Chapter 7
Urban Areas and Air Pollution: Causes, Concerns, and Mitigation

Shivali Gupta and Rakesh Kumar

Abstract Urbanization has proven to be a catalyst for global economic growth. However, the concomitant progress in economic development has led to a degradation in air quality within urban settlements, primarily attributable to copious anthropogenic sources of pollutant emissions. Air pollution has numerous negative impacts on the well-being of humans and the environment. This includes the deleterious impacts on climate change as well as the emergence of serious cardiovascular and respiratory diseases. This chapter, therefore, discusses urban air pollution, encompassing the causal factors, associated concerns, and various strategies employed to mitigate its adverse effects. These strategies involve regulatory, technological, and behavioural responses, which are imperative to effectively address the issue of air pollution. Therefore, the examination of the complex interplay between urbanization across varying stages of development and air pollution is integral in attaining ambient air quality targets with respect to upcoming economic advancement and sustainable progression.

Keywords Anthropogenic Sources · Air pollution · Climate change · Human health · Sustainable development · Urbanization

7.1 Introduction

Rapid industrialization has facilitated a significant surge in both urbanization and economic expansion, especially in the developing world. "Urbanization refers to the process of population growth in urban areas, accompanied by a multitude of transformations that entail moving away from rural lifestyles. Such changes impact various aspects of industry structure, living standards, employment opportunities, and public services in the urban context". The process of urbanization is the result of population growth, which leads to modifications in the size, structure, and growth of

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cities (Liang & Gong, 2020). Urban areas or agglomerations exhibit a high degree of population density and are characterized by a comprehensive network of built environment infrastructure. The elevated rates of economic growth within metropolitan regions serve as a driving force attracting individuals on account of the heightened availability of employment prospects, educational resources, and an improved standard of living (Ho, 2012). Approximately fifty per cent of the global populace currently dwells in metropolitan regions, with a projected substantial upsurge in this figure in the upcoming years (World Bank, 2022). Although urbanization has contributed significantly to the global economy, it has also resulted in various challenges to environmental sustainability. One of the most critical challenges is the degradation of air quality in rapidly expanding urban areas (Wang et al., 2020). The United Nations Environment Programme et al. (2002) estimated that approximately 1.1 billion individuals worldwide are exposed to air that fails to meet health standards. Urban air pollution is a critical issue leading to a substantial number of fatalities annually, with Chen et al. (2022) reporting that over two million individuals succumb to its deleterious effects. Air pollution arises from the accumulation and sustained presence of specific substances, commonly known as air pollutants, within the ambient air, resulting in detrimental consequences on both the health of humans and the natural environment. Air pollution has become a significant concern due to its contribution to social inequality, health conditions, and environmental degradation, which includes the occurrence of acid rain, eutrophication, urban smog, and possibly even climate change (Ahmad et al., 2015). Numerous sources, such as the manufacturing segment, combustion engines, biomass combustion, and other related sources of particulate emissions, have led to an exponential increase in anthropogenic air pollutants. The matter of significant concern pertains to the issue (Leung, 2015).

Any airborne physical, chemical, or biological substance of natural or anthropogenic origin that negatively alters the atmosphere's natural properties and results in adverse impacts on the health of human beings or other biosphere components is referred to as an air pollutant. Air pollutants can be gaseous pollutants [nitrogen dioxide (NO_2), volatile organic compounds (VOCs), sulphur dioxide (SO_2), ozone (O_3), and carbon monoxide (CO)], particulate matter (PM), that is, PM_{10} (aerodynamic diameter ≤10 μm) and $PM_{2.5}$ (aerodynamic diameter ≤2.5 μm), persistent organic pollutants (dioxins), or heavy metals (lead, mercury) (Agarwal et al., 2019). The dissimilarities among various categories of atmospheric pollutants are manifested through their unique chemical composition, distinct emission patterns, reaction dynamics, levels of environmental persistence, transportation capabilities over short or prolonged distances, and disparate impacts on the natural surroundings (Fino, 2018). The effects of aerosols on both human health and climate change are well documented in the academic literature. These particulate matter substances serve as critical radiative forcing agents, possessing the ability to generate either positive (warming effect) or negative (cooling effect) radiative forcing. The degree to which aerosols influence radiative forcing is dependent upon their microphysical properties, such as optics and size, as well as their specific composition. The impact of aerosols on circulation systems and the consequent deterioration of environmental quality have been extensively studied and documented in the scientific literature (Banerjee & Srivastava, 2011; Ramanathan & Carmichael, 2008). Some gaseous air pollutants have the capacity to absorb long-wave radiation, thereby making a significant contribution to climate change. The transport of air pollutants through the atmosphere can extend over considerable distances and traverse across continents, thereby increasing the complexity of regional air quality. Consequently, the investigation of the origins and ultimate occurrence of these gases within the atmosphere holds paramount significance (Agarwal et al., 2019; Mhawish et al., 2017). As reported by Bikis and Pandey (2021), the adverse effects of transportation-related air pollution are experienced by 40% of urban residents in Addis Ababa. Various sources, traversing route, and ramifications of airborne contaminants have been represented in Fig. 7.1.

There are multiple causes of intricate air pollution in urban areas, including emission sources, such as traffic or industrial processes, along with meteorological phenomena, such as insolation, wind patterns, temperature, and relative humidity. Furthermore, chemical transformations contribute significantly to the generation and evolution of air pollution through the occurrence of various chemical reactions and dry depositions (Ho, 2012). Pollution processes are inherently dependent upon the prevailing meteorological conditions as well as physical and chemical characteristics of contaminants, which together are vital in shaping overall pollution dynamics as well as the transportation, dispersion and eventual sink of air pollutants (Vallero, 2014b).

Henceforth, to mitigate air pollution and preserve human health and ecological balance, it is imperative that priority is given to the management of urban air quality.

