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RESEARCH PAPER

Digital Solutions and Technological Innovations Driving Public Awareness and Community Initiatives for Smog Reduction in Lahore: A Descriptive Overview

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ABSTRACT

This study examines smog-related challenges in Pakistan, emphasizing its sources, health, economic, and environmental impacts, and proposed solutions. Smog, primarily from vehicular and industrial emissions, poses health risks and socio-economic consequences. Lahore's severe smog episodes signify a larger national concern. Addressing smog demands a holistic approach integrating regulatory, technological, social, and behavioral interventions. Discussed preventive measures involve public awareness campaigns, real-time air quality monitoring using digital tools, promoting cleaner behaviors, and strict emission control policies. Initiatives like the Billion Tree Tsunami aim to reduce smog severity through expanded green plantation. Challenges include inadequate policy enforcement, the need for public transport encouragement, and reduction of private vehicle reliance. Addressing industrial emissions and transitioning to renewable energy are vital. Theoretical implications stress adopting technology and behavior models for community engagement and policy formation. Practical implications involve integrating digital tools like IoT sensors for improved air quality monitoring. The study emphasizes collaborative efforts between authorities and citizens to effectively combat smog. It underscores the necessity for future strategies involving innovative technology, expanded infrastructure, and knowledge-sharing for a cleaner environment, especially in cities like Lahore, Pakistan.

KEYWORDS Community Initiatives, Public Awareness, Smog

Introduction

Lahore, the heart of Pakistan, entangled in a recurring environmental crisis - smog. This annual menace has significantly influenced the city's populace, economy, and overall well-being. A culmination of vehicular emissions, industrial operations, agricultural practices, and geographical circumstances has transformed Lahore into one of the most polluted cities worldwide. The present endeavors aimed at economic advancement and swift industrial expansion have escalated the vulnerability to illnesses associated with pollution. Lahore holds the 20th position among the most polluted cities globally, exhibiting elevated levels of atmospheric particulate matter that surpass the baseline set by the WHO. Prolonged exposure to this air pollution has linked to cognitive impairment, deficiencies in working memory, executive function, attention, and fluid intelligence. Air pollution stands as the foremost environmental contributor to diseases and premature fatalities worldwide. According to Landrigan et al. (2019), approximately 9 million deaths annually attributed to air pollution.

Lahore situated in Pakistan, grapples annually with a severe environmental predicament characterized by intense smog, primarily originating from diverse sources such as vehicular emissions, industrial operations, agricultural methods, and geographic influences. This comprehensive analysis delves into the origins, ramifications, and prospective remedies for the prevailing smog predicament (Raza et al 2021). The culmination of vehicular emissions, unregulated industrial discharges, and burning of crop residues significantly contributes to the perilous air quality. The ensuing health implications encompass respiratory ailments and escalated cardiovascular risks, while ecological degradation affects agricultural produce, biodiversity, as well as the quality of air and water resources. Economically, the repercussions manifest as disruptions in transportation, augmented healthcare expenditures, and adverse impacts on both the tourism and agricultural sectors. Immediate interventions, including the enforcement of stringent emission regulations and the promotion of sustainable farming practices, coupled with enduring strategies such as the adoption of renewable energy sources and educational campaigns, deemed imperative. Collaborative endeavors involving governmental bodies, industries, farming communities, and public participation are pivotal in effectively mitigating Lahore's smog crisis and fostering a healthier, more sustainable future (waheed et al 2023).

Lahore, the heart of Pakistan, entangled in a recurring environmental crisis - smog. This annual menace has significantly influenced the city's populace, economy, and overall well-being. A culmination of vehicular emissions, industrial operations, agricultural practices, and geographical circumstances has transformed Lahore into one of the most polluted cities worldwide. Multiple factors contribute to the persistent smog in Lahore. Chief among these are the emissions from an escalating number of vehicles traversing the city's roads. Industries operating without adequate pollution control measures release substantial pollutants. Moreover, the customary burning of crop residue in the nearby agricultural regions, notably after the rice harvest, exacerbates air pollution. Geographical elements, such as temperature inversions and stagnant winds, further aggravate the situation by confining pollutants near ground level.

