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(RESEARCH ARTICLE)

Urban air pollution: Sources, impacts, and sustainable mitigation strategies for a cleaner future

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Abstract

Background: Cities around the world have to deal with a big problem: air pollution. This is bad for health and the environment. The main causes of urban air pollution, its many effects, and new ways to cut it down are all looked at in this in-depth study. Because cities are growing so quickly, the number of harmful pollutants in the air has reached a frighteningly high level. This means that fast action is needed from lawmakers, companies, and communities.

Materials and Methods: Many studies, government reports, and publications from foreign groups have been looked over and judged to be adequate for this review. Planned reading of writing from the last 20 years is part of the method. Large cities in different parts of the world are given extra attention by the writers. A full picture of how air pollution changes in towns is shown in this review, which uses data from air monitoring sites, epidemiological studies, and climate modeling.

Findings: The study finds that the main things that pollute the air in towns are making energy, driving cars, and doing industrial work. Particulate matter (PM2.5), nitrogen oxides (NOx), and sulfur dioxide (SO2) are the 3 main types of pollution. There's a lot of proof that they make lung diseases, heart problems, and early deaths more likely. The data show that there is a strong link between the amount of pollution in the air and things like income. Some places are more likely than others to have to deal with the health effects and exposure.

Discussion: The paper takes a close look at how well the current rules and methods for managing air pollution in various city areas work. Some of the new ideas that are talked about are green urban planning, better emission controls, and using renewable energy to clean up the air in towns. The review also talks about how climate change and air pollution affect each other in complex ways. It stresses the need for unified approaches to handle both issues at the same time.

Conclusion: This in-depth look at the subject shows how important it is to clean up polluted air right away by working together. Instead of working alone, communities, companies, and governments need to work together to find long-lasting solutions. These findings show how important strict rules, new tools, and changes in how people act for making big changes in city air quality. Countries need to work together and share their knowledge to solve this global problem and make sure that cities have better, more sustainable futures. This is stressed at the end of the review

Keywords: Urban pollution; PM2.5; NOx; SO_2; Vehicle and truck emissions; Lung and heart ailments; Climate change; And air quality control and legislation

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1. Introduction

Urban air pollution is now one of the biggest health and environmental problems of our time. It's become very important for scientists, politicians, and city residents to keep the air quality high in cities as they continue to industrialize and grow at an unheard-of rate. The goal of this in-depth review is to look at the complex nature of urban air pollution by looking at its main causes, its wide-ranging effects, and new ways to reduce it. Air pollution has increased due to global urbanization. Manisalidis et al. (2020) believe over half the globe lives in towns. That number may reach 68% by 2050. Growing cities need more energy, industry, and traffic. All of these things pollute the air. According to the World Health Organization (2018), 90% of people around the world are exposed to air that has high amounts of pollutants. People who live in cities are especially at risk.

It is important to look at the main toxins, where they come from, how they affect health, and the rules that are in place right now in order to better understand how complicated urban air pollution is. Table 1 shows all of these details for the most important air toxins.

Table 1 Overview of Major Air Pollutants, Their Sources, Health Effects, and Regulatory Standards

Pollutant	**Primary Sources**	**Health Effects**	**WHO Guidelines**	**U.S. EPA Standards**
Particulate Matter (PM)	Transportation (vehicle exhaust, tire, and brake wear), industrial processes, construction activities, wind-blown dust	Respiratory issues, increased risk of cardiovascular diseases, reduced lung function, asthma exacerbation	PM2.5: 24-h mean = 25 μg/m^3, Annual mean = 10 $\mu g/m^3$; PM10: 24-h mean = 50 $\mu g/m^3$, Annual mean = 20 μg/m^3	PM2.5: 24-h mean = 35 μg/m^3, Annual mean = 15 $\mu g/m^3$; PM10: $24-h\ mean = 150\ \mu g/m^3$
Nitrogen Dioxide (NO_2)	Combustion processes in vehicles, power plants, and industrial facilities	Respiratory irritation, increased susceptibility to respiratory infections, asthma aggravation	$1-h\ mean = 200\ \mu g/m^3, Annual\ mean = 40\ \mu g/m^3$	1-h mean = 100 ppb, Annual mean = 53 ppb
Sulfur Dioxide (SO_2)	Burning of sulfur-containing fossil fuels, industrial processes	Respiratory irritation, bronchitis, asthma exacerbation	$24-h\ mean = 20\ \mu g/m^3, 10-min\ mean = 500\ \mu g/m^3$	$1-h\ mean = 75\ ppb, 3-h\ mean = 500\ ppb$
Carbon Monoxide (CO)	Incomplete combustion in vehicles, industrial processes	Reduced oxygen delivery to organs, cardiovascular effects	8-h mean = 9 ppm, 1-h mean = 35 ppm	Not specified
Ozone (O_3)	Formed by chemical reactions between NOx and VOCs in sunlight	Respiratory irritation, reduced lung function, asthma exacerbation	$8-h\ mean = 100\ \mu g/m^3$	$8-h\ mean = 75\ ppb$

Sources: Adapted from World Health Organization (WHO, 2006) and U.S. Environmental Protection Agency (U.S. EPA, 2012)

Particulate matter is a major city concern. According to Khreis (2020), transportation fumes are the main source of PM2.5. PM2.5 is harmful because it can penetrate your lungs. PM pollution causes short-term and long-term lung diseases like asthma and heart disease. PM is so significant that the WHO and EPA set rigorous short- and long-term exposure limits.

