQ monitoring and regulatory standards need to be adopted in Pakistan.
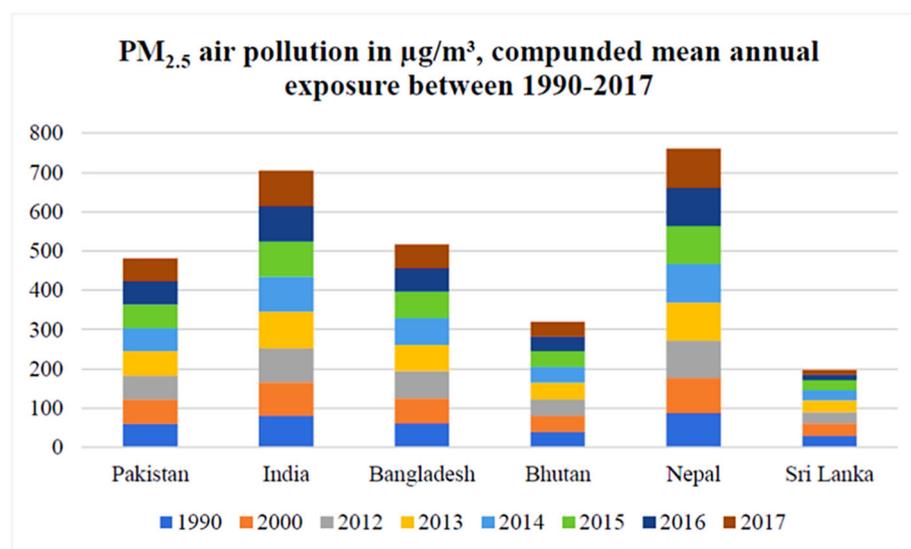
**Figure 6.** Population-weighted exposure to ambient PM$_{2.5}$ pollution expressed in μg/m^3 [117].

Additionally, building materials have been major sources of indoor PM, VOC, radioactivity, and other pollutants in Pakistan. The radioactive pollution was mainly released from building and decorating materials. The ceramic building materials and natural stones caused the radioactive pollution. Radon was also generated from the bricks, stones, concrete, and asbestos-based building materials [118]. Volatile toxins were released from decorating materials such as paints, dyes, carpet, etc. The floor boards and sticking panels were sources of formaldehyde pollution. All these pollutants were major causes of cancer risks [119]. The wall/floor/roof coatings and paints had VOC levels of ~50–100 g/L. In Azad Kashmir City of Pakistan, the radon (from soil, gravel, sands, and bricks) exhalation rate was observed in the range of 171–649 mBq m^{-2} h^{-1} [120]. In addition, the clinical and toxicological studies reported bacterial, fungal, and algal growth on the interior and exterior of buildings. Moreover, the microbes' colonization was detected on the stone/wall surfaces due to water, pH, and climatic factors. The resulting indoor PM, airborne particles, and bioaerosols caused several infectious and respiratory diseases. In Pakistan, the green building materials, low emissivity windows, as well as low VOC paints must be adopted for the ecofriendly and health purposes. Moreover, the cool bricks and fly ash bricks were suggested as the upcoming green materials in Pakistan [121].

3.3. Bioaerosols and Airborne Microflora in Residential Environments

The indoor air has been the main source of bioaerosols [122–124]. The bioaerosol concentrations in the indoor environments depend upon the building material, furniture, indoor inhabitants, and air from outside [125–127]. The indoor animals/pets in the rural and urban environments have produced bioaerosols in large amounts [128]. Mukhtar et al. [129] considered the bioaerosols (especially fungi) as hidden indoor killers in Pakistan. The genus Aspergillus of fungi was a predominant contaminant that caused serious health effects. This bioaerosol has been observed in numerous indoor buildings (houses, café, hospitals, laboratories) in Pakistan. Regular monitoring strategies have been required to investigate bioaerosol concentrations and health effects [130]. Nasir et al. [131] studied the bioaerosols in residential microenvironments in rural/urban sites. Among indoor bioaerosols, the Gram-negative bacteria and fungi were mainly detected [132]. The size distribution of the culturable indoor total bacteria, Gram-negative bacteria, and fungi was studied at the rural site. The six stage Andersen viable impactor was used for studying the indoor and outdoor bioaerosols. The impactor was designed for the particles of various size, shape, density, and aerodynamic size. The effects of humidity, temperature, and visible mold growth were recorded regarding human health and construction materials. The relative humidity and temperature were recorded using the Gasprobe IAQ 4 158 (BW Technologies

Ltd., Mississauga, ON, Canada). The indoor temperature was about 26–28 °C. The mean indoor relative humidity was in the range of 51–67%. The indoor bacteria concentration was found to be quite high at about 14,650 cfu/m^3. The size distribution of indoor bacteria was around 55–93%, that was higher than the indoor fungi [133]. The size distributions of indoor bacteria, Gram-negative bacteria, and fungi were also studied at the urban sites. High levels of the Gram-negative bacteria and fungi were observed [134]. Colbeck and co-workers [135] studied thirty residential houses in Lahore for indoor bioaerosols and PM levels. The indoor bioaerosols and PM were produced from cooking, cleaning, and smoking, along with the infiltrated outdoor air. The indoor air was simultaneously monitored in the kitchens and living rooms. The effect of ventilation on the IAQ level was observed for the change in indoor microenvironment per hour. High bioaerosol and PM$_{2.5}$ levels were observed during the winter season in Lahore. The low ventilation rates elevated the indoor bioaerosol and PM$_{2.5}$ levels.

Microflora have been a major source of toxins in the indoor environments [136,137]. Sidra et al. [138] monitored the microflora and PM in thirty houses in Lahore. The occurrences of airborne microorganisms and PM$_{2.5}$ were measured using the real time aerosol monitors (DustTrak model 8520; TSI Inc., Shoreview, MN, USA) in kitchens and living rooms. The temperature, relative humidity, and CO$_2$ levels were documented using the Gas probe IAQ (BW technologies). The temperature measured during the monitoring was about 18–37.8 °C, in the kitchens and living rooms. The average relative humidity levels were found to be around 20–75% in the kitchens and living rooms. Figure 7 demonstrates the percentage of different bacterial species detected in the kitchens and living rooms of different houses in Lahore.
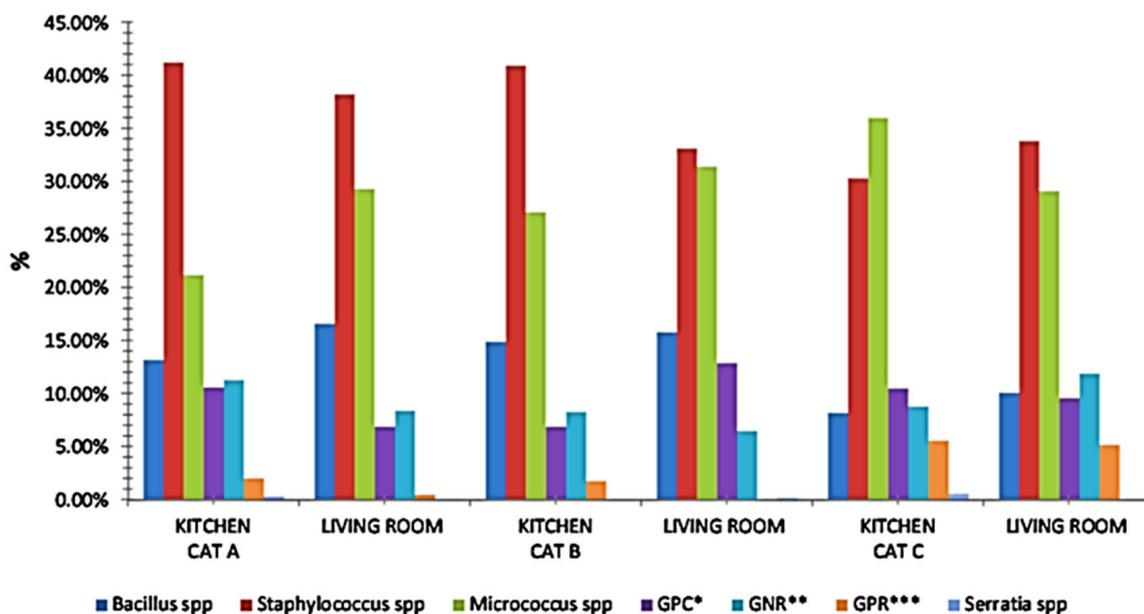
Figure 7. Percentage of bacterial species observed in kitchens and living rooms of different houses in Lahore [138]. Three housing categories were defined as follows: * = Small: $\leq$ 126.5 m^2; ** = Medium: > 126.5 m^2 to 253 m^2; *** = Large: > 253 m^2. Reproduced with permission from Research Repository.

The microflora concentrations in kitchens and living rooms were found in the range of 9829–14,469 cfu m^{-3}. The seasonal variations in the indoor microflora in kitchens and living rooms were observed. Out of 30 houses, the inhabitants in 16 houses revealed severe allergic reactions. The *Staphylococcus* spp. was found as a dominant bacterial species with about 37% and 35.4% concentrations in kitchens and living rooms, respectively. Hence, the bioaerosols and microflora were major sources, which caused the indoor pollution.

3.4. Low-Temperature Health Hazards

Pakistan lies in extreme temperate zones [139]. The Pakistani climate has wide variations between extreme hot and cold temperature conditions [140]. In urban areas, the building materials used affect the indoor temperature during winter/summer [141]. Likewise, the indoor thermal environment has been maintained in residential buildings through the roof thermal insulation [142]. Indoor air-conditioning and heating systems contributed to about 30% of indoor CO_2 emissions [137]. In rural areas in Peshawar, wood, mud bricks, leaves, and stones have been used as the raw building materials to maintain the comfortable indoor atmosphere. However, the indoor environment cannot be maintained in extremely cold rural areas such as Swat, Mansehra, Gilgit, etc. [143]. The cold weather has been found to be responsible for the indoor pollution due to the excessive fuel burning, less ventilation, as well as less cleaning possibilities. In the cold regions, the PM, CO, SOx, NOx, VOC, ozone, and lead were major indoor pollutants [144]. The air pollutant levels were found to be higher than the WHO safe standards [145]. In this contest, workplaces have been designed for cold environments and desired working conditions [146]. Subsequently, the indoor cold environments led to health hazards and low work productivity. The cold indoor environment caused health risks such as mental discomfort, respiratory, and skin complications [147]. In this case, safe heating systems must be used to maintain moderate indoor temperatures and to avoid the health effects. The indoor pollution control and monitoring systems must be utilized for attaining the safe IAQ levels [116].

