Site Suitability Analysis of Smog Cutting Towers in District Lahore, Pakistan

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Introduction/Importance of Study:
Lahore, one of Pakistan's most populous cities, is home to a diverse demographic comprising residents from various ethnic, linguistic, and cultural backgrounds. Recently, the city has been grappling with severe smog-related challenges, primarily due to vehicular emissions, industrial activities, and the burning of crop residues in neighboring agricultural regions. These factors have exacerbated numerous environmental and health issues, making the situation increasingly dire.
Novelty Statement:
Lahore's 24 major hospitals, while indicative of a robust healthcare infrastructure, also underscore the vulnerability of a significant number of patients to the adverse effects of smog. The Normalized Difference Moisture Index (NDMI) reveals limited water availability in Lahore, which hinders natural cleansing mechanisms like rainfall that typically help remove pollutants from the atmosphere.
Material and Methods:
This research relies on secondary data sources, including Sentinel 2 imagery, to analyze urban expansion and moisture levels in the city. Traffic control data has been used to pinpoint areas with high traffic congestion, while elevated air pollution levels have been overlaid with hospital locations, marked using Google Earth data. This comprehensive approach aims to mitigate smog's impact in Lahore by identifying areas most in need of smog-cutting towers.
Results and Discussion:
The research methodology focused on key parameters such as urban expansion, traffic choke points, vulnerable populations in hospitals, and the overall moisture index, which highlights the city's capacity to retain moisture. The analysis identified major congestion areas, including Garhi Shahu, McLeod Road, Mughalpura, and Shahdara, as significant sources of pollution. The NDMI further confirmed limited water availability, exacerbating smog retention. To address these challenges, the strategic placement of four smog-cutting towers within a 5 km range in Lower Mall Road, Thokar Niaz Baig, Mughalpura, and Model Town has been recommended. These locations, characterized by high traffic congestion, elevated air pollution levels, and significant urban development, present a targeted approach to reducing smog in Lahore.
Concluding Remarks:
The identified locations in Lahore—Lower Mall Road, Thokar Niaz Baig, Mughalpura, and Model Town—are crucial for the effective mitigation of smog. The strategic placement of at least four smog-cutting towers within these areas will significantly influence the rate of smog production, retention, and impact, given the high traffic congestion, elevated pollution levels, and substantial urban development in these regions.
Keywords: Smog; Lahore; Smog-Cutting Towers; Health: Sustainability; Normalized Difference Moisture Index; Site Suitability.

Introduction:

Smog is a type of air pollution characterized by the presence of elevated concentrations of pollutants such as ground-level ozone, particulate matter, nitrogen oxides, and volatile organic compounds [1]. It typically forms through complex photochemical reactions involving pollutants released from human activities, particularly the burning of fossil fuels and industrial processes. Smog has detrimental effects on human health, the environment, and visibility and is predominantly associated with urban and industrial areas [2][3]. It is essentially a combination of smoke and fog, manifesting as a visible haze or fog combined with air pollutants, commonly occurring in urban areas with high levels of vehicular emissions and industrial activities. This atmospheric phenomenon reduces visibility and can give the air a brownish or grayish tint. Smog formation is heavily influenced by meteorological conditions such as temperature inversions, which trap pollutants near the ground, and sunlight, which triggers photochemical reactions leading to the formation of ground-level ozone [4].

The primary cause of smog is the interaction of pollutants from human activities with atmospheric conditions. Combustion of fossil fuels, including vehicle emissions and industrial processes, releases nitrogen oxides (NOx) and volatile organic compounds (VOCs). These pollutants, under the influence of solar radiation, undergo photochemical reactions, resulting in increased levels of ozone gas and retention of particulate matter [5]. Meteorological factors like temperature inversions exacerbate smog formation by trapping pollutants close to the ground. The resulting smog poses significant health hazards by diminishing visibility and harming the environment [6].

Smog has severe impacts on human health, leading to respiratory problems, cardiovascular issues, and the aggravation of pre-existing conditions [7]. Prolonged exposure can result in chronic respiratory diseases and increased mortality. It also impairs visibility, posing risks for transportation safety. Ecosystems are adversely affected as smog damages plants, soil, and water [8]. The combination of ground-level ozone and particulate matter harms vegetation, reducing crop yields and forest vitality. Economic costs arise from healthcare expenses and diminished agricultural productivity [9]. Addressing smog requires stringent air quality regulations, emission controls, and sustainable urban planning to mitigate its adverse effects on public health, the environment, and the economy [10].

Novelty of Study:

This study analyzes suitable sites for the installation of smog-cutting towers, aiming to combat the escalating air quality crisis in Lahore. As urban areas continue to expand, the research can inform urban planners on integrating smog-cutting infrastructure into city layouts, fostering sustainable development. It will contribute to resource efficiency by guiding policymakers in allocating interventions where they are most needed. The research also focuses on vulnerable populations, their proximity to major pollution sources, and residential areas in the vicinity. The moisture index for the winter months is utilized to delineate areas with a higher risk of smog formation. The study is significant as it aims to identify critical areas for the placement of smog-cutting towers to mitigate the impact of smog effectively.

Research Objectives:

Identifying the optimum locations for the installation of smog-cutting towers in Lahore.

Study Area:

Lahore, the capital of Punjab Province in Pakistan, had a population of 6.3 million in 1998 and grew to 11.2 million by the 2017 census, representing a 3% annual growth rate. The district is located on the left bank of the Ravi River, within the geographic coordinates of 31°13'-31°43' N latitude and 74°0'-74°39.5' E longitude (Figure 1). Lahore is Punjab's most populous city, with over 98% of its residents living in urban areas. The city is often referred to as the "heart of Pakistan," known for its vibrant cultural scene, economic significance, and academic institutions. It is a major tourist destination, attracting both international and domestic visitors with its rich history spanning over a thousand years (Punjab Bureau of Statistics, 2016).

