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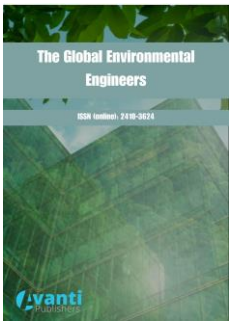

Challenges and Way Forward to Maintain Air Quality Standard in Urban Areas

Madhab C. Jena[1,*], Sarat K. Mishra[2] and Himanshu S. Moharana[3]

[1]*Biju Patnaik University of Technology, Rourkela, Odisha 769004, India*

[2]*Balasore College of Engineering & Technology, Balasore, Odisha 756060, India*

[3]*HiTech Institute of Technology, Bhubaneswar, Odisha 756060, India*

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ABSTRACT

This thesis explores the intricate relationship between urban air pollution, economic growth, population dynamics, and energy consumption. Addressing impacts on climate change, biodiversity, agriculture, and human health, it emphasizes compromised urban air quality due to pollution sources such as power generation, vehicle traffic, and construction. Key pollutants like particulate matter, carbon dioxide, sulfur dioxide, and nitrogen dioxide pose significant health risks. The study identifies road transportation as a primary contributor, underlining alarming statistics from WHO on global air quality, particularly impacting low-level socio-economic regions. Legislations and policies dating back over a century form the foundation for global air pollution control efforts. The research highlights innovative solutions like urban green spaces, smart traffic management, and renewable energy investments. It stresses the importance of public transportation, electric vehicles, clean construction practices, and initiatives to reduce industrial emissions. In response to challenges, the thesis proposes a comprehensive mitigation plan covering strategy such as promoting public transport, energy conservation, recycling, and afforestation. It outlines a way forward, emphasizing integrated urban planning, public awareness campaigns, government policies, and international collaboration. In conclusion, the thesis calls for collective responsibility to address urban air pollution's adverse effects on public health and the environment. The proposed roadmap aims to create sustainable, resilient, and healthier urban environments through a holistic and collaborative approach.

*Corresponding Author
Email: madhab_jena@rediffmail.com
Tel: +(91) 9934358754

1. Introduction

In today's context, air pollution is intricately linked to economic growth, population dynamics, and energy consumption. The intricate relationship involves maintaining economic development, improving living standards, accommodating population growth, meeting escalating energy demands, and subsequently witnessing a rise in the production and emission of air pollutants. Recognized as a serious issue, air pollution sparks concerns related to climate change, biodiversity reduction, impacts on crops and agricultural production, and soil acidification [1, 2].

Urban air quality faces continuous compromise due to pollution sources like power generation, vehicle traffic, and construction. Key pollutants, including particulate matter, carbon dioxide, sulfur dioxide, and nitrogen dioxide, pose significant health risks. To counteract this, innovative approaches have emerged, ranging from urban gardens, green spaces, smart traffic management, to low-emission zones. Pollution is exacerbated by activities such as urban expansion and deforestation, contributing to poor air quality prevalent in urban areas, affecting over 80% of the global urban population. The World Health Organization (WHO) further intensified concerns by lowering air pollution guidelines in 2021, particularly impacting metropolitan areas [3, 4]. Studies indicate that individuals in low-level socio-economic regions encounter high concentrations of air pollutants in ambient air, leading to various diseases, including respiratory issues, allergies, disturbances of the central nervous system, and circulatory problems [5-9].

Road transportation stands out as the primary source of air pollution, compounded by domestic, commercial, and industrial activities. A significant percentage (70–80%) of air pollution in large cities in developing countries is attributed to greenhouse gas emissions from a large number of worn-out vehicles, coupled with poor vehicle maintenance, inadequate road structures, and poor fuel quality [10-17]. The key air pollutants encompass particulate matters ($PM_{2.5}$ and PM_{10}), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO), and ozone (O_3) [18-25].