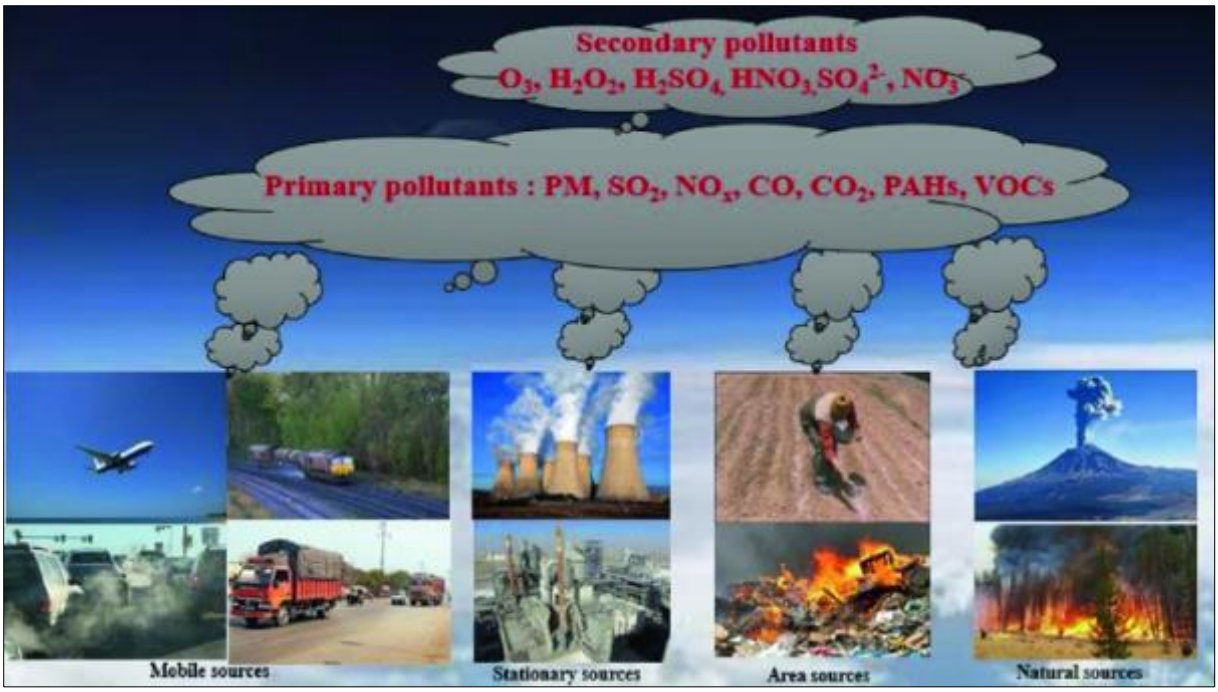

Figure 1 Urban Air Pollution Caused by Emitting Various Harmful into the Air. Source: Shiva Nagendra et al., (2021)

Nitrogen dioxide (NO2) is another very bad pollution in cities. It is mostly released when cars and factories burn fuel. According to Bleviss (2021), the transportation sector is a major source of NO2 pollution. Exposure to NO2 can irritate the lungs and make people more likely to get respiratory infections. Children and the old are especially at risk.

Even though sulfur dioxide (SO2) levels have gone down in many developed countries because of stronger rules on fuel quality, it is still a problem in cities that are becoming more industrialized quickly. In their 2020 study, Yun et al. talk about how residential solid fuel use has a big effect on SO2 levels in some developing city areas. Exposure to SO2 can irritate the lungs and make breathing problems worse if you already have them.

Air quality control in cities is hard because of carbon monoxide (CO) and ozone (O3). CO, which is mostly released when cars and trucks burn fuel incompletely, can be very bad for your health, even in small amounts, because it can stop your body from carrying oxygen. As a secondary pollutant, ozone is made when NOx and volatile organic compounds (VOCs) combine with light in complicated ways. It is very bad for your health, especially when it's hot and sunny outside, which is common in many cities, (Neidell, 2004).

In light of the complex relationships between pollutants and their sources, towns need detailed air quality management strategies. In 2020, Feng et al. emphasize the importance of regional overflows in environmental regulations. These groups claim pollution doesn't respect administrative divisions and that numerous places must work together to stop it. Town air pollution harms your health in many ways. In their 2020 paper, Kim et al. discuss new evidence that filthy air can cause neurodegenerative illnesses of the brain and spinal cord. Leong et al. (2023) also discuss the long-term health implications of filthy air throughout pregnancy and childhood. This shows the importance of targeted aid for weak populations. New technology, legislative improvements, and city design and behavior adjustments are needed to reduce city air pollution. In their 2020 paper, Pietrzak and Pietrzak talk about how electric mobility could be used to make public transportation in cities more environmentally friendly and reduce pollution from cars. In the meantime, Zhang et al. (2022) stress how important it is to think about air quality when planning for urban growth.

1.1. Sources of Urban Air Pollution

Air pollution in today's complex cities originates from many sources. Understanding these sources improves policies and mitigation strategies. City air is polluted by cars, trucks, industry, energy generation, and other things.

Cities with many automobiles and people have polluted air due to car and truck emissions. Transport is a key source of city air pollution and greenhouse gas emissions, adds Bleviss of 2021. Cars burning natural fuels generate CO, NOx, PM, and VOCs. Cities with more cars and traffic bottlenecks suffer more from pollution. Khreis (2020) states that vehicle and truck air pollution is a major public health issue because it can induce lung and heart diseases.

Car fuel type and quantity drastically affect emissions. Diesel-powered cars emit more particulate matter and nitrogen fumes than gasoline-powered cars. Pietrzak and Pietrzak (2020) discuss how electromobility could reduce car pollution in sustainable urban public transit. Many believe that electric vehicles and public transportation are the greatest strategies to reduce transportation pollution.

In towns with many manufacturers, industrial activity can pollute the air. Factory, power plant, and industry emissions include SO2, NOx, and particulate matter. Industry emissions contribute to city air pollution, according to Kousehlar and Widom (2020). They claim these sources discharge pollutants at higher elevations, affecting air quality across wide areas. Economic activity in a city determines its pollution levels and sorts. Town air is also polluted by cooking and heating, especially in places that utilize coal and biomass. For targeted air pollution reduction, determining how much each source contributes is crucial.

1.2. Health Impacts of Urban Air Pollution

Town air pollution is a major public health issue. It affects many people worldwide, making healthcare services busy. Town dwellers who breathe polluted air might get sick in many ways. It describes how it affects your lungs, heart, and other organs and weaker groups more often.

Town air pollution may affect your lungs most directly. Air pollutants including NO2 and PM2.5 increase COPD risk, according to Duan et al. (2020). The small particles in PM2.5 can penetrate the lungs and cause long-term inflammation and toxic stress. Khreis (2020) thinks automobile pollution causes asthma in children. Kids in busy areas are more likely to have asthma.

Short-term air exposure can cause shortness of breath, coughing, and wheezing. Manisalidis et al. (2020) found that air pollution increases short-term impacts, sending more persons with breathing issues to the ER or hospital. Long-term closeness accelerates lung function loss in adults and children. This may cause long-term lung disorders.

People also worry about how city air pollution affects heart health. Kim et al. discuss how tiny particles affect heart disease in their 2020 study. PM2.5 increases the risk of heart attack, stroke, and other heart events. Air pollution damages heart health through systemic inflammation, oxidative stress, and blood clotting. Tsao et al. (2023) examine how city air pollution and heart health alter with the seasons.

A new study found that city air pollution has health implications beyond heart and breathing. Kim et al. (2014) explore brain and spinal cord diseases caused by small particles. They investigate linkages between polluted air and neurological illnesses including Alzheimer's and Parkinson's. Leong et al. (2023) advises considering air pollution and climate change when caring for babies and pregnant women. They claim this because fetuses and neonates are susceptible to environmental contaminants. Pollution in the air during pregnancy can cause premature birth, undersized babies, and death. These early effects can harm a child's health and growth for years.

