PRINT ISSN 1119-8362
Electronic ISSN 2659-1499

Full-text Available Online at
https://www.ajol.info/index.php/jasem
https://www.bioline.org.br/ja

J. Appl. Sci. Environ. Manage.
Vol. 29 (5) 1621-1632 May 2025

Critical Review on Dispersion of Gaseous Pollutants from Indoor Cooking Facilities

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ABSTRACT: Pollutant emissions from indoor activities are an area of concern for human health worldwide. People spend about 90% of their time in indoor environments, and exposure to pollutants has a significant impact on their health and productivity. The objective of this paper is to provide a critical review of the dispersion of gaseous pollutants from indoor cooking using numerous scientific studies harvested from online and library sources. Data obtained reveal that there is evidence of health hazards of pollutants arising from several studies highlighting the danger of actual personal exposure. The current database of pollutant emissions from cooking processes offers limited information on the composition of harmful gaseous and particulate contaminants, as well as the methods by which they spread. Comprehensive evaluations of IAQ studies that explore the relationship between indoor cooking activities and pollutant emission rates are minimal. An analysis of the literature highlights the trends and gaps in cooking emissions in different countries/regions to enhance the understanding of their progress and limitations. This review has the potential to benefit individuals, policymakers, and institutions regarding the hazards of cooking-generated emissions.

DOI: https://dx.doi.org/10.4314/jasem.v29i5.29

Cite this Article as: AWOYELE, O. M; KAMIYO, O. M; ADEWUMI, O. O (2025) Critical Review on Dispersion of Gaseous Pollutants from Indoor Cooking Facilities *J. Appl. Sci. Environ. Manage.* 29 (5) 1621-1632

Dates: Received: 30 March 2025; Revised: 20 April 2025; Accepted: 06 May 2025; Published: May 2025

Keywords: Cooking; Biomass Solid Fuel; Pollutants; Dispersion; Indoor air quality

Atmospheric air pollution has been one of the leading global environmental crises over the last few decades (Mannucci and Franchini, 2017; Neisi *et al*., 2017; World Bank, 2016; OECD, 2016; Babatola *et al*., 2018). Air pollution is changing the air quality and climate of most countries (Kelly and Fussell, 2015; Tiwari *et al.*, 2018). Current statistics from the World Health Organization (WHO) indicate that approximately 91% of the world's population resides in places where air pollution exceeds the WHO guideline limits (Hachem *et al.*, 2019; WHO, 2021). Most cities have failed to comply with the acceptable air quality for humans, as recent reports show that approximately 8 million deaths each year have been attributed to air pollution (Marinello *et al.*, 2020; WHO 2021). Air pollution causes adverse health consequences because of short- or long-term exposure, either indoors or outdoors. In 2019, it was reported as the 4th leading risk factor for premature death globally (Health Effects Institute 2020). Exposure has been linked to lung cancer, respiratory, cardiovascular, reproductive, and other related diseases that have deleterious effects on human lives (Hachem *et al.*, 2019; Neisi *et al.*, 2017; Tajudin *et al.*, 2019; Babatola, 2018; Cepeda *et al.*, 2017; Rees, 2016). The burden of pollutant dispersion is relatively higher in developing countries, where population explosion in both rural and urban areas

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with widespread industrialization is prevalent (Mannucci and Franchini, 2017; Shi *et al.,* 2020; Tiwari *et al*., 2018; Babatola, 2018; Tajudin *et al.,* 2019). The lapses in identifying the pollution sources that are responsible for premature deaths continue with a large population, taking a significant toll on public health (Jerrett *et al.*, 2015). Recently, air pollution has had a far more devastating impact than exposure to malaria and other crises over the years in developing countries (World Bank, 2016). The dispersion of pollutants in the air decreases the life expectancy of people in the vicinity of polluted areas. Approximately 93% of deaths and non-fatal illnesses in these countries are attributable to annual air pollution (WHO, 2016). It has been estimated that approximately 4.2 million deaths occur each year because of exposure to pollution in outdoor environments, and 3.8 million deaths result from burning solid fuels in households (Oliva *et al*., 2019; Marinello *et al*., 2020; WHO, 2021). Regionally, the advent of these activities over the years has extensively held back economic growth due to their irreversible long-term damage to human health, ecosystems, productivity losses, and a decrease in revenues and incomes (World Bank, 2016; OECD, 2016). According to World Bank estimates, exposure to air pollution hit $5.11 trillion in welfare losses in the world's economy in 2013 (World Bank, 2016; Marinello *et al*., 2020). The negative impacts include several premature deaths and disabilities that impose a huge annual cost on the economy (OECD, 2016).