Lahore is administratively divided into nine towns, managed by Town Municipal Administrations (TMA), along with the Lahore Cantonment, which is under military control (Punjab Bureau of Statistics, 2016). The winter season in Lahore lasts from November to March, with the coldest months being December and January. The summer season extends from April to September, with May and June being the hottest months, reaching temperatures as high as 48°C, with average daytime temperatures between 40°C and 45°C. During the monsoon season, the city receives approximately 600 mm of rainfall annually, with July and August being the wettest months, while the rest of the year remains predominantly dry. The city has an extensive road network, including major highways and ring roads, ensuring smooth transportation within the city and to other parts of the country [11].

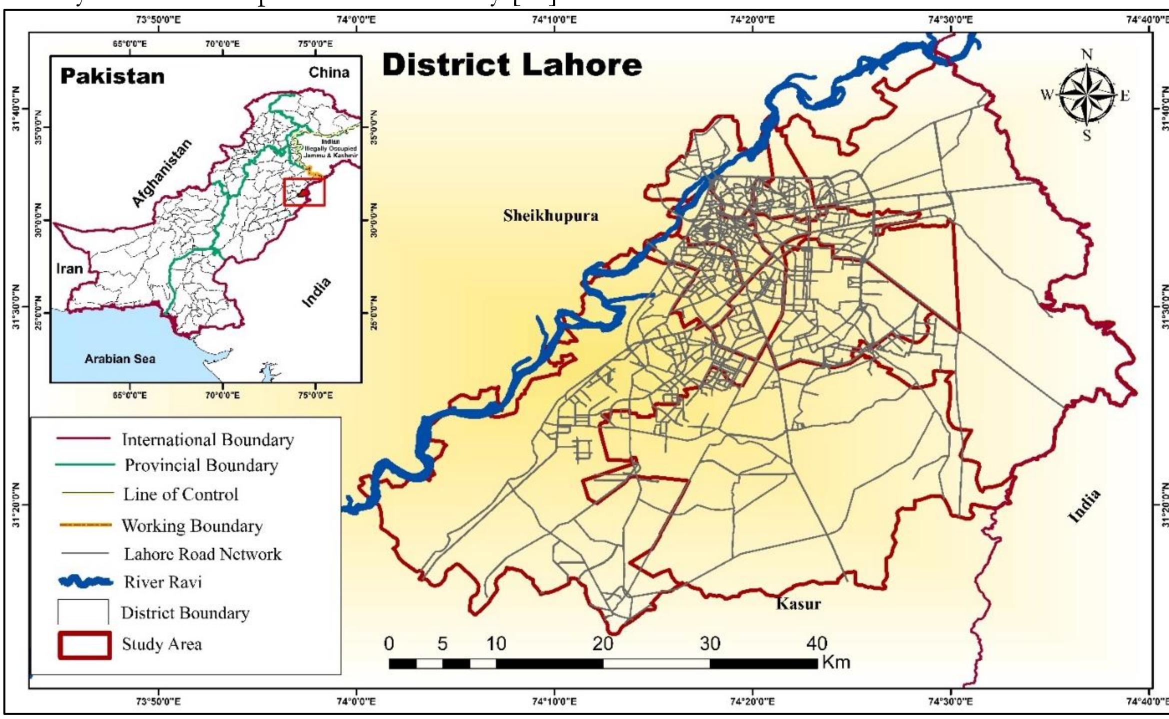

Figure 1: Location of Study Area

Literature Review:

Smog is a type of air pollution characterized by a mixture of smoke and fog, or other atmospheric pollutants, which often results in a hazy or brownish appearance in the air. It is primarily caused by the interaction of pollutants released from various sources, such as vehicle emissions, industrial processes, and the combustion of fossil fuels. Smog is a complex mixture of components, including ground-level ozone, particulate matter, nitrogen oxides, and volatile organic compounds [12]. This noxious combination poses significant health risks, particularly to the respiratory and cardiovascular systems. Smog also has adverse effects on visibility, climate, and ecosystems. Efforts to mitigate smog involve implementing air quality regulations, reducing emissions, and adopting sustainable urban planning practices [13].

Smog is primarily caused by vehicular emissions, industrial activities, and fossil fuel combustion, releasing pollutants like nitrogen oxides and volatile organic compounds. In sunlight, these pollutants undergo photochemical reactions, forming ground-level ozone and fine particulate matter. The resulting smog poses severe health risks, leading to respiratory and cardiovascular issues [14]. It also impairs visibility, causing transportation hazards, and adversely impacts ecosystems. Efforts to curb smog involve stringent emission controls, sustainable urban planning, and transitioning to cleaner energy sources to mitigate its detrimental effects on public health and the environment [15].

Lahore, a major city in Pakistan, frequently experiences high levels of smog, particularly during the winter months. The primary contributors to smog in Lahore include vehicular emissions, industrial activities, and the burning of crop residues in neighboring agricultural regions. The city's topography and meteorological conditions, such as temperature inversions, exacerbate the problem by trapping pollutants close to the ground [16]. Smog in Lahore poses significant health risks, leading to respiratory problems and other health issues. It also impairs visibility, disrupts transportation, and has adverse effects on the environment. Efforts to address smog in Lahore involve implementing air quality measures, regulating emissions, and promoting sustainable practices to improve overall air quality [17].

Multifaceted approach is employed for the assessment of smog levels including ground-based air quality monitoring stations equipped with sensors that provide real-time data on key pollutants such as ozone, particulate matter, and nitrogen dioxide. Satellite remote sensing contributes to large-scale spatial analysis, offering observations on aerosol concentrations and trace gas levels. Mobile monitoring units that are equipped with air quality sensors also facilitate on-the-move assessments. This is a useful way of assessing the variations in pollution levels across various locations [18]. The Air Quality Index (AQI) consolidates data into a standardized value, simplifying communication of air quality to the public. Chemical transport models simulate pollutant transport and transformation, predicting concentrations and identifying sources. Emission inventories compile data on pollutant emissions from various sources [19]. Lidar and remote sensing instruments, such as Differential Optical Absorption Spectroscopy (DOAS), provide detailed information on the vertical distribution of pollutants and specific gases contributing to smog. This comprehensive suite of methodologies facilitates a thorough understanding of smog dynamics, aiding in the development of effective air quality management strategies [20].

