Exploring the Impact of Land Cover Changes on Genesis of Smog in District Lahore, Pakistan

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Introduction: Smog is a major global issue, severely impacting Pakistan, particularly Lahore. This problem arises from a mix of natural factors and human activities, notably rapid urbanization, which has intensified fog into smog, affecting human health. In Lahore, urbanization has altered land use patterns, contributing to the urban heat island effect and elevated temperatures. Changes in land cover (LC), combined with pollution sources like industrial emissions and vehicle exhaust, play a significant role in smog formation.

Novelty Statement: This study highlights the long-term impact of LC changes on smog from 2002 to 2022. Water indirectly influences smog through meteorological conditions, while particulate matter (PM) from various sources poses health risks. The primary objective is to investigate how changes in land cover contribute to smog formation.

Material and Methods: ArcGIS was used to process data on land cover images, temperature, and air pollutants (NO_2, SO_2, and CO) within a controlled Geographic Information System (GIS) environment.

Results and Discussion: Land cover images of Lahore from different years were obtained using Google Earth Pro. ArcGIS was employed to analyze temperature data, and the inverse distance weighted (IDW) interpolation technique was used to visualize temperature variations and air pollutant concentrations over time. LC data for 2002, 2012, and 2022 were integrated into ArcGIS to demonstrate how land cover changes contribute to smog formation in Lahore.

Conclusion: The research highlights the need for effective management of urbanization and environmental challenges to address smog-related issues.

Keywords: Impact; Land Cover (LC); Smog; IDW; Lahore.

Introduction:

Globally, smog is a severe issue affecting many countries, with Pakistan being notably impacted. While fog is a natural phenomenon during winter in many regions, rapid urbanization and increased technology use have worsened air pollution, transforming fog into smog, a mix of smoke and fog [1]. Urban areas experience significant air pollution due to human activities. Major pollution sources include both natural and anthropogenic factors [2][3]. Lahore, a major urban center, is heavily affected by smog, particularly in winter, which has serious health repercussions. Human activities, more than natural forces, continuously alter the exchange of energy between the Earth's surface and the atmosphere through land cover (LC) changes, directly affecting Land Surface Temperature (LST) [4]. Population growth and urbanization drive these LC changes. Between 1950 and 2024, the global urban population increased from 751 million to approximately 4.4 billion, a nearly six-fold rise (UNPF). The proportion of urban residents grew from about 30% in 1950 to over 55% in 2024 (OWD). Urbanization involves replacing soil and vegetation with impervious surfaces, engaging in agricultural activities, and substituting low-density buildings with high-rise structures [5]. Consequently, urbanization replaces natural land cover with concrete, altering the city's biophysical climate and affecting LST. Rapid urbanization in Lahore over recent decades has led to substantial changes in land cover. The expansion of urban areas, increased industrialization, and growing vehicular traffic have transformed the landscape, replacing natural land covers with impervious surfaces like concrete and asphalt. This land cover change contributes to the urban heat island (UHI) effect, where surfaces absorb and re-radiate heat, raising local temperatures [6]. The UHI effect, driven by LC changes, significantly contributes to temperature increases in urban areas. As cities expand and become more densely populated, natural vegetation is replaced by impervious surfaces, reducing heat dissipation and causing urban areas to trap and retain heat. Numerous studies have documented the UHI effect's impact on temperature rise in urban environments [5][7]. The combination of altered land surfaces, increased energy consumption, and human activities in urban settings contributes to a warming trend, highlighting the intricate relationship between urbanization and rising temperatures. Changes in surface energy may result from converting land cover types, such as from green space to impermeable surfaces or from bare land to developed areas. These rapid shifts significantly alter the local climate, particularly affecting local air temperature and LST [8]. Climate change, land cover change, and human activity all contribute to atmospheric smog. Major sources of particulate matter contributing to smog include industrial coal burning, automobile emissions, crop burning, construction, fireworks, and brick kiln smoke [9]. According to [10], smog forms when air pollutants, fine particles, and static weather conditions combine to create PM2.5 (particulate matter with a diameter of less than 2.5 micrometers) and other contaminants. The most common air pollutants affecting air quality are lead (Pb), sulfur dioxide (SO2), particulate matter (PM), carbon monoxide (CO), and nitrogen oxides (NOx).

Lahore is severely affected by smog, with high particulate matter pollution due to suspended dust, vehicular emissions, industrial activities, and stubble burning [9]. The city's vegetation is increasingly being replaced by built-up areas, raising pollutant levels. Smog pollution varies with time and location due to atmospheric factors and criteria pollutants, primarily particulate matter (PM10, PM2.5). During winter, particulate matter and atmospheric aerosols accumulate in the boundary layer, with high humidity, low temperatures, and stable wind speeds accelerating smog formation [11][12]. Additionally, land cover changes have led to increased particulate matter levels. The expansion of residential and industrial areas contributes to higher particulate matter concentrations [13]. Therefore, this study examines the long-term transformation of land use and land cover (LULC) from 2002 to 2022 to understand how land cover changes cause smog. Humidity also plays a role in smog formation. While water itself does not directly contribute to smog formation in Lahore, the primary factors involve air pollutants

from vehicular emissions, industrial activities, and agricultural burning. The interaction of pollutants like nitrogen oxides (NOx) and volatile organic compounds (VOCs) in sunlight leads to ground-level ozone, a major component of smog. However, the indirect role of water is significant, as meteorological conditions influenced by atmospheric water vapor are crucial in smog formation. High humidity levels can enhance the transformation of precursor pollutants into secondary aerosols, worsening smog-related issues. The complex interplay between air pollutants and meteorological factors contributes to the persistent smog problem in Lahore [14].

Land cover data is essential for managing unregulated urbanization and environmental challenges, as different land cover types produce varying levels of pollutant emissions [15]. According to the WHO, PM2.5 increases the risk of lung, pulmonary, and heart infections and can also cause respiratory infections, eye and nose discomfort, and headaches [16]. Different locations have varying types and amounts of PM, with densely populated urban areas often exhibiting a broader range. The types of land cover practices in major cities can affect particulate matter (PM) concentrations. Intense urban sprawl, characterized by low-density, automobile-focused development, can significantly impact pollutant levels. Numerous studies have shown that particulate matter is the most harmful pollutant to human health and urban visibility [17]. Thus, the aim of this research is to explore the impact of land cover changes on smog formation in Lahore.