A report indicates that out of the 20 most populous countries in the world, $PM_{2.5}$ exposure has declined in 14 countries, including Indonesia and Egypt, over the past decades (HEI, 2020). However, some studies have reported ozone levels to be 30–70% higher than they were in the past 100 years on a global scale (OECD, 2019). According to GBD estimates, on average, global exposure to ozone increased in 2010-2019 by 4.7% (HEI, 2020). The emission of hazardous chemicals and particles into the atmosphere by industrial activities has contributed significantly to this increase (Babatola, 2018). However, tracking and monitoring the concentration levels of pollutants around the globe over time are important for evaluating their impact on human lives and the environment. A host of sectors with keen interest in air quality management at both national and international levels have advocated many interventions to reduce the dispersion of pollutants. Most cities in developing countries have limited air quality data availability because of the few operational monitoring stations. Even those available often provide short-term and irregular measurements. Special attention needs to be paid to environmental organizations and the government to ensure that adequate monitoring stations are provided in their localities. However, losses attributable to indoor air pollution (IAP) are significantly higher in many developing countries. The issue of IAP has triggered the interest of most researchers and scientists since the late 1970s, as evidence of ill health due to exposure increases rapidly. Investigations in this area are also stimulated by international organizations as well as environmental bodies that have been intensely interested in updating indoor air quality. Burning solid fuel for heating or cooking in three-stone fires or inefficient cookstoves with limited ventilation produces an array of pollutants, among other sources. Exposure to dangerous pollutants in homes is particularly prevalent in sub-Saharan African countries. Despite growing concerns regarding the rate of exposure to these harmful pollutants, more than 97% of the SSA population relies on solid fuels for cooking. The death tolls because of this exposure continue to increase rapidly throughout the region.

Although a large variety of literature on the sources, concentration, health effects, engineering, and policy is widely available, the identification of several sources of contamination in indoor microenvironments has not been adequately investigated and evaluated. The wide gap in the details of sources contributing to the pollutants' dispersion is quite apparent. This review highlights the principal pollutants dispersed in indoor environments and their sources, with a clear investigation of how they spread. Findings from published international projects and various articles on gaseous pollutants dispersed from different sources in indoor environments between 2010 and 2021 were collated and analysed.

MATERIALS AND METHODS

Methods of Selection: This paper updates the frameworks on the dispersion of pollutants from different sources in low- and medium-income countries.

Strategy for Searching Articles: A comprehensive search of literature from 2010 – 2021 was undertaken using a systematic peer-reviewed database across multiple disciplines, including Science Direct (Elsevier), African Journals Online, Research Gate, Academia, Scopus, Web of Science, Springer, Wiley Online Library, Taylor and Francis, and Oxford Academic. A rigorous search of extant literature for relevant articles includes working papers and reports from international governmental and non-governmental agencies such as the World Bank, UNEP, IEA, WHO, IRENA, and UNSD. A search of references in journal papers and results from grey works of literature through Google and Google Scholar was also performed. The coverage of papers was assessed using broad search terms, after which irrelevant ones were excluded. The search terms include pollutant dispersion, indoor pollutants from cooking, biomass smoke, indoor air pollution, developing countries, urban population, rural population, pollutant exposure, and household air pollution. The criteria for studies included in this review were based on facts and evidence of the related search terms published between 2010 and 2021. A stepwise process was carried out to determine the authenticity of the report. Abstracts of all papers were read, ensuring they suited the study's aim and objectives. After screening the desired papers, the methodology, findings, and discussion sections were read carefully for final full-text screening. In the selection process, duplication of studies was avoided.

Description of Selected Studies: The review was restricted to studies on pollutant dispersion in developing countries. The studies were based on evidence in case studies combining qualitative and quantitative analyses with empirical data. The study designs selected include cohort, case-control, and cross-sectional studies with randomized (experimental) controlled trials. The articles reviewed include those conducted in developing countries, stating their specific data.