Research Methodology:

The research relies primarily on primary data sources. Sentinel-2 Level-2A (L2A) satellite image with its high-resolution multispectral capabilities that was acquired for the month of January, 2024 facilitated the precise land cover classification, enabling the identification and mapping of land use and land cover. This also shows the extent of expansion of urban built-up land contributing to high population density. This was done through the supervised image classification [21]. There are three main classes made as per the requirement of the research, namely water, built-up and vegetation. Moreover, upon analyzing the updated satellite imagery acquired through Sentinel-hub, the results of the supervised classification performed in ArcGIS are further compared to prove that there has been a lot of urban expansion and urban congestion over the time in Lahore.

Google Earth and ArcGIS has been used for comprehensive spatial analysis focusing on major hospitals and traffic congestion areas. The methodology involves utilizing Google Earth to identify and mark major hospitals, capturing their geographic coordinates as point data. Simultaneously, traffic congestion areas are mapped for urban planning insights. The collected data is exported as KML files and opened in ArcGIS, where the KML files are converted into layers. This integration enables in-depth analyses, including overlaying hospital locations with traffic congestion data.

Moisture index quantify moisture levels as Normalized Difference Moisture Index (NDMI) which provide details of hydration status of vegetation which was obtained from Sentinel-hub for the month of December, 2023. The NDMI values proved to be an important parameter as the smog and moisture levels are interconnected. NDMI measures the vegetation and soil moisture, as moisture-rich vegetation can absorb pollutants like nitrogen oxides and volatile organic compounds, reducing smog formation and the adequate soil moisture suppresses dust, preventing it from becoming airborne and contributing to smog. The increased moisture level shows the greater chances of the particulate matter being airborne [22].

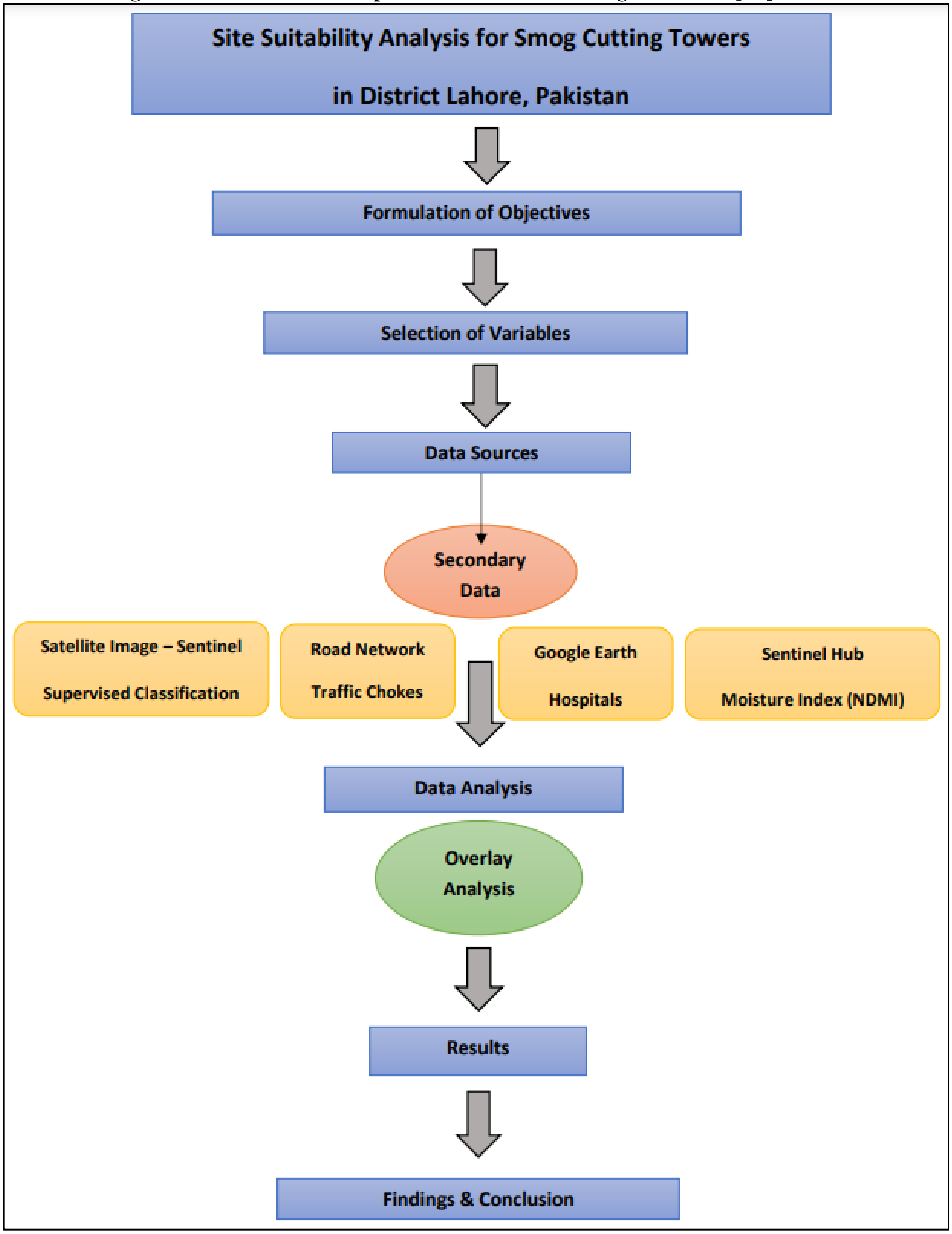

Figure 2: Flow Chart of Methodology.