Air pollution stands as a pressing environmental concern in Pakistan, notably exacerbating in Lahore, its provincial capital. Lahore, boasting a 4% annual economic growth rate and holding the rank of the country's second-largest city (Riaz and Hamid, 2018), has encountered escalated pollution levels. According to the latest Air Quality Index (AQI) rankings, Lahore secured the sixth position among the world's most polluted cities, registering an AQI value of 170, while Karachi, Pakistan's largest city, followed closely in the 16th position with an AQI value of 155 in 2019 (2019a). These rankings are based on the annual average concentrations of PM2.5 in 2018, indicating the severity of air quality deterioration (World's most polluted cities, 2018).

Recent reports from Amnesty International and the World Health Organization (WHO) have stressed the urgency of immediate and stringent measures to curb smog incidents, advocating comprehensive air quality legislation (Ali, 2019; CarmonaCabezas et al., 2020; Organization, 2007). Despite this, leveraging public awareness as a preventive tool for smog mitigation remains a viable strategy. However, its effectiveness, particularly in developing nations like Pakistan, may not be significantly impactful. The proliferation of smog in developing countries predominantly links to anthropogenic emission activities. Therefore, a concerted effort is imperative to educate the populace about smog's detrimental effects on human health and the environment, emphasizing preventive measures. Moreover, limited studies on smog's adverse health effects in Pakistan and scarce attempts to assess its economic impact pose significant challenges. Acquiring local data is crucial to bolster mitigation efforts, catalyzing a more prompt

public response. Despite the Pakistani government's efforts to address smog-related issues, further actions are imperative for comprehensive resolution. This paper aims to conduct an exhaustive analysis of smog, delineating its causes, detection methods, impacts, and socio-environmental repercussions. Additionally, it delves into preventive measures and outlines necessary steps to mitigate smog-related predicaments in Pakistan. Lastly, the paper proposes short- and long-term measures, facilitating regulatory authorities in implementing effective mitigation strategies to combat the pervasive smog issue.

Literature Review

Smog's intricate chemistry defies precise definition due to its ever-changing composition, both in time and space. Traditionally, it is categorized into two primary types: classical (or London type) smog and photochemical (or Los Angeles (LA) type) smog, each posing significant concerns for the environment and human health. More recently, a distinctive variant known as Polish smog has emerged.

Classical (London) Smog: This type, infamous for lethal environmental pollution, gained notoriety during the December 1952 London smog event, resulting in several thousand fatalities over approximately five days. Also called sulfurous smog, it originates from abnormally high sulfur oxide concentrations, primarily from coal combustion, notably reaching 1340 ppb of sulfur oxides in 1952. High humidity levels cause particulate matter to enlarge, forming fog droplets that dissolve sulfur dioxide and ultimately lead to acid rain. This smog's formation closely resembles the oxidation of sulfur dioxide by nitrogen dioxide in clouds, as confirmed by experimental studies.

*Photochemical (Los Angeles) Smog***:** Prevalent in highly urbanized areas, this smog arises from specific meteorological conditions and urban air's chemical constituents. It contains high concentrations of nitrogen oxides, ozone, carbon monoxide, and aldehydes. Nitrogen dioxide from vehicles and industries, under solar radiation, catalyzes ozone formation, leading to photochemical smog. The involvement of volatile organic compounds in this cycle further exacerbates its formation.

Polish Smog: Notably observed in Poland during 2015-2016, this smog differs chemically from previously identified types. It occurs at high atmospheric pressures and low temperatures, primarily due to household boilers releasing high concentrations of pollutants, leading to reduced life expectancies and premature deaths.