Research Objective:

This research aims to identify and analyze land cover changes in urban and peri-urban areas, investigate the impact of human activities on pollutant emissions causing smog, and assess the influence of natural factors on the relationship between land cover changes and smog formation.

Study Area:

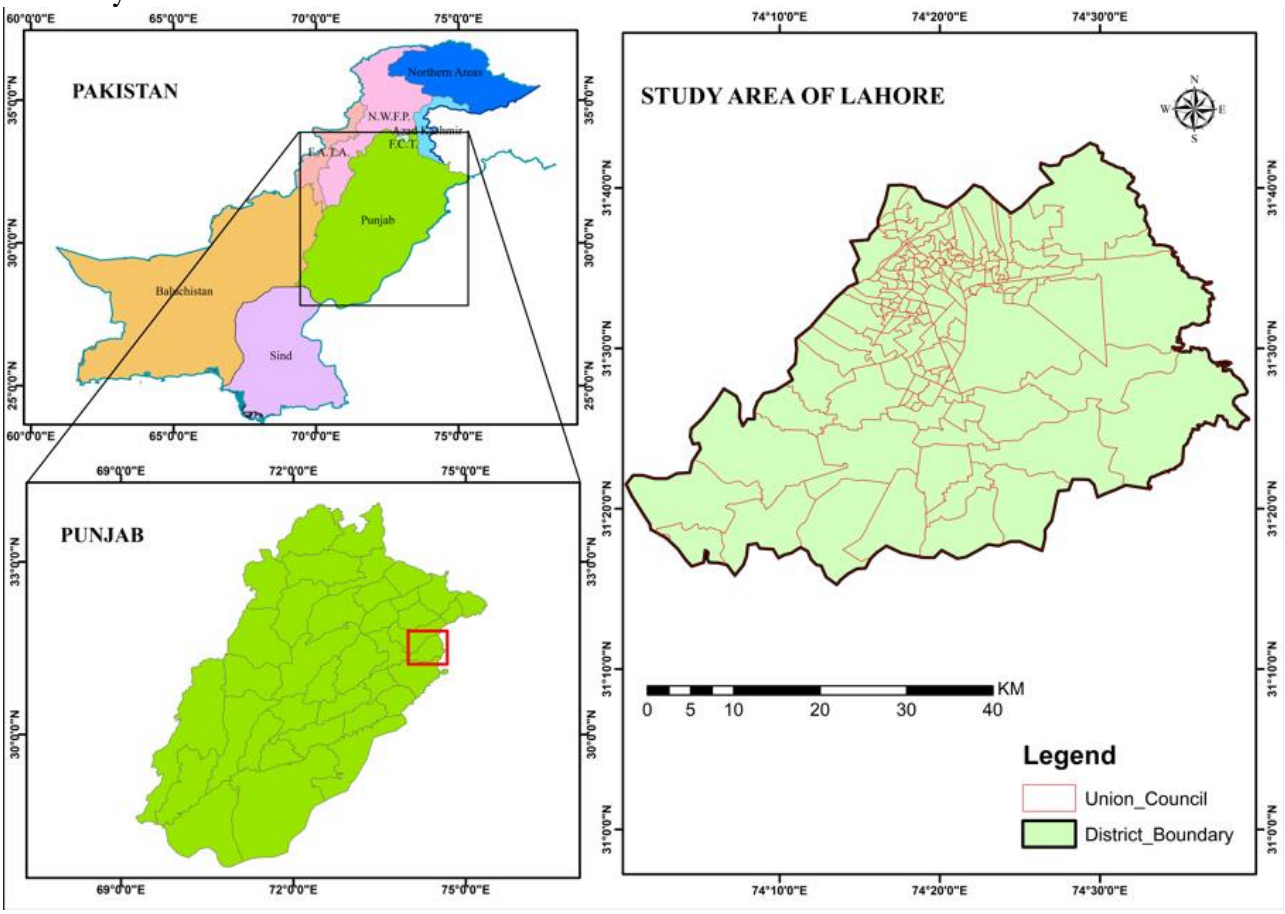

Figure 1: Study Area Map of Lahore

The study is conducted in Lahore, Pakistan, the largest city in the Punjab province and the second-largest city district in Pakistan. Lahore is experiencing rapid urbanization, evolving from a metropolitan city to a megalopolis. Located at 31°15'—31°45' N and 74°01'—74°39' E, Lahore is a sprawling megacity with a population of 11.3 million, which has doubled in the last decade, reflecting a growth rate of 3.58% as of 2018. The city is bordered by India to the east, Sheikhupura to the northwest, Kasur to the south, and the River Ravi to the north [18][19]. Lahore's substantial industrial activity includes pharmaceuticals, automobile production, chemical manufacturing, and other sectors. Situated in a subtropical arid region with high vehicular and industrial loads, Lahore faces increasing air pollution and associated health issues.

Smog in Lahore has become a significant environmental and public health concern. The city's rapid urbanization, industrial activity, and high vehicular emissions contribute to severe air pollution. During winter, the situation worsens as particulate matter (PM2.5 and PM10) and other pollutants accumulate, exacerbated by high humidity and low wind speeds. This combination creates dense smog that reduces visibility and poses serious health risks, particularly respiratory and cardiovascular issues. Industrial emissions, vehicular exhaust, crop burning, and construction activities are primary pollutant sources. The persistent smog in Lahore underscores the urgent need for comprehensive air quality management and pollution control measures to protect public health and the environment.

Research Methodology:

Data Collection:

This study used secondary data from online sources such as Terra-Climate, Google Earth Pro, NASA Giovanni, and USGS Earth Explorer. Land cover data for Lahore from 2002, 2012, and 2022 were analyzed to evaluate changes and their effects on temperature and smog. Additionally, air pollutant data (NO2, SO2, CO) for the same years were examined to assess pollutant concentrations.

