Remote sensing approach to evaluate the effects of urban vegetation loss on the urban thermal environment in the fastest-growing megacity of Pakistan

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Introduction

One of the most significant components that contribute to ecological balance and environmental sustainability is urban vegetation (Kafy et al. 2021). Due to rapid urbanization, the ecological and thermal environment of urban areas has been negatively impacted by the growing replacement of natural landscapes by artificial surfaces (Grimm et al. 2008). Cities are a major driver of economic growth, accounting for around 60% of global GDP (Un-Habitat 2018). Urbanization is a sign of economic success and prosperity, but it also has detrimental short-and long-term effects on the development of cities (Celik et al. 2019). As populations of cities grow, pressure is put on rural areas, the boundary is expanded, and natural resources (i.e., forest, vegetation, and agriculture) are replaced. Therefore, urbanization affects changes in land use and land cover (LULC) and is a crucial indicator of LULC changes that disrupt the balance of surface energy and raise surface temperatures (Matthews et al. 2015). Despite its importance for balancing the LST in urban environments, urban vegetation globally has dramatically decreased over the past few decades (Choudhury et al. 2019). According to Xiong et al. (2012), the loss of vegetation due to urbanization results in significant changes in the urban thermal environment (UTE), which ultimately deteriorates environmental sustainability by increasing land surface temperatures (LST). This contributes to the UHI (urban heat island) effect, which negatively affects both the comfortable everyday lives of people and the sustainable growth of cities (Mohan et al. 2022). Therefore, it is crucial to comprehend the role of urban land use, as well as its relationship with changes in the pattern of the urban area, and the impact of the loss of urban vegetation on urban LST.

The application of remote sensing and geographic information systems to assess LULC and LST changes in urbanized environments has grown significantly over time (Balogun and Ishola 2017). Analysis, monitoring, and simulation of LULC and LST variations are made simpler through the use of integrated GIS and RS techniques (Fu and Weng 2018). Thermal remote sensing technology, which monitors the UHI, is regarded to be a useful tool for evaluating the adverse impacts of human activities on local climate over the previous 20 years. Several researchers used thermal infrared sensors that were available at different spatial resolutions to investigate LST features for distinct LULC categories in various urban contexts (Fu and Weng 2018; Celik et al. 2019).

This research aims to develop an appropriate method for evaluating the effects of urban vegetation loss on the urban thermal environment of Lahore, Pakistan's fastest-growing megacity, utilizing satellite remote sensing (SRS) and GIS techniques. The current study used multi-temporal Landsat 5 & 8 (TM & OLI_TIRS) data to identify the LULC change between the years 2000 and 2020 and investigates the changes from natural vegetation cover to the urban area and its effect on the LST variations in Lahore, Pakistan. Moreover, this study examines how image processing and spatial analysis can be used to enhance urban green initiatives in Lahore and contribute to sustainable urban planning, ultimately fostering a healthier and more sustainable urban environment within the city. Urban planners and policymakers have found remote sensing techniques to be a very helpful tool for determining the best course of action to promote sustainable development, conservation of the city's natural resources, and minimizing the impact of urbanization on LST (Kafy et al. 2021).

Study Area Description

Lahore is Pakistan's second-largest metropolitan city after Karachi and 100% of its population lives in urban areas (GOP, 2017). The city of Lahore is situated on the left bank of the Ravi River and is located between 31°13′-31°43′ N latitude and 74°0′-74°39.5′ E longitude. Lahore is the core of cultural activities as well as the academic, social, economic, and administrative hub of the Punjab province of Pakistan. The total area of district Lahore is 1772 km^2 (Fig. 1).

Materials and Methods

The two most recent decades (2000 to 2020) were chosen for this study. Two Landsat Multi-spectral satellite data sets were downloaded from the USGS website to assess changes in urban vegetation cover and LST dynamics in the research area (Lahore) over these 20 years. The research area includes urban vegetation as well as the surrounding agricultural fields, which have been gradually turning into built-up land over the past few decades. Therefore, to avoid the impact of cooling and heating, the spring season