Vehicle emissions, construction, and industrial activities emerge as major contributors to urban air pollution. WHO data on air quality from some 6700 cities worldwide, updated in 2022, reveals that air pollution in 83% of high-income cities and 99% of low-income cities exceeds WHO recommended levels [5]. Nitrogen dioxide and particulate matter, especially $PM_{2.5}$, pose serious health risks, linked to organ damage, pregnancy complications, asthma in children, and declining lung function in the elderly. These pollutants stem from various sources, including vehicle emissions and industrial activities [4, 5].

The establishment of legislations, strategies, and policies in the field of air pollution brings inherent advantages, including preventive measures, controlling air pollution in emission sources, improving air quality, and averting negative health outcomes. Dating back more than a century, air pollution control efforts began with strategies like the Chicago legislation (1881), smoke abatement in Boston (1910–1912), and the Clean Air Act (1925) following the "Great London Smog" in the UK [26-28]. Subsequent legislations and programs have been enacted at international, national, and local levels. International actions, such as the Paris Agreement (2015), recommend countries to lower global warming below 2 °C and prevent dangerous climate change impacts [29, 30]. At the continental level, European Union (EU) Directives, the convention on long-range trans-boundary air pollution (CLRTAP), and protocols related to emission reductions address specific air pollutants [31, 32]. Local preventive air pollution actions include the prohibition of solid fuel use in homes, low emission zones (LEZs), and the introduction of vehicle exhaust catalysts (VECs) [27, 33-35].

In response to these challenges, innovative solutions have been developed. Urban gardens and green spaces absorb pollutants and release oxygen, reducing air pollution. Strategies like planting trees close together create wind paths, dispersing pollutants and cooling the environment. Smart traffic management, including adaptive traffic signals and policies to reduce private vehicle use, minimizes emissions [10]. For instance, London's Ultra-Low Emission Zone has significantly reduced air pollution. Investing in renewable energy, such as solar and wind farms, lowers emissions and benefits both air quality and climate change [11]. By adopting these creative approaches and monitoring air quality, we can strive for cleaner air in urban areas, ultimately enhancing the well-being of urban populations [36-39].

Numerous studies have been conducted during COVID-19, where it is clearly found that the air quality became better in different cities and other places of the world due to less activities of human being in the open environment [40-53]. The aim of this paper is to maintain the good quality of environmental standard hand on hand continuing the activities in a more sensible and scientific way.

This research highlights how important it is to recycle and reuse stuff. It also talks about using green infrastructure and technologies that save energy. The study says we should get local leaders involved to keep the air clean and make rules to control things that make the air dirty. To figure out good solutions, the study looked at real places, talked to people involved, read a lot of information, and did a field survey.

2. Materials and Method

This study involves field visits where on-site inspections and observations are conducted. Interviews have been conducted with all relevant stakeholders to gain insights into their perspectives and understand the challenges they face. Additionally, an extensive literature review has been undertaken, complementing the field survey. The combination of these approaches forms the basis for proposing comprehensive and well-informed solutions to address the identified issues.

3. Main Reasons of Air Pollution in Urban Areas

The quality of air in urban regions often falls below acceptable standards, posing serious risks to the health of the population. More than 80% of urban dwellers worldwide are exposed to air pollution levels exceeding the guidelines set by the World Health Organization (WHO) in 2005. This problem is particularly concerning for residents of low-income cities, who face a heightened risk of respiratory diseases and other health complications. A worrisome aspect is that the WHO revised these guidelines in 2021, which implies that an even larger proportion of urban areas will fail to meet the updated air quality standards if proactive measures are not taken.

One of the primary culprits of air pollution in urban areas is vehicle emissions, releasing both nitrogen dioxide and particulate matter into the atmosphere. Additional significant contributors to air pollution include construction activities, commercial cooking, wood burning, industrial boilers, and generators.

The details given above illustrates the percentage of the urban population in the European Union exposed to air pollution levels exceeding EU limits and the more stringent WHO guidelines. It is evident that a substantial portion of urban residents' experiences harmful levels of air pollution, leading to severe consequences for both human health and the environment.