Table 1: Data of air pollutants examined via satellites from the year 2002-2022

Sr. No.	Year	Satellite	Data Type	Spatial Resolution
1	2002	OMI (Aura)	NO_2	0.25°
2	2012	OMI (Aura)	NO_2	0.25°
3	2022	OMI (Aura)	NO_2	0.25°
4	2002	MERRA-2 (Reanalysis)	SO_2	0.5 x 0.625°
5	2012	MERRA-2 (Reanalysis)	SO_2	0.5 x 0.625°
6	2022	MERRA-2 (Reanalysis)	SO_2	0.5 x 0.625°
7	2002	MERRA-2 (Reanalysis)	CO	1°
8	2012	MERRA-2 (Reanalysis)	CO	1°
9	2022	MERRA-2 (Reanalysis)	CO	1°
10	2002	Terra (EOS AM-1)	Temperature	~4-km (1/24th degree)
11	2012	Terra (EOS AM-1)	Temperature	~4-km (1/24th degree)
12	2022	Terra (EOS AM-1)	Temperature	~4-km (1/24th degree)
13	2002	Landsat	LC	15 m
14	2012	Landsat	LC	15 m
15	2022	Landsat	LC	15 m

Data Processing:

Data was collected and processed within a GIS-controlled environment using ArcGIS. Land cover images from Google Earth Pro were utilized to illustrate changes in Lahore. Temperature data from Terra-Climate were converted to point data and analyzed using the IDW interpolation technique. Land cover data for 2002, 2012, and 2022 from USGS Earth Explorer were integrated into ArcGIS to visualize changes. Air pollutant data (SO2, NO2, CO) from NASA Giovanni were also analyzed with IDW to display pollutant concentrations. The weighted

overlay technique was employed to illustrate smog variation across different years, highlighting how urbanization and land cover changes affect temperature and contribute to smog formation.

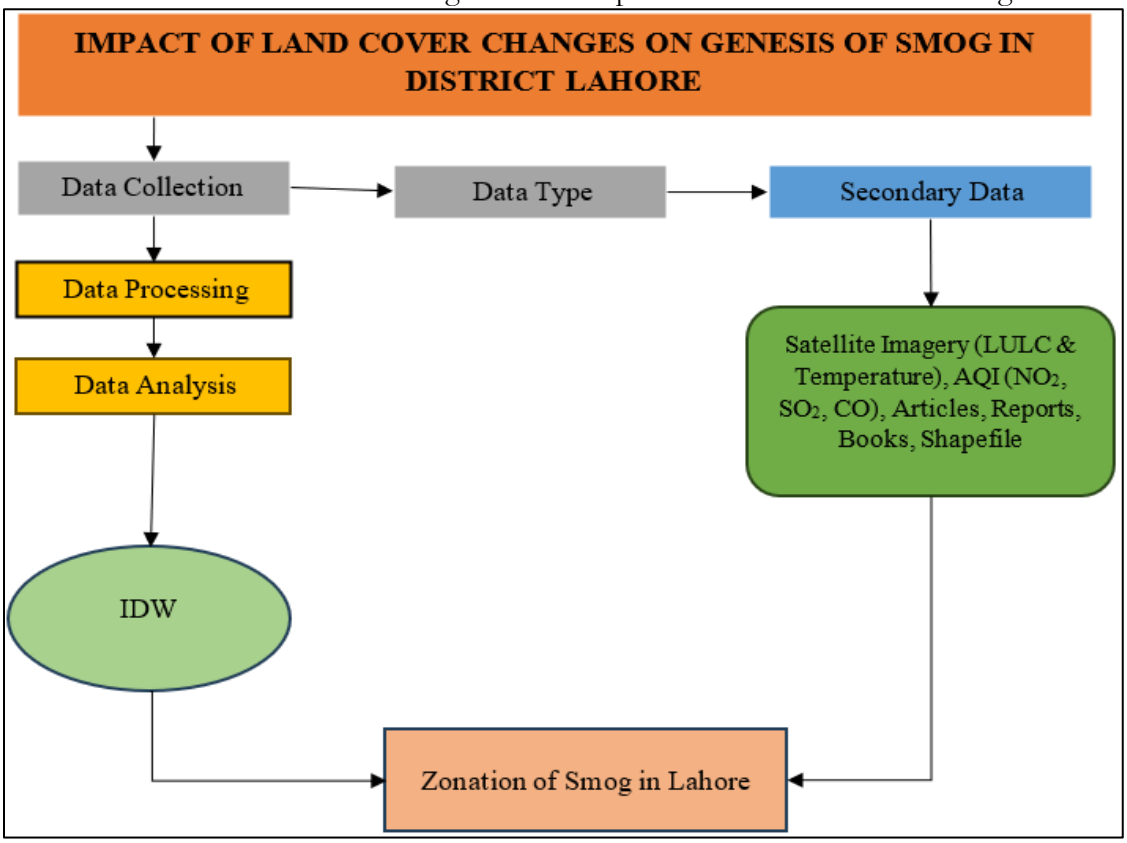

Figure 2: Methodology Flowchart

Results:

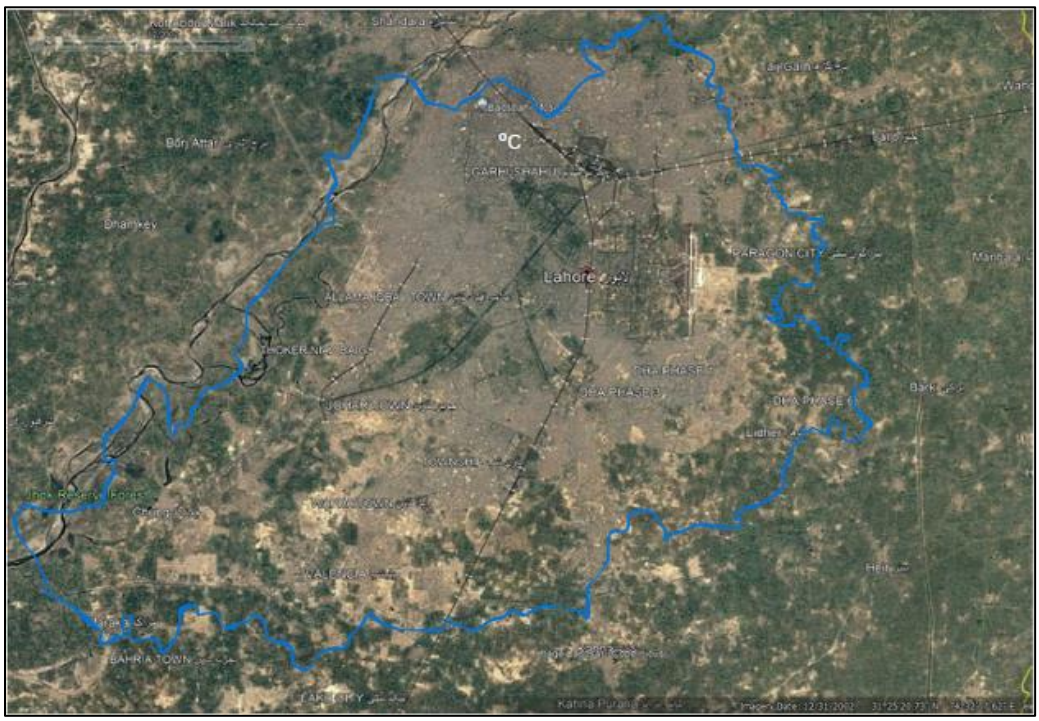

Figure 3: Land Cover of Lahore City in 2002

The research aimed to explore how land cover changes and human activities, such as industrial emissions, transportation, and urban development, contribute to smog formation.

Understanding these dynamics in the study region, especially regarding how land cover changes influence smog, required specific applications in this research.

Urbanization in Lahore has been increasing annually, leading to a rising population. Figures 3, 4, and 5 illustrate a decrease in vegetation cover and a corresponding rise in urbanization, which accelerates land cover changes. This urban expansion contributes to smog formation through a complex interplay of factors. The increase in industrial activities, vehicular emissions, and energy consumption releases significant amounts of pollutants—such as particulate matter, nitrogen oxides, and volatile organic compounds—into the atmosphere. The high density of emission sources in urban areas exacerbates pollutant concentrations. Additionally, urban landscapes with many impervious surfaces, like roads and buildings, alter meteorological conditions, causing phenomena such as temperature inversions that trap pollutants near the ground. These factors collectively lead to smog formation, characterized by a haze of pollutants that adversely affects air quality and human health in urbanized regions.

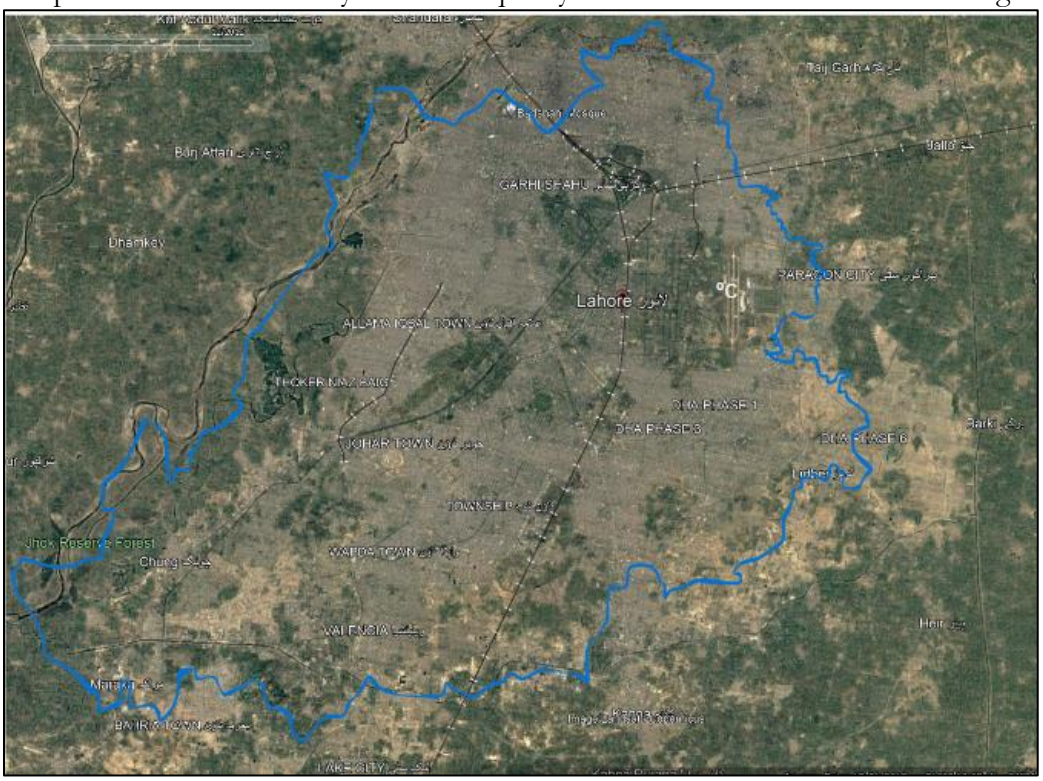

Figure 4: Land Cover of Lahore City in 2012

Lahore experiences a wide range of temperatures throughout the year. Summers, from April to June, are typically hot and dry, with average maximum temperatures between 35°C and 45°C (95°F and 113°F). Winter, from December to February, sees the lowest temperatures, averaging between 5°C and 7°C (41°F and 45°F). Spring and autumn are transitional seasons with milder temperatures. Temperature significantly affects ecosystem function, and visualizing temperature data for the study region can reveal trends and variations.

Figure 6 illustrates annual temperature changes in Lahore. Maps for 2002, 2012, and 2022 show that while temperatures decreased in 2002, they rose in 2012 due to urbanization. However, by 2022, temperatures had decreased again, a trend attributed to the COVID-19 pandemic. During the pandemic, various factors contributed to a temporary reduction in Lahore's temperature.