4. Indoor Air Effluence Threats

4.1. Major Health Hazards of Indoor Air Contamination

As discussed in the previous sections, there are various sources of indoor pollution and potential pollutants in Pakistan. This section briefly summarizes probable health hazards due to the indoor pollution in Pakistan [148]. The pollutants have been generated from the indoor smoke of household fuels and smoking activities [149–151]. The pollutants from indoor fuels, tobacco, and dust include PM, COx, NOx, VOC, radon, ozone, flame retardants, bioaerosol, and microflora [152–154]. However, the health impacts of the indoor pollutants have been inadequately explored in the rural/urban locations. The influence of indoor $PM_{2.5}$, CO, polyaromatic hydrocarbons, and formaldehyde pollutants (indoor fuel and dust) have caused chronic respiratory symptoms, asthma, and breath shortening [155]. For this purpose, the 8-channel indoor air quality monitor was used. Furthermore, continuous indoor exposure to these pollutants has produced cardiovascular mortality [156]. Farah et al. [157] studied the rural areas of Faisalabad. The 240 indoor inhabitants studied were focused on including the men and women. The health risks due to biomass fuel emissions involved breathing problems (60%), coughing (70%), asthma (38%), eye irritation (43%), allergies (33%), lung cancer (6%), along with other health issues. Here, the appropriate kitchen locations, lower cooking durations, safe fuel types, and pollution-free stoves have minimized the indoor air pollution. Kouser and Munir [158] investigated the acute respiratory infections due to indoor air pollution. The studies were carried out on community-level women and children under five years. The PM concentrations in the indoor air were responsible for the respiratory infections. The household fuel was suggested to be replaced with the safe energy sources, which prevented the health issues in indoor inhabitants [159].

Tariq et al. [160] reported that $PM_{2.5}$, formaldehyde, and CO were responsible for chronic respiratory diseases such as breath shortening, bronchitis, and asthma in Karachi. Aslam et al. [161] scrutinized the effects of indoor polychlorinated biphenyls on human health in the Pakistani population. The pollutants were inhaled or ingested through the indoor air. The polychlorinated biphenyls were found to cause a high cancer risk of about 4.32×10^{-4} to the indoor inhabitants. Khan et al. [162] investigated the damaging effects of flame retardants (indoor dust) on human health in rural and industrial inhabitants. The indoor flame retardants caused cardiac, respiratory, and carcinogenic effects [163,164]. Hamid et al. [165] studied the polyaromatic hydrocarbon in Rawalpindi and Islamabad,

cities of Pakistan. The high polyaromatic hydrocarbon concentrations of about 2132 pgm^{-3} (air) and ~90.0 ng·g^{-1} (dust) were observed. The indoor air and dust directly entered the human body through inhalation, which caused the respiratory system ailments and cancer risks [166]. The sustainable indoor fuels were suggested to meet the energy necessities and to lower the polyaromatic hydrocarbon generation [167]. Rafique et al. [168] studied radon in the indoor, enclosed residential houses. The radioactive radon concentrations increased the risk of lung cancer in the 35–55 years old population. The investigations of the indoor air pollutants and diseases provide the baseline data in Pakistan for taking further steps by the government/agencies and policy interventions.

4.2. Impact of Interior Physical Environment on Productivity of Indoor Workers/Academicians

Human productivity has been associated with indoor air pollution [169–171]. Saleem et al. [172] studied the indoor population in the higher education institutes of the Khyber Pakhtunkhwa in Pakistan. The institutes from Abbottabad, Peshawar, Mansehra, and Hazara were selected for the indoor air pollution investigations. It was observed that the building designs with the optimum ventilation, temperature comfort, as well as pollution monitoring contributed better towards the high indoor productivity of the academicians/workers. Cao et al. [72] discovered that the office dust contains high concentrations of toxic brominated or phosphorated flame retardants, which affected human health and workers' productivity. The mean concentrations of flame retardants in the offices were observed as high around 128,000 ng·g^{-1}, which caused the serious health effects. In the same way as other indoor pollutants, the dust particle concentration follows the seasonal order of winter > autumn > summer. Kamal et al. [173] investigated the effects of polycyclic aromatic hydrocarbons on the health and work efficiency of the auto-repairing and petroleum refinery workers. The high concentrations of polycyclic aromatic hydrocarbons were detected in white blood cells of the workers, which reduced the working efficiency and caused the lifetime cancer risks [174]. Lin et al. [175] measured the polyfluoroalkyl substances in the populations of northwestern Pakistan and western Afghanistan areas. The perfluoro butanoic acid was found as the major constituent of polyfluoroalkyl. The inhalation of polyfluoroalkyl in northwestern Pakistan and western Afghanistan areas was in the range of 0.07–3.98 and 0.01–0.33 pg/kg bw/d, respectively. The populations in both the countries revealed high carcinogenic effects.

4.3. Indoor Pollution in Hospital Environment

In Pakistan, the indoor pollution in the hospital environment has affected the work productivity of the doctors/nursing staff and the health of patients [176–178]. However, very few studies have been reported in this respect. Nimra et al. [179] correlated the airborne PM in operating theatres with the infection probability in patients. To study the effects of airborne PM on indoor air quality and patients' health, various sensing devices have been used. The PM$_{2.5}$ in air was monitored using the real time aerosol monitor (DustTrak, Model 8520, TSI Inc.). In addition, the CO$_2$, CO, temperature, and relative humidity were monitored using the Gas Probe (BW technologies). In operating theatres, the DustTrak DRX Aerosol Monitor (Model 8533, TSI Inc.) was utilized for sampling. The studies were conducted in two major hospitals of Lahore, i.e., Services Hospital and Shalamar Hospital. In the orthopedic operating theatres, the high PM concentrations in the range of 757–970 µg/m^3 were observed. Such high PM concentrations caused repeated infections in the patients who underwent operations. In this situation, the vertical laminar air-flow ventilation was used for cleaning the indoor air. In addition, the operation theater cleaning, personal hygiene, building age, and pollutant infiltration played important roles in maintaining the healthy indoor air quality in the hospitals to prevent infections/diseases [180].

5. Harmful Effects of the Indoor Pollution

- Around 2.4 billion people worldwide (i.e., one-third of the global population) use open fires and stoves fueled by the biomass (wood, animal dung, crop, etc.), coal,

and kerosene for cooking. These burning activities produce several harmful indoor air pollutants [181].

- The indoor air pollution has been responsible for >4 million deaths per year, including over 2 million deaths of children (under 5 years) [20].
- The effects of indoor pollution were observed in the form of >6 million premature deaths per annum [20].
- The indoor air pollution has led to diseases such as pulmonary infections, lung cancer, strokes, heart diseases, chronic lung diseases, and so on [182,183].
- Women and children seem to be more influenced by indoor cooking activities, which have caused great health effects [184].
- The Environmental Protection Agency (EPA) refers to the IAQ within and around buildings. According to the EPA, the indoor pollution can cause major environmental risks to the public health. The common indoor pollutants include CO, radon, pests, dust, mites, lead, smoke, bacteria, bioaerosols, etc., in addition to the increased humidity and precipitation levels.
- The indoor pollutants have caused short term effects such as eye irritation, nasal itching, throat rashes, headaches, fatigue, dizziness, asthma symptoms, etc. However, the long-term effects due to chronic exposure to indoor pollutants include the respiratory/heart diseases, as well as cancer effects.
- According to a careful estimate, acute lung cancer risks of ~6% have been reported in the adult population due to unhealthy fuel usage [157].
- According to a study in Pakistan, using unhealthy indoor fuels and living rooms with attached kitchens produced a child mortality rate of about 145 deaths/1000 live births [103]. On the other hand, houses using clean fuel or separate kitchens have ~10 deaths/1000 live births. Moreover, up to 80 deaths/1000 women have been reported because of indoor kitchen fuels [185]. Comparatively, the male population was found to be less affected.
- In this concern, using clean fuels and safe indoor burning sources can reduce the indoor pollution to protect from health hazards. As per the WHO guidelines, safe fuels include solar energy, electricity, biogas, natural gas, and liquefied petroleum gas, which minimize the environmental pollution [186].

6. Indoor Air Quality Management and Challenges on Monitoring/Regulating IAQ in Pakistan

According to an analysis of IAQ levels of Pakistan and south-east Asian countries, the policy implementations have been found indispensable for maintaining the public health [187]. In this context, the real-time monitoring stations have been installed across the main cities of Pakistan such as Islamabad, Lahore, Karachi, and Peshawar, and the measured air quality levels were uploaded on the open access website [188]. Figure 8 displays the locations of the monitoring stations. The PM$_{2.5}$ hourly real-time data were obtained from the official website. The image detection-based air quality research was performed through image processing and machine learning methods. In this method, the color of the sky can vary the PM$_{2.5}$ and PM$_{10}$ concentration detection using the visual camera images. Subsequently, the sensitivity was high and found to be affected by the weather conditions. In day time, high resolution camera images can be obtained. However, the image quality was compromised in the evening and night times. It was found difficult to access the remote areas with camera devices. On the other hand, the satellite images more effectively accessed the air quality situation. The indoor air cleaning set-ups have been designed and installed in offices, corporate spaces, and urban houses in Pakistan. The installation of air cleaning units can reduce the indoor dust pollution, VOC, and PM, which enhance the worker's productivity [189,190]. There has been an increasing need to educate the public regarding indoor pollution and installing air monitoring units in Pakistan [191,192].

Figure 8. Study area and distribution of monitoring stations [188].

Table 3 presents the situation of indoor pollutants in rural and urban areas of Pakistan. Currently, the indoor air pollution scenarios include the sources, pollutants, and reasonable solutions desirable for controlling the contamination conditions. One important solution has been the use of renewable energy sources [193–195]. The solar power plants have been used in the Punjab, Sind, Baluchistan, and Kashmir regions in Pakistan [196]. The employment of solar energy plants can fulfil the current energy crises in Pakistan [197]. Using indoor ventilation systems can also reduce indoor air pollution levels [198].

Table 3. Indoor pollutants, sources, and health effects in various rural and urban areas of Pakistan.

Region in Pakistan	Indoor Setting	Source	Pollutant	Concentration	Health Hazards	Ref.
Lahore	Living area	Traffic/seasonal changes	$PM_{2.5}$	>25 $\mu g/m^3$	Not reported	[49]
Karachi	Restaurants/cafés/clubs	Indoor smoking; heating; cooking; hospitality	$PM_{2.5}$	25–390 $\mu g/m^3$	Not reported	[54]
Rural areas of Pakistan	Living area/Kitchen	Use of biomass fuel; indoor cooking	PM_{10}, $PM_{2.5}$, PM_1	4000–8555 $\mu g/m^3$	Not reported	[59]

Table 3. *Cont.*

Region in Pakistan	Indoor Setting	Source	Pollutant	Concentration	Health Hazards	Ref.
Rural and urban areas of Pakistan	Living area/Kitchen	Indoor biomass burning	$PM_{2.5}$, PM_{10}	PM_{10} (>50 µg/m^3); $PM_{2.5}$ (>25 µg/m^3)	Not reported	[61]
Haripur city	Living area/Kitchen	Outside traffic	$PM_{2.5}$, PM_{10}	$PM_{2.5}$ 23.7–126.0 µg/m^3; PM_{10} 39.0–166.3 µg/m^3;	Not reported	[65]
Lahore	Living area/Kitchen	Outside air due to industrial and traffic pollution	$PM_{2.5}$, PM_{10}, CO, NO_2, SO_2, O_3	Not reported	64% of asthma patients	[66]
Northern Pakistan	Living area/Kitchen	Brick kilns	PM_1, $PM_{2.5}$, and PM_{10}	PM_1, $PM_{2.5}$, and PM_{10} concentrations 3377, 2305, and 3567.67 µg/m^3, respectively.	Not reported	[67]
Rural areas	Living area/Kitchen	Indoor dust exposure/ingestion	Polybrominated diphenyl ether, polychlorinated biphenyl, tri-(2-butoxyethyl) phosphate, triphenyl phosphate	~15.2 ng/kg bw/day	Not reported	[73]
Lahore, Faisalabad, Bahawalnagar	Living area/Kitchen	Indoor dust; polychlorinated biphenyl concentrations	Polychlorinated biphenyls	~34.39 ng/g, 9.94 ng/g, and 8.79 ng/g in Lahore, Faisalabad, Bahawalnagar, respectively	Not reported	[75]
Rural regions	Living area/Kitchen	Unhealthy fuel (wood, crop residues, charcoal, coal, kerosene, and animal dung)	Exposure to CO_2, CO	Not reported	Respiratory infections in children	[100]
Rural regions	Living area/Kitchen	Indoor biomass; fuel burning	PM, CO_2, CO	PM level 200–5000 µg/m^3 carbon monoxide (CO) level ~29.4 ppm	Not reported	[104]
Bungalows and apartments	Living area/Kitchen	Gas-fired kitchens	CO	CO concentrations in the range 2.13–5.29 ppm	Not reported	[106]
Lahore	Living area/Kitchen	Tobacco smoke	PM; CO_2 emissions	Not reported	Coughing/ sneezing; eye irritation	[112]
Pakistan cities	Indoor restaurants, bars, and cafes	Indoor smoking	PM, CO_2 emissions	High $PM_{2.5}$ level ~1745 µg/m^3	Not reported	[113]