The issue of elevated air pollution in urban areas is further exacerbated in economically developing cities. According to United Nations data, an alarming 98% of cities in low-income and middle-income countries with over 100,000 residents fail to comply with the aforementioned WHO air quality guidelines. In high-income countries, this standard is relatively lower, with 56% of cities not meeting the standards.

Nitrogen dioxide (NO_2) is a major air pollutant that significantly affects urban air quality. NO_2 pollution tends to remain concentrated in the vicinity of its source, with areas of heavy vehicle traffic, such as urban centers, experiencing the highest NO_2 levels. Exposure to NO_2 has been linked to various adverse health effects, including harm to organ health, developmental issues during pregnancy, the onset of asthma in children, and declining lung function in the elderly. To gain a more in-depth understanding of the detrimental consequences of nitrogen dioxide exposure, you can explore our dedicated blog on air quality measurements.

Particulate matter air pollution is another crucial factor in urban air quality. $PM_{2.5}$ comprises tiny particles, including soot, dust, smoke, and liquid droplets, all measuring less than 2.5 micrometers in diameter. These minuscule particles are particularly hazardous as they can penetrate deep into the lungs and enter the bloodstream, ultimately lodging in various organs.

PM2.5 can emanate from vehicle sources, generated by fuel combustion and friction between tires and brake pads during driving. Additionally, other sources of PM in urban areas encompass smoke from fires and emissions from power plants and industrial facilities [54]. Exposure to particulate matter has been associated with a range of health issues, including chronic inflammation, impaired lung development in pregnancy and early childhood, and declining lung function in older adults, akin to the effects of nitrogen dioxide exposure [35, 37, 38, 46].

The details given above provides an overview of the sources of air pollution in urban areas, categorized by personal transportation, the built environment, and emissions from supply chain activities and transboundary transportation. Within these categories, specific activities like construction, wood burning, private vehicle use, waste collection, and business deliveries are identified as contributors to overall air pollution emissions in cities.

Addressing the issue of air pollution in urban areas requires a comprehensive understanding of the primary sources and their associated health risks. Vehicles, construction, industrial processes, and other factors contribute to poor air quality, jeopardizing the well-being of urban populations. Efforts to mitigate air pollution and protect public health are essential in ensuring a cleaner and safer environment for all city residents.

4. Mitigation Proposal

Addressing air pollution in urban areas is a multifaceted challenge that requires a combination of innovative policies and individual actions. While various approaches have been implemented to combat air pollution, it is crucial to establish robust air quality monitoring networks to assess the effectiveness of these measures. There are multiple benefits in recycling and reuse of waste or used products as shown in Fig. (**1**).

Key strategies to mitigate air pollution in urban cities are given below (Fig. **2**).

- Promoting the Use of Public Transport: Encouraging the use of public transportation and carpooling can significantly reduce air pollution by reducing the number of vehicles on the road, resulting in lower emissions, less traffic congestion, and cost savings.

- Energy Conservation: Conserving energy by turning off lights when not in use and using energy-efficient lighting options can help reduce electricity consumption and minimize the environmental impact.

- Recycling and Reuse: Embracing the concept of recycling and reusing resources not only conserves materials but also reduces pollution emissions associated with the production of new items.

- Reducing Plastic Use: Minimizing the use of plastic products, which have a long decomposition period, in favor of eco-friendly alternatives like paper bags helps lower environmental pollution.

- Preventing Forest Fires and Smoking: Controlling garbage fires and discouraging smoking in public spaces can prevent air pollution episodes, especially in dry seasons.

- Energy-Efficient Cooling: Substituting air conditioners with fans is a greener option that conserves energy and reduces heat emissions.

- Chimney Filters: Installing filters on chimneys in homes and factories can help reduce harmful gas emissions into the atmosphere.