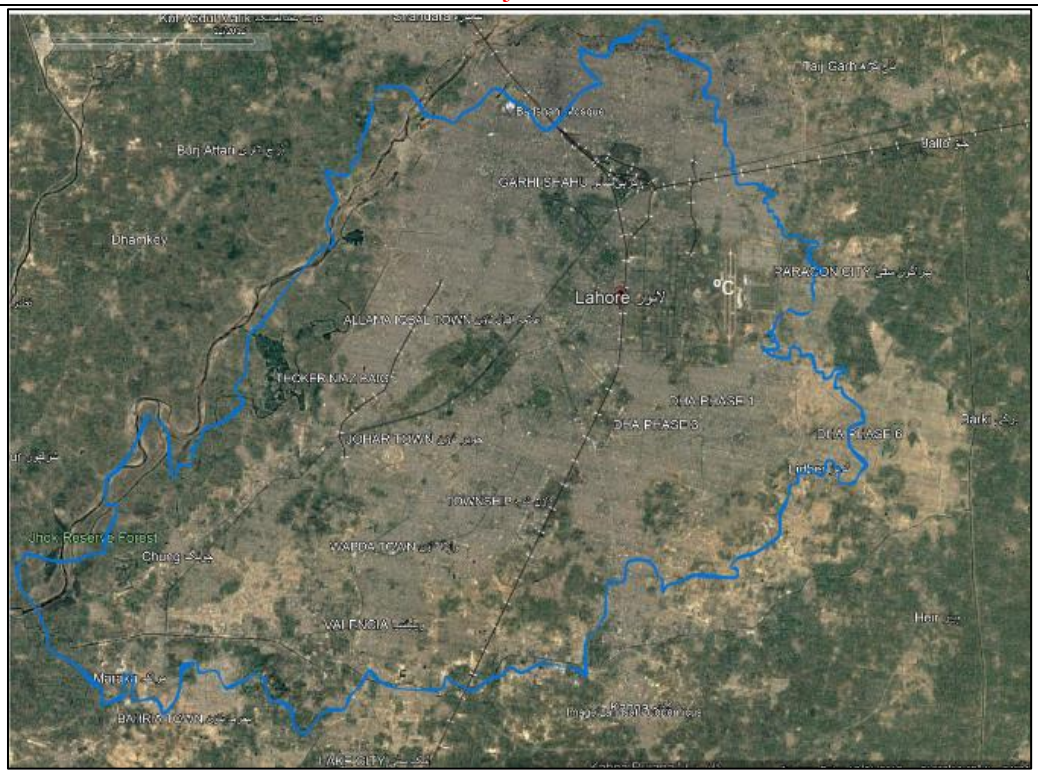

Figure 5: Land Cover of Lahore City in 2022

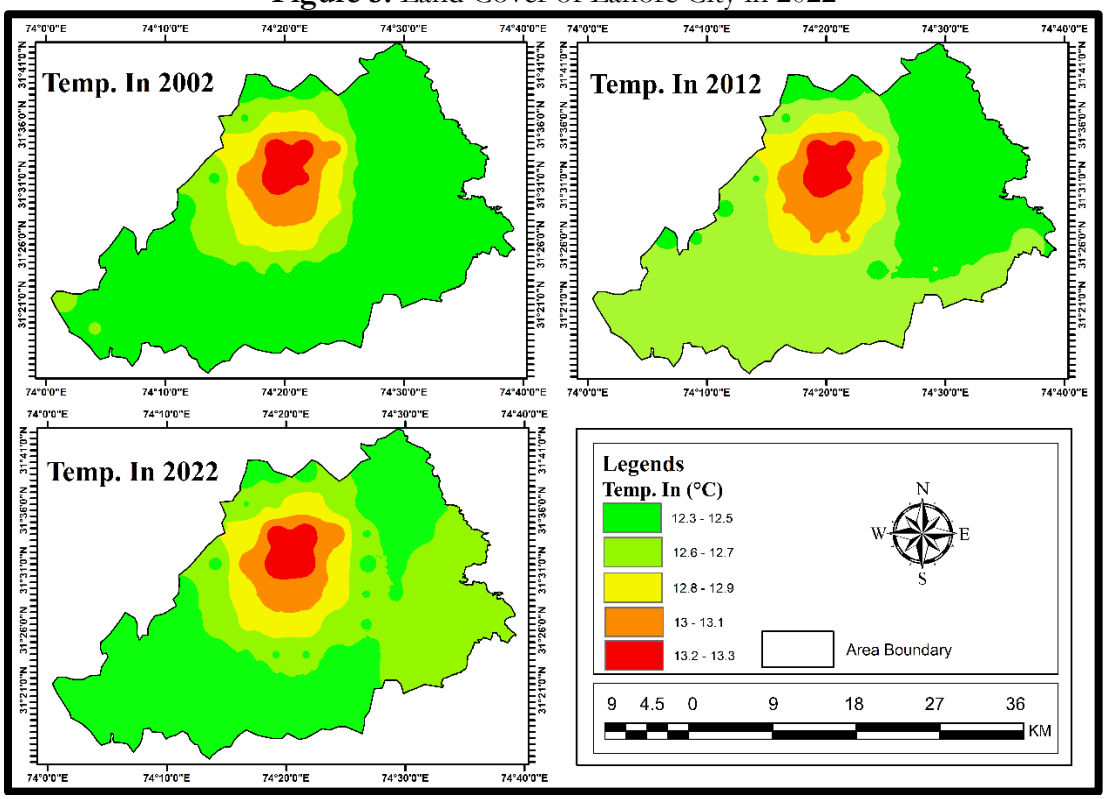

Figure 6: Temperature of Lahore in 2002, 2012 & 2022

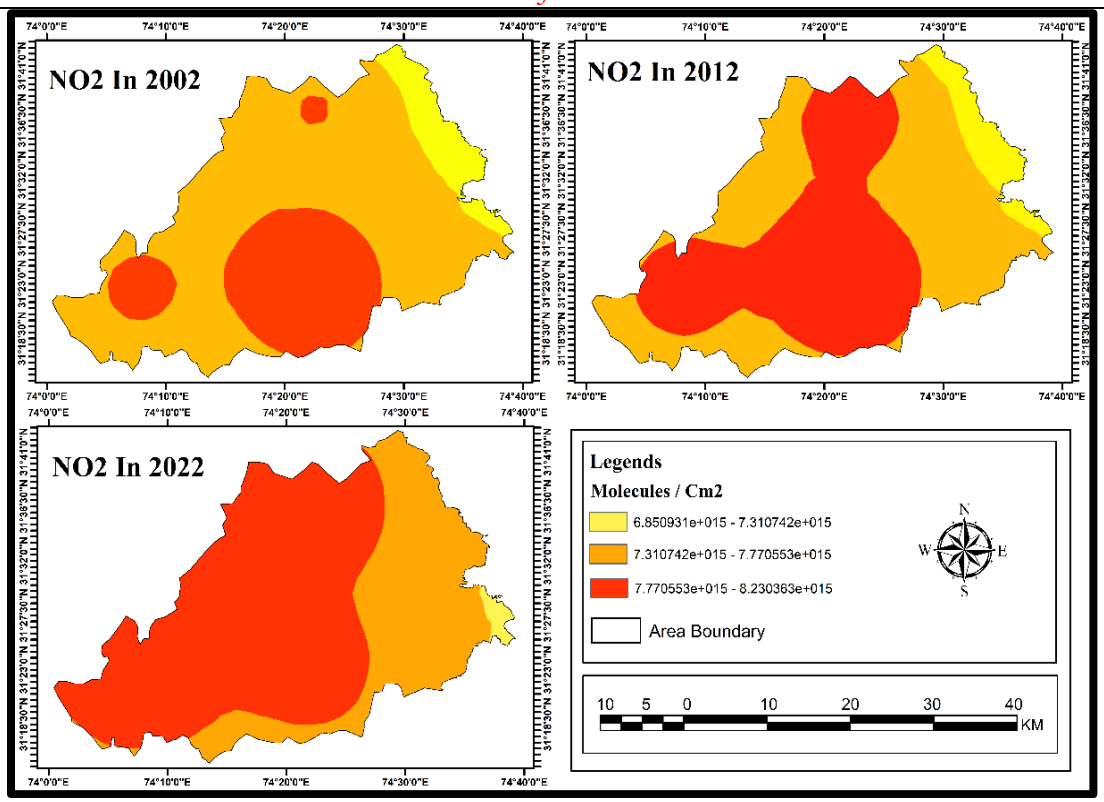

Figure 7: Concentration of Nitrogen Dioxide (NO2) of the Years 2002, 2012 & 2022 in Lahore

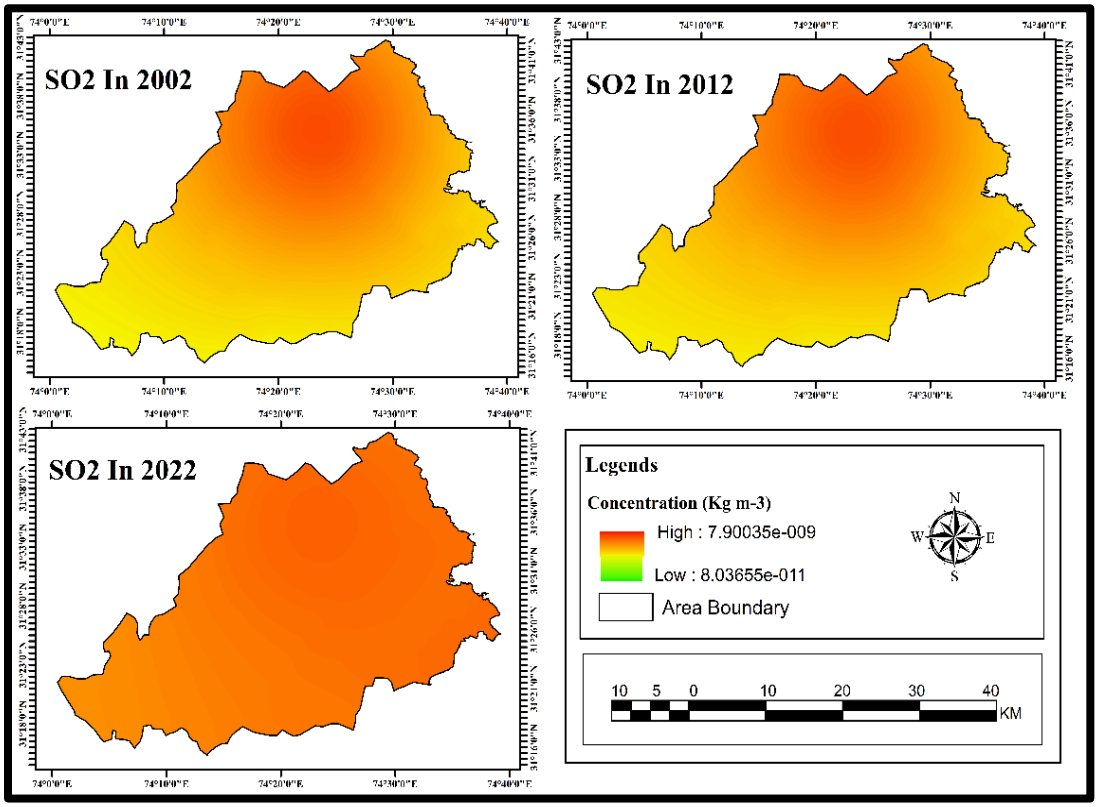

Figure 8: Concentration of Sulphur Dioxide (SO2) of the Year 2002, 2012 & 2022 in Lahore

Land Cover (LC) changes significantly contribute to smog formation, exacerbating air pollution issues. Urbanization and industrialization transform the landscape, leading to increased emissions of particulate matter (PM) and pollutants such as carbon monoxide (CO), sulfur

dioxide (SO2), and nitrogen dioxide (NO2). Figures 7, 8, and 9 illustrate the concentrations of CO, SO2, and NO2 in Lahore for the years 2002, 2012, and 2022. The data clearly show a yearly increase in the concentration of these air pollutants, which plays a major role in smog formation and adversely affects human health.