Table 3. *Cont.*

Region in Pakistan	Indoor Setting	Source	Pollutant	Concentration	Health Hazards	Ref.
Urban/Rural areas	Living area/Kitchen	Indoor bacteria	Bioaerosols	Concentration high i.e., 14,650 cfu/m^3	Not reported	[131]
Lahore	Kitchens and living rooms	Microflora concentrations	Microflora	~9829–14,469 cfu m^{-3}	Not reported	[138]
Rawalpindi and Islamabad	Living area/Kitchen	Indoor air	Polyaromatic hydrocarbon	~2132 pgm^{-3}; in dust ~90.0 ng·g^{-1}	Respiratory system/cancer risks	[165]
Urban areas	Offices	Indoor air	Brominated or phosphorated flame retardants	Flame retardants concentration 128,000 ng·g^{-1}	Loss of indoor working productivity	[72]
Lahore	Hospitals; operating theatres	Indoor air	PM	PM concentrations 757–970 µg/m^3	Repeated infections in patients	[179]

Using air-conditioners can easily clean the indoor air [199–201]. The air-conditioner filters have been used to filter dust in Lahore [202]. The air-conditioners can also filter the organochlorine pesticides [203]. In this way, the organochlorine pesticides concentration in the range of 7.53–1272.87 ng/g can be settled. The indoor setting of the organochlorine pesticide pollutants has been found to cause a lifetime cancer risk [204]. Moreover, the residential, schools, and office building designs must be reconsidered to avoid the pollution sources and to improve the IAQ levels. Poverty has also greatly contributed to the choice of indoor fuel and indoor air pollution [205]. Therefore, the collective efforts of individuals, industries, and local governments have been desirable in Pakistan for improving the economic conditions of the rural inhabitants. The Pakistani government must facilitate individuals and local governments for creating awareness among the rural population for using safe indoor fuel.

7. Need of Industry–Academia–Research Cooperation to Support Indoor Air Pollution Control

In Pakistan, people living in rural and semi-urban areas are not much aware of indoor air pollution problems. In particular, there is no knowledge about harmful indoor cooking vapors, indoor PM, dust, smoking, germs, aerosols, radon, etc., in the rural population. The academic people can play an important role for the public awareness regarding indoor pollutants and their better cultural habits. In order to control the indoor air pollution and to avoid harmful effects, the immediate education and awareness is desirable in the rural areas in Pakistan. As discussed in the above sections, stove burning using unhealthy fuels has been reported as a major source of indoor pollution. There is a complete lack of awareness in the population about using safe indoor fuels and taking necessary cleaning and ventilation steps. The academics can conduct planned visits to such areas and deliver their knowledge to keep the healthy indoor environments and cultural awareness. In developing countries such as Pakistan, there should be educational and awareness camps regarding the indoor air pollution to educate the common public. Such efforts will make Pakistan a healthier place to live safely for the next several generations.

In Pakistan, only a few government/non-government organizations and academic institutes have been found working to improve the indoor air quality situation using advanced monitoring strategies, policy interventions, as well as adopting renewable energy technologies [206]. The theoretical models must be developed for establishing strong links between the indoor air quality management, academic/research institutes, along with the desired policy interventions in Pakistan.

We think that the role of academia is important for interpreting the fundamental science involved in the pollution sources and generation. The research institutions in Pakistan can further explore the impacts of indoor pollutants and monitoring strategies. Accordingly, the government organizations must develop work plans, collate databases, and engage policymakers for the efficient solutions. Furthermore, the local and private organizations can be involved in approving the indoor environmental management legislation and for providing incentives for setting up mechanisms for indoor environmental protection. The active communications between different stakeholders and government organizations are needed for the active policy implementations. Moreover, the government organizations and research institutes must conduct the long-term planned studies in various rural and urban areas of Pakistan to estimate current and changing pollutant concentrations in the indoor environments. The long-term studies on the health effects of indoor air pollution also need to be performed. According to our analysis, the proper conferences and policy developments by Pakistani stakeholders are required to define the action agenda to control, monitor, and regulate the IAQ levels and human health. The public awareness of using safe fuel, heating systems, and IAQ monitoring/regulation systems have been found to be indispensable in the rural/urban areas of Pakistan [207–209]. Hence, the overall IAQ situation can be improved through the serious involvement of individuals, local/private organizations, as well as academic and research institutions.

8. Conclusions

In this review, the overall situation of the indoor pollution in rural and urban areas of Pakistan has been described considering the pollutant type, indoor pollution sources, exposure level, and health hazards. Cooking, combustion, and burning have been identified as the major sources of the emission of indoor pollutants. Additionally, indoor smoking and dust also produce airborne toxins. In this context, the major indoor pollutants include PM, COx, NOx, VOC, bioaerosols, microflora, flame retardants, and other airborne, noxious organic compounds. The indoor air pollutants cause several harmful health effects. Therefore, strategies are required for developing and implementing the IAQ level enhancement strategies. The construction materials such as paints, coatings, floors, furniture, etc., must be developed using safe and inert materials emitting low VOC and indoor pollutants. Indoor garages must be built outdoors to minimize the indoor CO pollution. In addition, the indoor surfaces must be kept clean and dry to prevent moisture, germs, and bacteria. For controlling and managing indoor pollution, the indoor ventilation systems must be used. However, the ventilation cannot completely remove PM, VOC, toxic gases, and microorganisms in the air. The outdoor air infiltration is also a source of indoor pollutants. Thus, the advanced IAQ technologies such as filtration, adsorption, UV photocatalyst, indoor green plants, etc., must be adopted to minimize the indoor pollution. For IAQ monitoring, the advanced sensors may result in the removal of indoor pollutants. Among various pollutants, the PM such as PM_1, $PM_{2.5}$, and PM_{10} have been observed as major toxins emerging from indoor fuels, heating, and smoking sources. Consequently, the PM concentrations were found high ~10,000 $\mu g/m^3$ in the indoor living places in Pakistan. The indoor PM pollutants affected the respiratory, pulmonary, cardiac, as well as nervous systems, which increased the cancer and mortality risks in adults. Furthermore, indoor dust has been found as a major source of airborne flame retardants. Subsequently, the ingestion of airborne flame retardants was found to be high at ~35 ng/g. The indoor microflora concentration was also detected as high in the range of 10,000–15,000 cfu m^{-3}. The indoor flame retardants and microflora caused cancer and respiratory ailments in children and adults. The poor IAQ can also affect the work productivity in offices, work places, and academic buildings. In rural areas, the unsafe indoor fuels need to be replaced with efficient and less polluting fuels. Moreover, the residential designs and building materials need to be improved to minimize indoor pollution.

In our view, the indoor air pollution issues can be prevented through the public awareness and practical guidance to manage the safe IAQ levels. In this respect, immediate

management practices must be adopted. It has been found to be extremely important to learn the principles for keeping the good indoor air quality. The maintenance of healthy and comfortable indoor environments demands urgent integration of monitoring and control systems along with the adaptations of indoor air quality standards. The buildings must be reassembled to attain good IAQ management practices. Creating necessary action plans can improve the IAQ and reduce IAQ problems. In this way, health risks can be minimized and indoor comfort and productivity can be increased. For attaining the safe indoor environment, there has been a strong need for long-term pollution studies, IAQ monitoring devices, government/agencies' involvement, policy making, interventions, as well as a role for academia–industry links. These efforts can open future ways towards a safe, healthy, and ecological indoor environment in Pakistan.

References

1. Kausar, A.; Ahmad, I.; Zhu, T.; Shahzad, H.; Eisa, M. Exigency for the Control and Upgradation of Indoor Air Quality—Forefront Advancements Using Nanomaterials. *Pollutants* **2023**, *3*, 123–149. [CrossRef]
2. Zeng, Y.; Laguerre, A.; Gall, E.T.; Heidarinejad, M.; Stephens, B. Experimental Evaluations of the Impact of an Additive Oxidizing Electronic Air Cleaner on Particles and Gases. *Pollutants* **2022**, *2*, 98–134. [CrossRef]
3. Dwivedi, S.; Taushiba, A.; Zehra, F.; Gupta, S.K.; Lawrence, A. Revelations to Indoor Air Pollutants and Health Risk Assessment on Women: A case study. *Hyg. Environ. Health Adv.* **2022**, *5*, 100038. [CrossRef]
4. Amen, N.-E.; Eqani, S.A.M.A.S.; Bilal, K.; Ali, N.; Rajeh, N.; Adelman, D.; Shen, H.; Lohmann, R. Molecularly tracing of children exposure pathways to environmental organic pollutants and the Autism Spectrum Disorder Risk. *Environ. Pollut.* **2022**, *315*, 120381. [CrossRef]
5. Imran, M.; Khan, S.; Nassani, A.A.; Haffar, M.; Zaman, K. Access to sustainable healthcare infrastructure: A review of industrial emissions, coal fires, and particulate matter. *Environ. Sci. Pollut. Res.* **2023**, *30*, 69080–69095. [CrossRef]
6. Khan, W.A.; Shah, S.A.; Khan, A. In Pakistan, the Transport and Urban Air Pollution Impacts on Human Health and Practical Steps to Avoid Them: A Review. *J. Int. Coop. Dev.* **2022**, *5*, 20. [CrossRef]
7. Udaipurwala, I.H. Air Pollution and Health Hazards: A Menacing Situation in Pakistan. *J. Bahria Univ. Med. Dent. Coll.* **2022**, *12*, 66–67. [CrossRef]
8. Imran, M.; Khan, S.; Zaman, K.; Khan, H.U.R.; Rashid, A. Assessing Green Solutions for Indoor and Outdoor Environmental Quality: Sustainable Development Needs Renewable Energy Technology. *Atmosphere* **2022**, *13*, 1904. [CrossRef]
9. Lolli, F.; Marinello, S.; Coruzzolo, A.M.; Butturi, M.A. Post-Occupancy Evaluation's (POE) Applications for Improving Indoor Environment Quality (IEQ). *Toxics* **2022**, *10*, 626. [CrossRef]
10. Lolli, F.; Coruzzolo, A.M.; Marinello, S.; Traini, A.; Gamberini, R. A Bibliographic Analysis of Indoor Air Quality (IAQ) in Industrial Environments. *Sustainability* **2022**, *14*, 10108. [CrossRef]
11. Kausar, A. Progress in green nanocomposites for high-performance applications. *Mater. Res. Innov.* **2021**, *25*, 53–65. [CrossRef]
12. Kausar, A.; Ahmad, I.; Maaza, M.; Eisa, M.; Bocchetta, P. Polymer/Fullerene Nanocomposite for Optoelectronics—Moving toward Green Technology. *J. Compos. Sci.* **2022**, *6*, 393. [CrossRef]
13. Kausar, A.; Ahmad, I.; Maaza, M.; Eisa, M. State-of-the-Art Nanoclay Reinforcement in Green Polymeric Nanocomposite: From Design to New Opportunities. *Minerals* **2022**, *12*, 1495. [CrossRef]
14. Hou, S.; Tang, Y.; Zhu, T.; Huang, Z.-H.; Liu, Y.; Sun, Y.; Li, X.; Shen, F. The molecular simulation and experimental investigation of toluene and naphthalene adsorption on ordered porous silica. *Chem. Eng. J.* **2022**, *435*, 134844. [CrossRef]
15. Hou, S.; Tang, Y.; Zhu, T.; Huang, Z.-H.; Liu, Y.; Sun, Y.; Li, X.; Shen, F. Adsorptive removal of gas phase naphthalene on ordered mesoporous carbon. *J. Hazard. Mater.* **2022**, *436*, 129208. [CrossRef]
16. Hou, S.; He, S.; Zhu, T.; Li, J.; Ma, L.; Du, H.; Shen, W.; Kang, F.; Huang, Z.-H. Environment-friendly preparation of exfoliated graphite and functional graphite sheets. *J. Mater.* **2021**, *7*, 136–145. [CrossRef]
17. Mata, T.M.; Martins, A.A.; Calheiros, C.S.; Villanueva, F.; Alonso-Cuevilla, N.P.; Gabriel, M.F.; Silva, G.V. Indoor Air Quality: A Review of Cleaning Technologies. *Environments* **2022**, *9*, 118. [CrossRef]
18. Colbeck, I.; Nasir, Z.A.; Ali, Z. The state of indoor air quality in Pakistan—A review. *Environ. Sci. Pollut. Res.* **2010**, *17*, 1187–1196. [CrossRef]