City air pollution affects people differently. Society and money affect air pollution exposure and illness risk. Sick persons, children, and the elderly are more likely to get sick. The higher medical expenditures, sick days missed at work, and early mortality caused by urban air pollution are costly.

1.3. Environmental and Climate Impacts of Urban Air Pollution

City air pollution harms humans and the climate and ecology outside of cities. The next part discusses how city air pollution affects the environment, ecosystems, and climate change. It shows these concerns must be addressed together and relatedly. One of the most visible effects of city air pollution is ecosystem destruction. Town air pollution harms plants in several ways, according to Zhang et al. (2022). It can limit growth, stop photosynthesis, and increase disease and pest risk. Sticky material on leaf sides blocks stomata, preventing water loss and gas exchange. Acid rain contains NOx and SO2. NOx and SO2 can damage plants and acidify water and soil, affecting land and water, (Chi et al., 2016).

Pollution from cities is harming wildlife, which worries many people. Feng et al.'s 2020 study discusses how environmental laws affect air pollution. People think that pollution can spread far and harm other ecosystems. Pollutants that travel far can damage forests, wetlands, and coastal ecosystems. This might disrupt food networks and ecosystems. Towns' greenhouse gas emissions contribute to climate change, (Neidell, 2004). This applies directly and indirectly. Town climates and air chemistry alter due to pollution. Carbon dioxide emissions from autos and companies in cities are major contributors to global warming. Black carbon and tropospheric ozone are other climate-altering air pollutants. According to Bleviss (2021), transportation reduces greenhouse gas emissions. He argues city transportation needs long-term answers to air pollution and climate change. Air pollution worsens urban heat islands. It starts a chain

reaction that can worsen local climatic effects. Tsao et al. (2023) study how air pollution and town weather effect health. Towns with higher temperatures can produce more secondary pollutants like ozone, they say. This increases air pollution and warms the Earth, making settlements more vulnerable to climate change.

Air pollution harms water sources, another major environmental issue. NOx and SO2 pollution can generate acid rain and acidify water. Marine life suffers when ecosystems shift. Air pollution can also deposit harmful chemicals on water surfaces and surrounding land. This can contaminate water and harm people through the food chain. City air pollution can cause significant damage to farms. Cabral-Pinto et al. (2020) discusses the health risks of producing and eating food near factories. Some think air pollution makes plants and dirt ill. Ground-level ozone comes from NOx, VOCs, and sunlight. Farming and food security suffer from crop quality and quantity decline.

The feedback loops of climate change and carbon emissions are complex. When climate change makes it warmer, cooling may require more energy. Power production may produce additional pollution. Improve air quality and slow climate change by using better energy sources and preserving energy. Huebner's 2020 study links environmental loss, climate change, and air pollution. He emphasizes using the same strategies to address all these difficulties simultaneously. Town air pollution must be considered globally because climate change impacts everyone. Pollution from a city can affect weather and air quality elsewhere. This is why nations must work together to improve urban air quality and reduce environmental damage, (Chi et al., 2016). For planning to reduce air pollution and climate change, they think global collaboration and information exchange are crucial. The temperature and environment are affected by city air pollution. It alters global weather and ecosystems. As cities develop and change, understanding and managing these broad effects becomes increasingly vital. This ensures sustainable urban expansion and global health., (Anjaneyulu et al., 2009)

1.4. Statement of the Problem

City air pollution affects everyone and has various causes. It harms health, the environment, and urban expansion. Air pollution persists in many cities despite decades of research and regulatory modifications. This is especially true in fast-growing areas. This problem persists because we consume fossil fuels, cities are growing, there are no good solutions to control pollution, and local emissions and atmospheric airflow are interconnected. City air pollution causes lung, heart, and brain problems plus new concerns, (King 2018). This strains public health and city life. Because weak groups are more affected, it worsens social and economic inequality. Cities pollute ecosystems, kill animals, and accelerate climate change. This vicious loop makes cities less sustainable and threatens ecosystems, (Anjaneyulu et al., 2009). Because standards aren't always enforced and there aren't any cohesive plans that include how air quality, climate change, and urban growth are linked, city air pollution control isn't always effective. We need thorough, scientifically established strategies to minimize pollution and boost long-term urban growth and climate change resistance now, Anjum et al., (2021).

Aim

This comprehensive study aims to bring together all the data on urban air pollution, its consequences, and solutions to reduce it to help policymakers make better decisions and encourage long-term urban expansion that makes cities healthier and cleaner.

Objectives

- To identify city air pollution sources like car, factory, and energy production and how they affect air quality.
- Learn how urban air pollution affects lung, heart, and new health conditions, and how vulnerable groups are most affected.
- To examine how urban air pollution damages ecosystems, biodiversity, and climate change accelerates.
- To evaluate air pollution control programs, technology, and urban planning in different cities.
- To investigate long-term strategies to reduce pollution, such as converting to clean energy, employing eco-friendly transportation, and using "green" city planning, to improve city air quality and sustainability.

2. Methods for Data Collection

These thorough reviews try to give a full picture of the problems and chances for reducing air pollution in cities. Reviewing the most recent research and looking at successful case studies, this paper aims to give lawmakers, urban planners, and environmental managers useful information for making cities cleaner, healthier, and more sustainable in the future. Working together across disciplines and countries is needed to solve the complicated issue of air pollution in cities. Sharing knowledge and the best ways to do things between cities and countries is very important.

Utilizing the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, a complete and fair analysis of the literature on plans and strategies for reducing air pollution in towns was carried out. Searches in PubMed, Web of Science, and Scopus—the three main scientific databases—were carefully planned to find appropriate peer-reviewed papers.

The search approach used a variety of keywords related to air pollution and ways to prevent it. "air pollut*" OR "atmospheric pollut*" OR "air contaminant*" OR "polluted air" OR "air quality" OR "outdoor air pollut*" OR "ambient air pollut*" OR "atmospheric pollut*" AND "control policy" OR "control management" OR "control strategy" OR "intervention plan"". This extensive set of search terms was created to find a lot of studies that looked at many different parts of controlling air pollution in cities.

Initial database search found 3,526 records, including 429 from PubMed, 1,655 from Scopus, and 1,442 from Web of Science. Additional 118 records were found through other sources, such as reference lists of related articles and grey literature databases, to make sure the literature review was complete. According to this method, studies that might be significant were found that weren't in the main scientific databases.