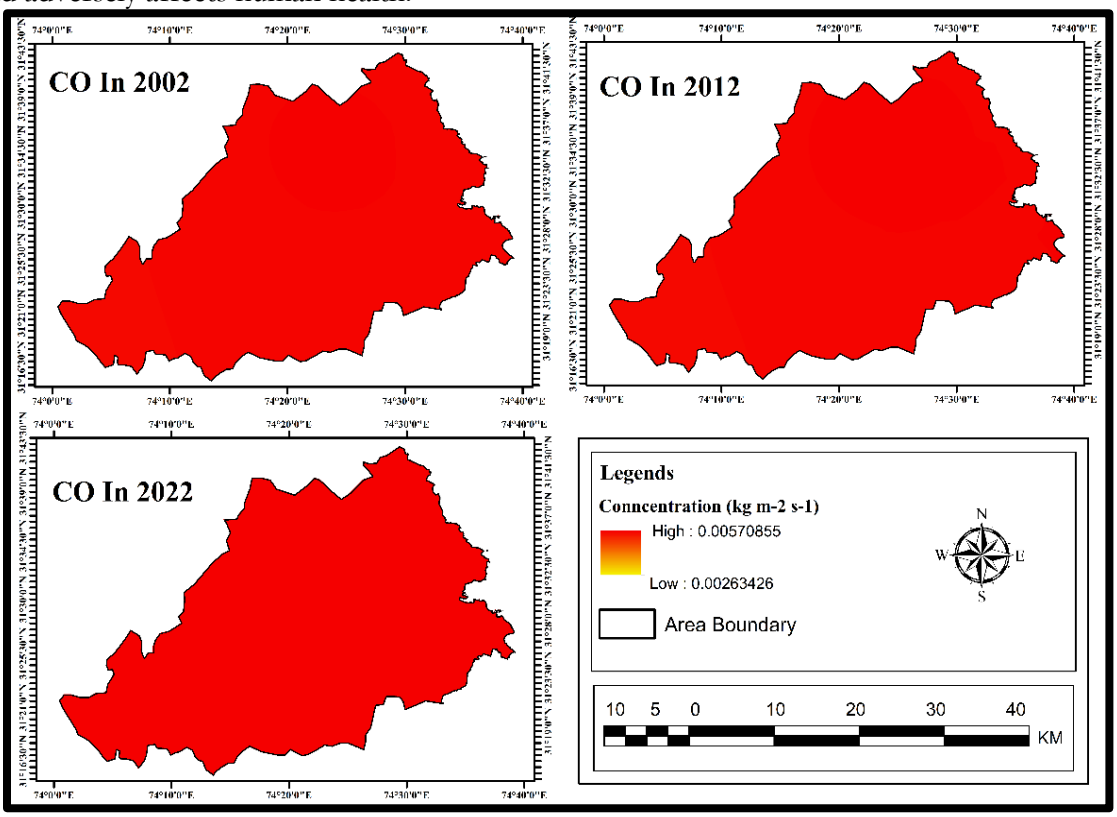

Figure 9: Concentration of Carbon Monoxide (CO) of Year 2002, 2012 & 2022 in Lahore

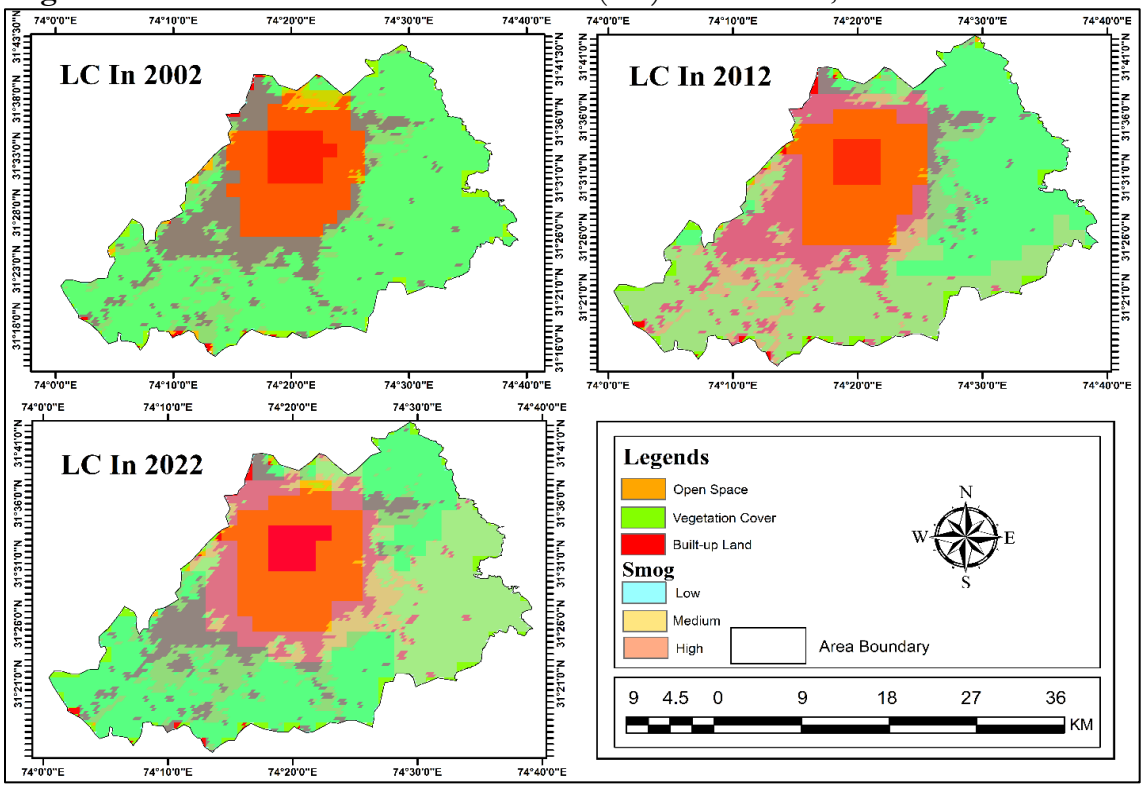

Figure 10: Land Cover and Smog Formation of Lahore in 2002, 2012 & 2022

Every year, Lahore, a rapidly expanding city in Pakistan, experiences dynamic changes in land cover. The city's growth and expansion continuously alter the terrain, with new commercial, residential, and infrastructure developments reshaping its urban fabric. A notable trend is the conversion of agricultural land into urban areas, driven by urbanization and population growth. Figure 10 illustrates the land cover of Lahore for the years 2002, 2012, and 2022, clearly showing these changes. These land cover modifications significantly contribute to smog formation in Lahore.