In Pakistan, determining smog's precise composition remains challenging due to multifaceted factors. However, the chemical makeup aligns with other recognized smog types. Various sources contribute to this crisis, including automobile exhaust gases, industrial emissions, improper waste disposal, agricultural practices, construction, restaurants, and cigarette waste. These sources significantly impact air quality and public health. Effective methods exist for early pollutant detection. Smog monitors like the AQS-1 efficiently measure smog severity and constituents, aiding in monitoring efforts. However, Pakistan's current monitoring system remains insufficient, prompting environmental activists to provide accurate data on smog events. Preventive measures tailored to Pakistan's demographics are proposed to combat this issue. The country's monitoring authorities, like the Pakistan Environmental Protection Agency (Pak-EPA), play a vital role, although challenges persist in aligning national air quality standards with international guidelines. Lahore, for instance, records levels of particulate matter significantly surpassing WHO guidelines, signaling a worsening air pollution crisis.

Material and Methods

The qualitative methodology employed in this descriptive investigation concerning smog-related issues in Pakistan is centered on acquiring non-numeric data to comprehend subjective experiences, perceptions, and opinions associated with smog. This research approach entails using qualitative methods like content analysis of textual sources, encompassing reports, articles, and policy documents. The data collection procedure emphasizes sourcing diverse articles, news, and viewpoints to articulate various experiences regarding smog, its impacts, and potential measures for mitigation. Ethical considerations, including consent and confidentiality, strictly upheld throughout the research process. The overarching objective of this qualitative methodology is to furnish a comprehensive and intricate comprehension of the qualitative dimensions of smog challenges, public perceptions, and reactions within the Pakistani context.

*Hazards of smog***:** The hazards posed by smog arise from its complex composition, primarily consisting of particulate matter (especially PM2.5), sulfur dioxide (SOx), nitrogen oxides (NOx), carbon monoxide (CO), volatile organic compounds (VOCs), ozone (O3), peroxylacyl nitrates (PAN), and aldehydes. Each component, when present in high concentrations, adversely affects humans, plants, animals, and the environment. Recent studies have highlighted various health impacts of smog, including asthma, diabetes, headaches, and other issues, primarily among medical students in Lahore (Butt et al., 2018). Smog significantly affects human health, especially the cardiovascular and respiratory systems. Inhalation of its components, such as PM2.5 and O3, resulted in nearly three million deaths globally in 2005 due to respiratory diseases, lung cancer, and cardiovascular issues. PM, a major smog component, is a known cause of premature mortality, with smaller particles posing greater risks by penetrating deeper into the respiratory system, causing extensive lung damage. Studies indicate a link between adult diabetes and air pollution. Moreover, children, more vulnerable to infections, face a higher risk of respiratory infections due to long-term exposure to high levels of PM2.5 in smog.

Exposure to PM2.5 in smog is also linked to intrauterine inflammation leading to preterm birth, resulting in both short-term and long-term adverse effects on health and life expectancy. Ozone, another significant component, poses serious health risks by attacking the cardiovascular and respiratory systems, particularly affecting children and women. Secondary oxidation products formed by ozone reactions can cause cell and tissue damage. Research shows that a 10 mg/m3 increase in ozone levels corresponds to a 0.26% rise in mortality risk. In Lahore, where PM levels surpass WHO limits nine times over, significant health effects from smog pollution are expected. Air quality reports from 2017 revealed that cities like Lahore exceeded international air quality limits, with PM2.5 levels well above recommended standards. Lahore notably experienced "very unhealthy and hazardous" air quality levels multiple times throughout the year.

Studies conducted on ocular surface diseases during smog events in Lahore in 2016 indicated a drastic increase in patients suffering from various ocular-related issues, such as irritation, lid erosion, corneal diseases, dry eyes, uveitis, and lacrimation. Smog components, particularly NOx, showed a significant increase in concentration compared to the previous year, exacerbating health problems. The observed rise in ocular diseases and the substantial increase in smog components underline the severe health impacts of smog pollution, emphasizing the urgent need for comprehensive measures to mitigate its effects on human health and well-being.