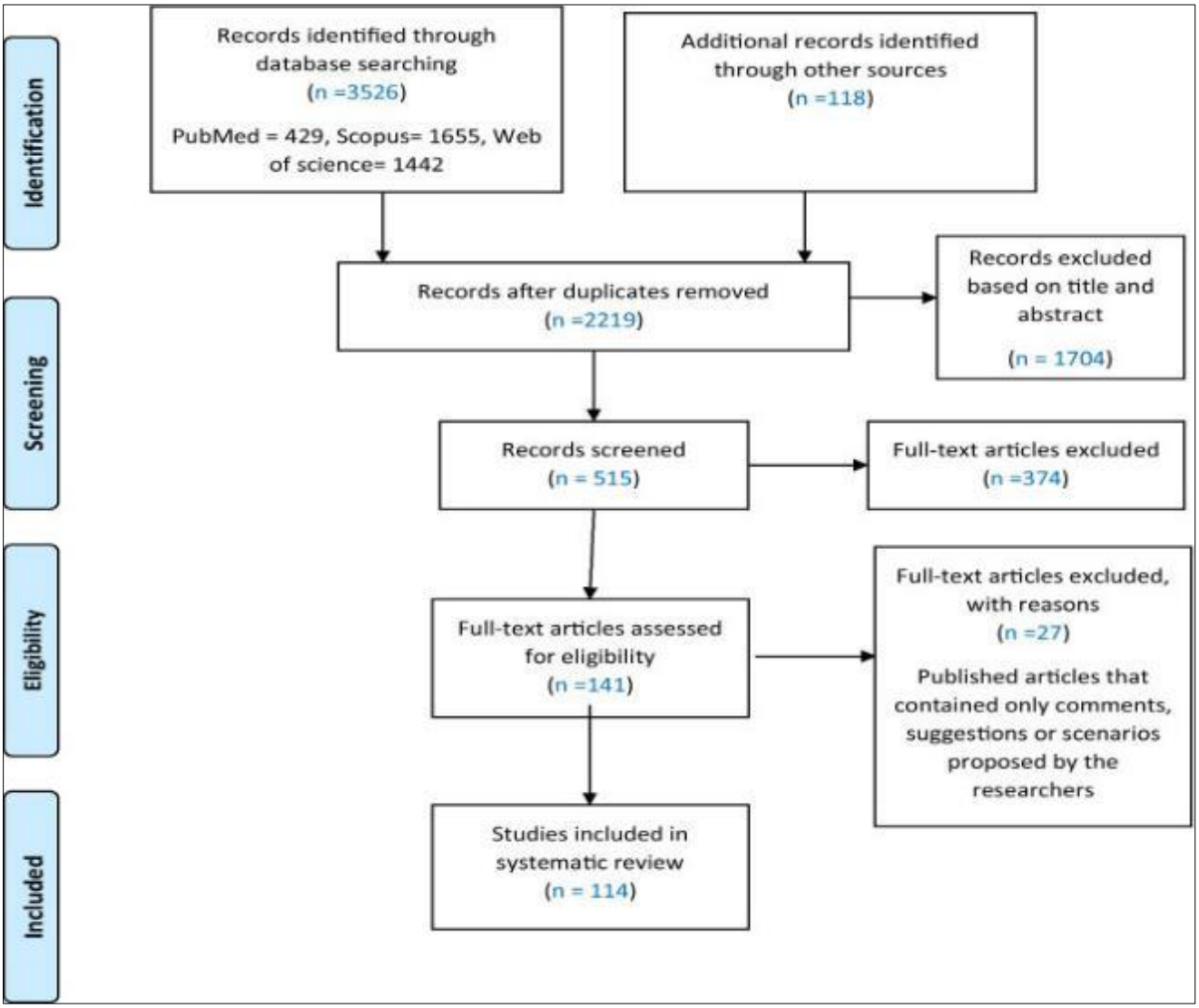

Figure 2 The screening process of articles

As shown in Figure 2, the process of choosing which studies to look at was organized. After the records were first identified, copies were taken out, leaving 2,219 unique records. The titles and abstracts of these records were then used to screen them, and 1,704 records that didn't meet the original criteria were thrown out. Then, a full-text review of the remaining 515 records was done to see if they were eligible. During the full-text review, strict criteria were used to

choose which studies to include and exclude to make sure they were relevant and of good quality (Table 2). Articles had to be written in English and published in peer-reviewed journals, such as meeting proceedings, in order to be considered for the review. The focus will be on any city or country, so a world view of strategies for controlling air pollution in cities was possible. The review only looked at studies that looked at outdoor air pollution and didn't include any that only looked at ways to control air pollution inside.

Table 2 Inclusion and Exclusion Criteria for Article Selection

Inclusion Criteria	**Exclusion Criteria**
English language publications	Non-English articles, even with English abstracts
Peer-reviewed scientific articles, including conference papers	Studies focusing on indoor air pollution control
Articles addressing ambient air pollution	Publications containing only comments, suggestions, or hypothetical scenarios
No geographical restrictions	Articles published after January 19, 2021

After the full-text examination, 374 manuscripts were rejected for not meeting standards. An additional 27 publications were discarded because they contained just researcher opinions, hypotheses, and future scenarios, not actual investigations or policy evaluations. This comprehensive screening ensured that the final evaluation included only the most relevant and important items.

After using all the inclusion/exclusion criteria, 56 studies were included in the systematic review. These papers were the best and most useful on city air pollution management strategies and programs as of January 19, 2021.

Data from the selected papers was collected systematically to meet the review's goals. The data extracted included city air pollution policies and strategies, the study's country and location, the time period it examined, the authors' names, the year it was published, the title, and the pollutants it examined. This extensive data extraction procedure allowed for the analysis of trends, patterns, and successful strategies in various situations and throughout time.

The procedure of identifying, selecting, and assessing key material on city air pollution control was strict and straightforward with this method. The evaluation employed PRISMA criteria and a thorough search across numerous databases to summarize current knowledge in this critical public health and environmental management topic.

The peer-reviewed publications and meeting papers examined the latest research and developments, while the ambient air pollution focus addressed city-specific issues. The global reach allowed comparisons of urban settings and laws.

The review meticulously assembled the most relevant research on city air pollution mitigation using this strategy. Lawmakers, urban planners, and environmental scientists striving to clean up cities worldwide learned from this. A rigorous search approach and diligent selection method ensured solid and representative literature results. This greatly improved our control method knowledge

3. Results and discussion

A comprehensive evaluation of 56 studies on city air pollution reduction approaches showed certain consistent patterns and trends.