Discussion:

Transport Congestion:

Lahore, like many rapidly growing cities, faces the twin challenges of severe traffic congestion and alarming air pollution levels, particularly smog. The analysis focuses on areas with high pollutant concentrations while strategically considering locations with intense traffic congestion [23]. By identifying these sites where high pollution intersects with heavy traffic, the installation of smog-cutting towers can be optimized for maximum impact, offering a sustainable solution to Lahore's complex smog and urban challenges. The primary resources were used to identify the major areas with daily congestion. These areas include Garhi Shahu, Mcleod Road, Mughalpura, Larri Adda, Shahdara, Wahdat Road, Ichhra, Mozang, Niaz Baig, Gulberg Main Market, Model Town, Township, Green Town, Kot Lakhpat, Kahna, Raiwind, Nawan, Kotwali, Cantt., and Upper and Lower Mall.

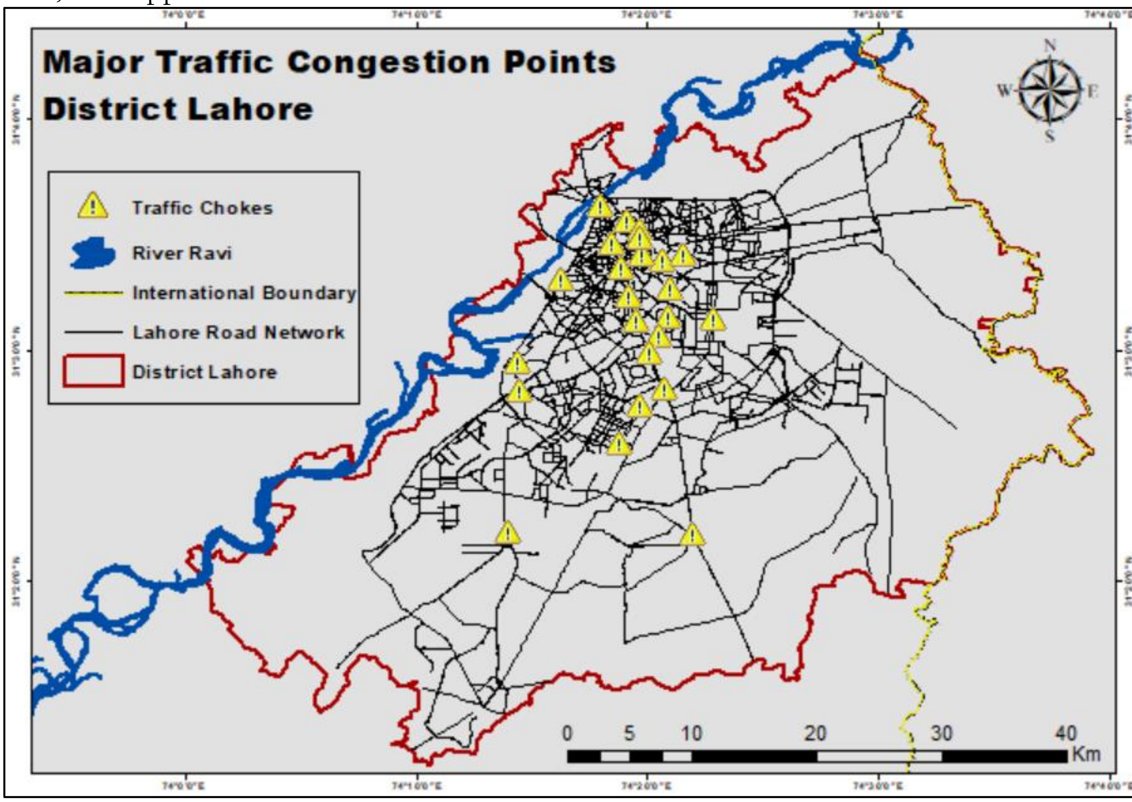

Figure 3: Major choke points of traffic congestion

Hospital and Health Care Facilities:

The presence of 24 major hospitals in Lahore reflects a robust healthcare infrastructure, but it also highlights the potential vulnerability of a large number of patients to the harmful effects of smog. Notable hospitals include Doctors Hospital, Fatima Memorial Hospital, Shalamar Hospital, Shaukat Khanum Hospital, Ghurki Hospital, Combined Military Hospital, Shaikh Zayed Hospital, The Children's Hospital & Institute of Child Health, Lahore General Hospital, Mayo Hospital, Pakistan Kidney and Liver Institute, Services Hospital, Sir Ganga Ram Hospital, and WAPDA Hospital.

Elevated levels of air pollution, especially during smog events, pose significant health risks, particularly for individuals with pre-existing respiratory and cardiovascular conditions. Smog can exacerbate respiratory issues and trigger cardiovascular problems, especially in patients with chronic illnesses, the elderly, and children. For those with respiratory conditions like asthma or chronic obstructive pulmonary disease (COPD), exposure to smog can worsen symptoms, leading to increased hospitalizations and the need for medical interventions.

Urbanized Area:

The interplay between extensive built-up land, high population density, numerous hospitals, and persistent traffic congestion presents a complex scenario of smog-related challenges in urban areas. As urbanization progresses, the expansion of built-up areas leads to increased population density, necessitating the establishment of more healthcare facilities to serve the concentrated population [24]. The combination of industrial activities, vehicular emissions, and healthcare infrastructure in these densely populated regions creates a significant source of pollutants, contributing to the formation and worsening of smog. Residents with respiratory and cardiovascular conditions who live near both healthcare facilities and traffic-congested zones are at heightened risk during periods of elevated air pollution.

