# SPATIOTEMPORAL ANALYSIS OF URBAN GROWTH AND LAND SURFACE TEMPERATURE: A CASE STUDY OF LAHORE, PAKISTAN

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**KEY WORDS:** Land use change, Urban growth, Land surface temperature, Landsat, Urban Heat Island

**ABSTRACT:**

Cities around the world are facing tremendous pressure due to rapid urbanization. They are being extended haphazardly especially in developing countries, putting strain on already depleting natural recourses. The land-use conversion to built-up areas harms the urban environment significantly. The most immediate implications of this land-use/land cover (LULC) conversion are the transition of Land Surface Temperature (LST) and the creation of Urban Heat Islands. This research investigates the spatial distribution of LST and LULC and their interrelation using satellite images from Landsat 5 (TM) and 8 (OLI/TRS) for the years 1998, 2010, and 2021. The built-up area in Lahore has grown enormously over the last two decades. Our results indicate that each year 1.26% of the land is being transformed into built-up area. Consequently, the prevailing urban development trends have also influenced the LST. In particular, we observed an average upsurge of 0.47ºC per year between 1998 and 2021. If our cities continue to expanqd in the same manner, this would have serious ecological implications in the future. Thus, urban planners and policymakers need to incorporate climate-adaptive design at the community and building levels to improve the situation.

## 1. INTRODUCTION

Urbanization is a global phenomenon, it has intensified and grown more dynamically in developing countries, particularly in South Asia. Urban areas in developing countries have seen a tremendous increase in both population and aerial extent (Li & Yao, 2009; Roy et al., 2020). Likewise, with the increasing trends of urbanization worldwide, growth patterns in Pakistan have also been escalating rapidly with an annual rate of 3 percent. In Pakistan, the urban population has grown from 32.5 percent in 1998 to 36.4 percent in 2017. It is expected that approximately 50 percent of the country's population will be residing in urban areas by 2025 (UNDP, 2019). Cities are being extended both horizontally and vertically to satisfy this growth, putting strain on natural resources by replacing agricultural and vegetation lands. While these land use/land cover (LULC) transformations have a positive impact on the urban economy, they harm the urban environment significantly (McCarthy, Best, & Betts, 2010). The most immediate implications of urban land conversion are the transition of Land surface temperature (LST) and the formation of an Urban Heat Island (UHI); the variance in temperature between the urban centers and the periphery non-urban areas (Achmad, Fadhly, Deli, & Ramli, 2022; Roy et al., 2020; Voogt & Oke, 2003). LST is a major climatic variable that varies based on the various uses of the land surface (Mundia & James, 2014; Xian & Crane, 2005). It primarily occurs as a result of the transformation of green areas (natural surfaces) into buildings (artificial surfaces).

Many studies have been led across the world to evaluate and simulate this connection in metropolitan settings using well-established methods and approaches (Renard, Alonso, Fitts, Hadjiosif, & Comby, 2019; Weng, 2001). However, the majority of the work has been directed in the developed countries with little attention being placed on developing countries experiencing huge population dynamics. Similarly, in Pakistan, very few studies have explored the association between LULC and LST, particularly in Lahore (Hussain & Karuppannan, 2021; Nadeem, Hameed, Basheer, Azam, & Ismail, 2015; Waseem & Khayyam, 2019). Lahore being the second-largest city in Pakistan and home to approximately 11 million people encounters the severe problem of air pollution due to accelerated urbanization, rapid economic growth, and a high level of migration. In November 2021, the city was ranked as the most polluted city worldwide for the consecutive second year. Moreover, heatwave has now become a frequent phenomenon in the major cities of Pakistan. Therefore, it is indispensable to investigate how land-use/land cover change has influenced the land surface temperature in Lahore. The precise assessment of LST and its Interrelation with LULC can be a key aspect in resolving many urban climatic issues. In this study, we have used satellite images from Landsat 5 and 8 for the years 1998, 2010, and 2021 to investigate the distribution and variation in LULC and LST. Moreover, this study also highlights the interrelation between LST and LULC.