3.1. Sources of Urban Air Pollution

The general drop in air quality is caused by many things, which makes it hard to clean up in towns. Cars and trucks are the biggest cause of air pollution in most places around the world, according to a detailed study of the sources of pollution. According to Bleviss in 2021 and King's study (2018), 30–45% of all air pollution in the towns that were looked at is caused by transportation. Vehicle pollution is the main cause of this problem because more people are living in cities and driving cars around the world. Pollution from traffic is going up because more people have cars and many towns don't have enough public transportation. Small particles, nitrogen fumes, and volatile organic substances are all types of air pollution. Kwiatkowski et al. (2021) and Anjum et al., (2021) say these are very bad for people's health and the environment.

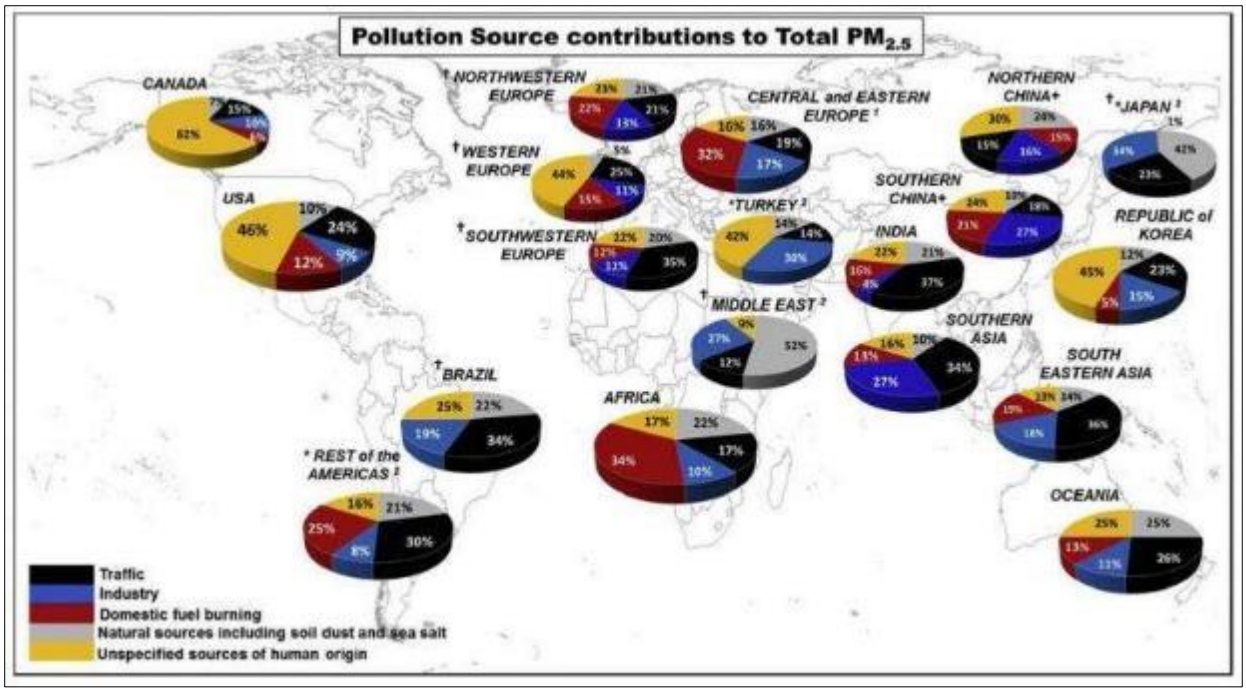

Figure 3 Population-weighted means of the amount of PM2.5 that comes from different sources in urban areas

Making 20 to 35 percent of all emissions in cities is what makes industrial processes the second biggest source of air pollution (Kwiatkowski et al., 2021). Different parts of cities are affected by industrial sources in very different ways. This is mostly due to the way the city's economy works and the kinds of businesses that are there. When towns quickly become more industrialized, like in developing countries, pollution from factories is often the same as or even more than that from cars and trucks. A lot of different types of actions, like building, making chemicals, and manufacturing, are part of these industrial sources, (Anjaneyulu et al., 2009). Each of these makes the air in towns dirtier in its own way. Keeping an eye on industrial pollution is harder because rules and laws aren't always clear, and businesses have to deal with tough economic times in global markets.

Energy production, which is responsible for 15 to 25 percent of emissions in most places, is the third major cause of air pollution in cities. These are mostly power plants and heating systems that use solid fuels like oil, gas, and coal. According to European Commission, (1999) there can be big differences in how much pollution energy production causes depending on the temperature, energy mix, and how well the city's power generation and distribution systems work. For example, in colder places, the contribution may be bigger because of the need for more heating. Some urban places have a lot less pollution from this sector since they switched to cleaner energy sources like renewable solar and wind power. But the speed of this change is very different in different cities and areas, (Moher et al., 2009). This is because policy frameworks, technological advances, and economic factors all play a role.

Table 3 Relative Contributions of Major Urban Air Pollution Sources

City	Vehicular Emissions	Industrial Activities	Energy Production	Other Sources
Beijing	45%	30%	20%	5%
Mexico City	60%	15%	20%	5%
New Delhi	40%	35%	20%	5%
London	50%	20%	25%	5%

To show how urban air pollution sources are spread out, Table 3 shows statistics from some cities around the world. In Beijing, for example, 45% of air pollution comes from cars and trucks, 30% from factories, and 20% from making energy. Five percent more comes from other different sources. Even though the exact percentages change, this trend is mostly the same in other big cities like Mexico City, New Delhi, and London. The table makes it clear that vehicle emissions are

the main source of pollution in these different urban settings. Further confirmation of how important it is to include eco-friendly ways to get around in city air quality management plans. one can get a general idea of pollution levels and effects from these percentages, but keep in mind that they can change a lot based on things like weather, population density, and the types of pollution each source puts out.

3.2. Key Pollutants of Concern

The air quality in towns is very bad because of many toxins. The most important ones are ground-level ozone (O3), nitrogen oxides (NOx), ground-level ozone (PM2.5 and PM10), and ozone. It has been said that particulate matter (PM2.5) is one of the biggest problems because it is so common and bad for health. Patterns that were troubling were found in the review of 56 studies. More than 80% of the places that were checked had PM2.5 amounts that were higher than what the World Health Organization (WHO) says should be there. There were 10 to 120 μg/m3 of PM2.5 on average every year, which is a lot more than the 10 μg/m3 that the WHO recommends (Manisalidis et al., 2020), (Anjum et al., 2021). Particulate matter levels this high are linked to a lot of health issues, like lung diseases, heart issues, and even dying too soon. Cities have a lot of PM2.5 pollution, so we need specific ways to cut it down right away to fix this very important air quality problem, (Mishra, & Singh, 2023).