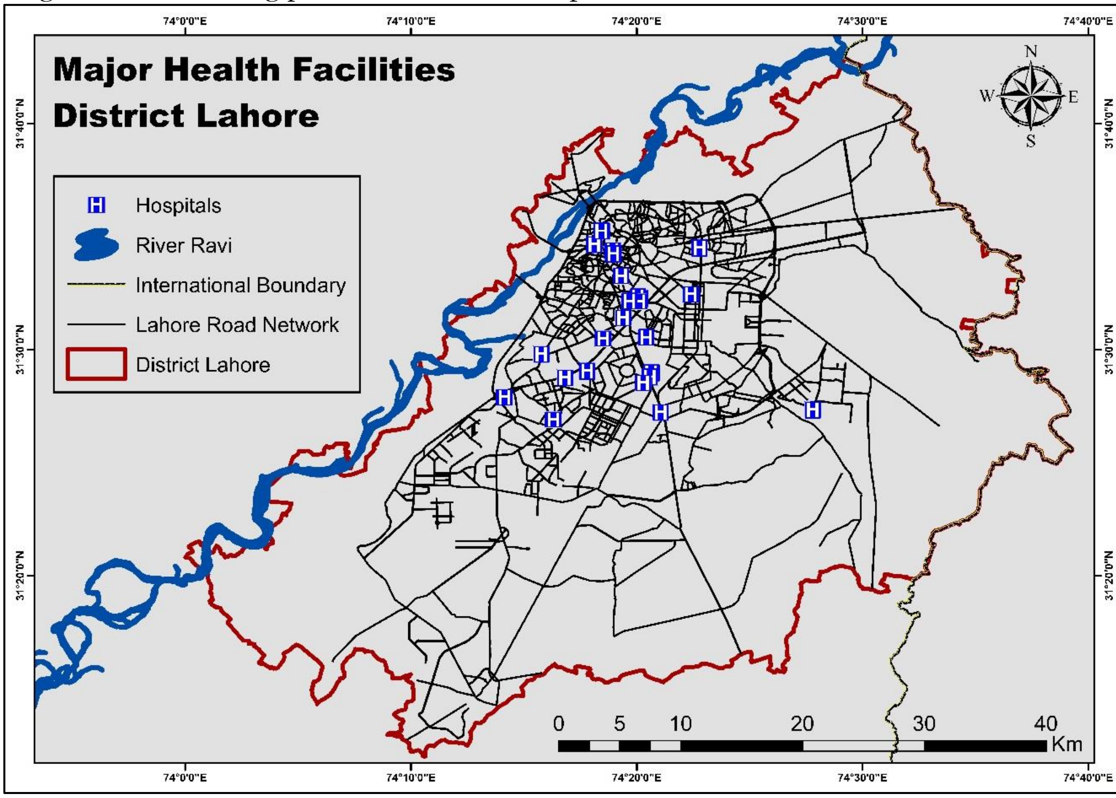

Figure 4: Major hospitals in Lahore

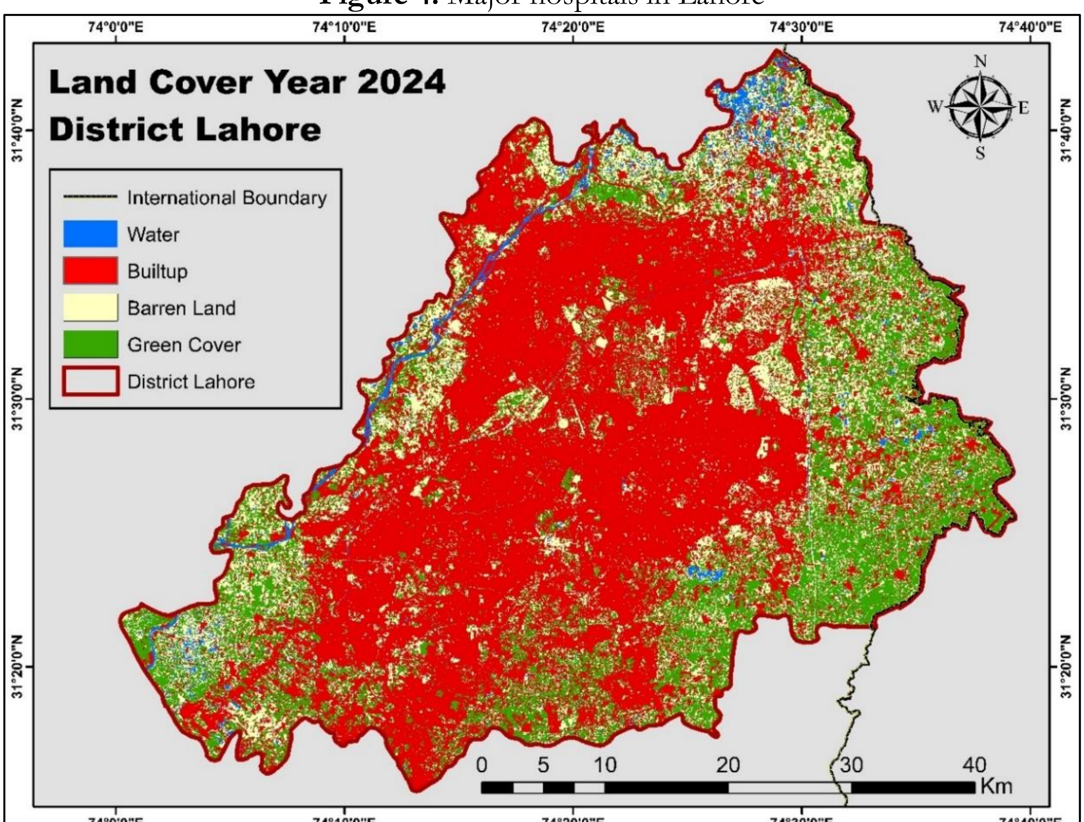

Figure 5: Image Classification of Lahore

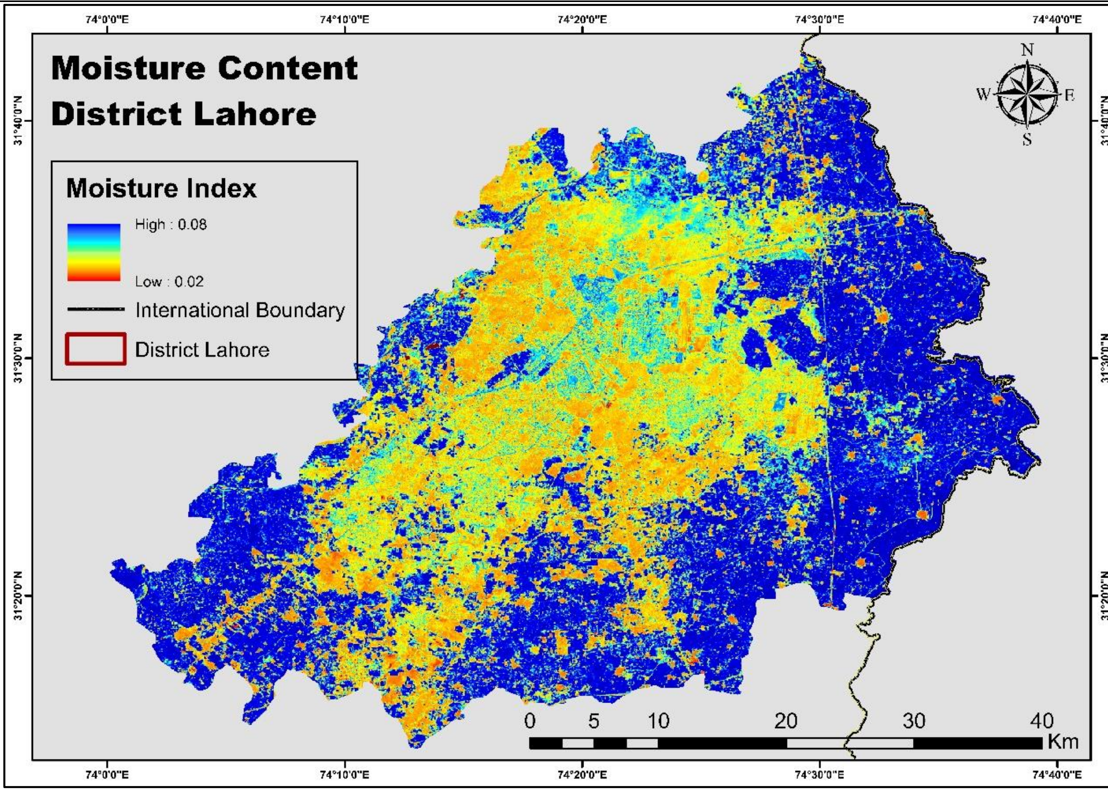

Figure 6: Moisture Index of Lahore

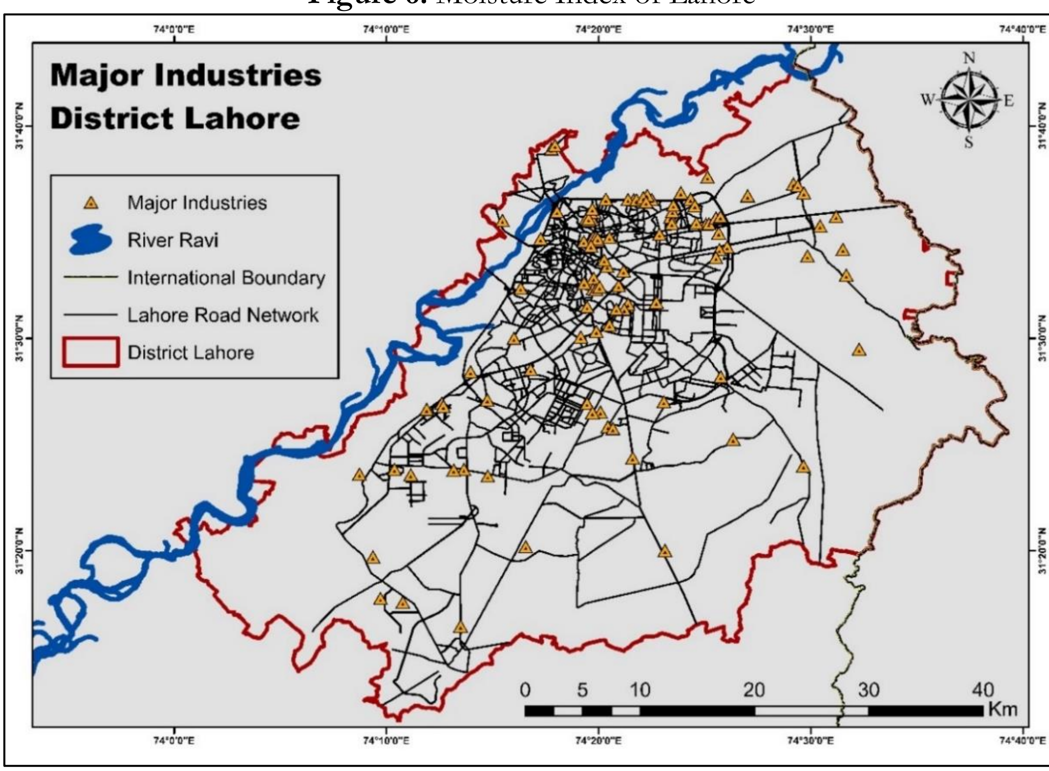

Figure 7: Major Industries in Lahore

Moisture Content:

The moisture index, particularly represented by the Normalized Difference Moisture Index (NDMI), ranges from 0 to -0.032 for Lahore. NDMI values within this range indicate a deficit in atmospheric moisture, reflecting arid to semi-arid climatic conditions. The negative values suggest reduced moisture content in vegetation, contributing to the region's susceptibility to smog events. Lower NDMI values signify limited water availability, which hampers natural atmospheric cleansing mechanisms, such as rainfall, that typically help remove particulate matter and pollutants. The inverse relationship between moisture levels and smog is significant; in drier conditions, indicated by lower NDMI values, pollutants from vehicular emissions, industrial activities, and biomass burning persist in the air, creating conditions conducive to smog formation [25]. Thus, NDMI values serve as a quantifiable measure of moisture content, crucial for understanding the atmospheric conditions that contribute to smog in Lahore.