- Avoiding Firecrackers: Implementing bans or restrictions on the use of firecrackers during festivals and events can prevent smog and air pollution.

- Reducing Chemical Product Usage: Minimizing the use of products containing strong chemicals or opting for organic and low-chemical alternatives can reduce air pollution and health risks.

- Afforestation: Planting and maintaining trees in urban areas can enhance air quality and provide numerous other environmental benefits.

- Additionally, urban strategies recommended by experts and organizations include:
- Adopting WHO's Air Quality Standards: Monitoring and identifying pollution priorities according to WHO standards.
- Promoting Clean Transportation: Encouraging zero-emission public transport and cycling paths to reduce emissions.
- Investing in Green Spaces: Creating urban gardens and green infrastructure to improve air quality, reduce heat, and promote food security.
- Regulating Industrial Emissions: Promoting the use of clean energy sources and emissions controls in industrial processes.
- Banning Burning of Garbage: Enforcing laws against burning garbage, which releases harmful pollutants into the air.
- Supporting Clean Construction: Encouraging sustainable construction practices to reduce carbon emissions and pollution.
- Engaging Local Champions: Promoting individuals and organizations to champion clean air initiatives and report concerns.

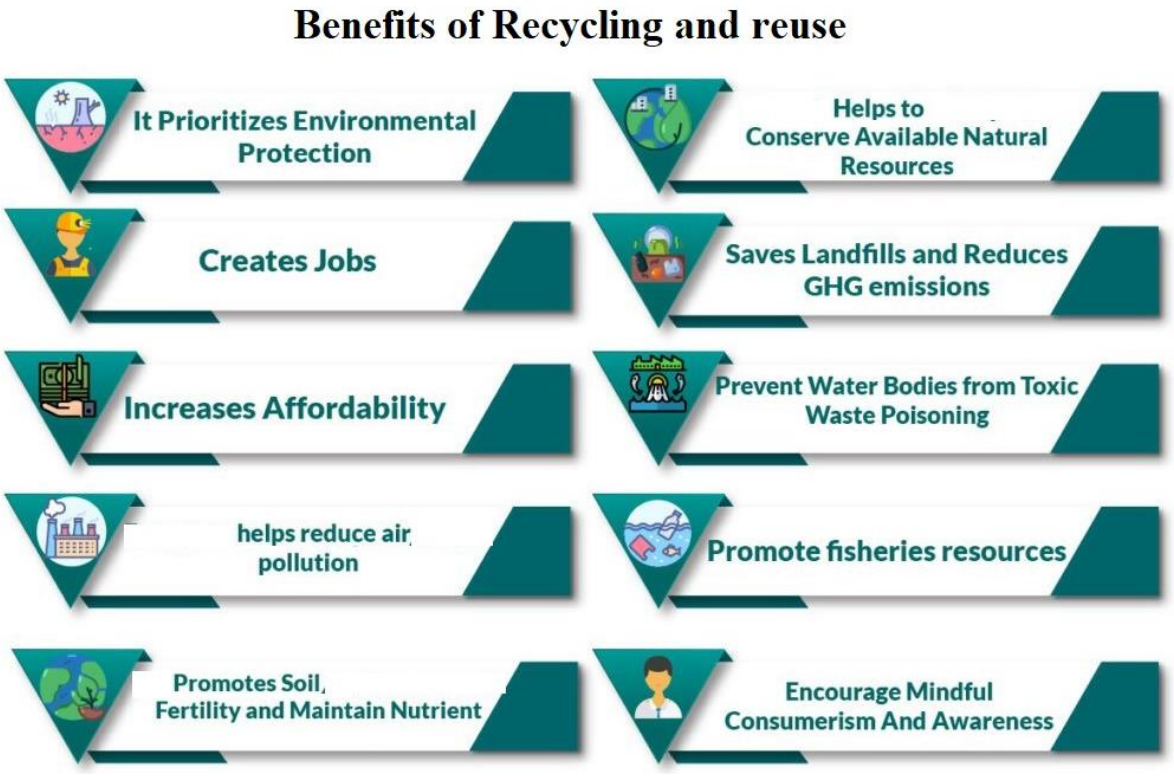

Figure 1: Benefits of recycling and reuse.