*Effect on agricultural sector***:** Aside from its impact on human health, smog exerts devastating effects on both plants and animals. Indirectly, it impedes plant and tree

growth by obstructing sunlight rays and directly harms crops and vegetation. Various crops, including wheat, tomatoes, soybean, cotton, and peanuts, suffer from infections and decreased immunity due to exposure to smog (Gheorghe and Ion, 2011). The adverse effects extend to the ecosystem, resulting in reduced biodiversity, decreased primary and secondary production, and heightened susceptibility to disease. While inert pollutant particles cause physical harm to vegetation, toxic chemical particles induce both physical and chemical damage (F. L. Farmer, 1993). Notably, the infiltration of harmful smog components into the soil is more detrimental than direct deposition onto plant surfaces (Seyyednejad et al., 2011).

The deposition of smog pollutants on plant surfaces, such as PM settling on leaves, interrupts photosynthesis, leading to premature leaf shedding and permanent damage to leaf tissues. Furthermore, smog negatively impacts the microorganisms inhabiting plants and trees, potentially impeding the decomposition process following litter fall (Graiver et al., 2003). Smog significantly affects Pakistan's crop exports, including cotton, wheat, and rice. Recent studies on the influence of smog, particularly PM and ozone, on crops in Pakistan indicate a notable decline in yields (Khan, 2013). Research on winter wheat revealed a substantial decrease in yield (34.8-46.7%) primarily due to ozone exposure (Wahid et al., 1995a). Similar studies on various wheat varieties highlighted reduced stomatal conductance, transpiration rate, and photosynthetic efficiency owing to smog components, especially ozone. Barley and rice crops also experienced significant yield reductions (13-44% and 37-42% respectively) when exposed to smog components like NOx, SOx, and ozone (Wahid, 2006; Wahid et al., 1995b).

Studies conducted on the impact of brick kiln emissions, a significant contributor to smog formation, on wheat production in Faisalabad, Punjab province, Pakistan, revealed losses in grain yield, reduced plant height and photosynthetic activity, and the presence of metals in crops due to exposure to such emissions (2019b). Such substantial decreases in crop yield pose a considerable concern for a developing country heavily reliant on agriculture, especially amid increasing demands driven by population growth. Addressing the negative effects of air pollution becomes crucial to optimize food production in Pakistan.

Effect on the economy: The relationship between air quality and a nation's economic progress is tightly interwoven. A robust economy relies on a healthy populace, active businesses, thriving tourism, and increased employment opportunities. However, air pollution, particularly smog, disrupts these facets and consequently impedes economic growth. The build-up of smog from morning till afternoon significantly hampers productivity during the workday. Recent instances of heavy smog led to prolonged closures of both public and private schools in Lahore in 2023. The significant economic corridor linking China and Pakistan, a massive 62 billion USD investment and one of Asia's largest economic projects, faces considerable challenges due to smog disrupting transportation routes within its vicinity (Kouser and Subhan, 2020; Raja et al., 2018).

Projections suggest that Pakistan's GDP, currently at 47.8 USD billion, could drop by more than 5.88% if smog is not effectively controlled. The severe impact of smog-related health issues (such as 11 million people complaining of eye irritation and headaches) and its toll on Pakistan's agricultural sector may translate into an economic slowdown (Sarfraz, 2020). Premature mortality and long-term illnesses resulting from smog pollution can lead to economic losses, including reduced family income for working individuals. In 2016, a World Bank report highlighted an annual 5 trillion USD economic loss due to air pollution, with developing countries like those in South Asia experiencing labor income losses equivalent to 1% of total GDP (World Bank, 2016).