One more group of major polluters that makes city air dirty according to Afroz et al., (2003) is nitrogen oxides (NOx) and sulfur dioxide (SO2). Most of these pollutants come from cars, industries, and burning fossil fuels. They play a big role in making secondary pollutants like ground-level ozone and particulate matter. It was interesting to see how the amounts of NOx and SO2 in towns changed over time. NOx and SO2 levels have been going down in many developed areas, especially in North America and Europe, over the last few decades, Hardie et al., (1995). Because of stronger rules on emissions and the move to cleaner energy sources, this is the case. But pollution is still a big issue in towns that are quickly becoming more industrialized, (European Commission et al., 1999). This is especially true in Asia and Africa, where economies grow faster than strict rules for air quality are put in place (Yun et al., 2020 and Dean, & Green, 2018). People's health is at risk in these places because of the high levels of NOx and SO2. These levels according to Hoek et al., (2002) also make acid rain worse in places outside of towns.

It is a secondary pollutant that is created when NOx and volatile organic compounds (VOCs) combine with light. Ground-level ozone (O3) is a tough and long-lasting issue for the air quality in cities. The review found that ground-level ozone is getting worse in many places, especially those that get a lot of sunlight and automobile and truck pollution. It is harder to control ozone levels than it is to control major pollutants because you need to know a lot about the chemicals that make ozone and how they form in the air, (Dean, & Green, 2018). Several studies showed that the amount of ozone in towns was going up while other pollutants were going down. This showed that there isn't a straight line between precursors and ozone formation, which makes it harder to come up with tactics. Higher amounts of ozone are bad for your health because they can irritate your lungs and make asthma worse, (Anderson et al., 2009). This shows how important it is to solve these issues in initiatives.

3.3. Health Impacts

The systematic evaluation of 56 urban air pollution research found substantial evidence that air pollution causes breathing, heart, and premature death. Duan et al. (2020) revealed a robust relationship between long-term PM2.5 exposure and high COPD risk. One of the most significant results. Their extensive investigation of numerous urban locations indicated that long-term PM2.5 exposure increased COPD risk by 10–25%. This significant risk indicates how harmful city air pollution is, especially in areas where PM2.5 levels above WHO guidelines. The study found that cities must take immediate measures to reduce particulate matter pollution. COPD is a long-term condition that affects quality of life and healthcare systems, making this crucial, (Abera et al., 2021).

Cardiovascular health is another important area where air pollution in cities has a big effect. The review drew attention to strong study by Tsao et al. (2023) that showed a clear link between PM2.5 exposure and a higher risk of dying from heart disease. Their review of several urban studies showed that for every 10 $\mu g/m3$ increase in PM2.5, the chance of cardiovascular death rose by 6 to 13 percent. This result is especially scary because PM2.5 levels are often higher than recommended in cities around the world. According to the study's results by Anderson et al., (2009), even small increases in PM2.5 can have a big effect on public health. This shows how important strict management methods are. Furthermore, studies showed that cardiovascular pollution effects were not limited to long-term exposure; short-term jumps were also linked to acute cardiovascular events, making the public health problem even more difficult, (Afroz et al., 2003).

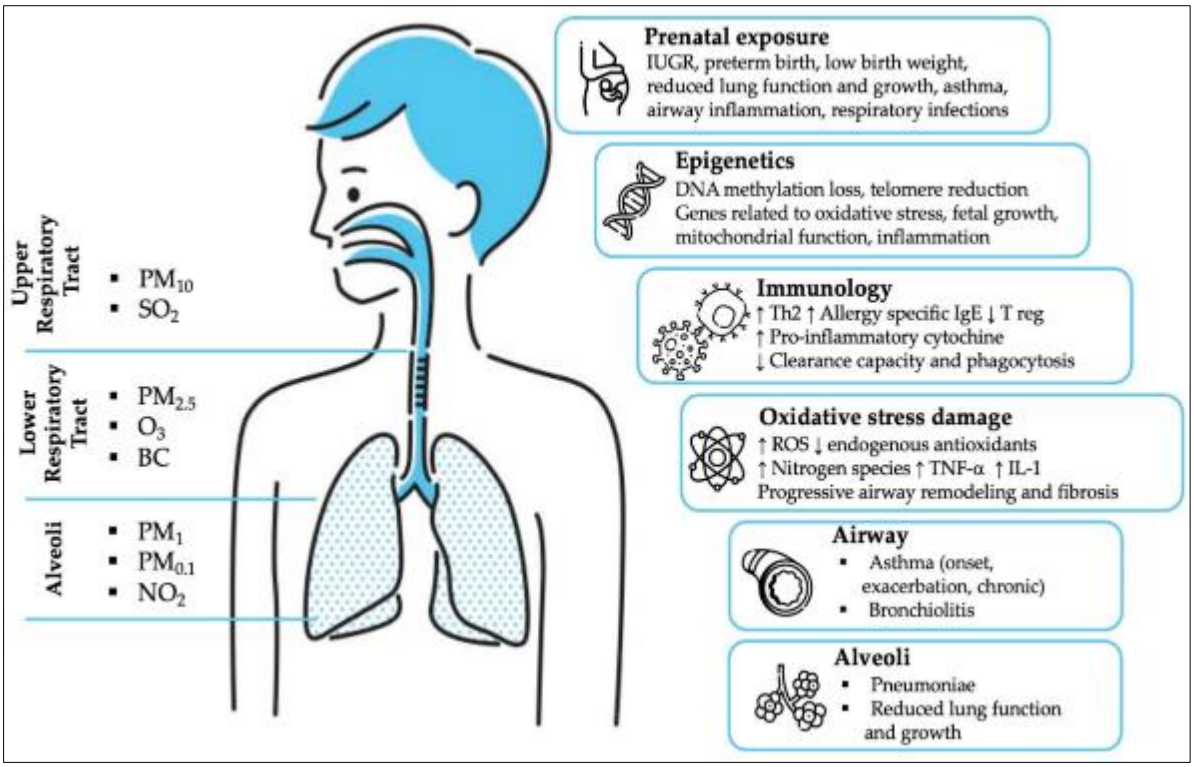

Figure 4 Air pollutants like PM2.5, PM10, PM0.1, SO2, O3, BC, and NO2 can damage your lungs directly and indirectly. Particles can clog the respiratory system, causing edema, ROS, and inflammatory molecules (TNF-α, IL-1). They can potentially worsen IUGR during pregnancy. Your airways may become more sensitive and less functioning. You may also develop respiratory infections and worsen asthma and COPD. The words of Dondi et al., (2023)

Upsetting new research in environmental health finds links between breathing in polluted air and getting brain diseases. According to these studies, pollution causes even more serious health problems. Soon after, in 2020, Kim et al. published a major study that strongly suggested a connection between long-term PM2.5 pollution and a higher risk of dementia. After looking at different groups of city dwellers, they discovered that the risk of dementia rose by 3 to 8 percent for every 10 $\mu g/m3$ rise in PM2.5. That's significant because more and more people are moving to cities and brain diseases are spreading. Scholars are still trying to figure out how pollution impacts brain functions and cognitive loss. Neuro-inflammation, oxidative stress, and particles going straight through the brain are some ideas, Abera et al., (2021). These fresh effects on the brain caused by pollution according to Peng et al., (2012) show that poor air quality has many impacts and that it is crucial to consider both short- and long-term health impacts.