Pollutants: Sources and Effects: Pollutants are mixtures of various components dispersed in the atmosphere in the form of gases, solid particles, and liquid droplets (Nathanson, 2021; Srivastava and Pawaiya, 2020). Generally, all physical, biological, and chemical agents that can alter the natural features of the atmosphere are referred to as pollutants (Penard-Morand and Barbu, 2011; Penard-Morand and Annesi-Maesano, 2004). The U.S. Environmental Protection Agency (EPA) designated six major pollutants as criteria pollutants, the concentrations of which were solely responsible for indicating the air quality of the areas under consideration. The major pollutants are carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), airborne particulate matter (PM), lead (Pb), and ozone (O_3), as shown in Table 1. These pollutants can also be classified as primary and auxiliary (secondary) air pollutants (Issakhov *et al.,* 2020). The primary pollutants that are directly emitted into the environment from their emission sources include carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and airborne particulate matter (PM). Auxiliary air pollutants are not released directly but are formed in the air because of the complex chemical reaction of NOx and VOCs in the presence of sunlight and heat to produce ozone (O_3) and other photochemical pollutants (Penard-Morand and Annesi-Maesano, 2004; Oswalt and Clatterbuck, 2015; Luliana and Barbu, 2011; Utell *et al.,* 1994). Apart from Pb, all other major pollutants are dispersed at a higher rate, especially in industrialized countries (Rani, 2014). For instance, sulfur dioxide (SO_2) is released from various industrial processes, and during the eruption of volcanoes, nitrogen dioxide (NO_2) is released from the combustion of fossil fuels at high temperatures and can also be dispersed naturally from electrical discharge during thunderstorms. Carbon monoxide (CO) is released as a result of the incomplete combustion of coal, natural gas, and wood (Saritha Rani, 2014; Li *et al.*, 2020; Luliana and Barbu, 2011; Munawer, 2017). Other significant pollutants that are also dispersed into the environment are volatile organic compounds (VOCs), organic chemicals, oils, solvents, asbestos, benzene, and greenhouse gases (GHGs), including carbon dioxide, chlorofluorocarbons (CFCs), methane, and polycyclic aromatic hydrocarbons. Generally, these pollutants are contaminants that have harmful effects on both humans and the environment. In most countries, their presence in indoor and outdoor environments has notable consequences for ecosystems, exposed materials, and populations (Oswalt and Clatterbuck, 2020; Oswalt and Clatterbuck, 2015). Most developed countries primarily regulate the concentration of these pollutants by establishing air quality standards for the safety of their ecosystems (Jerrett, 2015; Winkler *et al.,* 2018). However, these pollutants have emerged from both natural sources and human activities (Penard-Morand and Annesi-Maesano, 2004; Luliana and Barbu, 2011; Rees, 2016; Tajudin *et al*., 2019). Natural sources include volcanic eruptions, dust from the Earth's surface, thunderbolts, wind erosion, pollen grain dispersion, radioactive decay, evaporation of organic compounds, and debris from plants and animals (Neisi *et al.*, 2017; Srivastava and Pawaiya, 2020). However, human activities that lead to the release of pollutants into the atmosphere may either be stationary or mobile. Human activities include the combustion of fossil fuels, power generation, industrial plants and processing, construction work, vehicle emissions, smoking, aerosol spraying, waste disposal, agricultural processes, bush burning, waste incinerators, and burning of solid fuels for cooking. (Hachem *et al*., 2019; Zhang *et al.*, 2013; Okunola *et al.*, 2012; Marinello *et al*, 2020; Tajudin, *et al*., 2019; Zhang *et al* 2015; Neisi *et al.,* 2017; CEC, 2014; Munawer, 2017). In most cases, the combustion of fossil fuels in vehicles, power plants, and industrial plants is incomplete. Incomplete combustion produces carbon monoxide and hydrocarbons, which are dispersed in the environment. Ultimately, the dispersed pollutants have toxic effects on atmospheric chemistry, such that inhaling at high concentrations can impair and strain the human heart. In this case, released CO enters the bloodstream and reacts with haemoglobin in the human body, reducing the formation of oxyhemoglobin and causing the malfunctioning of vital organs and altering its biological functions at the cellular level (Utell *et al.,* 1994; Munawer, 2017; Anthonia *et al.,* 2019). The sulfur oxides released during coal combustion also pollute air, water, and land because of the formation of toxic SO_2 gas. SO_2 inhalation causes suffocation, wheezing, coughing, aggravation of asthma, reduction in lung function, and a decrease in the life expectancy of people within the vicinity of the polluted area (Rees, 2016). Similarly, the oxides of nitrogen dispersed because of a mixture of air, nitrogen, and oxygen from fossil fuel combustion have been associated with several diseases, such as pharyngitis, bronchitis, tonsillitis, cold, and sore throat (Mbuligwe and Kassenga, 1997). They are also major components of acidic rain that cause a diverse variety of skin diseases and heart-related problems (Munawer, 2017).However, as more industries evolved, VOCs, NO_x, and SO_2 emitted from the combustion of power stations and automobiles continued to rise rapidly. The presence of these pollutants in the air can cause damage to proteins and lipids, which contribute to DNA mutations in the human body (Munawer, 2017). This is responsible for impairing neurodevelopment, intelligence quotient, respiratory illness, and other chronic diseases in children (Perera, 2018; Munawer, 2017; Rees, 2016). Subsequently, heavier metals such as cadmium, aluminium, mercury, lead, and zinc, with some other specific pollutants, are also produced as a result of industrial processes. Meanwhile, long-term exposure to acid rain also damages buildings made of concrete, marble, and limestone by deteriorating the constituents of carbonates (Mbuligwe and Kassenga, 1997; Luliana and Barbu, 2011). Notably, the adverse effects of emissions from different sources have deteriorated air quality, leading to environmental disasters such as ozone layer depletion, acid rain, photochemical smog, lead poisoning, and other ecological imbalances (Mahajan, 2013; Issakhov *et al.,* 2020). Moreover, pollutants dispersed into the atmosphere interrupt and damage the entire ecosystem, especially plants and animals (Munawer, 2017; Oswalt and Clatterbuck, 2015). The acidification and absorption of these pollutants block the stomata of plant leaves and their respiration ability (Luliana and Barbu, 2011; Oswalt and Clatterbuck, 2015; Mbuligwe and Kassenga, 1997). This leads to stunted growth or the death of crops (Neisi *et al.,* 2017). Inhalation of these harmful pollutants and the grazing of contaminated grasses by animals may result in their death or affect the humans that consume them. (Luliana and Barbu, 2011).