19. Pluschke, P.; Schleibinger, H. *Indoor Air Pollution*; Springer: Berlin/Heidelberg, Germany, 2018.

20. Amegah, A.K.; Jaakkola, J.J. Household air pollution and the sustainable development goals. *Bull. World Health Organ.* **2016**, *94*, 215. [CrossRef]

21. Mata, T.M.; Felgueiras, F.; Martins, A.A.; Monteiro, H.; Ferraz, M.P.; Oliveira, G.M.; Gabriel, M.F.; Silva, G.V. Indoor air quality in elderly centers: Pollutants emission and health effects. *Environments* **2022**, *9*, 86. [CrossRef]

22. Peng, Z.; Deng, W.; Tenorio, R. Investigation of indoor air quality and the identification of influential factors at primary schools in the North of China. *Sustainability* **2017**, *9*, 1180. [CrossRef]

23. Liang, J. *Chemical Modeling for Air Resources: Fundamentals, Applications, and Corroborative Analysis*; Academic Press: Cambridge, MA, USA, 2013.

24. Gopalakrishnan, P.; Kavinraj, M.; Vivekanadhan; Jeevitha, N. *Effect of Indoor Air Quality on Human Health—A Review*; AIP Publishing LLC: New York, NY, USA, 2021; p. 030005.

25. Norris, C.L.; Edwards, R.; Ghoroi, C.; Schauer, J.J.; Black, M.; Bergin, M.H. A pilot study to quantify volatile organic compounds and their sources inside and outside homes in urban India in summer and winter during normal daily activities. *Environments* **2022**, *9*, 75. [CrossRef]

26. Li, C.; Zhu, Q.; Jin, X.; Cohen, R.C. Elucidating Contributions of Anthropogenic Volatile Organic Compounds and Particulate Matter to Ozone Trends over China. *Environ. Sci. Technol.* **2022**, *56*, 12906–12916. [CrossRef] [PubMed]

27. Zhang, G.; Xu, H.; Qi, B.; Du, R.; Gui, K.; Wang, H.; Jiang, W.; Liang, L.; Xu, W. Characterization of atmospheric trace gases and particulate matter in Hangzhou, China. *Atmos. Chem. Phys.* **2018**, *18*, 1705–1728. [CrossRef]

28. Villanueva, F.; Ródenas, M.; Ruus, A.; Saffell, J.; Gabriel, M.F. Sampling and analysis techniques for inorganic air pollutants in indoor air. *Appl. Spectrosc. Rev.* **2022**, *57*, 531–579. [CrossRef]

29. Zhu, Y.; Wei, Z.; Yang, X.; Tao, S.; Zhang, Y.; Shangguan, W. Comprehensive control of PM 2.5 capture and ozone emission in two-stage electrostatic precipitators. *Sci. Total Environ.* **2022**, *858*, 159900. [CrossRef]

30. Andersen, C.; Omelekhina, Y.; Rasmussen, B.B.; Nygaard Bennekov, M.; Skov, S.N.; Køcks, M.; Wang, K.; Strandberg, B.; Mattsson, F.; Bilde, M. Emissions of soot, PAHs, ultrafine particles, NOx, and other health relevant compounds from stressed burning of candles in indoor air. *Indoor Air* **2021**, *31*, 2033–2048. [CrossRef]

31. Kureshi, R.R.; Thakker, D.; Mishra, B.K.; Ahmed, B. Use Case of Building an Indoor Air Quality Monitoring System. In *Use Case of Building an Indoor Air Quality Monitoring System*; IEEE: Piscataway, NJ, USA, 2021; pp. 747–752.

32. Mehmood, T.; Zhu, T.; Ahmad, I.; Li, X. Ambient PM2. 5 and PM10 bound PAHs in Islamabad, Pakistan: Concentration, source and health risk assessment. *Chemosphere* **2020**, *257*, 127187. [CrossRef]

33. Chen, Y.; Lv, D.; Li, X.; Zhu, T. PM2. 5-bound phthalates in indoor and outdoor air in Beijing: Seasonal distributions and human exposure via inhalation. *Environ. Pollut.* **2018**, *241*, 369–377. [CrossRef]

34. Han, Y.; Li, X.; Zhu, T.; Lv, D.; Chen, Y.; Hou La Zhang, Y.; Ren, M. Characteristics and relationships between indoor and outdoor PM2. 5 in Beijing: A residential apartment case study. *Aerosol Air Qual. Res.* **2016**, *16*, 2386–2395. [CrossRef]

35. Sá, J.P.; Branco, P.T.; Alvim-Ferraz, M.C.; Martins, F.G.; Sousa, S.I. Radon in Indoor Air: Towards Continuous Monitoring. *Sustainability* **2022**, *14*, 1529. [CrossRef]

36. López, L.; Dessì, P.; Cabrera-Codony, A.; Rocha-Melogno, L.; Kraakman, B.; Naddeo, V.; Balaguer, M.; Puig, S. CO2 in indoor environments: From environmental and health risk to potential renewable carbon source. *Sci. Total Environ.* **2022**, *856*, 159088. [CrossRef]

37. Ubando, A.T.; Africa, A.D.M.; Maniquiz-Redillas, M.C.; Culaba, A.B.; Chen, W.-H. Reduction of particulate matter and volatile organic compounds in biorefineries: A state-of-the-art review. *J. Hazard. Mater.* **2021**, *403*, 123955. [CrossRef]

38. Zhang, Y.; Shen, F.; Yang, Y.; Niu, M.; Chen, D.; Chen, L.; Wang, S.; Zheng, Y.; Sun, Y.; Zhou, F. Insights into the Profile of the Human Expiratory Microbiota and Its Associations with Indoor Microbiotas. *Environ. Sci. Technol.* **2022**, *56*, 6282–6293. [CrossRef]

39. Zhou, F.; Niu, M.; Zheng, Y.; Sun, Y.; Wu, Y.; Zhu, T.; Shen, F. Impact of outdoor air on indoor airborne microbiome under hazy air pollution: A case study in winter Beijing. *J. Aerosol Sci.* **2021**, *156*, 105798. [CrossRef]

40. Niu, M.; Shen, F.; Zhou, F.; Zhu, T.; Zheng, Y.; Yang, Y.; Sun, Y.; Li, X.; Wu, Y.; Fu, P. Indoor air filtration could lead to increased airborne endotoxin levels. *Environ. Int.* **2020**, *142*, 105878. [CrossRef]

41. Figueiredo, D.M.; Duyzer, J.; Huss, A.; Krop, E.J.; Gerritsen-Ebben, M.; Gooijer, Y.; Vermeulen, R.C. Spatio-temporal variation of outdoor and indoor pesticide air concentrations in homes near agricultural fields. *Atmos. Environ.* **2021**, *262*, 118612. [CrossRef]

42. Li, T.; Yu, Y.; Sun, Z.; Duan, J. A comprehensive understanding of ambient particulate matter and its components on the adverse health effects based from epidemiological and laboratory evidence. *Part. Fibre Toxicol.* **2022**, *19*, 67. [CrossRef]

43. Duarte, R.M.; Gomes, J.F.; Querol, X.; Cattaneo, A.; Bergmans, B.; Saraga, D.; Maggos, T.; Di Gilio, A.; Rovelli, S.; Villanueva, F. Advanced instrumental approaches for chemical characterization of indoor particulate matter. *Appl. Spectrosc. Rev.* **2022**, *57*, 705–745. [CrossRef]

44. Ilacqua, V.; Scharko, N.; Zambrana, J.; Malashock, D. Survey of residential indoor particulate matter measurements 1990–2019′. *Indoor Air* **2022**, *32*, e13057. [CrossRef]

45. Busenkell, E.; Collins, C.M.; Moy, M.L.; Hart, J.E.; Grady, S.T.; Coull, B.A.; Schwartz, J.D.; Koutrakis, P.; Garshick, E. Modification of associations between indoor particulate matter and systemic inflammation in individuals with COPD. *Environ. Res.* **2022**, *209*, 112802. [CrossRef] [PubMed]

46. Ścibor, M.; Balcerzak, B.; Galbarczyk, A.; Targosz, N.; Jasienska, G. Are we safe inside? Indoor air quality in relation to outdoor concentration of PM10 and PM2. 5 and to characteristics of homes. *Sustain. Cities Soc.* **2019**, *48*, 101537. [CrossRef]

47. Elbayoumi, M.; Ramli, N.A.; Yusof, N.F.F.M.; Yahaya, A.S.B.; Al Madhoun, W.; Ul-Saufie, A.Z. Multivariate methods for indoor PM10 and PM2. 5 modelling in naturally ventilated schools buildings. *Atmos. Environ.* **2014**, *94*, 11–21. [CrossRef]

48. Tasić, V.; Jovašević-Stojanović, M.; Vardoulakis, S.; Milošević, N.; Kovačević, R.; Petrović, J. Comparative assessment of a real-time particle monitor against the reference gravimetric method for PM10 and PM2. 5 in indoor air. *Atmos. Environ.* **2012**, *54*, 358–364. [CrossRef]