Total welfare costs stemming from air pollution are categorized into direct market costs, indirect costs, disutility, and mortality. In 2015, global welfare costs due to atmospheric air pollution amounted to 3.8 trillion USD, a figure anticipated to escalate to 24-31 trillion USD by 2060 (OECD, 2016). As this study primarily considers PM2.5, ozone, and other smog components, it indicates that stringent policies for pollution control are urgently required to avert grave future repercussions. This underscores the necessity for immediate and stringent measures to mitigate the detrimental effects of smog to safeguard both public health and economic stability.

Effects on tourism: Smog significantly impacts tourism within a country, causing substantial harm to key attractions like historical buildings and monuments (Peng and Xiao, 2018). Notably, many tourists tend to avoid visiting countries known for high air pollution due to health concerns. The allure of a destination often lies in its landscapes, rivers, mountains, and historical or modern architectural marvels. However, smog disrupts the tourist experience by reducing visibility and diminishing the scenic beauty of these locales. Reduced visibility due to smog increases the risk of road accidents, leading to tragic incidents, such as the November 2017 accident where impaired visibility from smog resulted in 10 fatalities and several injuries (Shabbir et al., 2019). Poudyal et al. (2013) revealed through econometric models that a mere 10% increase in visibility could potentially attract an additional one million visitors to a park.

Pakistan boasts a wealth of historic sites and archaeological destinations, positioning itself with a burgeoning tourism industry and the potential to emerge as a prominent global tourist hotspot (Manzoor and Wei, 2018; World Asia, 2018). However, severe smog-related air pollution in major cities like Lahore and Peshawar has raised significant concerns, not only among the local population but also among international visitors, including members of the Sikh community who frequent their holy shrine in Katarpur (Khan, 2013; Khilji, 2019). Therefore, to sustain and foster the growth of Pakistan's burgeoning tourism industry, it becomes imperative to address and mitigate the sources of air pollution linked to smog.

Results and Discussion

*Smog preventive measures for Pakistan***:** The primary precursors for all types of smog predominantly stem from human-made emissions. Consequently, effective mitigation of these emissions is essential to combat smog. Numerous strategies have been developed on local, regional, and international levels to address this issue (Shi et al., 2016). However, the prevention of smog, aimed at enhancing air quality indices in a given area, seldom relies on a singular intervention. Instead, it typically requires a combination of various abatement measures working synergistically. These interventions encompass regulatory, economic, social, or technical approaches (Shi et al., 2014). While each of the activities outlined below can individually alleviate smog formation and its associated risks, their collective implementation yields the most impactful results. In this section, we present an in-depth discussion of diverse potential preventive measures—technical, fundamental, and administrative—tailored specifically to the case of Pakistan.

Technical Measures

Transportation: Owing to a rapid surge in population and economic growth, Pakistan has witnessed a significant escalation in transportation usage, emerging as a leading contributor to smog incidents. According to Xi et al. (Xie et al., 2019), nearly half of the global emissions of volatile components impacting air quality stem from vehicles. Pakistan faces substantial challenges in its transportation sector, necessitating an upgrade to cleaner vehicle models and the implementation of legislation concerning

vehicle maintenance and monitoring (Shah and Arooj, 2019). The proliferation of private vehicles, notably in Punjab province, which boasts around 19.6 million vehicles, including 6.2 million in Lahore alone (Zahid, 2020), poses a grave threat to air quality. Notably, two-stroke engine vehicles like motorcycles and motorized rickshaws, prevalent in Lahore, rank among the most polluting combustion engine vehicles.

The large number of private vehicles contributes significantly to the emission of gaseous pollutants, acting as major precursors for smog production. To address this, a reduction in private car usage and the promotion of public transport—possibly through the establishment of "low emissions zones" similar to those in London (2020)—are essential steps. Song et al. (2016) suggested that the development of mass transit railway systems, such as high-speed electric trains, could substantially enhance air quality. Additionally, effective policies for monitoring and controlling traffic congestion play a pivotal role in curbing harmful emissions and subsequent smog formation. Strengthening monitoring and emission policies for new automobiles, reducing direct emissions per unit distance, advocating for renewable energy vehicles, and embracing clean technologies are key measures to progressively mitigate the likelihood of smog events (Xie et al., 2019). Routine vehicle maintenance and inspections significantly contribute to emission reduction. The engine's condition holds crucial importance in determining pollutant emissions, emphasizing the need for regular tuning and consistent inspection of components such as the engine case ventilating system, muffler, and fuel system (Sassykova et al., 2019).