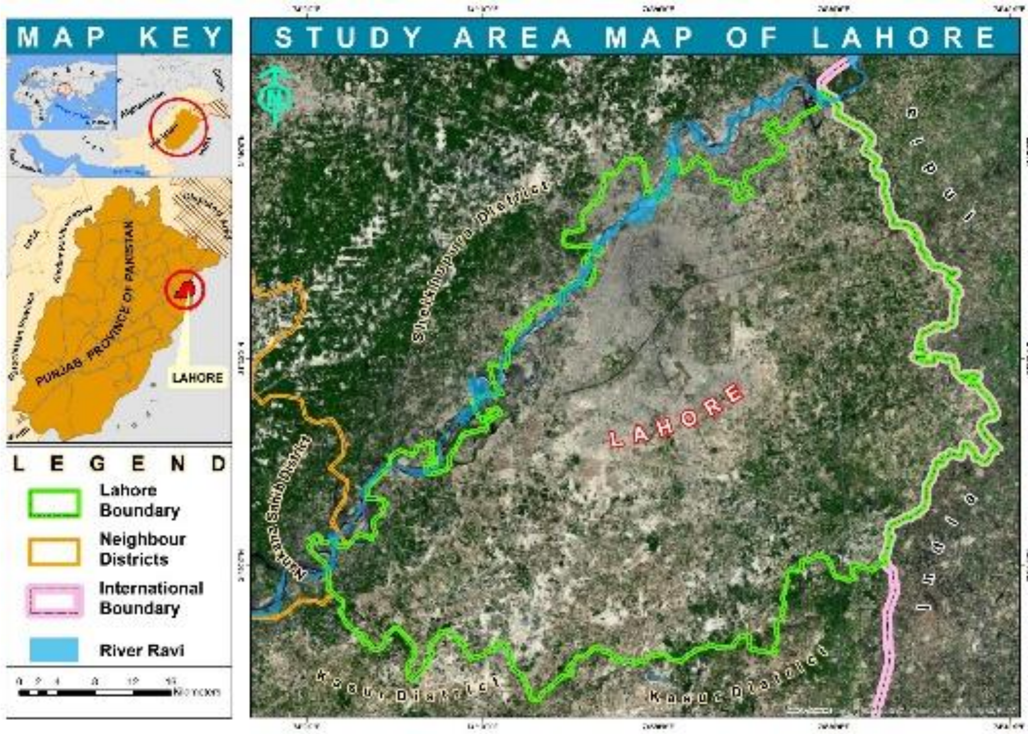

Fig. 1: Location map of the study area district Lahore (own draft)

and the month of March were selected for the analysis as it is the most suitable season for land use classification and retrieval of LST (Nasar-u-Minallah et al. 2023; Nasar-u-Minallah 2020).

The collected Landsat images between the years 2000 and 2020 were divided into the four LULC classes of built-up area, vacant land, vegetation, and water bodies. To estimate the LULC classification, the Maximum Likelihood Supervised Classification (MLSC) technique was applied (Nasar-u-Minallah et al. 2021). The Radiative Transfer Method (RTM) was employed (Nasar-u-Minallah 2019) in the study to estimate LST and examine the effects of UHI over 20 years. Fig. 2 depicts a comprehensive methodology.

Results and Discussion

LU changes and vegetation loss

With an overall 85% accuracy across all parameters for several years, the LU classification accuracy showed great results. In the LU classifications of the study period (2000-2020), two notable changes have been found. The first is an increase in the built-up area with a marked reduction in the amount of vegetation cover, vacant land, and water bodies. In 2000, Lahore had 25.12% of built-up area, 59.95% of vegetation cover, 13.67% of vacant land, and 1.26% of water bodies. However, after twenty years, in 2020, the LU distribution of Lahore has been changed to 43% of built-up area, 46% vegetation cover, 10% of vacant land, and 0.86% of water bodies. As illustrated graphically (Fig. 3), over the last two decades +17.88% of the built-up area was increased, resulting in -13.95%, -3.67%, and- 0.4% decrease in urban vegetation cover, vacant land, and water bodies, respectively.

The urban population of the city increased as a result of new employment opportunities in a variety of economic sectors, including commerce, industry, business, and transportation. A key factor in the city's urban growth was the population increase. Additionally, migration from rural to urban areas in search of jobs, an increase in commercial activity, and the availability of superior academic and medical facilities have been the main drivers of Lahore's expansion and changes in land use.

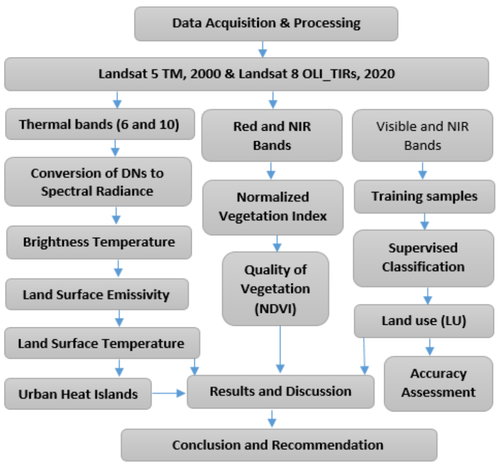

Fig. 2: Flow chart for details of the methodology (own draft)