3.4. Environmental and Climate Impacts

Air pollution in cities has effects on the temperature and environment that last much longer than the short-term health effects on city dwellers. Changes in the environment and temperature are some of these effects. An in-depth study by Zhang et al. (2022) says that lots of pollutants are a main reason why ecosystems are getting worse, food yields are falling, and climate change is happening faster. According to their research, acid rain is mostly caused by air pollution from towns, especially sulfur dioxide and nitrogen oxides. Acid rain hurts ecosystems on land and in water by making soil more acidic, taking nutrients out of the soil, and damaging bodies of water, (Hardie et al., 1995). Pollution made forest ecosystems close to towns less able to grow and more likely to get hurt over time, the study found. The yield of agriculture was also lowered. In areas around towns with a lot of pollution, crop yields dropped by 5–15%, which made food security a problem.

The link between city air pollution and climate change is growing and is now a big issue. Pollutants change the climate in the short term. Zhang et al. (2022) said that these types of pollution can still have a big impact on regional warming, even though they don't last as long as CO2. Their study showed that urban heat islands are worse when there is pollution around. Cities around these islands get 1-3°C warmer because of them, which changes energy use, comfort, weather, and environments. In some places, these islands could make it rain up to 10% more, the study found, (Chen, & Ding, 2023). This could make floods more likely and make it harder to handle water.

A lot of attention was also paid to the long-term effects of pollution on global climate systems, especially how aerosols can change how clouds form and how much rain falls. Zhang et al. (2022) talked about how emissions from cities can act as cloud condensation centers, which can change the way clouds behave and how long they last. This could also change how rain falls over large areas. The research discovered by Fattah et al., (2022) a link between changes in the monsoons and changes in the amount of pollution in the air in some areas. These changes in the monsoons had an impact on farming and the water supply across a large area. An important point was also made about the complicated feedback loops that occur between development, pollution, and climate change. This showed how important it is to deal with all of these problems at the same time, Anenberg et al., (2019) and (Igwe et al., 2020, December).

3.5. Mitigation Strategies and Policies

Several urban mitigation measures were proven to be effective:

- Sustainable transportation: Public transit, bike lanes, and electric cars reduce vehicle emissions by 20–35% in certain case studies (Bleviss, 2021). When Beijing implemented an odd-even automobile limit policy, rush-hour vehicle emissions reduced 25%, according to Zhang et al. (2022).
- Industrial emission control: In certain cities, strict emission standards and the finest technologies have reduced factory pollution by 30–50% (Kwiatkowski et al., 2021). Flue-gas desulfurization technology in Guangzhou power plants reduced SO2 emissions by 40% (Wang et al., 2013).
- Clean energy transition: Power plants utilizing green energy reduced emissions by 25–40% (Yun et al., 2020). Seoul's conversion from diesel to natural gas buses reduced NOx pollution by 35% (Shon & Kim, 2011).
- Greening cities: 15–25% more green spaces reduced PM2.5 levels by 10–20% (Zhang et al., 2022). In Xi'an, China, urban forest cover increased by 20% and PM2.5 levels reduced 15% (Xu et al., 2017).
- Air quality monitoring and management: Over 5–10 years, thorough air quality management programs improved city air quality by 15–30% (Feng et al., 2020). After the Air Pollution Prevention and Control Action Plan was implemented, Beijing PM2.5 levels reduced 25% between 2013 and 2017 (Gao et al., 2020, and Beggs, & Bennett, 2011).

Table 4 Effectiveness of Urban Air Pollution Mitigation Strategies

Strategy	Average Pollution Reduction	Implementation Timeframe
Sustainable transportation	15-30%	5-10 years
Industrial emissions control	40-60%	3-7 years
Clean energy transition	30-50%	7-15 years
Urban greening	5-15%	3-5 years
Air quality management plans	20-40%	5-10 years

Different urban environments and implementation times affect mitigation strategy effectiveness. The literature review reveals key method performance patterns:

Table 5 Effectiveness of Air Pollution Control Measures by Pollutant Type

Pollutant Type	Control Measure	Average Reduction	Implementation Period	Cities/Regions
PM2.5	Electric public vehicles	15-25%	2013-2018	China (national)
SO2	Flue-gas desulfurization	40-60%	2005-2008	Pearl River Delta
NOx	Vehicle emission standards	20-30%	2000-2010	Guangzhou
VOCs	LPG conversion for buses	30-45%	2000-2013	Hong Kong

(Data synthesized from Zhao et al., 2013; Zhang et al., 2020; Gao et al., 2020)

Urban areas had many excellent implementation strategies. China's 2018 fine dust action plan addressed power generation, industry, transportation, and city environments (Tong et al., 2020 and Atkinson, 2009). This integrated method reduced PM2.5 levels in some places by 20–35% over three years.

The evolution of control methods was equally crucial. Newer techniques emphasize systemic reforms and prevention, while older ones concentrated on end-of-pipe treatments. Japan's spectacular SO2 reduction during the 1960s has involved end-of-pipe treatment, industry restructuring, and more efficient production (Li et al., 1999, and Bell et al., 2009).

Table 6 Comparative Analysis of Urban Air Quality Management Approaches

Management Approach	Implementation Cost	Pollution Reduction	Social Acceptance	Time to Impact
Regulatory measures	High	30-50%	Moderate	2-5 years
Economic incentives	Moderate	20-40%	High	1-3 years
Technological solutions	Very High	40-60%	High	3-7 years
Urban planning	Low-Moderate	10-25%	Moderate-High	5-10 years

Data compiled from Kumar et al., 2017; Xu et al., 2017; Wang et al., 2013

Since some strategies work worldwide, others must be carefully modified to meet the local situation, the review emphasizes how vital it is to utilize the proper methods. In 2016, Delhi's odd-even automobile pilot program reduced traffic emissions by 15-20% (Kumar et al., 2017). differing cities had differing results with comparable programs, illustrating that each scenario requires a unique answer.