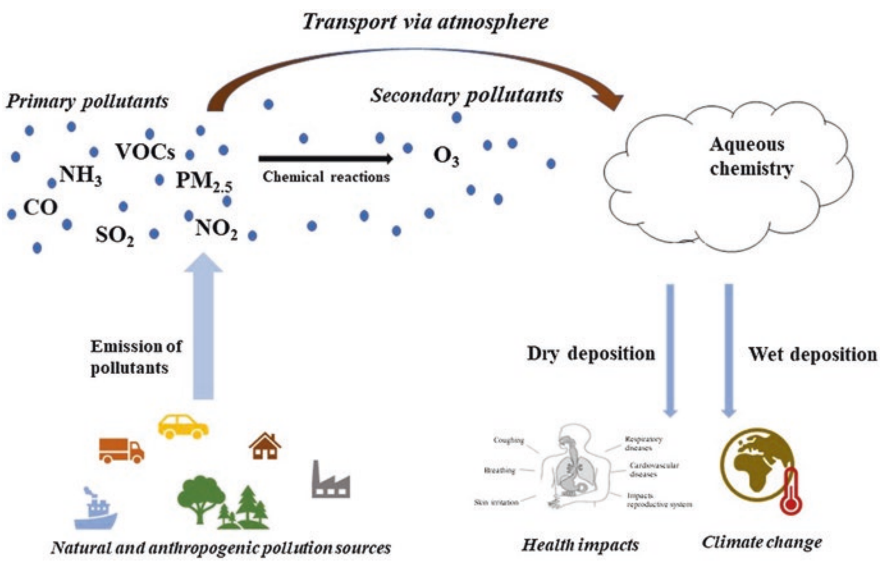

Fig. 7.1 Sources, pathways, and effects of air pollutants

An imperative requirement for rigorous scientific assessment pertaining to the assessment of the ramifications that urbanization on the quality of atmospheric composition. This chapter provides an overview of urban air pollution, encompassing factors causing such pollution, adverse effects pertaining to health and the environment, and possible remedial actions to reduce air pollution and counter the detrimental association between urbanization and pollution for the promotion of sustainable urban developmental practices.

7.2 Air Pollutant Types

The effects of air pollutants are subject to differential impacts on individuals, contingent upon factors such as concentration, toxicity, and duration of exposure (Leung, 2015). Air pollutants are categorized into two types, namely, primary pollutants and secondary pollutants, depending on their source of origin. Primary pollutants refer to the contaminants emitted directly from their source into the environment, specifically into the atmosphere. Examples of these primary pollutants include SO_2, CO, and CO_2. The term "secondary pollutants" pertains to particles generated because of chemical interactions between materials in a mixed gas phase that are exposed to solar radiation or due to reactions between primary pollutants (Agarwal et al., 2019; Banerjee et al., 2015; Kumar et al., 2016), for instance, the formation of ozone, which is a secondary pollutant (Ahmad et al., 2015).

The air pollutants are further divided into outdoor pollutants and indoor air pollutants (Fig. 7.2). Outdoor air pollutants are composed predominantly of NOx, SO_2, O_3, CO, PM, and hydrocarbons (HCs). In metropolitan regions, these emissions originate predominantly from motor vehicles, with additional contributions stemming from power generation facilities, industrial boilers, incineration operations, petrochemical manufacturing plants, aviation, marine transportation, and related sources. The variability in atmospheric conditions depends upon geographical location and the directionality of prevalent air currents. Urban areas exhibit reduced significance in the contribution of long range sources of pollution owing to the extended distance from such sources (Leung, 2015). The reduction in air dispersion in the urban environments can be attributed to the presence of densely located buildings which inhibits air circulation (Cheng et al., 2009; Li et al., 2009). Conversely, proficient urban planning can mitigate the challenges related to the accumulation of air pollution by means of the wide dispersion of pollutants (Leung, 2015; Li et al., 2009).

Indoor air pollutants mainly include CO, O_3, SO_2, NOx, radon, PM, VOCs, semi-volatile organic compounds, and microorganisms. The presence of these contaminants is prevalent in both interior and exterior environments, and certain sources of origin for these pollutants may exist in external contexts (Leung, 2015). Sick building syndrome (SBS) is a prevailing adverse effect that triggers acute health symptoms, including irritation, allergies, and other related conditions. The aetiology of the syndrome remains largely unknown, albeit it may exhibit a time-limited

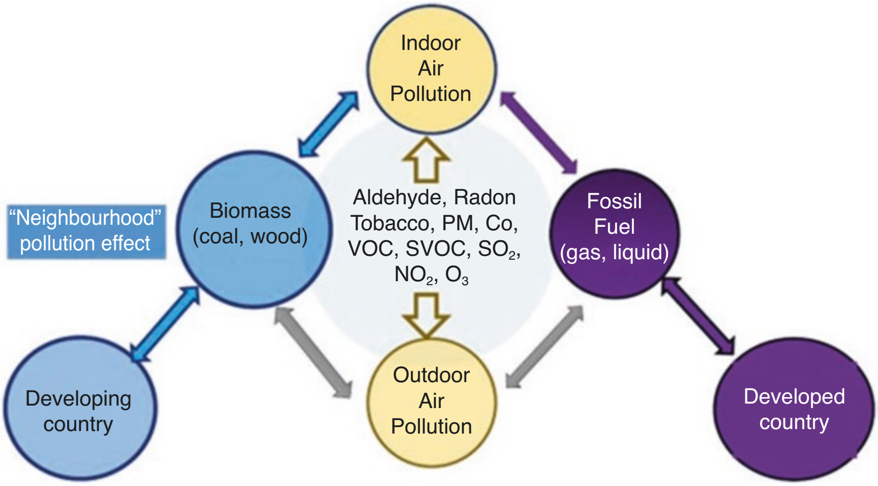

Fig. 7.2 Indoor and outdoor air pollution and its sources. (Source: Rosário Filho et al., 2021)

propensity in which cessation of exposure to the occupational or environmental setting could lead to its resolution. According to Wargocki et al. (2000), enhanced ventilation can reduce SBS and improve indoor air quality. Radon is a radioactive, odourless, and colourless gas that is known to be a significant contributor to the incidence of lung cancer in numerous countries. It is considered an indoor air pollutant that is commonly found in stony construction materials or inadequately ventilated basements of residential homes. The quality of indoor air is contingent upon specific indoor activities, including smoking, cleaning, and employing wood burning for the purposes of heating and cooking (He et al., 2004; Leung, 2015). He et al. (2004) assessed the concentrations and emission rates of particulates in indoor environments resulting from various indoor activities and sources. The findings of the study revealed that cooking-related activities could increase the PM number concentration by a factor ranging between 1.5 and 27 times. Additionally, the urban heat island effect has been observed to create numerous challenges for individuals especially residing in tropical regions with high atmospheric temperatures (Memon et al., 2009). The urban heat island phenomenon is exacerbated in metropolitan regions as a consequence of global climate change, resulting in prolonged periods of indoor occupancy and escalated reliance on air conditioning systems. Consequently, increased exposure of humans to indoor biological and chemical pollutants may potentially generate deleterious consequences on public health (Leung, 2015).