Recent advancements in the automobile industry have introduced the concept of hybrid motors to promote the use of environmentally friendly energy sources (Prajapati et al., 2014). Additionally, Benajes et al. (2020) proposed advanced combustion modes employing plug-in hybrid electric vehicle technology to cut down CO2, nitrogen oxides, and soot emissions by 12-30%. However, considerations regarding operational and manufacturing costs, as well as long recharging times, should be weighed since consumers tend to be hesitant to switch to new vehicle options until they are more user-friendly compared to existing technologies (Millo et al., 2014).

Domestic: Domestic carbon emissions, particularly from gas-powered appliances like heaters, stoves, generators, pumps, compressors, and other equipment such as high-pressure washers, floor buffers, and drills, contribute significantly to carbon monoxide (CO) emissions (Hanzlick, 2007). The resolution to this issue involves transitioning to technologies powered by electricity or compressed air, provided these options are accessible and can be used safely (Garcia et al., 2007). Smog in Pakistan has escalated due to rapid industrialization and domestic activities. Ali et al. (2019a) showcased the use of the fuzzy VIKOR model to mitigate the detrimental impact of toxic smog on human health by formulating suitable environmental policies in Pakistan. The results from this model demonstrate that curtailing industrial waste and educating farmers and other communities on emission reduction strategies can effectively diminish their contribution to smog formation, thereby minimizing its adverse effects. The implementation of such a model holds promise for guiding the Pakistani government in shaping future policies. Recently, Saeed and colleagues initiated a project aimed at constructing a 25-foot solar-powered smog-cleaning tower in Pakistan. They claim that this project has the capacity to deliver smog-free, clean air to approximately 90,000 residents in the surrounding area (Hadid, 2020).

Industrial: As a developing economy, Pakistan doesn't consistently adopt preventive measures to reduce emissions responsible for smog and mitigate its adverse effects. The country houses a substantial number of registered vehicles and industries

that lack state-of-the-art technologies to curb emissions leading to smog. For instance, the brick manufacturing process typically involves chimney-based brick kilns fueled by wood, crop residue, and coal (Sarfraz, 2020; Shabbir et al., 2019). Pakistan operates approximately 20,000 brick kilns, many situated near urban centers, posing significant environmental challenges due to emitted pollutants (Khan et al., 2019; Mondal et al., 2017). To avert smog incidents, the brick industry in Pakistan must prioritize emission reduction. Implementing solutions such as smoke treatment with wet or dry filters, employing purifiers, and adopting modern artisanal brick kilns are pivotal steps in addressing this issue. Employing air pollution control equipment, including baffle arrangements within chimneys, and integrating gas bypass systems can assist in pollution mitigation. Upgrading technology with mechanical feeders and cleaner methods like vertical shaft kilns can ensure more efficient coal combustion, thereby reducing emissions (Skinder et al., 2014). The shift from conventional fossil fuels to renewable energy sources, such as solid waste and biomass fuels, is being explored as a feasible option to power future industries in Pakistan, aiming to decrease methane and N2O emissions from landfills (Herbert and Krishnan, 2016).

Anthropogenic activities also significantly contribute to chemical pollution that can spread over vast distances, impacting the global environment (Himawan and Sari, 2018; MIRO et al., 2019). Coal remains the predominant source, accounting for over 90% of industrial emissions worldwide, surpassing other anthropogenic sources like mercury mining, gold smelting, nonferrous smelting, iron steel production, domestic wastes, and cement production (Huang et al., 2017). Industrial emissions, particularly from solid fuel combustion, often constitute major but unacknowledged precursors to smog in Pakistan and other developing nations. Consequently, substituting industrial fuels with alternatives such as oil and gas, and exploring renewable energy sources for energy generation can effectively mitigate smog formation in Pakistan (Liu et al., 2016).