The burden of disease caused by long-term and short-term exposure to air pollution is revealed in scientific evidence and reports from many countries worldwide. Recently, the risks of air pollution have become unquantifiable, as several health problems have arisen. Many epidemiological studies have revealed the impact of human exposure on premature death and diverse diseases (Kelly and Fussell, 2015). Short-term exposure to air pollution causes difficulty in breathing, coughing, and wheezing, and sometimes triggers asthma symptoms that worsen respiratory and cardiac conditions. Such effects can cause an increase in doctors' prescriptions, hospitalization, and even premature deaths in the worst cases (Tajudin *et al.,* 2019). There have been many scientific studies on the effects of long-term exposure to air pollution over the last few decades. It has been linked to an increased risk of illness and premature death from lung cancer, chronic obstructive pulmonary disease (COPD), stroke, diabetes, lower respiratory infections, and adverse birth outcomes (Croitoru *et al.,* 2020). Studies have also linked air pollution to severe mental illness and its significant impact on infant mortality (Arceo-Gomez *et al.,* 2012; Oliva *et al.,* 2019). This significant burden of diseases reflects the consequences of long-term exposures to air pollution, which also contributes to adverse non-communicable diseases. According to IHME reports on the state of global air pollution in 2019, air pollution was estimated to have contributed to 6.67 million deaths worldwide. Based on these facts and figures, air pollution is recognized as a leading environmental risk factor for premature death worldwide. Its total impact is exceeded only by high blood pressure, tobacco use, and dietary risks. Globally, Asian and African countries experience a high burden of diseases attributable to death due to high exposure to harmful pollutants, as shown in Table 2. Apart from the lapses in development in these regions, the vulnerable population's social, economic, and demographic factors also contribute to the underlying health defects. Apparently, children and the elderly were the most affected across all age groups. The severe impacts of air pollution in developing countries have lasting, significant consequences on the populace, firms, and governments, as they hold back economic growth. On a global scale, the welfare costs from premature death were estimated as over US$3 trillion in 2010 and are anticipated to be over US$25 trillion in the next 40 years (Marinello *et al.,* 2020; Oliva *et al.,* 2019). Researchers also discovered the indirect impact of air pollution on productivity, decreased total number of working hours, and migration patterns in some countries (OECD, 2016; Oliva *et al.,* 2019). Not only does air pollution result in pervasive consequences on the populace, but it also incur large costs on the economy.

Factors Affecting Dispersion of Pollutants: Globally, the emergence of civilization and rapid development in most cities contributed to high emissions of a wide range of atmospheric pollutants. With the advent of the COVID-19 pandemic, many countries worldwide have experienced a significant reduction in pollutant concentrations for the first time in many years (Health Effects Institute, 2020). However, the ozone level gradually increased because of a reduction in NO_2 and some changes in meteorological factors. These changes may be temporal in most countries as emissions rise on lifting restrictions. Air pollution is not only determined by the intensity of the emission, but several factors may influence the dispersion of the pollutant and its time in the microenvironments; these include meteorology, topography, and emission sources. The meteorological variables have a significant effect on the dispersion of the pollutants in the atmosphere (Tajudin *et al.,* 2019; Penard-Morand and Annesi-Maesano, 2004; Luliana and Barbu, 2011; Shi *et al.,* 2020; Tiwari *et al.,* 2018; Hachem *et al.,* 2019). Several researchers observed that the rate of pollutant’s dispersion in the atmosphere are strongly affected by seasons and meteorological conditions such as temperature, humidity, atmospheric pressure and wind speed (Tiwari, *et al.,* 2018; Wu, *et al*., 2013; Kaur and Nieuwenhuijsen, 2009; Tajudin, *et al*., 2019; Penard-Morand and Annesi-Maesano, 2004; Wang *et al*., 2016; Li *et al.,* 2020). In most cases, low atmospheric pressures are accompanied by strong air turbulence, such that it increases the rate and speed at which pollutants are dispersed. The wind direction and force also determine these pollutants' transmission and dilution degree in the atmosphere (Shi *et al*., 2020; Zhang *et al.,* 2015; Zagury *et al.,* 2000). However, pollutants such as CO, HC, CO_2, and NO_x emitted to the atmosphere follow a different pattern and they tend to be higher than other pollutants (Amirjamshidi *et al.,* 2013). During summer, the solar rays and high temperature react on NOx and contributes to photochemical formation of ozone (Wang *et al.,* 2016; Luliana and Barbu, 2011). Meanwhile, the dispersions of SO_2 and PM are higher in winter because of the emissions from the combustion of fossil fuels in power plants and other heating systems. Nevertheless, in the emissions of dioxins from biomass burning, the rate of pollutant dispersion is determined by the combustion conditions, chlorine content, and number of pesticides absorbed into the leaves (CEC, 2014). In addition to these findings, some researchers also reported that the amount and relative dispersion of pollutants produced by solid fuel combustion indoors depend on the type of fuel and moisture content, stove technology, and ventilation (Clark *et al.,* 2013). Several studies have reported the effects of outdoor pollutants infiltrating indoor spaces. Some of the studies found that proximity to busy roads, wind speed, and the perimeter and surface of the window determine the concentration of outdoor pollutants infiltrated and diffused into indoor environments (Avery *et al.,* 2019).