Air pollutants are further classified as hazardous air pollutants and criteria air pollutants, although both types of pollutants are "hazardous" (Vallero, 2014a).

Hazardous Air Pollutants

Hazardous air pollutants, commonly called "air toxics", are the chemical substances recognized to induce cancer and other chronic illnesses in individuals, including reproductive complications and birth abnormalities, even at very minimal concentrations. Hazardous air pollutants typically exhibit spatial limitations within localized regions, commonly referred to as “hot spots”. These regions are predominantly found in industrial and urban areas, which may exhibit high concentration of hazardous pollutant like benzene or other chemical associated with a specific industrial activity (Vallero, 2014a).

Ecotoxicity, which is alternatively referred to as ecosystem toxicity, characterizes the potential threat that a substance may impose on divergent organisms inhabiting an ecosystem. Chemical hazards encompass several potential harms, including the risk of fire, chemical reactivity, and corrosivity. Hazards may potentially have biological attributes, such as biohazards, and physical attributes, including radioactivity. Biohazards are a category of biological agents that comprise various microorganisms, such as bacteria and viruses, as well as fragments of larger organisms, such as pollen and spores. Physical hazards can also be a consequence of air pollution, for example, an increase in melanoma cases because of increased exposure to UV radiation brought on by air pollutants that reach the stratosphere and react with ozone. The critical determinants of a compound's potential hazard are its intrinsic toxicity, mobility within environmental media and tissues, durability, and tendency to amass in living tissue (Vallero, 2014a).

Criteria Pollutants

The criteria pollutants are those that are used to determine the quality of air in a region based on common standards. The criteria pollutants refers to prevalent air pollutants that possess the potential to adversely impact the health or well-being of the general public (Vallero, 2014a). The National Ambient Air Quality Standards (NAAQS) have been set up for each of the criteria air pollutants. In general, for the criteria air pollutants, the acceptable levels of exposure can be determined and for which an ambient air quality standard has been established e.g. particulate matter, ground-level ozone, sulphur dioxide, nitrogen dioxide, carbon monoxide and lead. Particulate matter (PM) refers to solid or liquid particles suspended in air and is one of the most important criteria pollutants monitored throughout the world. Particulate matter is further classified based on their aerodynamic diameter, as fine ($PM_{2.5}$) or coarse (PM_{10}) particles. PM is notorious for its propensity to induce severe health impacts, reduce visibility, and exacerbate climatic perturbations through radiative forcing.

Ground-level ozone (O_3) is a colourless gas known to provoke deleterious effects on both the environment and human well-being, specifically on vegetation and wildlife. Exposure to this pollutant can result in short-term effects such as respiratory distress, whereas long-term issues may arise, including chronic respiratory conditions such as asthma, bronchitis, and emphysema (Vallero, 2014a). Ground-level O_3 is also a primary ingredient of smog, another important air pollutant in the urban regions.

NO_2 is generated by numerous sources during the combustion process of fuel at elevated temperatures. NO_2 exhibits reactivity with various atmospheric constituents, resulting in the generation of a number of hazardous pollutants. Specifically, in the presence of water vapour, NOx undergoes reaction with ammonia and other relevant compounds, it forms fine particulates and favors the formation of ground-level O_3 upon reaction with VOCs. Studies have shown that even short term exposure to NO_2 can be detrimental to human health. For instance, an exposure for a duration of less than 24 hours has been documented to contribute to negative respiratory consequences, including the exacerbation of asthma episodes and inflammation of the airways among individuals without pre-existing respiratory conditions (Vallero, 2014a).

SO_2 is another important air pollutant which possesses the capacity to induce respiratory irritation, inflict damage upon crops through foliar stress, and cause degradation of materials when it encounters acidic aerosols. Additionally, atmospheric SO_2 has been found to be responsible for reduction in atmospheric visibility affecting road, rail and air traffic. Sulphur dioxide and other sulphur oxides undergo chemical reactions within the atmosphere, resulting in the formation of acids, with sulphuric acid (H_2SO_4) being a prominent constituent of acid rain.

Carbon monoxide (CO) is a by-product of inefficient or incomplete combustion processes. Carbon monoxide has been shown to elicit diverse health effects by binding to haemoglobin, resulting in the formation of carboxyhaemoglobin (COHb). The accumulation of COHb in the bloodstream leads to a reduction in the availability of oxygen (i.e. hypoxia) due to the increased concentrations of COHb in the blood (Vallero, 2014a). Furthermore, the respiratory system, the central nervous system, and the development of the foetus may also experience additional effects from its exposure.

Lead, a metallic element, is utilized in a plethora of industries, and it is primarily procured through mining activities, smelting operations, battery recycling procedures, and waste incineration facilities. The detrimental impacts of lead exposure in the atmospheric environment on human health include the manifestation of lead poisoning, neurotoxicity, and numerous other deleterious effects.

7.3 Status in Cities

Air pollution is a grave environmental concern, particularly in urbanized regions where a large population is exposed to air quality levels that exceed the established emission thresholds. It has been projected that by 2025, urban areas will be inhabited by approximately 60% of the global populace. As per projections, the overwhelming majority (93%) of urban expansion will be observed in emerging nations, especially Asia and Africa which are projected to exhibit high growth rates (80%) (Sofia et al., 2020). Urban areas occupy $<5\%$ of the Earth's surface, yet they are accountable for generating as much as 80% of global CO_2 emissions (Ghosh & Maji, 2011). According to estimates from the World Health Organization (WHO), the inhalation of $PM_{2.5}$ particles contributed to the premature deaths of 4.2 million people worldwide as of 2016 caused by ambient air pollution (Fino, 2018).

Urban form, which pertains to the spatial configuration, composition, and compactness of urban land uses, will experience significant transformations in the future as a result of the extensive urbanization (Liang & Gong, 2020). Small cities having high residential density promotes the usage of public transportation and walking (Liang & Gong, 2020; Rodriguez et al., 2016). According to a study of 83 urban regions around the world, those with closely spaced built-up areas release less NO_2 (Bechle, 2011) and are thus effective at reducing air pollution, while dispersed cities can decentralize industrial polluters, enhance the efficiency of fuel and reduce transportation congestion (Glaeser & Kahn, 2003), enabling the decentralization of jobs, which reduces pollution emissions. A dispersed city's greater open spaces promote air dilution. However, compact cities are frequently associated with greater urban heat island effects influencing the availability and advection of air pollutants (Liang & Gong, 2020). The behavioural aspects of the people residing in compact cities appear to be an important factor in determining air pollution levels (Piracha & Chaudhary, 2022). Indicators of urbanization included population and development level and scale of the city, which have direct effects on the prevalence of air pollution. Increased building construction in cities led to a decrease in vegetation areas as well as reduced plant adsorption capacity for air pollutants, along with higher concentrations of particulate matter and dust in the air (Chen et al., 2022). Thus, the conflicting findings reveal the intricate interaction between air pollution and urban form, suggesting that an erratic association may be present in cities at various levels of urbanization and at different times. As a result, any planning strategy intended to reduce air pollution should take into account the current state of development and adapt its future plan accordingly (Liang & Gong, 2020).