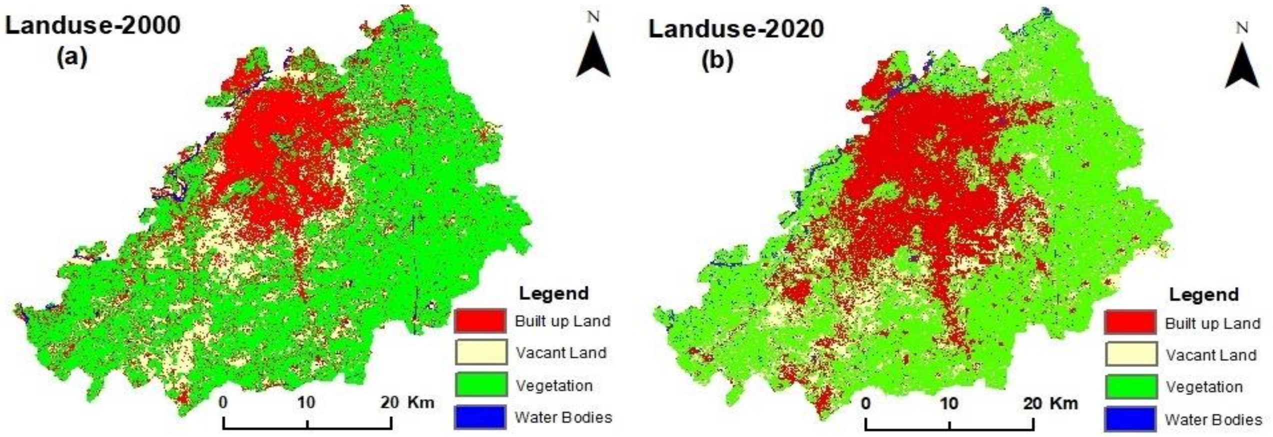

Fig. 3: Land use distribution of district Lahore between 2000 and 2020 (own draft)

The study area's built-up land grew as a result of the development of commercial areas and several new housing societies on the east and west-south sides. Our findings showed that urban vegetation cover and vacant land were transformed into roads, industrial and commercial centres, and residential areas. According to the 2017 census, the population reached 11.2 million, up from 6.3 million in 1998, with a 3% annual growth rate (GOP, 2017). Different areas of district Lahore experienced an increase in urban built-up land as a result of the growing population.

Land Surface Temperature Changes

Fig. 4 shows the spatiotemporal and areal distribution of LST for the years 2000 and 2020. Fig. 4 uses a colour gradient from dark brown to light brown to represent temperature variations. The colour scheme exhibits a smooth transition, wherein dark brown is employed to signify regions with higher temperatures, while light brown is employed to denote areas characterized by lower temperatures. The spatiotemporal patterns of LST and alterations in LST concentration show the rapid evolution of LULC classes. LST was typically measured to range between 14.32°C and 27.53°C in 2000 and 12.57°C and 31.61°C in 2020. This rise is entirely mathematical; however, a more precise increase in temperature was estimated using the spatial mean temperature (20.94°C for 2000 & 22.09°C for 2020), and it indicates that from 2000-2020, LST has increased by 1.12°C. The central area of the city exhibited a substantial rise in temperature values in 2020 (Fig. 4).

In the year 2000, there was a noticeable difference in temperature between industrial areas and the city centre. Industries consistently played a significant role in increasing localized temperatures. Specifically, the prominent industrial areas of Lahore including Badami Bagh, Chunia Industrial Estate, and Kotlakhpat had a substantial impact on rising surface temperatures compared to the areas around them in 2000 (Fig. 4a). However, over time, there was a decrease in green spaces, and with the development of urban areas and transportation networks, population density increased rapidly in the city centre of Lahore. This causes identical surface temperature values across the study area. Eventually, this trend led to a consistent, higher land surface temperature (LST) across the entire district, eliminating the initial distinctions between industrial zones and the city centre.

The study area's increased built-up area between 2000 and 2020 led to an increase in the LST (Fig 4(b). Due to more urban vegetation and agricultural fields, the study area's eastern, southern, and western regions experience cooler temperatures. In contrast, the central region of Lahore displays an intensification of LST as a result of the accelerated urbanization process, and a decrease in urban vegetation cover in the city centre and surrounding areas. Furthermore, in 2020, the Lahore central area, which is heavily urbanized, dense and rapidly expanding (Fig. 4b), where the maximum surface temperature was assessed, establishes a positive correlation between built-up areas and surface temperature.