RESULTS AND DISCUSSION

Indoor Dispersion of Pollutants: Globally, people spend a substantial amount of time in indoor environments (Davardoost and Kahforoushan, 2019). Time spent indoors varies with season, gender, age, occupation, and people's health conditions (Leung, 2015). The air quality in residences, offices, schools, health care facilities, day care centers, and public and private buildings plays an important role in public health as it determines the health and well-being of the occupants. In recent years, the indoor air quality has been taken with more consideration on its associated health risks, determinants factors, techniques for prevention, and mitigation measures. In spite of increasing awareness and authorities' attention in different countries, indoor air pollution is regarded as a leading risk factor for the causes of death, including lung cancer, heart disease, diabetes, and pneumonia globally. According to the Global Burden of Disease (GBD) study, 1.6 million premature deaths occurred due to exposure to indoor air pollution in 2017. The higher proportion of the mortality rate is especially from the low and medium-income countries. The problem of poor indoor air quality has almost been eliminated across high-income countries as a result of the statutory framework for implementing ambient air quality standards for pollution sources (Ielpo *et al.,* 2018). However, the relevance of indoor air quality in developing countries has become enormously apparent in response to the adverse ill effects. The health risks posed by the dispersion of pollutants are determined by the personal exposure of the individuals to the contaminants. Consequently, the individual’s exposures are based on the amount of the pollutant concentration encountered in the indoor environment with respect to time spent in the location.

Table 1: Major pollutants, sources, and effects

Major Pollutant	Sources	Maximum Acceptable Limit	Environmental Impact	Health Impact
Carbon monoxide (CO)	Vehicle emissions, bushfires, and Industrial processes	35 ppm (1-hour period); 9 ppm (8-hour period)	Smog formation	Worsen the symptoms of heart disease, causes vision impairment, and reduces physical and mental stability
Nitrogen oxides (NO and NO_2)	Vehicle emissions, Combustion in power plants, Industrial processes	0.053 ppm (1-year period)	Causes stunted growth and death of plants; Causes smog formation	Block breathing passages, resulting in inflammation and irritation
Sulphur dioxide (SO_2)	Combustion of fossil fuels, power generation, industrial plants and processing, and vehicle emissions	0.03 ppm (1-year period); 0.14 ppm (24-hour period)	Acid rain formation, which subsequently damages the leaves of plants and buildings	Causes breathing difficulties, especially for asthma and heart disease patients
Ozone (O_3)	Nitrogen oxides (NO_x) and volatile organic compounds (VOCs) from industrial, vehicle emissions, gasoline vapours, and chemical solvents.	0.075 ppm (8-hour period) 0.12ppm (1-hour period)	Block the stomata of the plant leaves and their ability to respire, thereby causing stunted growth and death of the crops	Causes irritation and inflammation of the breathing passages. Also reduces lung function;
Particulate matter ($PM_{2.5}$ & PM_{10})	Bush fires and burning, building and construction works, traffic congestion, combustion in power plants, and vehicle emissions	150 µg/m^3 (24-hour period for particles <10 µm); 35 µg/m^3 (24-hour period for particles <2.5 µm)	Acid rain formation, which changes the pH balance of waterways, damages plants and crops, buildings, and monuments	Exacerbate Asthma, irritation in breathing, and irregular heartbeat
lead (Pb)	Combustion of fossil fuels, metal processing, waste incineration	0.15 µg/m^3 (rolling three-month average); 1.5 µg/m^3 (quarterly average)	Biodiversity loss, a decrease in reproduction, and neurological defects in vertebrates	Causes impairment in young children, cardiovascular effects in adults

Table 2: Concentration of pollutants and the number of deaths attributable to air pollution in some selected countries in 2019

Developing Countries	Population (In millions)	Average Annual Population Weighted $PM_{2.5}$ (ug/m^3)	Average Seasonal Population Weighted Ozone (ppb)	Proportion of Population Using Solid Fuels	Number of Death Attributed to Air Pollution
Bangladesh	163,046,161	63.4	64.6	0.759	173,500
Cameroon	25,876,380	64.5	49.7	0.725	22,400
Dr Congo	86,790,567	35.9	47.4	0.93	69,500
Ethiopia	112,078,730	33.8	44.3	0.963	77,000
Ghana	30,417,856	54	49.3	0.702	23,800
India	1,366,417,754	83.2	66.2	0.607	1,667,000
Indonesia	270,625,568	19.4	37.6	0.339	186,300
Kenya	53,771,296	21.6	39.1	0.867	27,700
Malawi	19,129,952	22.3	39.2	0.967	13,700
Nigeria	200,963,599	70.4	52.6	0.774	197,600
Pakistan	216,565,318	62.6	63.3	0.53	235,700
Philippines	109,581,078	18.8	24.4	0.481	74,800
Rwanda	12,626,950	36.2	47.4	0.99	9,290
Senegal	16,743,927	60.2	42.4	0.782	12,500
South Africa	58,558,270	38.7	39.9	0.125	29,800
Thailand	69,625,582	27.4	45.5	0.212	40,900
Togo	8,278,724	46.2	51.8	0.912	6,710
Tunisia	11,694,719	30.4	52.8	0.0029	7,530
Turkey	83,429,615	26	49.4	0.0065	44,200
Uganda	45,741,007	35.2	43.4	0.978	27,700
Vietnam	96,462,106	20.4	38.7	0.408	71,700
Zimbabwe	14,645,468	20.8	41.9	0.688	12,700

Data Source: Global Burden of Disease Study 2019. IHME, 2020.