49. Anjum, M.S.; Ali, S.M.; Subhani, M.A.; Anwar, M.N.; Nizami, A.-S.; Ashraf, U.; Khokhar, M.F. An emerged challenge of air pollution and ever-increasing particulate matter in Pakistan; a critical review. *J. Hazard. Mater.* **2021**, *402*, 123943. [CrossRef]

50. Leffel, B.; Tavasoli, N.; Liddle, B.; Henderson, K.; Kiernan, S. Metropolitan air pollution abatement and industrial growth: Global urban panel analysis of PM10, PM2. 5, NO_2 and SO_2. *Environ. Sociol.* **2022**, *8*, 94–107. [CrossRef]

51. Dang, N.; Zhang, H.; Salam, M.M.A.; Li, H.; Chen, G. Foliar dust particle retention and metal accumulation of five garden tree species in Hangzhou: Seasonal changes. *Environ. Pollut.* **2022**, *306*, 119472. [CrossRef]

52. Aslam, R.; Sharif, F.; Baqar, M.; Shahzad, L. Source identification and risk assessment of polycyclic aromatic hydrocarbons (PAHs) in air and dust samples of Lahore City. *Sci. Rep.* **2022**, *12*, 2459. [CrossRef]

53. Kansiime, W.K.; Mugambe, R.K.; Atusingwize, E.; Wafula, S.T.; Nsereko, V.; Ssekamatte, T.; Nalugya, A.; Coker, E.S.; Ssempebwa, J.C.; Isunju, J.B. Use of biomass fuels predicts indoor particulate matter and carbon monoxide concentrations; evidence from an informal urban settlement in Fort Portal city, Uganda. *BMC Public Health* **2022**, *22*, 1723. [CrossRef]

54. Nafees, A.A.; Taj, T.; Kadir, M.M.; Fatmi, Z.; Lee, K.; Sathiakumar, N. Indoor air pollution ($PM_{2.5}$) due to secondhand smoke in selected hospitality and entertainment venues of Karachi, Pakistan. *Tob. Control* **2012**, *21*, 460–464. [CrossRef]

55. Tao, S.; Shen, G.; Cheng, H.; Ma, J. Toward clean residential energy: Challenges and priorities in research. *Environ. Sci. Technol.* **2021**, *55*, 13602–13613. [CrossRef]

56. Yaqoob, H.; Teoh, Y.H.; Din, Z.U.; Sabah, N.U.; Jamil, M.A.; Mujtaba, M.; Abid, A. The potential of sustainable biogas production from biomass waste for power generation in Pakistan. *J. Clean. Prod.* **2021**, *307*, 127250. [CrossRef]

57. Arif, M.; Parveen, S. Carcinogenic effects of indoor black carbon and particulate matters ($PM_{2.5}$ and PM_{10}) in rural households of India. *Environ. Sci. Pollut. Res.* **2021**, *28*, 2082–2096. [CrossRef]

58. Cush, K.; Koh, K.; Saikawa, E. Impacts of biomass and garbage burning on air quality in South/Southeast Asia. In *Biomass Burning in South and Southeast Asia*; CRC Press: Boca Raton, FL, USA, 2021; pp. 3–20.

59. Colbeck, I.; Nasir, Z.A.; Ali, Z. Characteristics of indoor/outdoor particulate pollution in urban and rural residential environment of Pakistan. *Indoor Air* **2010**, *20*, 40–51. [CrossRef]

60. Mendell, A.Y.; Mahdavi, A.; Siegel, J.A. Particulate matter concentrations in social housing. *Sustain. Cities Soc.* **2022**, *76*, 103503. [CrossRef]

61. Junaid, M.; Syed, J.H.; Abbasi, N.A.; Hashmi, M.Z.; Malik, R.N.; Pei, D.-S. Status of indoor air pollution (IAP) through particulate matter (PM) emissions and associated health concerns in South Asia. *Chemosphere* **2018**, *191*, 651–663. [CrossRef]

62. Qayyum, F.; Mehmood, U.; Tariq, S.; Nawaz, H. Particulate matter ($PM_{2.5}$) and diseases: An autoregressive distributed lag (ARDL) technique. *Environ. Sci. Pollut. Res.* **2021**, *28*, 67511–67518. [CrossRef]

63. Anwar, M.N.; Shabbir, M.; Tahir, E.; Iftikhar, M.; Saif, H.; Tahir, A.; Murtaza, M.A.; Khokhar, M.F.; Rehan, M.; Aghbashlo, M. Emerging challenges of air pollution and particulate matter in China, India, and Pakistan and mitigating solutions. *J. Hazard. Mater.* **2021**, *416*, 125851. [CrossRef]

64. Kamran, M.; Cheema, A.M.; Saima, M.I.T.K.; Fatima, Z.; Nosheen, B.; Shahid, M.K. Global Concern Of Air Pollution And The Case Of Pakistani Society: An Islamic Perspective On Green Environment. *Webology* **2022**, *19*, 8321–8325.

65. Asghar, K.; Ali, A.; Tabassum, A.; Nadeem, S.; Hakim, S.; Amin, M.; Raza, G.; Bashir, S.; Afshan, N.; Usman, N. Assessment of particulate matter (PM) in ambient air of different settings and its associated health risk in Haripur city, Pakistan. *Braz. J. Biol.* **2022**, *84*, 256190. [CrossRef]

66. Aslam, R.; Sharif, F.; Baqar, M.; Nizami, A.-S.; Ashraf, U. Role of ambient air pollution in asthma spread among various population groups of Lahore City: A case study. *Environ. Sci. Pollut. Res.* **2022**, *30*, 8682–8697. [CrossRef] [PubMed]

67. Jiao, X.; Xiong, R.; Luo, Z.; Li, Y.; Cheng, H.; Rashid, A.; Shen, G.; Tao, S. Household energy stacking and structures in Pakistan–results from a multiple-energy study in Azad Kashmir and Punjab. *J. Environ. Sci.* **2022**, *133*, 152–160. [CrossRef]

68. Rashid, F.; Sarwar, S.; Habib, S.; Tahir, H.; Ali, I.N.; Abbas, T.A. Particulate Matter Concentration and Microbial Load in Heavy Traffic Areas of District Lahore, Pakistan: PM and Microbial Concentration in Heavy Traffic Areas. *Pak. BioMedical J.* **2022**, *5*, 34–39. [CrossRef]

69. Barr, K.J.; Johnson, C.L.; Cohen, J.; D'Souza, P.; Gallegos, E.I.; Tsai, C.-C.; Dunlop, A.L.; Corwin, E.J.; Barr, D.B.; Ryan, P.B. Legacy Chemical Pollutants in House Dust of Homes of Pregnant African Americans in Atlanta. *Toxics* **2022**, *10*, 755. [CrossRef] [PubMed]

70. Wu, Z.; Lyu, H.; Ma, X.; Ren, G.; Song, J.; Jing, X.; Liu, Y. Comparative effects of environmental factors on bacterial communities in two types of indoor dust: Potential risks to university students. *Environ. Res.* **2022**, *203*, 111869. [CrossRef]

71. Zhu, J.; Zhang, X.; Liao, K.; Wu, P.; Jin, H. Microplastics in dust from different indoor environments. *Sci. Total Environ.* **2022**, *833*, 155256. [CrossRef]

72. Cao, Z.; Xu, F.; Covaci, A.; Wu, M.; Yu, G.; Wang, B.; Deng, S.; Huang, J. Differences in the seasonal variation of brominated and phosphorus flame retardants in office dust. *Environ. Int.* **2014**, *65*, 100–106. [CrossRef]

73. Ali, N.; Van den Eede, N.; Dirtu, A.C.; Neels, H.; Covaci, A. Assessment of human exposure to indoor organic contaminants via dust ingestion in Pakistan. *Indoor Air* **2012**, *22*, 200–211. [CrossRef]

74. Ali, N.; Ali, L.; Mehdi, T.; Dirtu, A.C.; Al-Shammari, F.; Neels, H.; Covaci, A. Levels and profiles of organochlorines and flame retardants in car and house dust from Kuwait and Pakistan: Implication for human exposure via dust ingestion. *Environ. Int.* **2013**, *55*, 62–70. [CrossRef]

75. Khalid, F.; Qadir, A.; Hashmi, M.Z.; Mehmood, A.; Aslam, I.; Zhang, G.; Ahmed, Z. Evaluation of ceiling fan dust as an indicator of indoor PCBs pollution in selected cities of Punjab, Pakistan: Implication on human health. *Arab. J. Geosci.* **2022**, *15*, 874. [CrossRef]

76. Waheed, S.; Khan, M.U.; Sweetman, A.J.; Jones, K.C.; Moon, H.-B.; Malik, R.N. Exposure of polychlorinated naphthalenes (PCNs) to Pakistani populations via non-dietary sources from neglected e-waste hubs: A problem of high health concern. *Environ. Pollut.* **2020**, *259*, 113838. [CrossRef]

77. Dai, Q.; Min, X.; Weng, M. A review of polychlorinated biphenyls (PCBs) pollution in indoor air environment. *J. Air Waste Manag. Assoc.* **2016**, *66*, 941–950. [CrossRef]

78. Yana, S.; Nizar, M.; Mulyati, D. Biomass waste as a renewable energy in developing bio-based economies in Indonesia: A review. *Renew. Sustain. Energy Rev.* **2022**, *160*, 112268. [CrossRef]

79. Kaygusuz, K. Energy for sustainable development: A case of developing countries. *Renew. Sustain. Energy Rev.* **2012**, *16*, 1116–1126. [CrossRef]

80. Kaygusuz, K. Energy services and energy poverty for sustainable rural development. *Renew. Sustain. Energy Rev.* **2011**, *15*, 936–947. [CrossRef]

81. Hattori, S.; Iwamatsu, T.; Miura, T.; Tsutsumi, F.; Tanaka, N. Investigation of Indoor Air Quality in Residential Buildings by Measuring CO_2 Concentration and a Questionnaire Survey. *Sensors* **2022**, *22*, 7331. [CrossRef]

82. Morris, J.; Reilly, J.; Paltsev, S.; Sokolov, A.; Cox, K. Representing Socio-Economic Uncertainty in Human System Models. *Earth's Future* **2022**, *10*, e2021EF002239. [CrossRef]

83. Patel, N.; Okocha, B.; Narayan, S.; Sheth, M. Indoor air pollution from burning biomass & child health. *IJSR* **2013**, *2*, 492–506.