The remainder of this paper is organized as follows: Section 2 explains the data sources and methodology used to explore the changes in LULC and LST in the study area. Section 3 represents the results of our analysis. The last section 4 of the paper provides insight into important findings of this research and concludes by recommending remedial measures to improve the situation.

## 2. MATERIAL AND METHODS

### 2.1. Study Area

This research is performed for the Lahore administrative area. Lahore is situated between 31°15′—31°45′ N and 74°01′—74°39′ E. The city has an estimated GDP of $84 billion in 2019 and spans over an area of 1772 sq. km. The city's urban population has grown by 116.3% from 5.14 million in 1998 to 11.12 million in 2017 (GOP, 2018). Lahore has already established itself as a megacity. However, if it continues to

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increase at its current rate, it will soon become one of the world's most crowded cities. Urbanization and influx of urban migration have strong effects on the urban expansion and economy including labor market opportunities, education, family structures, governance, and environment management. The expansion of the service sector has been the most noticeable element of urban growth in Lahore.

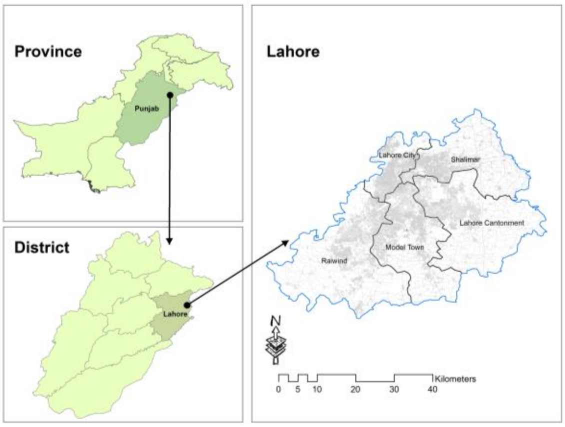


**Figure 1**. Location Map

## 2.2. Data Sources

This study uses spatial analysis and remote sensing (RS) techniques in geographical information systems (GIS) to estimate LST and LULC. The spatial distribution of LST and its association with LULC are studied using satellite images from Landsat 5 (TM) and 8 (OLI/TRS). Satellite imagery enables urban surface exploration and monitoring (Mallick, Kant, & Bharath, 2008). The temporal satellite imagery from Landsat 5 (TM) and Landsat 8 (OLI/TIRS) for the years 1998, 2010, and 2021 was obtained from USGS (https://earthexplorer.usgs.gov/) (Table 1).

| Sensor | Acquistion Date | Time (GMT) |
|---|---|---|
| Landsat 5 TM | 1998-07-28 | 05:14:55 |
| Landsat 5 TM | 2010-06-27 | 05:27:10 |
| Landsat 8 OLI/TIRS | 2021-06-09 | 05:36:23 |

**Table 1**. Landsat imagery description

## 2.3. Land use/land cover (LULC) Classification

In this research, the landsat imagery is classified into four LULC categories including built-up areas, soil, water bodies, and vegetation. A built-up area contains houses, roads, pavements, bridges, and other alike features. Waterbodies consist of rivers, lakes, etc. The vegetation category includes grasslands, trees, and fields that have not been developed yet (Achmad et al., 2022; Estoque & Murayama, 2012). LULC is identified using the Semi-Automated Classification (SCP) plugin, available in QGIS. A combination of the band is used for LULC classification. In this study, a band combination of 2,5,6,7 is used for Landsat 8 while a band combination of 1,4,5,7 for Landsat 5 (Yu et al., 2019). A supervised classification technique and 50 regions of interest (ROIs) were used for each LULC class. Spectral signatures are calculated for each region based on ROIs and subsequently, classification is performed using spectral angle mapping. The same imaging was also used to identify LSTs.