To date, numerous studies have investigated the dispersion of pollutants in various indoor environments across the globe. Diverse individual groups usually study indoor air quality with an emphasis on pollutant levels and health impact assessment. The indoor pollutants are particulates, gases, toxins, and micro-organisms such as CO, VOCs, PAHs, respirable particles, and ultrafine particles emitted indoors. Several studies have identified the emission of these pollutants as a possible cause of various diseases. So far, there is wide evidence linking the emission rate of pollutants and their adverse effects on the health of people staying indoors. The impact of the dispersion is based on the concentration level of the pollutants emitted from various sources indoors (Gennaro *et al.,* 2016). The sources that dispersed airborne contaminants in indoor environments can be in homes (Fan *et al.,* 2021; Akther *et al.,* 2018; Shen *et al.,* 2020), offices (Nandan *et al.,* 2020; Pantelic *et al.,* 2019), Museums (Uring *et al.,* 2020; Holt *et al.,* 2017), laboratory (Davardoost and Kahforoushan, 2018), educational building (Arar *et al.,* 2019; Madureira *et al.,* 2015), bakery (Ielpo *et al.,* 2017; Downward *et al.,* 2017), library (Sahu and Gurjar, 2019), theatres (Holt *et al.,* 2017) and transport microenvironments (Akcetin et al., 2020; Zalauf et al., 2019) as shown in Table 1. Toxic pollutants can be dispersed from buildings and construction materials (Liu et al., 2019; Akhter *et al.,* 2018), indoor equipments such as printers, photocopiers, heating systems, airconditioners, ovens (Nandan *et al.,* 2020; Gennaro *et al.,* 2015; Ielpo *et al.,* 2017; Fan *et al.,* 2021), or due to human activities indoor such as combustion of solid fuels for cooking or heating (Clark *et al.,* 2013), tobacco smoking (Marcham *et al.,* 2019; Ni *et al.,* 2019), burning of candles and incense sticks (Petry *et al.,* 2014; Manoukian *et al.,* 2013). Other sources may include emissions from building materials and furniture, house dust (Arar *et al.,* 2019; Kayama *et al.,* 2016), toiletries, indoor pesticides (Fan *et al.,* 2021; Holt *et al.,* 2017), use of household cleaning products such as air fresheners or fragrances (Fontal *et al.,* 2016), and other consumer products (Petry *et al.,* 2014). Moreover, the presence of molds, dampness, and other biological contaminants such as allergens, insects, pollen, and bacterial endotoxins were also recognized as pollutants emitted indoors (Filho *et al.,* 2021).

However, some studies reported that the indoor air quality is mainly influenced by outdoor pollution, while others argued that exposure to indoor pollutants far exceeds exposure to outdoor pollution (Kang *et al.,* 2021; Dedele and Miskihyte, 2016; Elf *et al.,* 2017; Jeong *et al.,* 2019; Johnson *et al.,* 2016; Avery *et al.,* 2019). Apparently, the exposure to indoor pollution cannot be characterized by ambient measurement alone; there is a need for accurate knowledge of the sources that generate contaminants indoors to enhance the assessment of the quality of air in indoor environments. Evidence from different researchers in both developed and developing countries reported cooking as the primary source of indoor air pollution that contributes enormously to the emission of gaseous and particulate pollutants (Chen *et al.,* 2018; Cao *et al.,* 2016; Klein *et al.,* 2019; Adeniran *et al.,* 2020; Dobbin *et al.,* 2018; Duffy *et al.,* 2021; Liu *et al.,* 2017). Most of the results of these studies show that the amount of pollutant dispersed from cooking exceeds the US EPA and WHO's required standard limits in most cases. Globally, exposure to cooking-related risks regardless of race, age, wealth, cultural cooking styles, and preference significantly impacts the populace’s health. Apart from the combustion of fuel used, the processes and methods used in cooking also contribute enormously to the emission of gaseous and particulate pollutants indoors (Chen *et al.,* 2018). Cooking methods such as frying, roasting, boiling, broiling, and grilling generate primary aerosols and other toxic elements. Some researchers also pointed out that the cooking ingredients, temperature, duration, styles, and ventilation during cooking can lead to direct emissions of vapors and respirable particles (Klein *et al.,* 2019; Adeniran *et al.,* 2020).

Forms of Indoor Air Pollution: In the past decades, the continuous negative impact and the unsatisfactory implementation of modern fuels for cooking by households in developing countries have been of great concern to key environmental bodies. The emission from these sources contributes to risks of morbidity and mortality, as shown by epidemiological studies and environmental impact assessments carried out by these international organizations. The burden of indoor air pollution continues to be a prominent topical issue among impoverished households in developing countries. The hazardous effects associated with exposure to indoor air pollution (IAP) are quite terrible, and it is often regarded as a silent killer in these countries. About 3 billion people are at risk of ill health and premature death because of the exposure. This practice tends to worsen in rural communities due to a lack of other forms of energy (Rees, 2016).