84. Yousafzai, A.W.; Khan, S.A.; Bano, S.; Khan, M.M. Exploring the phenomenon of suicidal behaviour (SB): An explanatory, mixed-method study in rural Pakistan. *Int. J. Soc. Psychiatry* **2022**, *68*, 1629–1635. [CrossRef]

85. Imran, M.; Zahid, A.; Mouneer, S.; Özçatalbaş, O.; Ul Haq, S.; Shahbaz, P.; Muzammil, M.; Murtaza, M.R. Relationship between Household Dynamics, Biomass Consumption, and Carbon Emissions in Pakistan. *Sustainability* **2022**, *14*, 6762. [CrossRef]

86. Mboumboue, E.; Njomo, D. Potential contribution of renewables to the improvement of living conditions of poor rural households in developing countries: Cameroon's case study. *Renew. Sustain. Energy Rev.* **2016**, *61*, 266–279. [CrossRef]

87. Qi, J.; Liu, L.; Wu, J. Improving Combustion Technology for Cooking Activities for Pollutant Emission Reduction and Carbon Neutrality. *Atmosphere* **2022**, *13*, 561. [CrossRef]

88. Woolley, K.E.; Dickinson-Craig, E.; Lawson, H.L.; Sheikh, J.; Day, R.; Pope, F.D.; Greenfield, S.M.; Bartington, S.E.; Warburton, D.; Manaseki-Holland, S. Effectiveness of interventions to reduce household air pollution from solid biomass fuels and improve maternal and child health outcomes in low-and middle-income countries: A systematic review and meta-analysis. *Indoor Air* **2022**, *32*, e12958. [CrossRef] [PubMed]

89. Rehman, A.; Ma, H.; Ozturk, I.; Ulucak, R. Sustainable development and pollution: The effects of CO_2 emission on population growth, food production, economic development, and energy consumption in Pakistan. *Environ. Sci. Pollut. Res.* **2022**, *29*, 17319–17330. [CrossRef] [PubMed]

90. Soomro, H.; Shah, S.F.; Sahito, W.S.; Uqaili, M.A.; Kumar, L.; Nixon, J.D.; Harijan, K. Assessment of Sustainable Biomass Energy Technologies in Pakistan Using the Analytical Hierarchy Process. *Sustainability* **2022**, *14*, 11388. [CrossRef]

91. Yousaf, H.; Amin, A.; Baloch, A.; Akbar, M. Investigating household sector's non-renewables, biomass energy consumption and carbon emissions for Pakistan. *Environ. Sci. Pollut. Res.* **2021**, *28*, 40824–40834. [CrossRef]

92. Imran, M.; Özçatalbaş, O.; Bakhsh, K. Rural household preferences for cleaner energy sources in Pakistan. *Environ. Sci. Pollut. Res.* **2019**, *26*, 22783–22793. [CrossRef]

93. Irfan, M.; Zhao, Z.-Y.; Panjwani, M.K.; Mangi, F.H.; Li, H.; Jan, A.; Ahmad, M.; Rehman, A. Assessing the energy dynamics of Pakistan: Prospects of biomass energy. *Energy Rep.* **2020**, *6*, 80–93. [CrossRef]

94. Ahmed, M.; Shuai, C.; Abbas, K.; Rehman, F.U.; Khoso, W.M. Investigating health impacts of household air pollution on woman's pregnancy and sterilization: Empirical evidence from Pakistan, India, and Bangladesh. *Energy* **2022**, *247*, 123562. [CrossRef]

95. Pope, D.P.; Mishra, V.; Thompson, L.; Siddiqui, A.R.; Rehfuess, E.A.; Weber, M.; Bruce, N.G. Risk of low birth weight and stillbirth associated with indoor air pollution from solid fuel use in developing countries. *Epidemiol. Rev.* **2010**, *32*, 70–81. [CrossRef]

96. Haider, M.R.; Rahman, M.M.; Islam, F.; Khan, M.M. Association of low birthweight and indoor air pollution: Biomass fuel use in Bangladesh. *J. Health Pollut.* **2016**, *6*, 18–25. [CrossRef]

97. Nasir, Z.A.; Murtaza, F.; Colbeck, I. Role of poverty in fuel choice and exposure to indoor air pollution in Pakistan. *J. Integr. Environ. Sci.* **2015**, *12*, 107–117. [CrossRef]

98. Siddiqui, A.R.; Peerson, J.; Brown, K.H.; Gold, E.B.; Lee, K.; Bhuta, Z.A. Indoor air pollution from solid fuel use and low birth weight (LBW) in Pakistan. *Epidemiology* **2005**, *16*, S86. [CrossRef]

99. World Health Organization (WHO). Indoor Air Pollution from Solid Fuels and Risk of Low Birth Weight and Stillbirth. In *Report from a Symposium Held at the Annual Conference of the International Society for Environmental Epidemiology (ISEE), 13–16 September 2005, Johannesburg, South Africa*; World Health Organization: Geneva, Switzerland, 2007.

100. Khan, M.S.B.; Lohano, H.D. Household air pollution from cooking fuel and respiratory health risks for children in Pakistan. *Environ. Sci. Pollut. Res.* **2018**, *25*, 24778–24786. [CrossRef]

101. Taksande, A.M.; Yeole, M. Risk factors of Acute Respiratory Infection (ARI) in under-fives in a rural hospital of Central India. *J. Pediatr. Neonatal Individ. Med.* **2016**, *5*, e050105.

102. Quinn, A.K.; Bruce, N.; Puzzolo, E.; Dickinson, K.; Sturke, R.; Jack, D.W.; Mehta, S.; Shankar, A.; Sherr, K.; Rosenthal, J.P. An analysis of efforts to scale up clean household energy for cooking around the world. *Energy Sustain. Dev.* **2018**, *46*, 1–10. [CrossRef]

103. Naz, S.; Page, A.; Agho, K.E. Household air pollution from use of cooking fuel and under-five mortality: The role of breastfeeding status and kitchen location in Pakistan. *PLoS ONE* **2017**, *12*, e0173256. [CrossRef]

104. Fatmi, Z.; Rahman, A.; Kazi, A.; Kadir, M.M.; Sathiakumar, N. Situational analysis of household energy and biomass use and associated health burden of indoor air pollution and mitigation efforts in Pakistan. *Int. J. Environ. Res. Public Health* **2010**, *7*, 2940–2952. [CrossRef]

105. Yasmin, N.; Grundmann, P. Home-cooked energy transitions: Women empowerment and biogas-based cooking technology in Pakistan. *Energy Policy* **2020**, *137*, 111074. [CrossRef]

106. Shams, Z.I.; Javed, T.; Zubair, A.; Waqas, M.; Ali, S.; Ahmed, A. Carbon Monoxide Concentrations in Kitchens of Gas-fired Burners, Karachi, Pakistan: Carbon Monoxide in Karachi Bungalow and Apartment Kitchens. *Pak. J. Sci. Ind. Res. Ser. A Phys. Sci.* **2022**, *65*, 25–32. [CrossRef]

107. Iqbal, S.; Anwar, S.; Akram, W.; Irfan, M. Factors leading to adoption of biogas technology: A case study of District Faisalabad, Punjab, Pakistan. *Int. J. Acad. Res. Bus. Soc. Sci.* **2013**, *3*, 2222–6990. [CrossRef] [PubMed]

108. Yasmin, I.; Akram, W.; Adeel, S.; Chandio, A.A. Non-adoption decision of biogas in rural Pakistan: Use of multinomial logit model. *Environ. Sci. Pollut. Res.* **2022**, *29*, 53884–53905. [CrossRef] [PubMed]

109. Karanasiou, A.; Alastuey, A.; Amato, F.; Renzi, M.; Stafoggia, M.; Tobias, A.; Reche, C.; Forastiere, F.; Gumy, S.; Mudu, P. Short-term health effects from outdoor exposure to biomass burning emissions: A review. *Sci. Total Environ.* **2021**, *781*, 146739. [CrossRef] [PubMed]

110. Chen, P.W.; Lu, H.F.; Liu, Z.S. Development and application of the Ames test using a direct-exposure module: The assessment of mutagenicity of incense and sidestream cigarette smoke. *Indoor Air* **2022**, *32*, e13140. [CrossRef]

111. Öberg, M.; Jaakkola, M.S.; Woodward, A.; Peruga, A.; Prüss-Ustün, A. Worldwide burden of disease from exposure to second-hand smoke: A retrospective analysis of data from 192 countries. *Lancet* **2011**, *377*, 139–146. [CrossRef]

112. Naeem, A.; Rafiq, L.; Nazar, R.; Kashif, M.; Naqvi, S.H.Z. An assessment of Risk Factors and Health Impacts Associated with Indoor Air Pollution and Tobacco Smoke in Lahore, Pakistan. *J. Qual. Assur. Agric. Sci.* **2022**, *2*, 37–45.

113. Zaidi, S.; Moin, O.; Khan, J. Second-hand smoke in indoor hospitality venues in Pakistan. *Int. J. Tuberc. Lung Dis.* **2011**, *15*, 972–977. [CrossRef]

114. Khan, J.A.; Amir Humza Sohail, A.M.; Arif Maan, M.A. Tobacco control laws in Pakistan and their implementation: A pilot study in Karachi. *J. Pak. Med. Assoc.* **2016**, *66*, 875.

115. Amir, M.; Khan, U.; Baig, M. Evaluation of Consequences of Cigarette smoking on General Population of Pakistan. *Asian J. Multidisc. Stud.* **2020**, *8*, 5.

116. Khwaja, M.A.; Shams, T. *Pakistan National Ambient Air Quality Standards: A comparative Assessment with Selected Asian Countries and World Health Organization (WHO)*; Sustainable Development Policy Institute: Islamabad, Pakistan, 2020.

117. Abdul Jabbar, S.; Tul Qadar, L.; Ghafoor, S.; Rasheed, L.; Sarfraz, Z.; Sarfraz, A.; Sarfraz, M.; Felix, M.; Cherrez-Ojeda, I. Air quality, pollution and sustainability trends in South Asia: A population-based study. *Int. J. Environ. Res. Public Health* **2022**, *19*, 7534. [CrossRef]

118. Ahmed, T.; Usman, M.; Scholz, M. Biodeterioration of buildings and public health implications caused by indoor air pollution. *Indoor Built Environ.* **2018**, *27*, 752–765. [CrossRef]

119. Farooq, S.; Yaqoob, I. Awareness towards efficiency of green and conventional building materials used in Pakistan. *Proc. Pak. Acad. Sci. A Phys. Comput. Sci.* **2019**, *56*, 75–84.

120. Rafique, M.; Rahman, S.U.; Mahmood, T.; Rahman, S.; Rehman, S.U. Radon exhalation rate from soil, sand, bricks, and sedimentary samples collected from Azad Kashmir, Pakistan. *Russ. Geol. Geophys.* **2011**, *52*, 450–457. [CrossRef]

121. Majid, M.I.; Khan, M.I. Techno-economic analysis of green construction regulations plus survey for prototype implementation in karachi. *Pak. J. Sci. Ind. Res. Ser. A Phys. Sci.* **2021**, *64*, 161–172. [CrossRef]

122. Nazaroff, W.W. Indoor bioaerosol dynamics. *Indoor Air* **2016**, *26*, 61–78. [CrossRef]

123. Nimra, A.; Ali, Z.; Sultan, S.; Nasir, Z.A.; Sidra, S.; Hussain, A. Molecular sequencing and phylogenetic analysis of bioaerosols in hospital wards with different ventilation conditions. *J. Infect. Dev. Ctries.* **2022**, *16*, 157–165. [CrossRef]

124. Lee, G.; Yoo, K. A review of the emergence of antibiotic resistance in bioaerosols and its monitoring methods. *Rev. Environ. Sci. Bio/Technol.* **2022**, *21*, 799–827. [CrossRef]

125. Mandal, J.; Brandl, H. Bioaerosols in indoor environment—A review with special reference to residential and occupational locations. *Open Environ. Biol. Monit. J.* **2011**, *4*, 83–96.

126. Hassan, A.; Zeeshan, M. Microbiological indoor air quality of hospital buildings with different ventilation systems, cleaning frequencies and occupancy levels. *Atmos. Pollut. Res.* **2022**, *13*, 101382. [CrossRef]

127. Grogan, S.N.; Mainelis, G. Effect of sampling duration on culturable and viable bioaerosol determination when using Rutgers Electrostatic Passive Sampler (REPS). *J. Aerosol Sci.* **2022**, *166*, 106066. [CrossRef]

128. Wathes, C. Bioaerosols in Animal Houses. In *Bioaerosols Handbook*; CRC Press: Boca Raton, FL, USA, 2020; pp. 547–577.