In essence, the fight against air pollution in cities involves a combination of individual responsibility, government policies, and innovative urban planning. By implementing these strategies, cities can improve air quality, reduce pollution, and create healthier, more sustainable environments for their residents. Collaboration among governments, communities, and individuals is essential to combat the pressing issue of air pollution and its adverse effects on both public health and the environment.

Depicted in the elaborate details of Fig. (**2**) is an all-encompassing sustainable smart city model, meticulously designed to address a myriad of crucial factors essential for the establishment of an environmentally conscious urban landscape. This intricate model encompasses a proactive stance towards afforestation, advocating for the expansion of green spaces within the city. Simultaneously, it implements a categorical ban on firecrackers to mitigate air pollution and noise disturbances. The model places a strong emphasis on promoting the use of battery-operated vehicles, thereby significantly reducing emissions and contributing to a cleaner atmosphere.

Furthermore, the smart city model staunchly supports the adoption of shared public transport systems, strategically implemented to alleviate the overall burden of vehicular emissions. The integration of green energy sources, particularly solar power, is seamlessly woven into the fabric of the model, serving as a fundamental pillar in the fight against pollution. Additionally, the model is underpinned by a commitment to energy conservation techniques, further ensuring the city's sustainable and eco-friendly development.A pivotal aspect of this model is its unwavering resolve to combat environmental pollution by steering clear of the use of plastics. This resolute decision not only addresses the issue of plastic waste but also sets a precedent for responsible and sustainable practices within the urban landscape.

In essence, Fig. (**2**) unfolds a comprehensive vision for a sustainable smart city, encompassing a multifaceted approach to environmental conservation and eco-friendly urban living.