Dispersion of Cooking with Biomass Solid Fuels (BSF): Out of the different sources responsible for indoor air pollution, combustion from cooking with biomass solid fuels (BSF) contributes mainly to the dispersion of obnoxious pollutants (Embiale, 2020). Oftentimes, the BSF are employed in poorly ventilated homes or unvented stoves typically made up of 3 stones, U-shaped holes in a block of clay, or a pit in the ground (Balmes, 2019). The World Health Organization (WHO) reported that about 3 billion people in the world use the dirty solid fuel(such as wood, charcoal, coal, animal dung and crop wastes) for cooking and heating on open firesplaces, unvented cooking stoves in homes (Downward *et al.,* 2015; Anthonia *et al.,* 2019). These practices generate hazardous smoke depending on the type of BSFs burnt. The pollutants emitted as a result of incomplete combustion include CO, SO_2, NO_x, PM, formaldehyde, black carbon, toxic organic compounds, and other polycyclic aromatic hydrocarbons (Chen *et al.,* 2018; Chen *et al.,* 2020). The emissions of these respirable particles and gases are qualitatively similar to tobacco smoking in some cases (Balmes, 2019).

The public health effect of exposure to hazardous indoor pollutants from cooking with BSFs on inefficient and poorly ventilated stoves remains high despite progress made over the years to combat this effect. According to recent reports, 3.8 million deaths per year were estimated to be attributable to pollution from solid fuel use for cooking indoors across the globe (Balmes, 2019; Chen *et al.,* 2020). The rise in the estimates is due to the rampant use of BSF for cooking in low and middle-income countries (LMIC), especially Sub-Saharan Africa (SSA) and Asia (Elf *et al.,* 2017; Embiale *et al.,* 2020). Exposure to pollutants emitted from BSF forms leading health risks in these countries, especially for the most impoverished populations (Balmes, 2019). Evidence from several epidemiologic studies shows the adverse health effects of the exposure, particularly on women and young children (Kephart *et al.,* 2021; Filho *et al.,* 2021). In rural areas of LMIC, women often spend many hours cooking with their infants and toddlers carried on their backs. The immature immune systems of the children exposed them to smoke concentrations that exceed the recommended WHO standard limits and are at high risk of suffering a variety of diseases (Filho *et al.,* 2021).

Apart from the significant health impacts, the felling of trees for solid fuel results in environmental degradation and local and regional climate changes. The report indicates that about 20% of black carbon is emitted globally from cooking with BSF on traditional stoves and open fire, especially from LMIC. Several research studies on the emission and dispersion of pollutants from BSF have been conducted across many regions of LMC, showing vast differences in the level of pollutants. Globally, diverse researchers have reported pollutant concentration levels and exposure rates among impoverished households. Site- and laboratory-based measurement indicates the periodic concentration of pollutants emitted during cooking.

Outdoor dispersion of Pollutants: The air quality of most developed countries has substantially improved because of regulatory interventions by their authorities (Jerrett, 2015; Winkler *et al.,* 2018; Penard-Morand and Annesi-Maesano, 2004; Tiwari *et al.,* 2018; Rees, 2016). Over the past decades, there has been a substantial increase in studies that reported the benefits of these improvements on public health, but other regions in developing countries still face the challenges of poor air quality (Hasunuma *et al.,* 2014; Mahesh *et al.,* 2018; Tajudin et al., 2019). Pollutants dispersed from outdoor activities in these countries include fossil fuel combustion, vehicle emissions, bush burning, gas flaring, combustion of biomass solid fuel for cooking and heating, thermal power plants, mining operations, and farming chemicals (Issakhov *et al.,* 2020; CEC, 2014; Zagury *et al.,* 2000; Rahman and Kim, 2012; Winkler *et al.,* 2018; Brugge *et al.,* 2007; Wu *et al.,* 2018)

In quest to the detrimetal influence of these deleterious effects of these pollutants, several studies reported the health and environmental impacts of decomposition, oxidation, hydration and other chemical reactions of pollutants dispersed outdoor (Tiwari *et al.,* 2018; Perera, 2018; Brugge *et al.,* 2007; Issakhov *et al.,* 2020; Kelly and Fussell, 2015; Zhang *et al.,* 2013; Luliana and Barbu 2011; Hasunuma *et al.,* 2014; Tajudin *et al.,* 2019; OECD, 2016; Saritha Rani, 2014; Munawer, 2017; Oswalt & Clatterbuck, 2015; Utell *et al.,* 2004). The author of these works has identified outdoor air pollution as responsible for premature deaths and diverse illnesses, as well as a significant threat to global warming and greenhouse gas emissions in both developed and developing countries. Moreover, the changes in the air quality have drastically caused the depletion of the ecosystem (Munawer, 2017).