Basic measures to improve air quality

*Expanding green cover***:** Presently, Lahore encounters severe air pollution between November and February, creating a haze that blankets the city and extends to certain districts of Pakistan's Khyber Pakhtunkhwa (KPK) province (Jahan et al., 2019). Scholars emphasize the pivotal role of increasing greenery in mitigating environmental pollution, including smog (Saxena, 2014; Zona et al., 2014). Governments worldwide have launched new policies, including afforestation projects around major industrial cities, forming green barriers between industrial and urban zones. Pakistan's government has initiated the Billion Tree Tsunami Afforestation Project to bolster plantation efforts (Kamal et al., 2019). Greenery and forest growth aid in controlling microclimates, shielding inhabitants from heatwaves, and enriching the atmosphere with oxygen. Research by Leung et al. (2011) indicates that shade can reduce extreme smog concentrations by 5%, equivalent to curbing smog precursor NOx by 175 tons/day (25 times more than the 4 tons/day reduction achieved by cutting power plant emissions). However, caution is warranted; certain plant species emit biogenic volatile organic compounds that might exacerbate air quality by increasing ozone and particulate matter (Florence, 2004; Kegge and Pierik, 2010; Tresaugue). Additionally, plant-based pollen grains and fungal spores can pose health risks, particularly to allergy-prone or sensitive individuals.

Electric Vehicles (EVs) Pakistan has begun gradually adopting electric vehicles (EVs) to counter rising pollution levels, especially in densely populated urban centers like Lahore, Karachi, and Islamabad. The government has incentivized EV usage by offering tax benefits to manufacturers and consumers. Despite this, challenges like the high initial cost, limited charging infrastructure, and consumer apprehension regarding

range limitations have impeded widespread EV adoption. Nevertheless, some companies have introduced electric cars and bikes in the market, signifying a promising albeit nascent step towards a more eco-friendly transportation system in Pakistan. Efforts are underway to expand charging facilities and develop policies encouraging the shift to EVs, aiming to reduce carbon emissions and promote cleaner transport alternatives in the country.

Adopting Healthier Practices: Given that vehicular emissions significantly contribute to smog, adopting simple preventive practices like walking, biking, and using public transport can yield positive outcomes. Transitioning to eco-friendly consumer products with low levels of volatile organic compounds (VOCs) in paints, papers, plastics, and sprays can also help mitigate air pollution. Laumbach et al. (2015) highlighted individual efforts to reduce personal health risks during smog events, suggesting measures such as staying indoors, filtering indoor air, and minimizing physical exertion. The Provincial Disaster Management Authority (PDMA) in Pakistan has issued guidelines advising against outdoor activities during smog events, promoting the use of masks, and advocating for the use and maintenance of indoor air filters (PDMA, 2017).

Administrative Measures

Raising Public Awareness: Educating the public about smog's adverse effects on human health and the environment is crucial and shouldn't be overlooked when addressing these challenges (Ahsan et al., 2020b; Wang et al., 2016a). A recent survey conducted by Saleem et al. (2019) in Punjab, Pakistan, involving 607 participants, underscored the significance of enhancing public awareness through social seminars, conferences, and community campaigns to mitigate smog-related air pollution. Widening public knowledge about smog's hazardous effects through informative sessions and preventive programs (Mehiriz and Gosselin, 2019) is pivotal. Studies, like that by Ahsan et al. (2020a), revealed that sociodemographic factors, particularly education levels, play a vital role in comprehending smog hazards and related policies among Lahore residents. Leveraging online media content and mobile apps to alert the public about air pollution's severity can empower individuals to safeguard their health by staying indoors and reducing physical exertion (Li & Tilt, 2019).