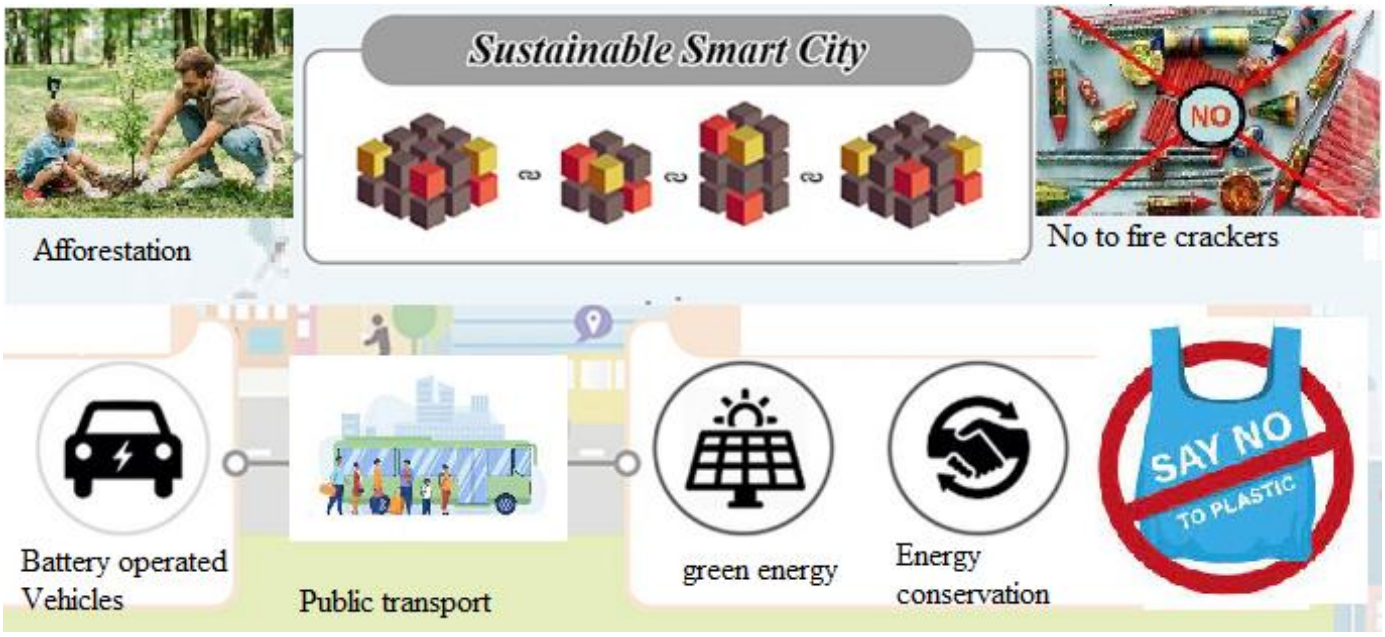

Figure 2: Techniques on air pollution mitigation proposal in urban area.

5. Challenges for Implementation

Infrastructure and Funding: Developing an efficient and widespread public transportation system requires substantial infrastructure investment. This includes building reliable and well-connected networks of buses, trains, and other public transit options. Funding for such projects can be a significant hurdle.

Behavioral Change: Convincing individuals to shift from personal vehicles to public transport or carpooling necessitates a major shift in behavior. Many people are accustomed to the convenience of private transportation and may resist changes to their daily routines.

Technological Adoption: The adoption of energy-efficient technologies, such as LED lighting or electric vehicles, may be hindered by initial costs and a lack of awareness. Government incentives and public awareness campaigns are crucial to overcome these barriers.

Waste Management Infrastructure: Establishing effective recycling and waste management systems requires significant investment in infrastructure and education. In many cases, the lack of proper waste disposal facilities and awareness can impede recycling efforts.

Plastic Alternatives: Finding and promoting viable alternatives to plastic can be challenging. Identifying and implementing eco-friendly alternatives on a large scale may require research and development efforts, as well as overcoming resistance from industries invested in plastic production.

Enforcement of Regulations: Implementing and enforcing regulations against forest fires, smoking in public spaces, and the use of firecrackers during festivals require a robust legal framework and effective law enforcement. Inconsistent enforcement can undermine the impact of these regulations.

Technological Retrofitting: Installing chimney filters in homes and factories may require retrofitting existing structures, which can be costly. Ensuring compliance with these measures poses its own set of challenges.

Cultural Practices: Implementing bans or restrictions on the use of firecrackers during festivals may face resistance due to cultural traditions. Balancing cultural practices with environmental concerns is a delicate task.

Chemical Product Alternatives: Encouraging the use of organic and low-chemical alternatives may face challenges in terms of availability, cost, and effectiveness compared to traditional chemical products.

Land Use Planning: Planting and maintaining trees in urban areas require careful urban planning. Balancing the need for green spaces with the demands of urban development is crucial.

Policy Implementation: Adopting international air quality standards which can proactively help to improve air quality standards like banning of private vehicle in the cities, banning of polluted industrial activities in the cities, banning of fossil fuel operated vehicles etc. and implementing effective regulations may face resistance from industries and may require strong political will and collaboration among various stakeholders.

Community Engagement: Engaging local champions and communities in clean air initiatives requires sustained efforts in awareness building and community participation. Building a sense of responsibility and ownership among residents can be time-consuming.

Monitoring and Data Accuracy: Establishing and maintaining air quality monitoring networks necessitates ongoing investment in technology and infrastructure. Ensuring the accuracy and reliability of collected data is crucial for assessing the effectiveness of mitigation measures.

Addressing these challenges requires a comprehensive and collaborative approach involving governments, communities, industries, and environmental organizations.