129. Mukhtar, S.; Mukhtar, S.; Hani, U.; Iram, S. Scenario Of Aspergillus Indoor Contamination In Pakistan (2000–2020)—A Review. *Environ. Contam. Rev.* **2021**, *4*, 24–28.

130. Bukhari, S.S.I. Characterization of Bioaerosols and Particulate Matter (PM) in Residential Settings of Asthmatic Patients of Lahore, Pakistan Air Microflora and Particulate Matter in Asthmatic Houses. *Iran. J. Allergy Asthma Immunol.* **2021**, *20*, 147. [PubMed]

131. Nasir, Z.A.; Colbeck, I.; Sultan, S.; Ahmed, S. Bioaerosols in residential micro-environments in low income countries: A case study from Pakistan. *Environ. Pollut.* **2012**, *168*, 15–22. [CrossRef] [PubMed]

132. Roy, R.; Jan, R.; Joshi, U.; Bhor, R.; Pai, K.; Satsangi, P.G. Characterization, pro-inflammatory response and cytotoxic profile of bioaerosols from urban and rural residential settings in Pune, India. *Environ. Pollut.* **2020**, *264*, 114698. [CrossRef] [PubMed]

133. Colbeck, I.; Nasir, Z.A.; Hasnain, S.; Sultan, S. Indoor air quality at rural and urban sites in Pakistan. *Water Air Soil Pollut. Focus* **2008**, *8*, 61–69. [CrossRef]

134. Hafeez, S.; Ali, Z.; Nasir, Z.A.; Sultan, S. Assessment of Microbial Air Quality within Facilities of Waste Transfer Stations and Disposal Sites of Lahore, Pakistan. *Pol. J. Environ. Stud.* **2021**, *30*, 5567–5576. [CrossRef]

135. Colbeck, I.; Sidra, S.; Ali, Z.; Ahmed, S.; Nasir, Z.A. Spatial and temporal variations in indoor air quality in Lahore, Pakistan. *Int. J. Environ. Sci. Technol.* **2019**, *16*, 2565–2572. [CrossRef]

136. Safdar, S.; Ali, Z.; Colbeck, I.; Nasir, Z.A. Airborne Microflora and Particulate Matter in Residential Houses in Lahore, Pakistan'. Available online: https://scholar.googleusercontent.com/scholar?q=cache:eKkf7eG3b6MJ:scholar.google.com/+Airborne+microflora+and+particulate+matter+in+residential+houses+in+Lahore,+Pakistan&hl=zh-CN&as_sdt=0,5 (accessed on 20 February 2023).

137. Kumar, P.; Singh, A.; Singh, R. Seasonal variation and size distribution in the airborne indoor microbial concentration of residential houses in Delhi and its impact on health. *Aerobiologia* **2021**, *37*, 719–732. [CrossRef]

138. Sidra, S.; Ali, Z.; Sultan, S.; Ahmed, S.; Colbeck, I.; Nasir, Z.A. Assessment of airborne microflora in the indoor micro-environments of residential houses of Lahore, Pakistan. *Aerosol Air Qual. Res.* **2015**, *15*, 2385–2396. [CrossRef]

139. Sajjad, H.; Ghaffar, A. Observed, simulated and projected extreme climate indices over Pakistan in changing climate. *Theor. Appl. Climatol.* **2019**, *137*, 255–281. [CrossRef]

140. Dilawar, A.; Chen, B.; Arshad, A.; Guo, L.; Ehsan, M.I.; Hussain, Y.; Kayiranga, A.; Measho, S.; Zhang, H.; Wang, F. Towards Understanding Variability in Droughts in Response to Extreme Climate Conditions over the Different Agro-Ecological Zones of Pakistan. *Sustainability* **2021**, *13*, 6910. [CrossRef]

141. Abbas, S.; Ali, G.; Qamer, F.M.; Irteza, S.M. Associations of air pollution concentrations and energy production dynamics in Pakistan during lockdown. *Environ. Sci. Pollut. Res.* **2022**, *29*, 35036–35047. [CrossRef]

142. Maan, Y.A.M.A.; Jameel, M.; Akhtar, M. A Simulation Based Study of Energy Conservation of Residences In Lahore, Pakistan. *J. Arts Soc. Sci.* **2021**, *8*, 104–113.

143. Colbeck, I.; Nasir, Z.A.; Ali, Z. The state of ambient air quality in Pakistan—A review. *Environ. Sci. Pollut. Res.* **2010**, *17*, 49–63. [CrossRef]

144. Munir, R.; Khayyam, U. Tropospheric Ozone Concentration Over PAKISTAN. In *Asian Atmospheric Pollution*; Elsevier: Amsterdam, The Netherlands, 2022; pp. 349–365.

145. Rabbani, U.; Razzaq, S.; Irfan, M.; Semple, S.; Nafees, A.A. Indoor air pollution and respiratory health in a metropolitan city of Pakistan. *J. Occup. Environ. Med.* **2022**, *64*, 761–765. [CrossRef]

146. Ghani, N.; Tariq, F.; Javed, H.; Nisar, N.; Tahir, A. Low-temperature health hazards among workers of cold storage facilities in Lahore, Pakistan. *Med. Pr.* **2019**, *71*, 1–7. [CrossRef]

147. Cocchiara, R.A.; Mannocci, A.; Backhaus, I.; Thiene, D.D.; Sestili, C.; Barbato, D.; Torre, G.L. The Relationship Between Environment and Mental Health. In *Environmental Alteration Leads to Human Disease*; Springer: Berlin/Heidelberg, Germany, 2022; pp. 229–240.

148. Smith, K.R.; Mehta, S.; Maeusezahl-Feuz, M. Indoor air pollution from household use of solid fuels. *Comp. Quantif. Health Risks: Glob. Reg. Burd. Dis. Attrib. Sel. Major Risk Factors* **2004**, *2*, 1435–1493.

149. Hu, F.; Guo, Y. Health impacts of air pollution in China. *Front. Environ. Sci. Eng.* **2021**, *15*, 74. [CrossRef]

150. Pandey, A.; Brauer, M.; Cropper, M.L.; Balakrishnan, K.; Mathur, P.; Dey, S.; Turkgulu, B.; Kumar, G.A.; Khare, M.; Beig, G. Health and economic impact of air pollution in the states of India: The Global Burden of Disease Study 2019. *Lancet Planet. Health* **2021**, *5*, e25–e38. [CrossRef]

151. Balakrishnan, K.; Dey, S.; Gupta, T.; Dhaliwal, R.; Brauer, M.; Cohen, A.J.; Stanaway, J.D.; Beig, G.; Joshi, T.K.; Aggarwal, A.N. The impact of air pollution on deaths, disease burden, and life expectancy across the states of India: The Global Burden of Disease Study 2017. *Lancet Planet. Health* **2019**, *3*, e26–e39. [CrossRef]

152. Yamamoto, S.; Phalkey, R.; Malik, A. A systematic review of air pollution as a risk factor for cardiovascular disease in South Asia: Limited evidence from India and Pakistan. *Int. J. Hyg. Environ. Health* **2014**, *217*, 133–144. [CrossRef] [PubMed]

153. Paleologos, K.E.; Selim, M.Y.; Mohamed, A.-M.O. Indoor Air Quality: Pollutants, Health Effects, and Regulations. In *Pollution Assessment for Sustainable Practices in Applied Sciences and Engineering*; Elsevier: Amsterdam, The Netherlands, 2021; pp. 405–489.

154. Sarwar, F.; Alam, K.; Chow, C.W.; Saeed, M.; Malik, R.N. Pulmonary Dysfunction Augmenting Bacterial Aerosols in Leather Tanneries of Punjab, Pakistan. *Int. J. Chronic Obstr. Pulm. Dis.* **2021**, *16*, 2925. [CrossRef] [PubMed]

155. Rabbani, U.; Razzak, S.; Burney, P.; Nafees, A.A. Indoor Air Pollutants and Respiratory Outcomes Among Adult Pakistani Papulation: A Cross Sectional Survey. *Eur. Respir. Soc.* **2020**, *56*, 1299.

156. Jordanova, D.; Jordanova, N.; Lanos, P.; Petrov, P.; Tsacheva, T. Magnetism of outdoor and indoor settled dust and its utilization as a tool for revealing the effect of elevated particulate air pollution on cardiovascular mortality. *Geochem. Geophys. Geosystems* **2012**, *13*, Q08Z49. [CrossRef]

157. Farah, N.; Khan, I.A. Awareness about the health impacts of indoor air pollution on rural women in District Faisalabad. *J. Glob. Innov. Agric. Soc. Sci* **2015**, *3*, 90–95. [CrossRef]

158. Kouser, S.; Munir, S. Does communal women empowerment mitigate the risk of acute respiratory infection among under-five children in Pakistan? *Public Health* **2022**, *205*, 133–138. [CrossRef]

159. Nair, A.N.; Anand, P.; George, A.; Mondal, N. A review of strategies and their effectiveness in reducing indoor airborne transmission and improving indoor air quality. *Environ. Res.* **2022**, *213*, 113579. [CrossRef]

160. Tariq, N.; Jaffry, T.; Fiaz, R.; Rajput, A.M.; Khalid, S. Awareness About Indoor Air Pollution In General Population Of Rawalpindi And Islamabad. *Pak. J. Public Health* **2018**, *8*, 80–83. [CrossRef]

161. Aslam, I.; Baqar, M.; Qadir, A.; Mumtaz, M.; Li, J.; Zhang, G. Polychlorinated biphenyls in indoor dust from urban dwellings of Lahore, Pakistan: Congener profile, toxicity equivalency, and human health implications. *Indoor Air* **2021**, *31*, 1417–1426. [CrossRef]

162. Khan, M.U.; Besis, A.; Li, J.; Zhang, G.; Malik, R.N. New insight into the distribution pattern, levels, and risk diagnosis of FRs in indoor and outdoor air at low-and high-altitude zones of Pakistan: Implications for sources and exposure. *Chemosphere* **2017**, *184*, 1372–1387. [CrossRef]

163. Khan, M.U.; Li, J.; Zhang, G.; Malik, R.N. New insight into the levels, distribution and health risk diagnosis of indoor and outdoor dust-bound FRs in colder, rural and industrial zones of Pakistan. *Environ. Pollut.* **2016**, *216*, 662–674. [CrossRef]

164. Rehman, K.; Fatima, F.; Waheed, I.; Akash, M.S.H. Prevalence of exposure of heavy metals and their impact on health consequences. *J. Cell. Biochem.* **2018**, *119*, 157–184. [CrossRef]

165. Hamid, N.; Syed, J.H.; Junaid, M.; Mahmood, A.; Li, J.; Zhang, G.; Malik, R.N. Elucidating the urban levels, sources and health risks of polycyclic aromatic hydrocarbons (PAHs) in Pakistan: Implications for changing energy demand. *Sci. Total Environ.* **2018**, *619*, 165–175. [CrossRef]

166. Sonwani, S.; Madaan, S.; Arora, J.; Suryanarayan, S.; Rangra, D.; Mongia, N.; Vats, T.; Saxena, P. Inhalation exposure to atmospheric nanoparticles and its associated impacts on human health: A review. *Front. Sustain. Cities* **2021**, *3*, 690444. [CrossRef]

167. Bai, L.; Li, C. Investigation of Indoor Polycyclic Aromatic Hydrocarbons (PAHs) in Rural Northeast China: Pollution Characteristics, Source Analysis, and Health Assessment. *Buildings* **2022**, *12*, 153. [CrossRef]

168. Rafique, M.; Manzoor, N.; Rahman, S.; Rahman, S.; Rajput, M. Assessment of lung cancer risk due to indoor radon exposure in inhabitants of the state of Azad Kashmir Pakistan. *Int. J. Radiat. Res.* **2012**, *10*, 19–29.