## 2.4. Land Surface Temperature (LST)

### 2.4.1. Brightness Temperature Calculation

The process of computing LST from landsat data entails transforming digital numbers (DNs) into light, subsequently used to calculate at sensor brightness temperature (Avdan & Jovanovska, 2016; Estoque & Murayama, 2017). The method employs formulas obtained from the USGS for estimating the top of atmospheric spectral radiance ($L\lambda$) (see eq. 1).

$$L\lambda = M_L * Q\text{cal} + A_L \tag{1}$$

Where $M_L$ is a band-related multiplicative rescaling factor, Qcal represents the thermal band image, and $A_L$ is the band-related additive rescaling factor.

Once the spectral radiance is obtained using DNs, the following equation (2) is employed to convert spectral radiance ($L\lambda$) to brightness temperature (BT).

$$BT = \frac{K_2}{\text{In}[\left(\frac{K_1}{L\lambda}\right)+1]} - 273.15 \tag{2}$$

$K_1$ and $K_2$ represent the constant for band-specific thermal conversion.

### 2.4.2. Emissivity Correction using NDVI

The brightness temperature have to be on a scale that takes into account the emissivity of surface materials to determine LST. The following expression (3) is used to estimate surface emissivity (Avdan & Jovanovska, 2016; Sobrino, Jiménez-Muñoz, & Paolini, 2004).

$$\varepsilon = m\, Pv + n \tag{3}$$

In this research, a value of 0.004 and 0.986 is used for n and m respectively (Achmad et al., 2022). $Pv$ represents the vegetation proportion as shown in eq. 4 and is extracted through normalized difference vegetation index (NDVI) (see 5).

$$Pv = \frac{(NDVI - NDVI_{min})}{(NDVI_{max} - NDVI_{\text{min}})^2} \tag{4}$$

$$NDVI = \frac{(NIR-RED)}{(NIR+RED)} \tag{5}$$

Where NIR = Band 5 and RED = Band 4.

Lastly, the LST is estimated using BT and surface emissivity. Eq 6 is used to calculate LST.

$$LST = \frac{BT}{1+\left(\lambda * \frac{BT}{\rho}\right)\ln \varepsilon} \tag{6}$$

Where $\lambda$ corresponds to the wavelength of light emitted; $\rho$ = h x c/δ, h represents Plank's constant (6.626 x $10^{-34}$ js), c represents the velocity of light (2.998 x $10^{8}$ m/s), and δ represent the Boltzmann constant (1.38 x $10^{-23}$ J/km) (Achmad et al., 2022; Avdan & Jovanovska, 2016).

| LULC | 1998-2010 | | 2010-2021 | | 1998-2021 | |
|---|---|---|---|---|---|---|
| | **LULC changes/ percentage (%)** | **Annual growth rate (ha/year)** | **LULC changes/ percentage (%)** | **Annual growth rate (ha/year)** | **LULC changes/ percentage (%)** | **Annual growth rate (ha/year)** |
| Built-up | 17970/11 | 1497.5 | 29280/18 | 2661.81 | 47250/29 | 2054.34 |
| Vegetation | -7300/-7 | -608.33 | -25960/-13 | -2360 | -33260/-20 | -1446.08 |
| Waterbodies | -13020/-6.5 | -1085 | -1973/-1.5 | -179.36 | -14993/-8 | -651.86 |
| Soil | 5210/4 | 434.16 | -11580/-7 | -1052.72 | -6370/-3 | -276.95 |

**Table 2**. LULC changes

# 3. RESULTS

## 3.1. LULC Change

Land use/land cover classification for 1998, 2010, and 2021 for the ROI are shown in Figure 2. Overall, there has been a transformation in all the land use types, where vegetation and water bodies were found to be on the decline, while built-up use grew significantly. The LULC classification indicated that between 1998-2010, an area of 7,300 hectares of vegetation was transformed to other land uses (84,290-76,990). The vegetation area further declined to 51,030 hectares in 2021.