Major Industries:

Analyzing the distribution of major industries in District Lahore is essential for identifying optimal sites for smog-cutting towers. Industries are significant contributors to air pollution, particularly in urban areas. Mapping their locations allows for the identification of pollution hotspots where smog tends to accumulate. Strategically placing smog-cutting towers near these industrial zones can maximize their effectiveness in reducing air pollution. Proximity to the road network also facilitates easy maintenance and monitoring of the towers, ensuring efficient operation. This analysis, therefore, informs strategic placement, optimizing the towers' impact on improving air quality in Lahore.

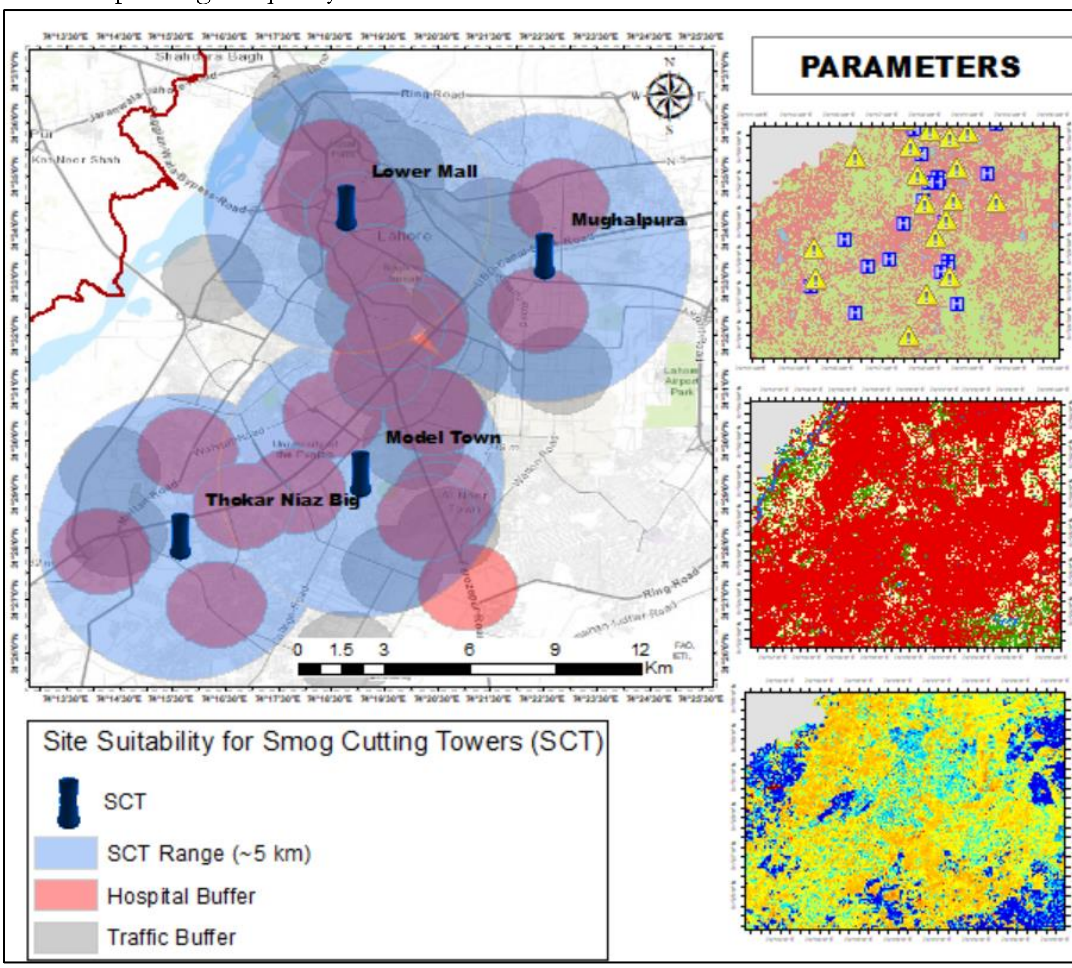

Figure 8: Sites for Smog Cutting Towers in Lahore

Site Suitability for Smog Cutting Towers:

The strategic placement of four smog-cutting towers with a 5 km range in Lahore was determined by analyzing key parameters, including hospital proximity, traffic congestion, moisture index, and urban expansion. Lower Mall Road, Thokar Niaz Baig, Mughalpura, and

Model Town emerged as optimal locations due to their high traffic congestion, elevated air pollution levels, and significant urban development.

Discussion:

Lahore, one of Pakistan's most populous cities, is home to a diverse population with various ethnic, linguistic, and cultural backgrounds. In recent years, the city has faced severe smog-related challenges, primarily due to vehicular emissions, industrial activities, and the burning of crop residues in surrounding agricultural areas, which have escalated environmental and health issues. The city's 24 major hospitals, while a testament to its robust healthcare infrastructure, also highlight the vulnerability of many patients to the adverse effects of smog. This vulnerability underscores the necessity of research that utilizes secondary data, including Sentinel-2 imagery, to analyze urban expansion and moisture levels [26]. Traffic control data identifies areas with high traffic congestion, and elevated air pollution levels are overlaid with hospital locations mapped via Google Earth [27]. The integration of NDMI data with urban and traffic analysis provides a crucial foundation for effective urban planning and pollution control strategies in Lahore, particularly in areas at high risk of smog [28].