Social and Behavioral Changes: Incorporating trust in disseminated information is crucial. China's 2013-2014 initiative, providing real-time air quality assessments, resulted in notable household behavior shifts, increased online searches on pollution, altered consumption habits reducing pollution exposure, and a greater willingness to pay for housing in less polluted areas (Barwick et al., 2019). As a consequence, short- and long-term behavioral changes led to a nearly 7% reduction in mortality due to air pollution. The estimated annual benefits of approximately 18 billion USD from the program far exceeded its associated costs (Ito and Zhang, 2020). Improved public awareness and encouragement of social and behavioral changes are recommended to address smog episodes and their effects in Pakistan. Proposed Policy Instruments for Regulatory Bodies: Short- and long-term policy instruments aligning with the discussed preventive measures are suggested to assist regulatory bodies in Pakistan in mitigating smog-related problems.

Conclusion

Several major cities globally, including Beijing, Delhi, Lahore, Mexico City, Los Angeles, and Tehran, grapple with smog-related challenges. Pakistan's dependency on fossil fuels for rapid urbanization and industrialization significantly contributes to smog

occurrences. Vehicular emissions and burning of crop and solid waste are among Pakistan's primary smog sources. Smog poses detrimental effects not only on human health but also on animals, tourism, and the economy. Lahore, Pakistan's second-largest city, faces severe winter smog episodes.

Theoretical and Practical Implications:

The integration of digital solutions and technological innovations in fostering public awareness and community initiatives against smog in Lahore holds substantial theoretical and practical implications. Theoretically, these advancements align with behavioral change models such as the Diffusion of Innovation Theory, elucidating how technology adoption influences attitudes and behaviors toward embracing cleaner practices. Additionally, community engagement frameworks like the Social-Ecological Model could shed light on the impact of these digital interventions in fostering community participation and collaboration in combating smog-related issues. On a practical level, the application of digital tools—IoT sensors, mobile apps, and data visualization platforms—facilitates real-time air quality monitoring and information dissemination, empowering citizens with actionable insights. Furthermore, these innovations aid evidence-based policymaking, assisting policymakers in formulating effective strategies, zoning regulations, and emission standards for smog reduction. Collaborative efforts among stakeholders, infrastructure development, and innovative technological solutions show promise in creating sustainable pathways toward cleaner air in Lahore.

Future Directions:

Leveraging digital solutions and technological innovations to combat smog in Lahore will require a multifaceted approach in the foreseeable future. Advancements in technologies like Artificial Intelligence, Big Data Analytics, and Machine Learning will refine air quality monitoring, enhancing predictive capabilities and data accessibility. Establishing a comprehensive network of monitoring stations and electric vehicle charging points across the city will be pivotal in expanding smart infrastructure. Innovative public engagement strategies, such as gamification and augmented reality applications, must be emphasized to disseminate accessible and engaging smog-related information across diverse communities. Simultaneously, robust policy frameworks developed through collaborative efforts among governmental bodies, tech industries, and research institutions will guide sustainable interventions. Prioritizing educational programs, research initiatives, and global partnerships will foster knowledge exchange, nurturing a culture of innovation and informed decision-making for a cleaner and healthier Lahore environment.

Recommendations

Based on the extensive exploration of smog-related challenges in Pakistan, several key recommendations emerge to combat and alleviate the detrimental impacts of this environmental issue. First and foremost, robust policy enforcement and the introduction of stringent regulations are imperative, particularly focusing on reducing vehicular emissions in urban centers like Lahore through the promotion of public transportation and incentivizing eco-friendly vehicles. Concurrently, targeting industrial emissions, especially from sectors like brick kilns, demands the implementation of green industrial policies and cleaner technologies to curb pollutant output. Encouraging the adoption of renewable energy sources within industrial and domestic sectors could significantly diminish smog-causing emissions. Public awareness campaigns and educational

programs must be intensified to inform and engage citizens about smog hazards and encourage behavioral changes.

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