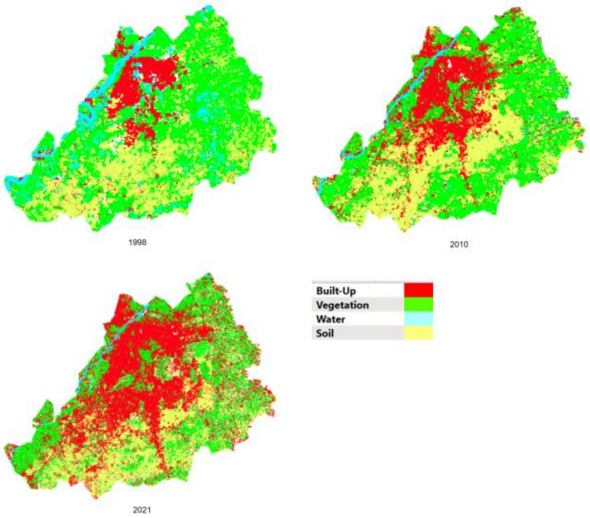


**Figure 2**. Land use classification 1998, 2010, and 2021

Similarly, there was a reduction in waterbodies from 16,610 to 1,617 hectares between 1998 and 2021. In contrast, the built-up has shown a considerable increment. In Lahore, the built-up area has increased from 17,930 hectares (10%) to 35,900 hectares (21%) between 1998 and 2010, while it has surged from 35,900 hectares (21%) to 65,180 hectares (39%) from 2010 to 2021. The land use/land cover transformation for the different time periods in Lahore are shown in Figure 3 and Table 2.

## 3.2. LST Change

The land surface temperature (LST) distribution in Lahore in 1998 varies from a minimum of 17.47ºC to a maximum of 34.46ºC. In 2010, LST has a minimum of 23.25ºC to a maximum of 40.69ºC. While in 2021, the LST values vary from a minimum of 26.32ºC to a maximum of 43.52ºC. The LST distribution in Lahore for each year is shown in Figure 4. In 1998, 2010, and 2021, the average LST was 26.52ºC, 32.87ºC and 37.40ºC, respectively (see Table 3). Overall there is an average increase of 0.47ºC per year between 1998 and 2021.

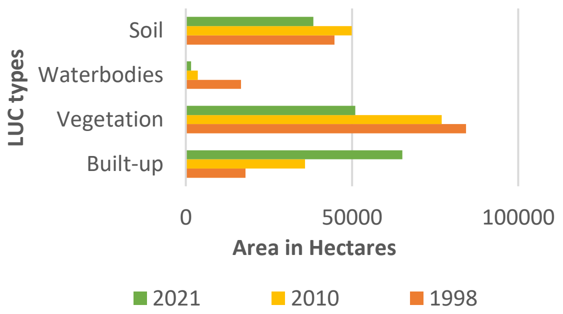


**Figure 3**. LULC area changes

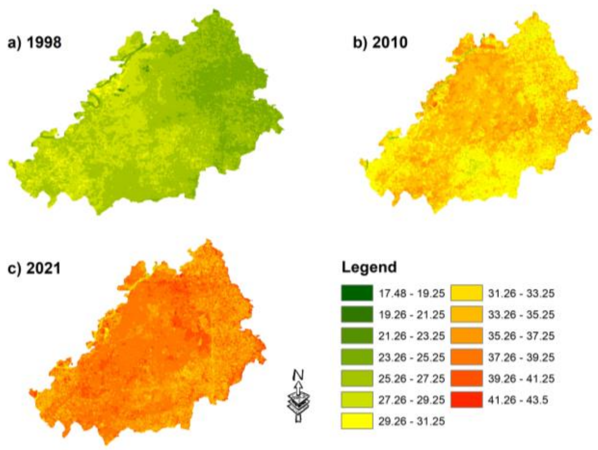


**Figure 4**. LST distribution in Lahore

## 3.3. Interrelation between LULC and LST

The variations in LULC and LST for different time periods are discussed in the previous sections. In this section, the interrealtion between LULC and LST in Lahore was investigated. Figure 5 displays the interaction plot between LST and LULC. The plot shows that each LULC category has a different effect on LST. The values for LST in built-up areas and soil has grown more quickly compared to other LULC classes.