169. Xue, S.; Zhang, B.; Zhao, X. Brain drain: The impact of air pollution on firm performance. *J. Environ. Econ. Manag.* **2021**, *110*, 102546. [CrossRef]

170. Wang, L.; Dai, Y.; Kong, D. Air pollution and employee treatment. *J. Corp. Financ.* **2021**, *70*, 102067. [CrossRef]

171. La Nauze, A.; Severnini, E.R. *Air Pollution and Adult Cognition: Evidence from Brain Training*; National Bureau of Economic Research: Cambridge, MA, USA, 2021.

172. Saleem, A.; Ali, S.A.; Zaman, K.; Muhammad, A.; Shehzad, K.; Ullah, I. Impact of Interior Physical Environment on Academicians'productivity In Pakistan Higher Education Institutes Perspectives. *Iran. J. Manag. Stud.* **2012**, *5*, 25–46.

173. Kamal, A.; Cincinelli, A.; Martellini, T.; Palchetti, I.; Bettazzi, F.; Malik, R.N. Health and carcinogenic risk evaluation for cohorts exposed to PAHs in petrochemical workplaces in Rawalpindi city (Pakistan). *Int. J. Environ. Health Res.* **2016**, *26*, 37–57. [CrossRef]

174. Zhao, L.; Liu, M.; Liu, L.; Guo, W.; Yang, H.; Chen, S.; Yu, J.; Li, M.; Fang, Q.; Lai, X. The association of co-exposure to polycyclic aromatic hydrocarbon and phthalates with blood cell-based inflammatory biomarkers in children: A panel study. *Environ. Pollut.* **2022**, *307*, 119479. [CrossRef] [PubMed]

175. Lin, H.; Taniyasu, S.; Yamashita, N.; Khan, M.K.; Masood, S.S.; Saied, S.; Khwaja, H.A. Per-and polyfluoroalkyl substances in the atmospheric total suspended particles in Karachi, Pakistan: Profiles, potential sources, and daily intake estimates. *Chemosphere* **2022**, *288*, 132432. [CrossRef] [PubMed]

176. Baqer, N.S.; Mohammed, H.A.; Albahri, A.; Zaidan, A.; Al-qaysi, Z.; Albahri, O. Development of the Internet of Things sensory technology for ensuring proper indoor air quality in hospital facilities: Taxonomy analysis, challenges, motivations, open issues and recommended solution. *Measurement* **2022**, *192*, 110920. [CrossRef]

177. Baqer, N.S.; Mohammed, H.A.; Albahri, A. Development of a real-time monitoring and detection indoor air quality system for intensive care unit and emergency department. *Signa Vitae* **2022**, *1*, 16.

178. Zhou, Y.; Yang, G. Real-time monitoring of pollutants in occupied indoor environments: A pilot study of a hospital in China. *J. Build. Eng.* **2022**, *59*, 105105. [CrossRef]

179. Nimra, A.; Ali, Z.; Khan, M.; Gulshan, T.; Sidra, S.; Gardezi, J.; Tarar, M.; Saleem, M.; Nasir, Z.A.; Colbeck, I. Comparative ambient and indoor particulate matter analysis of operation theatres of government and private (trust) hospitals of Lahore, Pakistan. *J. Anim. Plant Sci.* **2015**, *25*, 628–635.

180. Gholami Motlagh, V.; Ahmadzadehtalatapeh, M.; Mohammadi, O. Effect of Turbulent and Laminar Flow Mechanisms on Airflow Patterns and CO_2 Distribution in an Operating Room: A Numerical Analysis. In *Scientia Iranica*; Sharif University of Technology: Tehran, Iran, 2022.

181. World Health Organization (WHO). WHO Guidelines for Indoor Air Quality. In *Selected Pollutants*; World Health Organization, Regional Office for Europe: Geneva, Switzerland, 2010.

182. Apte, K.; Salvi, S. Household air pollution and its effects on health. *F1000Research* **2016**, *5*, 2593. [CrossRef]

183. Raju, S.; Siddharthan, T.; McCormack, M.C. Indoor air pollution and respiratory health. *Clin. Chest Med.* **2020**, *41*, 825–843. [CrossRef]

184. Zhang, J.; Smith, K.R. Indoor air pollution: A global health concern. *Br. Med. Bull.* **2003**, *68*, 209–225. [CrossRef]

185. World Health Organization (WHO). Situation Analysis of Household Energy Use and Indoor Air Pollution in Pakistan. In *Situation Analysis of Household Energy Use and Indoor Air Pollution in Pakistan*; World Health Organization: Geneva, Switzerland, 2005.

186. Organizatio, W.H. WHO Guidelines for Indoor Air Quality. In *Household Fuel Combustion*; World Health Organization: Geneva, Switzerland, 2014.

187. Irfan, M.; Cameron, M.P.; Hassan, G. Interventions to mitigate indoor air pollution: A cost-benefit analysis. *PLoS ONE* **2021**, *16*, e0257543. [CrossRef]

188. Ahmed, M.; Xiao, Z.; Shen, Y. Estimation of Ground PM2. 5 Concentrations in Pakistan Using Convolutional Neural Network and Multi-Pollutant Satellite Images. *Remote Sens.* **2022**, *14*, 1735. [CrossRef]

189. Butt, M.S.; Kuklane, K.; Saleem, J.; Zakar, R.; Bukhari, G.M.J.; Ishaq, M. Evaluation of occupational exposure to heat stress and working practices in the small and mid-sized manufacturing industries of Lahore, Pakistan. *Avicenna* **2022**, *2022*, 5. [CrossRef]

190. Sheraz, M.; Mir, K.A.; Anus, A.; Kim, S.; Lee, W.R. SARS-CoV-2 airborne transmission: A review of risk factors and possible preventative measures using air purifiers. *Environ. Sci. Process. Impacts* **2022**, *24*, 2191–2216. [CrossRef]

191. Ramzan, M.; Qasim, M.; Habib, A.; Mukhtar, R. A Study on Uses and Management of Indoor Plants in Pakistan. *Int. J. Agric. Biol.* **2007**, *9*, 517–518.

192. Nasir, Z.A.; Colbeck, I.; Ali, Z.; Ahmad, S. Indoor particulate matter in developing countries: A case study in Pakistan and potential intervention strategies. *Environ. Res. Lett.* **2013**, *8*, 024002. [CrossRef]

193. Raza, M.Y.; Wasim, M.; Sarwar, M.S. Development of Renewable Energy Technologies in rural areas of Pakistan. *Energy Sources Part A Recovery Util. Environ. Eff.* **2020**, *42*, 740–760. [CrossRef]

194. Ponce, P.; Khan, S.A.R. A causal link between renewable energy, energy efficiency, property rights, and CO_2 emissions in developed countries: A road map for environmental sustainability. *Environ. Sci. Pollut. Res.* **2021**, *28*, 37804–37817. [CrossRef]

195. Assadi, M.R.; Ataebi, M.; sadat Ataebi, E.; Hasani, A. Prioritization of renewable energy resources based on sustainable management approach using simultaneous evaluation of criteria and alternatives: A case study on Iran's electricity industry. *Renew. Energy* **2022**, *181*, 820–832. [CrossRef]

196. Khalil, F.A.; Asif, M.; Anwar, S.; ul Haq, S.; Illahi, F. Solar Tracking Techniques and Implementation in Photovoltaic Power Plants: A Review: Solar Tracking Techniques and Implementation in Photovoltaic Power Plants. *Proc. Pak. Acad. Sci. A Phys. Comput. Sci.* **2017**, *54*, 231–241.

197. Chien, F.; Kamran, H.W.; Albashar, G.; Iqbal, W. Dynamic planning, conversion, and management strategy of different renewable energy sources: A sustainable solution for severe energy crises in emerging economies. *Int. J. Hydrog. Energy* **2021**, *46*, 7745–7758. [CrossRef]

198. Zender–Świercz, E. Improvement of indoor air quality by way of using decentralised ventilation. *J. Build. Eng.* **2020**, *32*, 101663. [CrossRef]

199. Singh, R.; Dewan, A. Implementation of the Right to Healthy Environment: Regulations for running air conditioners in public buildings and recognition of biological pollutants. *Res. Sq.* **2022**, preprint. [CrossRef]

200. Chen, Y.; Li, X.; Zhang, X.; Zhang, Y.; Gao, W.; Wang, R.; He, D. Air conditioner filters become sinks and sources of indoor microplastics fibers. *Environ. Pollut.* **2022**, *292*, 118465. [CrossRef] [PubMed]

201. Yang, Z.; Xiao, H.; Sun, H.; Wang, B.; Lin, B.; Shi, W.; Huang, W. Performance analysis of room air conditioners via questionnaire and integrated field test. *Appl. Therm. Eng.* **2021**, *196*, 117243. [CrossRef]

202. AlMulla, A.A.; Berekaa, M.; Dahlawi, S. Human Exposure Assessment to Air Pollutants in AC Filters from Agricultural, Industrial, and Residential Areas. *Atmosphere* **2022**, *13*, 1899. [CrossRef]

203. Aslam, I.; Mumtaz, M.; Qadir, A.; Jamil, N.; Baqar, M.; Mahmood, A.; Ahmad, S.R.; Zhang, G. Organochlorine pesticides (OCPs) in air-conditioner filter dust of indoor urban setting: Implication for health risk in a developing country. *Indoor Air* **2021**, *31*, 807–817. [CrossRef]

204. Arif, S.; Tabusum, S.; Gul, N. Pesticides Residues In The Human Breast Milk Of Primiparous And Multiparous Women Of Karachi, Pakistan. *Feb-Fresenius Environ. Bull.* **2022**, *31*, 9494–9498.

205. Waleed, K.; Mirza, F.M. Examining fuel choice patterns through household energy transition index: An alternative to traditional energy ladder and stacking models. *Environ. Dev. Sustain.* **2023**, *25*, 6449–6501. [CrossRef]

206. Shahid, M.A.K.; Ahmad, N.; Hussain, K.; Ahmad, N. Indoor, Out Door Air Pollution (Ioap), Cost Effective Methodologies And Potential Intervention Strategies. *iJCEM* **2015**, *1*, 11–25.

207. Wang, Y.; Sun, M.; Yang, X.; Yuan, X. Public awareness and willingness to pay for tackling smog pollution in China: A case study. *J. Clean. Prod.* **2016**, *112*, 1627–1634. [CrossRef]

208. Loewy, S.A.; Kelly, G.W.; Nathanson, M.D. Indoor Pollution in Commercial Buildings: Legal Requirements and Emerging Trends. *Temp. Envtl. L. Tech. J.* **1992**, *11*, 239.

209. Kankaria, A.; Nongkynrih, B.; Gupta, S.K. Indoor air pollution in India: Implications on health and its control. *Indian J. Community Med.* **2014**, *39*, 203.