The analysis also reveals an increase in the moisture retention index, which helps identify areas with daily traffic congestion, such as Garhi Shahu, McLeod Road, Mughalpura, and Shahdara, where vehicular pollution is prevalent. The Normalized Difference Moisture Index (NDMI) indicates limited water availability in Lahore, which hampers natural cleansing mechanisms like rainfall that typically remove pollutants. In response to these challenges, four smog-cutting towers have been strategically placed within a 5 km range at Lower Mall Road, Thokar Niaz Baig, Mughalpura, and Model Town [29]. These locations, characterized by high traffic congestion, elevated air pollution levels, and significant urban development, provide a comprehensive approach to mitigating the impact of smog in Lahore.

Research on Site Suitability Analysis for Smog Cutting Towers in Lahore is vital for targeted pollution mitigation, as it identifies optimal locations for these towers, directly benefiting public health [30][31]. The data-driven approach, utilizing satellite imagery, traffic congestion, and hospital locations, enables informed decision-making that can enhance urban planning by integrating environmental and urban considerations, paving the way for sustainable city development. Agencies like the National Disaster Management Authority (NDMA) and Environmental Protection Agency (EPA) can consider this research for future projects and infrastructural zoning. Additionally, it emphasizes the need for healthcare impact assessments by zoning areas where vulnerable populations, such as hospital patients, are most affected, aiding in prioritized interventions.

The Site Suitability Analysis of Smog Cutting Towers in District Lahore, Pakistan, plays a critical role in enhancing urban resilience by addressing the severe air pollution challenges that threaten public health and the overall quality of life in the city. As smog becomes increasingly prevalent, particularly during winter, identifying optimal locations for these towers can significantly reduce air pollution levels in densely populated and vulnerable areas. This analysis contributes to urban resilience by ensuring that resources are strategically deployed to maximize their impact, protecting residents from the harmful effects of smog, and strengthening the city's ability to withstand and adapt to environmental stressors. By integrating this analysis into broader urban resilience strategies, Lahore can create a healthier, more sustainable urban environment, enhancing its capacity to recover from and adapt to ongoing air pollution challenges [32].

The impact of this research can be further enhanced through advanced data integration, utilizing real-time data from air quality monitoring stations, weather forecasts, and traffic data to develop predictive models that better identify optimal locations for smog-cutting towers. This ensures that the towers are strategically placed where they can most effectively mitigate pollution. Additionally, involving local communities in data collection and awareness campaigns about smog issues ensures that the outcomes reflect local perspectives and needs. A multidisciplinary approach, involving experts from environmental science, urban planning, public health, and engineering, is essential. Collaboration across disciplines allows for comprehensive solutions that consider environmental, social, and economic factors, facilitating evidence-based policy decisions and sustainable urban development strategies in Lahore.

Conclusion:

Lahore, one of Pakistan's most populous cities, is characterized by a diverse and dynamic population from various ethnic, linguistic, and cultural backgrounds. The primary contributors to smog in Lahore include vehicular emissions, industrial activities, and the burning of crop residues in neighboring agricultural regions. The city's topography and meteorological conditions, such as temperature inversions, exacerbate the problem by trapping pollutants close to the ground. Major areas with daily congestion, identified using primary resources, include Garhi Shahu, McLeod Road, Mughalpura, Larri Adda, Shahdara, Wahdat Road, Ichhra, Mozang, Niaz Baig, Gulberg Main Market, Model Town, Township, Green Town, Kot Lakhpat, Kahna, Raiwind, Nawan Kot, Kotwali, Cantt., and Upper and Lower Mall. The presence of 24 major hospitals in Lahore signifies a significant healthcare infrastructure, but it also underscores the potential vulnerability of a substantial number of patients to the adverse effects of smog. Prominent hospitals include Doctors Hospital, Fatima Memorial Hospital, Shalamar Hospital, Shaukat Khanum Hospital, Ghurki Hospital, Combined Military Hospital, Shaikh Zayed Hospital, The Children's Hospital & Institute of Child Health, Lahore General Hospital, Mayo Hospital, Pakistan Kidney and Liver Institute, Services Hospital, Sir Ganga Ram Hospital, and WAPDA Hospital.

As urbanization intensifies, the proliferation of built-up areas becomes a hallmark of heightened population density, attracting the establishment of numerous healthcare facilities to cater to the concentrated populace. The moisture index, particularly represented by the Normalized Difference Moisture Index (NDMI), ranges between 0 to -0.032 for Lahore. Lower NDMI values signify limited water availability, affecting natural cleansing mechanisms in the atmosphere, such as rainfall, which helps remove particulate matter and pollutants. The optimal placement of four smog-cutting towers with a 5 km range in Lahore has been determined to be in Lower Mall Road, Thokar Niaz Baig, Mughalpura, and Model Town, as these areas exhibit a combination of high traffic congestion, elevated levels of air pollution, and significant urban development.

Recommendations:

There is a greater need to combat the air pollution and de-escalate the rate of smog in Lahore considering its adverse environmental and health effects in the recent years. Considering the fact that the climate reparations and national fundings are still underway. There are a few ways which can prove fruitful in eradicating smog at individual and organizational levels. Firstly, there is a need to regulate industrial activities in order to control the release of pollutants into the air along with the improvements in the air quality monitoring. The public transport should be subsidized and its use must be promoted to reduce the emissions from vehicles. There is so much need of public awareness and health advisories. In financial profanity, the strategical deployment of smog-cutting towers will totally prove to be a game-changer in combating smog and mitigating its effects in the Lahore's territorial jurisdiction. Agriculturally, there is a need to curb the agricultural practices causing smog along with the improvement in urban planning for better air quality.

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