Although air pollution is a global problem, as it affects all places, considerable variation in air pollution levels is observed in different regions. For illustration, the $PM_{2.5}$ annual average concentration in the most polluted cities was approximately 20 times higher than that in the cleanest metropolis in a survey of 499 global cities (Liang & Gong, 2020). The average total number of O_3 and $PM_{2.5}$ days from 2008 to 2012 ranged from 3.81 days and 0.95 days in non-core counties to 47.54 days and 11.21 days in large central metropolitan counties, respectively (Strosnider et al., 2017). Therefore, to estimate variations in air quality caused by urbanization, more thorough analyses with improved modelling techniques may be needed.

7.4 Monitoring of Air Pollutants

Ambient air monitoring is the systematic and long-term measurement of air pollution levels and specific pollutant types in ambient air. The ambient air quality monitoring network entails the selection of locations, pollutant types, infrastructural facilities, duration, frequency and procedures of sampling, operation, and manpower (Haque & Singh, 2017). In 1984, India's Central Pollution Control Board (CPCB) launched National Ambient Air Quality Monitoring (NAAQM), later renamed the National Air Monitoring Programme (NAAQP), for the continual monitoring of air quality in major cities and industrial towns of the country.

To monitor air pollution, different methods, such as automatic, semiautomatic, and manual methods, are used. Automatic methods involve the use of equipment that directly measures pollution, allowing for real-time monitoring of air pollution. Semiautomatic approaches involve the collection of air quality samples from equipment at specific locations and then transporting and analysing these samples in the laboratory. Manual methods involve collecting samples manually, for example, CO monitoring. Developing an emission inventory (EI) is critical for describing pollutant emissions and regulating air quality. For modelling air pollution, many different scales are available, including microscales (street canyons), mesoscales (country, city), and global, regional, or continental scales. Numerous mesoscale models, including CHIMERE, METPOMOD, CMAQ, and TAPOM, are used to simulate the air quality of urban areas. EIs, land use, meteorological conditions, terrain, and borders are all input parameters into these air quality models (Ho, 2012).

GIS Tools in Air Pollution Studies

Geographical Information System (GIS) is a computer assisted program that maps and analyses the Earth and other geographical data. GIS applications combine distinct visualizations with databases that enable data acquisition, collection, storage, manipulation, modelling, analysis, retrieval, and display of georeferenced data (Ahmad et al., 2015). Information from sources such as remote sensing, including satellite and aerial images, earthbound surveys, and cartography, that is, maps, is used by GIS to construct overlapping layers that may be accessed and edited interactively in one spatial structure (Kamińska et al., 2004).

GIS can be used to analyse trends and environmental effects brought on by human activities, as well as to help predict potential outcomes and plans at various governmental levels. GIS applications include creating dynamic databases and developing spatial correlations with the temporal distribution of epidemiological data. The application of GIS tools in monitoring, analysing, and modelling pesticide migration in the environment and its ultimate health impacts has increased. Studies related to public health and the environment using GIS analysis have produced significant findings that may ultimately aid in preventing excessive or uncontrolled exposure to xenobiotics. Such studies, however, still rarely employ GIS technology, especially in developing nations where there is little awareness of the technology's availability and advantages (Kamińska et al., 2004).

There are numerous ways to use data from real-world GIS database models for environmental investigations. Data inputs, database transformation (data query and data analysis), and data output are the three basic GIS components. Input data include points (e.g. for soil pit locations), linear features (e.g. for depicting networks of roads), aerial polygons (e.g. for depicting forest areas), and other sources, such as information from traditional maps and ground surveys (registered by GPS), provided they provide spatial information. Input data are typically in vector or raster format. GIS provides output as digital or analogue maps, tabular data, and reports that contain records on the outcomes and a list of the processes followed throughout database analysis. Primarily, GIS enables transforming the coordinate system of input data, converting raster images into vector images, and extracting, overlaying, and managing data (Kamińska et al., 2004).

GIS has wide applications in air pollution studies, including air quality assessments, pollution data visualization, and decision-making processes, and thus, regulates pollution and air quality (Sówka et al., 2020; Tecer & Tagil, 2013). GIS applications can be used to monitor air pollutant emissions from various sources, manage spatial and statistical data, and facilitate visualization of the relationship between environmental health and the number of times human activities result in poor air quality. GIS modelling and statistical analysis can be used to study and predict the effects of climatic factors on air pollution. Air pollution mapping helps identify sources of pollution, determine the concentration of pollutants, and control emissions. A number of GIS-based air pollution studies have been undertaken. For environmental modelling with GIS applications, air quality management systems (AQMSs) are used to locate monitoring stations, develop geospatial models, and support spatial decision-support systems. GIS applications can be used to create three-dimensional spatial records of pollutants in AQMSs (Ahmad et al., 2015). Bozyazi et al. (2000) performed GIS spatial analysis to determine Istanbul's air pollution levels in connection to land use, and their findings revealed that the city's air pollution levels were closely associated with land use type.

Surface modelling using spatial interpolation is an advanced GIS tool for location-oriented analysis. Sówka et al. (2020) found that the ordinary kriging method, which is a widely used technique for geospatial interpolation and estimation, enabled accurate spatial presentation of variation in $PM_{2.5}$ concentrations at sites not covered by measuring systems. According to Ung et al. (2002), "virtual stations" are also generated using GIS statistical interpolations. The thin plate spline approach of geographic databases and remotely sensed data from the LANDSAT Thematic Mapper sensor are combined to carry out this process. Additional measurements from virtual stations serve as input data for additional extrapolation and interpolation techniques. The method of "virtual measuring stations" has also been used in a study by Beaulant et al. (2008) to virtually densify the network of permanent measuring stations. The quality of interpolation is intended to be improved by increasing the amount of pollutant concentration data.