The surface temperature data from the day of image acquisition and the air temperature data from the PMD weather station were also used for comparison and validation of the LST collected from the Landsat images. Table 1 compares the surface temperature from the Landsat images with the air temperature from the weather station, which shows a temperature difference between 2000 and 2020.

Table1. LST and air temperature comparison (own draft)

Date	LST	Air Temperature	Temperature Difference
11-03-2000	20.94	21.1	-0.16
18-03-2020	22.09	19.85	2.24

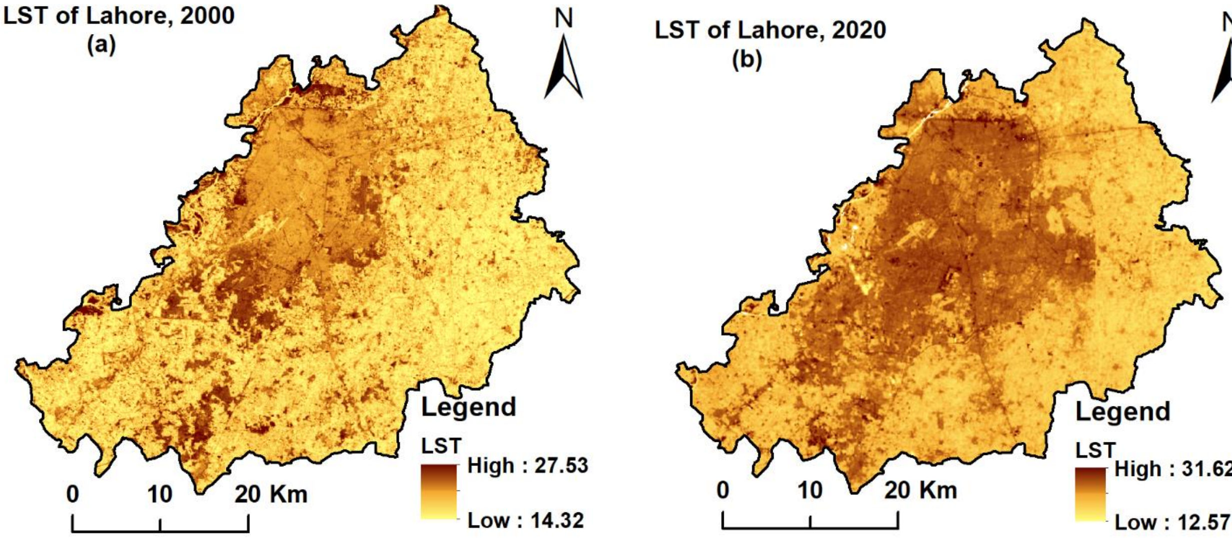

Fig. 4: LST of District Lahore for the Years 2000 and 2020 (own draft)

Urban Vegetation Cover Change

The NDVI was used to assess changes in vegetation cover using Landsat data from 2000 and 2020, as shown in Fig. 5. The NDVI images for 2000 and 2020 provide valuable insights into the temporal dynamics of vegetation in Lahore.

In the research area, the NDVI values ranged from -0.2 in light green colour to 0.7 in dark green colour from 2000 to 2020. In the first-year image, which corresponds to 2000, the landscape exhibits a vibrant spectrum of green hues, indicating dense vegetation cover. Whereas, a shift to the NDVI image of the same area for 2020 exhibits a notable transformation. The green colour shows a prominent decrease, signifying a pronounced decline in both vegetation vitality and its spatial extent. A noticeable reduction in vegetation coverage is evident adjacent to major roads and settlements.

These findings thus demonstrate that the effects of urban growth can result in a reduction of vegetation-covered regions. Changes in LULC and loss of vegetation directly influence the LST. The finding indicates that as urban areas have grown and green areas have disappeared between 2000 and 2020, the NDVI values have decreased. The dense vegetation cover has lower LST, as indicated by the negative association between LST and NDVI. LST increases are a result of the gradually declining amount of vegetation and green space.