Discussion:

Urbanization in Lahore is accelerating, leading to a notable rise in population and alterations in land cover. This expansion has reduced vegetation cover while increasing industrial activities, vehicular emissions, and energy consumption, all of which contribute to smog formation. The dense concentration of emission sources, combined with altered meteorological conditions like temperature inversions, traps pollutants near the ground. Consequently, air quality deteriorates, posing elevated health risks to the city's residents.

Lahore experiences substantial temperature variations throughout the year, with hot, dry summers averaging between 35°C and 45°C (95°F to 113°F) and cold winters with lows ranging from 5°C to 7°C (41°F to 45°F). Spring and autumn offer milder, transitional weather. Over the decades, urbanization and human activities have influenced temperature trends in Lahore. The proliferation of impervious surfaces like concrete and asphalt has intensified the Urban Heat Island (UHI) effect, leading to elevated temperatures [20]. However, the COVID-19 pandemic temporarily altered this trend. During the lockdowns, reduced industrial activity and transportation led to lower emissions of greenhouse gases and particulate matter, resulting in improved air quality and decreased temperatures in 2022. This stands in contrast to 2012, when urbanization contributed to rising temperatures. These observations highlight the complex interplay between urban development, human-induced emissions, and climatic changes, underscoring the impact of both natural and anthropogenic factors on Lahore's temperature dynamics.

Land Cover (LC) changes significantly exacerbate smog formation, compounding air pollution challenges. Urbanization and industrialization transform the landscape, leading to increased emissions of particulate matter (PM) and pollutants such as carbon monoxide (CO), sulfur dioxide (SO_2), and nitrogen dioxide (NO_2). For example, a study by [21] reveals that rapid urbanization in Chinese cities has resulted in higher concentrations of NO_2 and SO_2, correlating with increased smog and deteriorating air quality. Similarly, research by [22] indicates that industrial activities in Indian cities significantly contribute to urban air pollution, with rising CO and NO_2 levels due to industrial emissions and vehicular exhaust. Data visualizing the concentrations of NO_2, SO_2, and CO for the years 2002, 2012, and 2022 in Lahore clearly shows an upward trend in these pollutants over time. This trend aligns with studies such as [23], which document rising air pollution levels in Pakistani cities due to industrial growth and urban sprawl. The increasing concentrations of these pollutants play a major role in smog formation, severely impacting human health by causing respiratory and cardiovascular problems, as highlighted by the World Health Organization (WHO).

Each year, Lahore undergoes significant land cover changes driven by urbanization. The city’s landscape evolves with new commercial, residential, and infrastructure developments, leading to the conversion of agricultural land into urban areas. Initiatives like parks and green belts aim to enhance green spaces and sustainability. Factors such as population growth, urban planning, and economic development influence these changes. Monitoring and analyzing these fluctuations are essential for sustainable development. These transformations also contribute to smog formation, underscoring the importance of environmental management. Over the past few decades, rapid urbanization in Lahore has led to significant land cover changes. The

expansion of urban areas, increased industrialization, and rising vehicular traffic have replaced natural land covers with impervious surfaces like concrete and asphalt. This alteration contributes to the urban heat island effect, where surfaces absorb and re-radiate heat, elevating local temperatures [24]. Therefore, managing these environmental changes and their impact on smog formation is crucial for improving air quality and public health in Lahore.

Conclusion:

Smog has become a critical global issue, particularly severe in countries like Pakistan, with urban areas such as Lahore being notably affected. The growing problem of air pollution, driven by human activities, has transformed winter fog into harmful smog, significantly impacting human health. Rapid urbanization in Lahore over recent decades has drastically changed land cover patterns, contributing to the urban heat island effect and elevated temperatures. These transformations, combined with increased energy consumption and other human activities, promote a warming trend, illustrating the complex relationship between urbanization and rising temperatures.

Land-cover changes, especially the conversion of natural areas to impervious surfaces, have direct effects on surface energy and local climate, influencing both land surface and air temperatures. This study highlights the connection between land-cover changes and persistent smog issues, with particulate matter being a major contributor to air pollution. Additionally, water distribution indirectly affects smog formation by influencing meteorological conditions.

The study aimed to explore how changes in land cover contribute to smog formation. Temperature data was utilized to illustrate the impact of land cover on temperature variations. Analyzing land cover data from 2002, 2012, and 2022 revealed the extent of these changes and their role in smog formation. Findings show that increasing urbanization and land cover changes in Lahore lead to higher emissions of pollutants such as carbon monoxide (CO), nitrogen oxides (NOx), volatile organic compounds (VOCs), particulate matter, and sulfur dioxide (SO_2), all of which are crucial to smog formation.

The research emphasizes the need for managing urbanization through effective land cover policies to address environmental challenges and mitigate health risks associated with smog. Developing effective mitigation strategies requires a thorough understanding of these interconnections to create targeted policies that address the root causes of smog linked to land cover changes and pollutant emissions. Tackling these issues is essential for improving air quality and safeguarding public health in Lahore and similar urban areas.

Recommendations

The following recommendations can help us to control the land cover changes and reduce the formation of smog in Lahore.

- Amendment in Urban Planning and Plantation in Public Green Spaces [25]
- Afforestation and Reforestation
- Air Quality Monitoring and Regulation
- Transportation Management
- Stakeholder Collaboration and Public Awareness

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