| LULC | 1998 | | | 2010 | | | 2021 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Max | Min | Mean | Max | Min | Mean | Max | Min | Mean |
| **Built-up** | 32.46 | 24.89 | 27.57 | 40.50 | 27.93 | 34.20 | 42.30 | 29.34 | 38.23 |
| **Vegetation** | 31.65 | 23.63 | 26.00 | 38.90 | 26.86 | 31.82 | 41.10 | 28.23 | 35.99 |
| **Water** | 32.05 | 23.25 | 26.06 | 38.51 | 26.11 | 29.99 | 38.15 | 29.16 | 30.48 |
| **Soil** | 31.24 | 23.68 | 27.19 | 38.78 | 26.46 | 33.78 | 42.02 | 31.96 | 38.14 |

**Table 3**. LST changes for LULC classes

As disccused earlier the built up area has shown a significant increase between 1998 to 2021. The expansion of built area is alsp associated with an upsurge in land surface temperature. The mean LST value for the built-up area has risen from 27.57ºC in 1998 to 38.23ºC in 2021. This is due to the rapid development in the city. The effect of this urbanization can be observed on vegetation as it has been reduced by 20%.

This process of continuous land-use conversion is alarming and is the primary driver of urban heat islands (Roy et al., 2020). Similarly, other LULC categories including vegetation and water have also shown an increment in LST. However, the change in LST for vegetation and water is smaller compared to other land use classes.

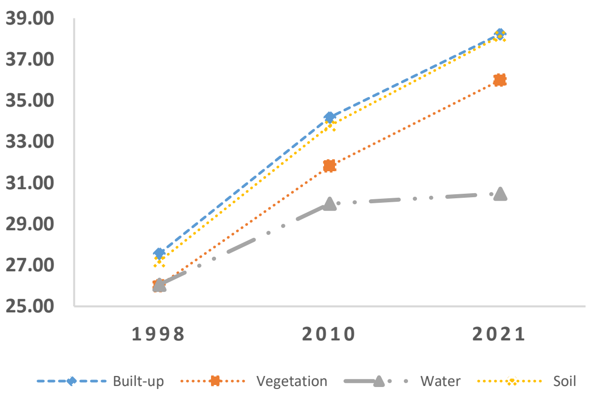


**Figure 5**. Interaction plot for LST versus LULC

## 4. DISCUSSION AND CONCLUSION

The built-up area in Lahore has grown enormously over the last two decades. Each year 1.26% of the land is being transformed into built-up area. Whereas, the area under vegetation use is diminishing at a quicker pace. The conversion of land use from vegetation to built-up has also escalated the land surface temperature (LST). The mean LST value in the city of Lahore has upsurged from 26.52ºC to 37.40ºC between 1998 and 2021 indicating an increase of 0.47ºC per year. In contrast, the association between LULC and LST implies that built-up regions observed the highest increase in LST while areas under water and vegetation have the least variation in LST values. This shows that heatwaves and Urban Heat Island (UHI) are mostly caused by uncontrolled urban growth, a constant loss of vegetation owing to urbanization, and an increase in the area covered by impermeable surfaces.

The prevailing trends indicate that if our cities continue to grow at the same pace, this would have serious ecological implications in the future. Thus, there is a need to incorporate LST variables for sustainable urban planning. Since urbanization and haphazard development is a prevalent phenomena in most cities of Pakistan, proactive planning and active implementation are essential to confront the challenges of urban sprawl. Urban planners and policymakers should take into account the necessity of minimizing urban heat islands (UHI) by introducing green materials in buildings and adopting a clustered greening idea at the urban level. Climate adaptive design at the community and building level could also help to improve the situation.

Urban development authorities should modify urban development plans to protect natural resources like water lands and prime agricultural land. Incrementing vegetation use is a lucrative method that could help to lessen the impacts of UHI in Lahore. Such areas can be fostered as parks, urban forests, playgrounds, along-road medians, and next to water bodies. One adaptation strategy on the level of the building is to use light colors for paint and construction materials with good emissivity (Kikon, Singh, Singh, & Vyas, 2016). In developing countries, a local and cost-effective strategy could be to paint roofs with clay. Nevertheless, measures at all levels of the urban hierarchy are indispensable to improving the situation.

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