Geostatistics uses spatial correlation to solve estimation problems, presented using variogram models (Bozyazi et al., 2000). These methods have been applied to several issues, including mapping. By using GIS geostatistical analysis, the relationship between long-term exposure to air pollution and illness incidence rates (such as cancer and bronchitis) can be determined. Geostatistics finds application in providing predictions for unsampled locations, as exhaustive studies are costly and time-consuming (Pandey et al., 2013). GIS facilitates decision-making by preparing thematic maps of variations in pollutants, which also helps in analysing the cause of decreases or increases in value, determining the most afflicted localities and subsequently taking the appropriate remedial measures by decision makers (Vaddiraju, 2020).

GIS is useful in creating health risk maps, as it assists in establishing relationships between population density, distribution of air quality, and health risk. Spatial interpolation techniques can be used to create a health risk map that depicts the spatial distribution of respiratory symptoms and disorders (Pandey et al., 2013). Thus, GIS tools have various applications in monitoring pollutant emissions and serve as a powerful tool for conserving the quality of air.

7.5 Causes of Air Pollution

Air pollution can result from both natural and anthropogenic sources. Natural sources polluting air include dust storms, volcanic eruptions (emitting S, Cl, ash particulates), sea salt spray, wildfires (releasing smoke, CO), pollen dispersal, vegetation (giving off VOCs), and natural radioactivity (e.g. radon gas formed from radium decay). Population density, housing, traffic, and industry accumulation are anthropogenic causes that intensify air pollution in urban areas (Martínez-Bravo and Martínez-del-Río, 2019). Anthropogenic activities causing air pollution include transport, power plants, waste treatment, industrial processes, households, agriculture, construction, mining, and warfare that are associated with the combustion of fuels of different kinds (Ahmad et al., 2015).

Sources of air pollution are also divided into point sources and non-point sources. Sources involving the emission of pollutants from a single place are referred to as point sources. It typically involves a combustion or mechanical process. Anthropogenic examples of point sources include power plants with smokestacks, and natural examples include the eruption of a volcano. Non-point sources involve the release of pollutants over a wide area and are classified as linear and area sources. A linear source corresponds to the main communication pathways, for example, roads and railways. An area source involves the release of pollutants within a defined geographic area. Human examples include a sizable port complex or oil refinery run by several different enterprises. Natural examples are a large agricultural field and a forest with a variety of coniferous and deciduous trees (Shendell, 2019).

Furthermore, pollution sources can be stationary (fixed or a preset pollutant emitter, e.g. refineries and power plants) or mobile (non-stationary, e.g. vehicles) sources (Ahmad et al., 2015). Different fuels are used to operate mobile sources, such as compressed natural gas, unleaded gasoline, and diesel (high or low sulphur content). Mobile sources of air pollution are further divided into two categories: on-road and off-road mobile sources. A few examples of on-road mobile sources related to human activity include automobiles, and off-road mobile sources include construction and farming equipment such as tractors and trains (on-land); aircraft carriers, motor-driven boats, cargo vessels, and submarines (on-water); and helicopters and aeroplanes (in-air). A “mobile line source” is a highway or main primary road that runs through suburban or urban areas (Shendell, 2019).

7.6 Concerns of Air Pollution in Urban Areas

Health Effects

Air pollution is linked to a plethora of negative health effects, such as cardiovascular and respiratory disorders, diabetes, infertility issues, cancer, and neurological diseases. Thus, the estimation of pollution cost is an economic assessment of the probability of becoming ill or premature death (Ferrante et al., 2015). Human beings are subjected to airborne pollutants through inhalation via the nose or mouth, ingestion of food that has been found to be contaminated, exposure to ocular pollutants via the eyes, and contact with environmental pollutants through the dermal or skin layers, regardless of whether the skin is intact or has open cuts (Shendell, 2019). Research by the United States Environmental Protection Agency (USEPA) finds that certain health conditions, such as the respiratory effects of air pollution exposure, can be directly linked to their economic consequences, such as the costs associated with doctor visits, lost school and work days, hospital visits, and, ultimately, deaths (Fig. 7.3).

The presence of airborne contaminants is accountable for the onset and persistence of acute or chronic respiratory illnesses. Acute illnesses encompass a spectrum of conditions, ranging from minor irritations to inflammatory responses, allergic reactions, compromised lung function, and even eventual respiratory collapse, contingent upon the exposure extent. Chronic diseases, which encompass cardiovascular diseases, chronic obstructive pulmonary diseases, and various types of cancers such as lung cancer are prevalent health concerns worldwide. The phenomenon of oxidative stress, stemming from air pollutant exposure, has been established to substantially contribute to chronic diseases, as postulated by Vallero (2014c). Current research suggests that chronic exposure to air pollution may induce neurological disturbances through the processes of atherosclerosis and oxidative stress (Manisalidis et al., 2020). The critical factors pertaining to particulates are their size, soluble fraction, and density. One example may be seen in the case of ultrafine particles, whose aerodynamic diameter measures less than 100 nm. These minute particles possess the ability to infiltrate deep into the lungs, as their penetration depth is inversely proportional to their size. Vapour pressure, density, and solubility are significant variables in assessing gaseous pollutants. High vapour pressure air pollutants are more prone to remain suspended in the atmosphere due to their propensity to exist in a vaporous state compared to those compounds that exhibit lower vapour pressures. The respiratory system may be subjected to detrimental impacts by several principal air pollutants in the vapour phase, including sulphur oxides, CO, NOx, O_3, and PM (Vallero, 2014c).

Particulate matter in diverse manifestations has been linked to the development of cancer, particularly concerning the organic portion of aerosols. Chemical substances, such as polycyclic aromatic hydrocarbons (PAHs), are associated with the occurrence of respiratory system cancers, specifically lung cancer. For instance, the compound benzo(a)pyrene has been found to be a causative agent in these cancers (Ferrante et al., 2015). Additional PM-related alterations include genotoxicity,