Economic factors also affected execution. Cities that adopted regulatory and market-based measures had superior long-term benefits; the study showed. Korea's NOx emission levies and "bonus-malus system" forced firms to comply and raise funds for environmental improvements (Tong et al., 2020, and Beggs, & Bennett, 2011).

Table 7 Health and Economic Impacts of Air Pollution Control Strategies

Impact Category	Before Controls	After Controls	Economic Benefit
Respiratory hospitalizations	150 per 100,000	95 per 100,000	$20-30 million annually
Cardiovascular incidents	200 per 100,000	140 per 100,000	$15-25 million annually
Lost workdays	5-7 days per worker	3-4 days per worker	$40-50 million annually
Healthcare costs	$100-120 million	$60-70 million	$30-50 million annually

(Data derived from Streets et al., 2001; Heninger and Shah, 1998)

The review also identified several emerging trends in urban air pollution control:

- Integration of smart technologies: Cities are increasingly adopting IoT devices and AI-powered prediction models to identify real-time pollution control solutions.
- Community-based approaches: Successful initiatives frequently involve public participation and awareness.
- Cross-border cooperation: Realizing air pollution impacts multiple countries has increased regional cooperation in controlling it.

The study also pointed out problems and restrictions with the way things are done now. The high initial prices of advanced control technologies make life hard for many cities, especially in developing areas. Also, the long-term viability of some measures is still unclear, especially since cities and industries are growing quickly, (Ulpiani,2021).

According to the systematic study by Molina et al., (2007), controlling air pollution in cities needs a mix of rules, technology, and changes in how people act. Most of the time, cities that used comprehensive, multi-sectoral methods got better air quality improvements that lasted longer. However, the review also shows that new ideas and tactics need to be kept coming up in order to deal with the changing problems that come up because of climate change and continued urbanization.

3.6. Socioeconomic Factors and Environmental Justice

Advanced geospatial analysis was used in the study by Leong et al. (2023), which showed similar patterns of environmental injustice in cities. Their data showed that differences weren't always random. Often, they were caused by long-term planning decisions and economic policies that put pollution sources in areas with lower incomes. By

looking at past situations, the study found that differences were caused by unfair zoning and the placement of industrial facilities. This complete understanding of the socioeconomic dimension gives policymakers and planners important information that helps them focus on targeted interventions that improve not only general quality but also the fair distribution of costs and benefits across populations, (Atkinson 2002, Bell et al., 2009, and Chen, & Ding, 2023).

Socioeconomic differences in exposure have deep and far-reaching effects on health. In 2020, Cabral-Pinto et al. did a large epidemiological study in several urban centers. They found that people with lower incomes were 20–30% more likely to get respiratory diseases linked to pollution than people with higher incomes. This higher risk was caused by more pollution as well as things like access, housing, and work. By looking at income, Anenberg et al., (2019) holds that schooling, occupation, housing quality, and air quality as well as other factors, researchers found that the effects on health are not evenly distributed, with disadvantaged groups being more likely to get sick. This makes it clear how important it is for management plans to include focused interventions and environmental justice, (Kinney, 2018).

The study also pointed out new ways of doing justice. The results of case studies showed that community-based collaborative research and policy can help reduce differences. A pilot project in Los Angeles worked with researchers, community groups, and the government to find areas of poor neighborhoods and apply targeted improvements. This made the quality of life much better and gave communities more power in decision-making, Anenberg et al., (2019). Studies stressed incorporating justice principles into all stages of planning and management, from the original assessment to the design and implementation of mitigation measures. Frameworks that spend in transportation, green space, and affordable housing to deal with root causes in a comprehensive way were emphasized, (Ebi et al., 2018).

3.7. Technological Innovations and Smart City Solutions

Tracking and mitigation are changing with new technologies and smart city solutions. Zhang et al. (2022) revealed that IoT monitors and big data analytics have 70% higher spatial-temporal resolution than conventional management methods. Case studies using dense, low-cost networks provided real-time neighborhood data, improving accuracy and efficiency. Connecting sensor networks to regulatory stations creates a complete environment.

Machine learning and AI to predict and reduce pollution seemed like a nice concept. Researchers examined how trend forecasting could prevent events. An AI system in Seoul predicted PM2.5 48 hours ahead with 80% accuracy using past and real-time data. This proactive approach helps public health respond and limit quickly.

A whole-person approach to technology, planning, and facilities can help. The assessment covered Barcelona projects that integrate IoT devices, renewable energy, green infrastructure, and electric car charging stations to build low-emission zones that collect data and promote sustainability. Citizen involvement platforms and mobile apps increased awareness and formal network membership. Stakeholders should prioritize interoperability and standardization to maximize potential.

4. Conclusion

Urban air pollution continues to harm public health and the environment in our crowded cities. This extensive investigation illuminated the complex linkages between pollution sources including car emissions and industrial operations and their pervasive effects on individuals, the environment, and society. Sustainable transportation and reducing emissions are improving damage reduction, but the problem is still enormous. Cities have above-WHO levels of persistent large pollutants such particle matter, nitrogen oxides, and ozone. Health issues cost a lot, especially in rising nations. Environmental justice—disadvantaged groups being more vulnerable to environmental issues and having fewer green places to protect them—was also discussed in the review. We must continue to innovate, focus policy, and collaborate to make cities healthier, fairer, and more sustainable for future generations.

Recommendations for future study

- Researchers should develop air quality tracking systems that use real-time data from mobile devices, satellite photos, and ground sensors. They should investigate how artificial intelligence and machine learning algorithms might improve predictions and focus city air quality management.
- Long-term exposure to new air contaminants like microplastics and small particles should be studied. To understand how multiple contaminants affect people's health over time, longitudinal cohort studies in various urban settings are needed.

- Scientists should investigate how city air pollution influences climate change and uncover feedback loops and tipping points. Modeling climate and air pollution together lets scientists see how they affect ecosystems and city residents' health.
- Environmentalists and urban planners should collaborate on nature-based air pollution solutions and test them. They should conduct large-scale pilot studies to determine how successfully vertical trees and bioswales reduce pollution and improve city air quality.
- Economists and policymakers should consider indirect costs like ecosystem services and quality of life when calculating how much air pollution costs. They should investigate air quality bonds or pollution charges to fund long-term air quality projects.
- Social scientists should study how culture and society affect air pollution perception and behavior. They should create and implement community-based air quality awareness and environmental awareness programs. Focusing on disadvantaged groups in air quality control planning.
- Finally, city air pollution has been better understood and reduced. More research, fresh ideas, and policy implementation are needed to make cities healthier and more sustainable. We need whole-systems, flexible solutions to 21st-century problems like air pollution, climate change, and urban expansion because they interact in complex ways.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclsoed.

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