Chiang *et al.* (2012) investigated the chemical constituents of the exhaust emissions from vehicles, industrial plants, and densely populated areas. The authors identified the significant impact of the emissions, which is of great concern to the public. Moreover, most researchers reported that the rapid increase in vehicles and industries, especially in the cities, results in higher dispersion of contaminants into the atmosphere (Tajudin *et al.,* 2019; Shi *et al.,* 2020; Li and Huang, 2011; Kurnykina *et al.,* 2018; Mbuligwe and Kassenga, 1997). Their reports indicate the hazardous effects the contaminants may cause on exposed materials as well as the undue expansion, corrosion, fading, and scaling of their surfaces. Obviously, the primary pollutants dispersed include carbon monoxide (CO), hydrocarbons, oxides of nitrogen, sulphur dioxide (SO_2), lead, and particulate matter because of incomplete fuel combustion (Mahajan, 2013; Zhang and Batterman, 2013; Kurnykina *et al.,* 2018; Winkler *et al.,* 2018). Furthermore, vehicles emission is also a significant source of volatile organic compounds which contains different carcinogenic substances that can stimulates visual and nasal organs resulting in anemia and acute poisoning in human (Wang *et al*., 2016; Rahman and Kim, 2012;). The VOCs can be transformed into secondary organic aerosols through photochemical oxidation and also react with NO_x generated in combustion process to form ozone under intense light (Wang *et al.,* 2016; Issakhov *et al.,* 2020; Marinello *et al*, 2020; Houston *et al.,* 2004; Tajudin *et al.,* 2019). Additionally, the domestic and industrial burning of fossil fuel in chemical plants releases SO_2, H_2S, NO_2, and hydrogen sulfide into the atmosphere. The chemical reaction of these pollutants in the presence of sunlight and volatile organic compounds from either vegetation or human activities also produces photochemical smog (Luliana and Barbu, 2011; Penard-Morand and Annesi-Maesano, 2004; Oswalt and Clatterbuck, 2015). The increase in emissions of chemicals that form ozone by industrial processes and the rising global and local temperatures contribute to its formation. According to the IHME report, the global ozone exposure varies between 12.2ppb and 67.2ppb worldwide. In 2019, Asia and the Middle East were the top countries with the highest average ozone exposure. The steady rise in ozone levels in these countries has been a great concern for public health recently. Over the time frame between 2010 and 2019, some countries in SSA, including Ethiopia, Nigeria, and the Democratic Republic of the Congo, also experienced increases in ozone levels. Similarly, the particulate matter emitted from vehicles, waste burning, coal burning power plants, industrial processes, and all other human or natural activities has increased rapidly in the advent of civilization and modernization. Over 90% of the world's population is exposed to $PM_{2.5}$ that exceeded WHO guidelines in 2019 (HEI, 2020). Most countries in Asia, Africa, and the Middle East experienced higher annual average exposures, contributing to the burden of disease and mortality in the region, as shown in Table 2 (Babatola *et al.,* 2018).

Pollutant dispersion from open-air burning of agricultural waste is frequently practiced in many countries to eliminate waste and prepare the fields for planting (CEC, 2014; Rees, 2016; Wu *et al.,* 2018). According to a UNEP report, 3 billion people lack access to waste management services globally and are left with no other option than burning wood, trees, grasses, leaves, and other wastes openly (Rees, 2016). These practices dispersed carbon monoxide (CO), carbon dioxide (CO_2), black carbon, particulate matter (PM), mercury, and polycyclic aromatic hydrocarbons (PAHs) into the atmosphere (CEC, 2014; Wu *et al.,* 2018; Rees, 2016). It also releases carcinogenic pollutants, a significant source of highly toxic dioxins that contribute significantly to climate change. A small amount of these dioxins remains in the atmosphere for a long period of time before degrading into other chemical forms. The accumulation of these pollutants in the fatty tissues of humans and animals is linked to various harmful effects that can lead to premature death. However, pollutants from agricultural sources are regarded as leading sources of mortality in some countries (CEC, 2014). In this case, the livestock and fertilizers used in agricultural processes release ammonia into the atmosphere to produce ammonium nitrate and sulphate particles.

This forms the second largest contributor to mortality globally (Jerrett, 2015). Exposure to biomass burning and tobacco smoke, either active smoking or second-hand exposure, is associated with death attributable to stroke and cardiovascular diseases (Ni *et al.,* 2021).

Conclusion: Most studies about pollutant dispersion and its consequences were done without considering the variety of pollutants during cooking in an indoor environment. This paper provides literature from diverse countries on pollutant dispersion from various activities, particularly indoors. Lack of household energy data linked to indoor air concentration levels in these countries generates barriers to formulating local policies required for effective air pollution management. The extent of different pollutants' dispersion in many countries calls for global mitigation and actions to reduce their impacts and address their growing threat to future generations. However, the underlying trends that drive these menaces are due to the neglect by concerned institutional bodies. There is a need for a collaborative and coordinated effort from the multi-sectoral establishment across all countries.

Declarations of Conflict of Interest: The authors declare no conflict of interest

Data Availability Statement: Data are available upon request from the corresponding author.

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