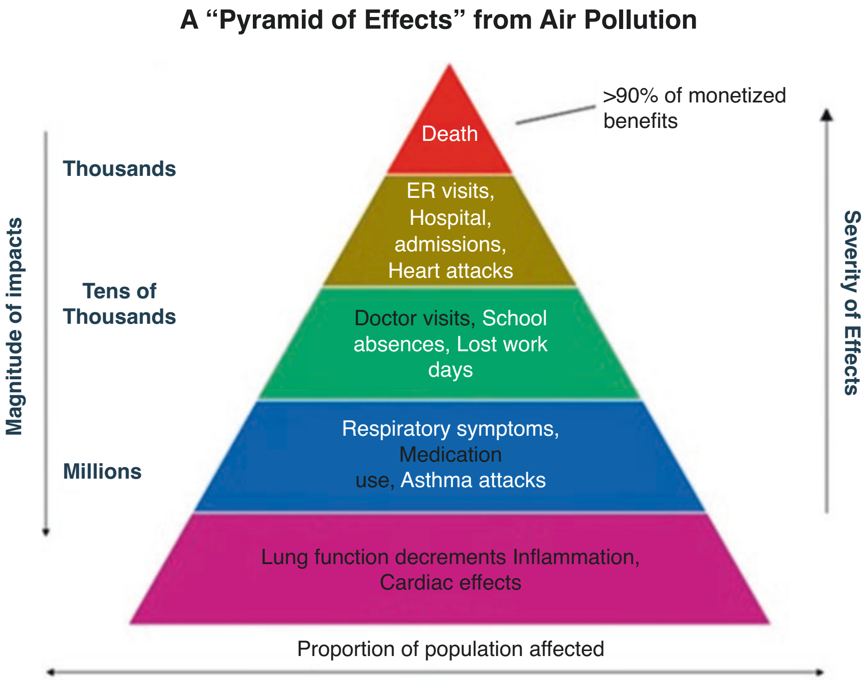

Fig. 7.3 Pyramid of effects from air pollution. (Source: United States Environmental Protection Agency, USEPA)

infertility, and low birth weight (Fortoul-van der Goes et al., 2015). Inhaling acute NO_2 concentrations causes respiratory distress, which has been linked to increased hospital emergency visits (Vallero, 2014a). Higher tropospheric O_3 concentrations are especially harmful to children, older adults, people doing heavy exercise or work who have elevated ventilation rates and therefore respiratory exposure dosages, and people already suffering from asthma or lung conditions. Since infants' lungs continue to develop postbirth and have prolific tissue that is more susceptible to environmental contaminants, infants are also vulnerable to higher ground-level O_3 concentrations (Vallero, 2014c). Black lung disease or pneumoconiosis is caused by coal dust. Silicosis is caused by rock dust from silica-containing rocks. Brown lung illness, also known as Byssinosis, has been linked to textile fibre exposure and may be caused by bacteria in cotton, making it a combination physical-chemical-biological air pollutants (Vallero, 2014c). Skin ageing, atopic dermatitis, eczema, urticaria, acne, dyschromia, and psoriasis may be caused by the absorption of air pollutants by human skin and are typically brought on by PM, oxides, and photochemical smoke upon exposure. Skin cancer has also been linked to pollutants (Eleni et al., 2014; Manisalidis et al., 2020). Suspended pollutant exposure also affects eyes, causing asymptomatic eye outcomes, irritation (Weisskopf et al., 2015), dry eye syndrome, or retinopathy (Manisalidis et al., 2020; Mo et al., 2019).

Air pollutants can harm the respiratory system's fluid dynamics directly (for example, by inflammation of airways) or indirectly (for example, by changing the immunological response). Air pollutants can cause lungs to become rigid by affecting surfactant chemistry and thus hindering inflation (Vallero, 2014c). Urban residents are more vulnerable to harmful health impacts caused by air pollutants due to extremely degraded air quality in urban areas produced mainly by heavy road emissions and myriad of other pollution sources. There is always a potential risk of industrial accidents that can lead to the spread of toxic fog and can prove devastating to the local populace. Overpopulation and unregulated urbanization, combined with industrialization, exacerbate the problem in emerging countries. Epidemiological studies have been carried out to verify the existence and quantification of adverse health consequences produced by air pollution, as well as to estimate dose–response relationships (Manisalidis et al., 2020). Statistical evaluations of monitoring and biomonitoring data also demonstrate a link between air pollution levels and morbidity and mortality rates. Furthermore, indoor, urban, and high-risk site outdoor pollution has different characteristics due to poor ventilation of houses, which permits the accumulation of different biological and chemical pollutants not found in comparable outdoor concentrations in severe pollution events. The concentration of heavy metals, which are often more prevalent and have a wide range of species in urban and industrial air pollution, is a significant difference between indoor and outdoor air pollution. In places with significant urban agglomerations, the incidence of neoplastic disorders is higher (Ferrante et al., 2015).

Metals that enter the respiratory system by direct interaction with DNA may result in chromosome abnormalities or gene mutations; these changes may promote cell proliferation and lead to the development of cancer (Cope et al., 2004). Depending on the amount absorbed, heavy metals such as lead can cause acute poisoning or chronic intoxication in humans (Manisalidis et al., 2020). Manganism, an extrapyramidal neurological condition that is characterized by bradykinesia, rigidity action tremor, and cognitive failure, may develop in workers exposed to airborne Mn. Cadmium affects the cardiovascular system and causes hypertension and atherosclerosis. Very low concentrations of mercury cause cardiovascular diseases and promote atherosclerosis. Mercury is also associated with neurotoxic effects (Alissa & Ferns, 2011). Even though these elements have serious harmful consequences, very scant knowledge is available specifically regarding the relationship between inhalation exposure and certain diseases (Fortoul-van der Goes et al., 2015). More research is needed to fully understand the damage mechanisms caused by pollutants to human health and to reduce exposure and mitigate its negative consequences.

Environmental Effects

Air pollution has adverse effects on the environment, including acid rain, smog, eutrophication, and damage to agriculture and ultimately ecosystems. According to Ashmore (2013), air pollutant problems may vary spatially, including regional problems such as acid deposition and tropospheric ozone caused by long-range pollutant transport or local environmental impacts of pollution, such as being limited to the area in the vicinity of a factory or a road.

Climate change, a consequence of environmental pollution, affects the geographical distribution of several infectious diseases (Manisalidis et al., 2020). Black carbon and ozone (short-lived climate pollutants) can exacerbate climate change, altering the frequency and duration of heat waves and cold spells, ultraviolet radiation exposure, precipitation patterns, etc. These changes can indirectly threaten urban lives and livelihoods (Mitchell et al., 2016). A warmer climate can affect surface pollutant concentrations by affecting the rate of atmospheric chemical reactions, biogenic VOC emissions, and atmospheric boundary layer height (Heal et al., 2013). Pollutant impacts may also vary temporally, for instance, the release of large pollutant concentrations accidentally, therefore causing immediate effects on biodiversity, which may further result in a delayed and gradual recovery, whereas other impacts may be the outcome of pollutant accumulation over years (Ashmore, 2013). Therefore, it is imperative to consider city pollution, regional pollution, and hot spot occurrences, which are defined by higher-than-average pollutant peaks followed by gradual restoration of normal limits while evaluating urban pollution (Ferrante et al., 2015).