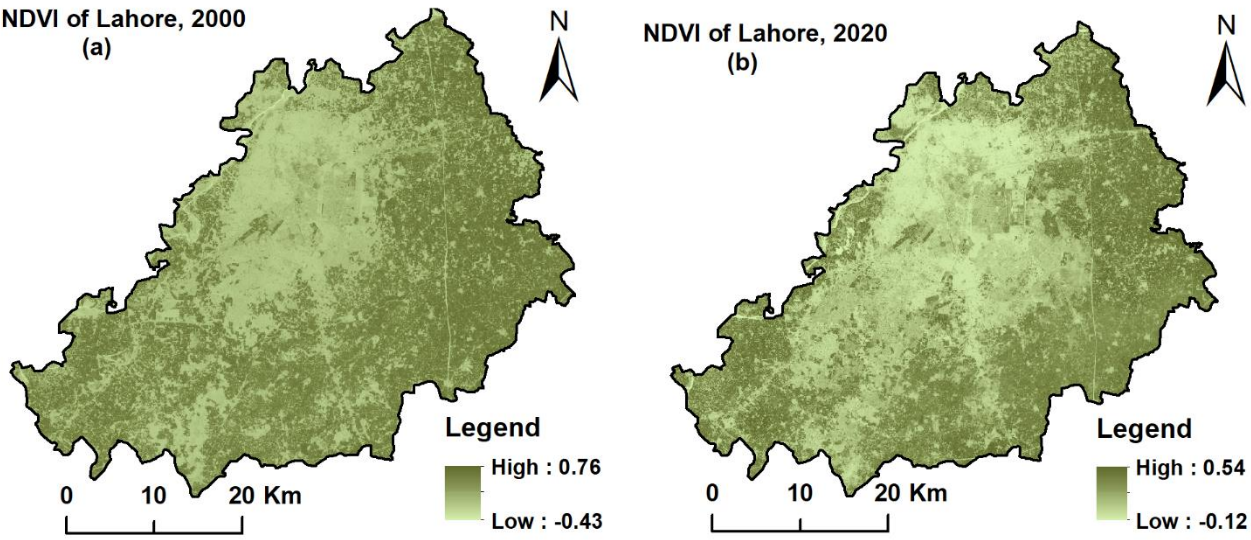

Fig. 5: The NDVI of district Lahore for the years 2000, and 2020 (own draft)

Surface Urban Heat Islands (SUHI)

Figs. 3 and 4 reveal that urban built-up areas and LST grew simultaneously, demonstrating their direct correlation. Urban growth is the primary factor contributing to the LST's growing tendency. The distinction between the urban and rural buffers reveals the impact of SUHI. To calculate surface UHI, the difference between the mean LST of urban and rural areas has also been employed. This study has found evidence of the impact of SUHI as a result of rapid urbanization. Temperature differences between urban and rural areas show that SUHI has also been rising over time. SUHI has increased from 1.91°C in 2000 to 2.41°C in 2020, and a relative change of roughly 0.50°C has been seen. However, it is noteworthy to mention that the mean minimum temperature decreased from 14.3 °C in 2000 to 12.57°C in 2020. The one of the obvious reasons for this drop in the mean minimum temperature in March 2020 were travel restrictions, lockdowns, and a downturn in economic activity, which all contributed to a reduction in man-made heat sources like transportation, industrial processes, and evening commercial activity. This reduction in anthropogenic heat emissions can result in lower nighttime temperatures (Roshan et al. 2021). In contrast to prior research, which solely focused on diurnal temperature values, this study investigates both the maximum and minimum temperatures derived from LST (Pal et al., 2021; Roshan et al., 2022). The LST map indicates the urban heat island phenomena (Fig. 4). It confirms that impervious structures, which have an impact on the local climatic conditions, are the reason for the concentration of heat in metropolitan areas.

Megacities often have surface UHI because of the heat-trapping effects of tall buildings and extensive infrastructure, which can ultimately have a negative influence on the local thermal environmental conditions and the population's health. Unfavorable ecological conditions may be brought on by the high surface UHI. Therefore, to achieve a sustainable urban environment and development in urban areas and reduce the effects of surface UHI by increasing the amount of vegetation cover that can deflect solar radiation utilizing green rooftops. This can lower the temperature by 0.5 to 3°C (Macintyre and Heaviside 2019). This study has shown how LULC changes can be used to track changes in urban climate. The urban climate is significantly affected by urbanization. The outcome of this research also showed that the effects of surface urban heat islands were not always felt in the city centres but could also occur in areas where there were active development projects aimed at bringing about urban growth.

Conclusion

The findings of this study show a significant change in land use and land cover, particularly in urban vegetation cover, agricultural land and built-up areas between 2000 and 2020. Compared to the year 2000, overall 756.44-km^2 (i.e., 43%) area urbanized in 2020 caused a 14% decrease in vegetation. The increase in urbanization brought on by the expansion of built-up regions over urban green spaces is evident when comparing the NDVI of the years 2000 and 2020. It increased to the mean and maximum land surface temperature. The result was an accelerated urban heat island effect in Lahore, which changed the nature of the urban climate of Lahore. The findings are an important consideration for environmentalists and city planners who want to mitigate the effects of urban climate change and urban heat islands effects by implementing appropriate measures, including rooftop gardening.

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