6. Way Forward for Implementation

The way forward involves a combination of strategic planning, collaboration, and sustained efforts. Here's a roadmap to address the challenges and move towards a cleaner and healthier urban environment:

Integrated Urban Planning: Develop and implement comprehensive urban planning that integrates sustainable transportation, waste management, and green spaces. Prioritize mixed-use developments to reduce commuting distances and promote walkability.

Public Awareness Campaigns: Launch extensive public awareness campaigns to educate citizens about the impact of their actions on air quality. Highlight the benefits of sustainable practices and the long-term health and environmental advantages.

Government Policies and Incentives: Formulate and enforce policies that promote clean transportation, energy efficiency, and waste reduction. Provide financial incentives for businesses and individuals adopting eco-friendly practices and technologies.

Investment in Infrastructure: Allocate funds for the development and maintenance of robust public transportation systems, waste management facilities, and green infrastructure. Seek public-private partnerships to expedite the implementation of key projects.

Technological Innovation: Invest in research and development of innovative technologies for clean energy, waste management, and air purification. Encourage the adoption of smart city technologies to monitor and manage environmental parameters.

International Collaboration: Collaborate with international organizations and other cities to share best practices and learn from successful initiatives. Participate in global efforts to address climate change and air quality issues.

Community Engagement: Foster community engagement through participatory decision-making processes. Empower local champions and community leaders to drive change at the grassroots level.

Inclusive Policies: Ensure that policies are inclusive and considerate of diverse cultural practices. Seek input from communities to tailor policies to local needs and traditions. Continuous Monitoring and Evaluation: Establish and maintain a robust air quality monitoring system to track progress and identify areas that need attention. Regularly evaluate the effectiveness of implemented measures and adjust policies accordingly.

Capacity Building: Build the capacity of local governments, industries, and communities to implement and sustain pollution control measures. Provide training and resources for effective enforcement of regulations.

Research and Development: Invest in ongoing research to identify emerging sources of pollution and develop effective solutions. Foster collaboration between academic institutions, research organizations, and industries.

Green Innovation Hubs: Establish innovation hubs focused on green technologies and sustainable practices. Encourage startups and businesses to develop and implement eco-friendly solutions.

Transparency and Accountability: Foster transparency in decision-making processes and ensure accountability at all levels of governance. Encourage open communication between the government, industries, and the public.

By combining these approaches, cities can work towards creating a more sustainable and resilient urban environment, improving air quality, and ensuring a better quality of life for their residents. The key is a holistic and collaborative approach that involves all stakeholders in the process of positive change.

7. Conclusion

This thesis sheds light on the critical issue of urban air pollution, affecting a substantial portion of the global urban population and exacerbated by the World Health Organization's revised guidelines in 2021. The identified health risks associated with pollutants like nitrogen dioxide and $PM_{2.5}$ underscore the urgency of implementing innovative solutions and comprehensive mitigation strategies.

Promising approaches, including urban green spaces and smart traffic management, demonstrate potential in combating air pollution. Successful initiatives, such as London's Ultra-Low Emission Zone and the adoption of renewable energy sources, serve as effective models for achieving cleaner air in metropolitan areas.

Mitigation proposals, spanning from promoting public transport to afforestation, offer a multifaceted approach. However, challenges such as infrastructure funding, behavioral change, and technological adoption require collaborative efforts from governments, communities, and industries.

The way forward involves integrated urban planning, public awareness campaigns, government policies, infrastructure investment, technological innovation, international collaboration, community engagement, inclusive policies, continuous monitoring, capacity building, research, and green innovation hubs. This comprehensive roadmap aims to create sustainable, resilient, and healthier urban environments, emphasizing the collective

responsibility of all stakeholders in combating the adverse effects of air pollution on public health and the environment.

In essence, the conclusion highlights the urgency of immediate action, the success of existing initiatives, and the need for a collaborative and holistic approach to ensure a cleaner and healthier future for urban populations worldwide. The future scope of the work would be a detailed case study on the highlighted issues in a metropolitan city to drill down further on this subject.

Conflict of Interest

The authors declare no conflict of interest.

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