The pathways followed by pollutants to enter ecosystems may be directly related to their impacts. Pollutants enter ecosystems as gases, particles, or both. Gaseous pollutants can be taken up through stomata or inhaled directly by animals. Pollutants may infiltrate ecosystems by rainfall, mist, or as particles in other instances. Gaseous pollutants such as NOx, SO_2, and NH_3 are also deposited as particulates, that is, nitrate, sulphate, and ammonium, through wet deposition and can not only impact organisms directly but also cause eutrophication and acidification of the environment over longer periods. Photochemical oxidants, such as O_3, are secondary pollutants formed in the presence of sunlight from chemical reactions involving VOCs and NOx. Direct uptake of O_3 by leaf tissue damages plant cells and reduces overall plant productivity. O_3 also causes substantial damage to a variety of materials, such as metals, paint, plastics, rubber, and fabrics. Metal deposition mainly occurs via rainfall or as particulate matter. Metals on deposition accumulate in soils or leach into freshwaters, which results in deleterious effects on soil organisms or plant roots at toxic concentrations. Persistent organic pollutants (POPs), another group of chemicals, raise concerns due to their possibility of large bioaccumulation in the food chain. The process of "global distillation", in which compounds volatilize in warmer portions of the Earth at ambient temperatures and become redeposited at cooler latitudes, provides evidence that the atmosphere can operate as a conduit to disperse these compounds. Their bioaccumulation in polar areas is therefore of considerable concern. For instance, it has been observed that fish from Antarctica, which is far from any immediate sources of pollution, have POP concentrations that are comparable to those found in fish from the North Sea (Ashmore, 2013).

Pollutant effects on organisms are intricate and dependent on a variety of variables. The amount of pollution, that is, dose ingested, is the most crucial of these variables. This will depend on pollutant concentration in the air and exposure duration to it. Acute toxicity is a short-term consequence of exposure to air pollution at higher concentrations, characterized by direct damage to exposed tissue and leaf damage. In contrast, chronic toxicity, which may be caused by exposure to air pollution over an extended period and at much lower concentrations, is typically characterized by changes in reproduction, growth, and physiology (Ashmore, 2013). Air pollutants rarely occur alone, and responses to mixtures of pollutants can result in synergistic or antagonistic effects. When the combined effect of two pollutants is larger than their individual effects, it is referred to as a synergistic response. For instance, when NO_2 and SO_2 are taken up together, they often have synergistic effects on vegetation. When the impact of a pollutant mixture is the same as that of individual pollutants or even has a lessened impact, it is called an antagonistic interaction. Furthermore, the deposition of one pollutant can affect the uptake and impacts of another pollutant over time. For instance, increased bioaccumulation of metals such as cadmium, mercury, and lead in fish and birds can be caused by freshwater acidification brought on by the deposition of nitrate and sulphate (Ashmore, 2013).

Therefore, estimating how much pollutant emissions should be reduced to ensure an acceptable degree of biodiversity protection is crucial. Not only are higher concentrations of air pollutants of concern but so are widely distributed contaminants with lesser quantities, the effects of which become apparent over many years. It is also essential to fully understand how pollution interacts with climatic, biological, and soil variables to precisely analyse the effects of pollution within an ecological context.

7.7 Challenges and Solutions

Challenges

Considerable challenges are posed to future urban resilience and public health protection by the climate change caused by air pollution, as urban populations would be subjected to greater temperatures than experienced at present (Milner et al., 2019). The physical and sociological characteristics of urban environments constantly change, which makes the intricate linkages between air pollution, metropolitan climate, and public health more difficult to understand and anticipate. Climatic conditions are further modified by emissions from vehicular traffic, vegetation, and urban structures, resulting in significant spatial gradients of heat and air pollution, which may eventually exacerbate health risks and social disparities in time and space. Changes in demographics or the built environment, whether planned or unplanned, may alter patterns of exposure to air pollution, temperature extremes, or other environmental hazards and may also aggravate deleterious impacts on the health of the urban population.

The growing population in urban centres is another cause creating complexities for city dwellers, such as housing shortages, lack of open spaces, traffic problems, slums, waste accumulation, and air pollution (Haque & Singh, 2017; Kumar & Singh, 2003; Singh et al., 1972). Urban air pollution impacts the urban poor more than the general population due to their greater susceptibility to diseases, as their health is below average, their housing quality is low, they lack knowledge about pollution, and they have less awareness of indoor pollution due to fuel burning for heating and cooking purposes, as is the case with slum dwellers, the most vulnerable section of urban society.

Inadequate monitoring and enforcement of regulations could result in more toxicity and higher emissions (Shendell, 2019). Additionally, little research has been undertaken to determine air pollution reduction caused by smart growth and other compact city design concepts (Piracha & Chaudhary, 2022). Therefore, to resolve the problems and conflicts among various economic, social, and environmental concerns at various levels, it is necessary to effectively regulate urban air pollution (Salmond et al., 2018).

Solutions or Mitigation Strategies

Reducing air pollution is essential for human health and environmental protection. Air pollution mitigation helps tackle climate change and forms the basis of sustainable development. The mitigation measures or solutions to curb air pollution and its consequent effects can be broadly grouped as regulatory measures, technological solutions, and behavioural changes.

Various regulatory steps or measures taken to mitigate air pollution include defining air quality legislation, various WHO air quality guidelines (AQGs) based on health-effect evidence, air quality standards, and the environmental policies established at the international level; for example, measures limiting emissions from vehicles, industries, and other sources, such as imposition of emission standards for vehicles such as limiting NOx emissions (Fino, 2018).

To regulate air quality, a number of laws have been enacted to govern air pollutant emissions in the atmosphere, such as the Clean Air Act 1956 introduced by the British Parliament in the aftermath of the Great Smog of London (1952), the U.S. Clean Air Act (CAA, 1963), administered by the United States Environment Protection Act (EPA), and the Air (Prevention and Control of Pollution) Act, 1981, in India to control and prevent air pollution nationwide. Ambient air quality standards (AAQS) have been adopted by the WHO (Table 7.1), many industrialized nations, and certain rapidly expanding economies (such as China and India) (Shendell, 2019). An air quality standard is defined as a specific level of air pollution adopted as enforceable by a regulatory authority. Standard formulation includes elements such as monitoring and measurement strategies, data handling processes, statistics, and quality control and assurance (Fino, 2018). The primary and secondary AAQS have been specified in the United States Federal Clean Air Act Amendments of 1990. The primary and secondary AAQS are given for certain pollutants, which vary depending on the emphasis placed on protecting human or ecological health as well as the quality of the environment. Primary AAQS is based on research related to human health (epidemiology, exposure assessments, toxicology, etc.). Secondary AAQS is established based on an emphasis on factors such as resource degradation, aesthetics, and visibility. Air quality standards are defined for specific time intervals, with specific measurement units and statistics (Shendell, 2019). As per resolution WHA68.8 adopted by the World Health Assembly, when using the WHO AQGs to develop standards, regulatory bodies and policy-makers must take social, cultural, and economic factors into consideration (Fino, 2018). The shipping industry and marine traffic contribute a significant proportion of global anthropogenic emissions. Shipping is intrinsically international; therefore, it is necessary to strictly implement uniform regulations at the global scale. Various measures have been taken, including the adoption of the MARPOL Convention and Emission Control Areas (ECAs) designation by the International Maritime Organization (Komar & Lalić, 2015). Furthermore, efforts that target transboundary air pollution need to be intensified and coordinated at local, national, and international levels. The Convention on Long-range Transboundary Air Pollution (CLTRAP) marked the beginning of a legally binding framework for addressing air pollution on a regional basis, adopted in 1979 by the UNECE (Fino, 2018).

Technological solutions to combat air pollution may include the usage of cleaner technologies in industries, renewable energy (energy generation), promoting hybrid vehicles with much less pollutant emissions, and growing urban vegetation that filters airborne PM. To reduce pollution emissions from automobiles, electric vehicles and hydrogen cell vehicles with no emissions (at tailpipe) must be used (Piracha & Chaudhary, 2022). The concept of a "smart city" is another important step that responds to the needs of inhabitants in a more efficient and sustainable manner (Cariolet et al., 2018).

The green infrastructure approach for cities such as growing plants can be used as barriers between people and air pollution from automobiles as well as to absorb air pollution (Piracha & Chaudhary, 2022). Barwise and Kumar (2020) discovered that certain biological characteristics of plants can effectively minimize transport-related air pollution and developed a framework for selecting plants to lessen exposure to air pollution. Overall, small leaf size, ideal vegetation height and density, and high leaf complexity are all factors in the elimination of transport-related air pollution, with taller vegetative barriers (between humans and traffic) being more beneficial in cases of open roads and shorter ones in cases of street canyons.

Table 7.1 Recommended 2021 AQG levels and 2005 air quality guidelines (WHO, 2021)

Pollutant	Averaging time	2005 AQGS	2021 AQGS
$PM_{2.5}$, μg/m^3	Annual	10	5
	24-hour[a]	25	15
PM_{10}, μg/m^3	Annual	20	15
	24-hour[a]	50	45
O_3, μg/m^3	Peak season[b]	–	60
	8-hour[a]	100	100
NO_2, μg/m^3	Annual	40	10
	24-hour[a]	–	25
SO_2, μg/m^3	24-hour[a]	20	40
CO, mg/m^3	24-hour[a]	–	4

Source: https://www.ncbi.nlm.nih.gov/books/NBK574591/table/ch3.tab 26/
[a]99th percentile (i.e. 3–4 exceedance days per year)
[b]Average of daily maximum 8-hour mean O_3 concentration in the six consecutive months with the highest 6-month running-average O_3 concentration

Building materials and design also have a significant influence on decreasing air pollution by using light-sensitive titanium dioxide to make buildings serve as a photocatalyst that reacts with and neutralizes air pollutants in the presence of oxygen and water vapours, converting harmful nitrogen oxide into nitrates. Strategies to mitigate the negative health effects of the urban heat island effect include increasing the solar reflectance and emittance of roofs and pavements by light-coloured roofs and increasing green areas to reduce heat capture (Piracha & Chaudhary, 2022). Minimizing emissions and increasing natural sinks of air pollutants is another solution to meet environmental challenges. Eco-friendly and sustainable practices are needed to reduce air pollution. According to Weyens et al. (2015), phytoremediation is an effective plant-based, economical, soil-stabilizing, sustainable, and environmentally friendly process to reduce air pollutants attributable to the gas-exchange mechanism in plants exchanging gases with ambient air. Through various mechanisms, plants and allied microbes absorb contaminants, both organic and inorganic, from the surrounding air and break down or detoxify them. However, uncertainties regarding the suitability and potential of particular species for specific pollutants still prevail, which necessitates future research in this field. Additionally, the slow removal process of phytoremediation, allowing the build-up of pollutants over a confined area, is another barrier to its widespread use (Agarwal et al., 2019).

Lifestyle changes such as the use of energy-efficient appliances, and public transport or bicycles for shorter distances are some behavioural responses to the mitigation of air pollution. Various governments and non-governmental organizations around the world have implemented low-carbon measures to direct sustainable urbanization practices towards improved health, such as the Istanbul Declaration of the North Atlantic Treaty Organization and the UN's Millennium Declaration. Urbanization had positive effects on global health in general. However, the health benefits of urbanization could be reversed by air pollution. To promote sustainable growth, the government should strike a balance between air pollution regulation and urbanization (Wang, 2018). Environmental governance should be processed concurrently with economic and urban development. It is necessary to raise public awareness along with the multidisciplinary approach by scientific professionals. More research on air pollution, including forecasting air pollutant quantities, especially the impacts of air quality indicators and long-term monitoring in different weather conditions, is required for sustainable development and formulation of government policies.

7.8 Conclusions

Urban populations experience multiple exposures to air pollution, resulting in severe health effects in terms of morbidity and premature deaths. The ever-increasing size of the population; lack of knowledge and awareness about air pollution; low housing quality in poor sections of urban society; indoor pollution, which has emerged as a major issue; and inadequate monitoring of emissions are some of the challenges that exacerbate urban air pollution problems. Deleterious environmental and health concerns due to urban air pollution must be addressed by adopting various mitigation strategies, such as renewable energy, green infrastructure, and low-carbon emissions, and by the introduction and stringent implementation of policies and air quality legislation. Understanding the perplexing relationship between air pollution and urban forms and tackling air pollution in conjunction with climate and public health issues can result in substantial progress towards sustainable urbanization.

Conflict of Interest The authors have no conflicts of interest.

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