Assessing Urban Heat Island Intensity and Thermal Field Variance in Faisalabad, Pakistan: An Ecological Monitoring Approach

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ABSTRACT

The analysis in this paper will be done using the Multi-temporal Landsat satellite images of the city of Faisalabad, a fast industrial city in Pakistan to understand the spatial and temporal dynamics of the Urban heat Island (UHI) effect in the city in 2015, 2020, and 2025. It is mostly used to quantify the changes in the Land Surface Temperature (LST), the variation in land cover in relation to the UHI intensity and to identify the thermal and ecological conditions using the Urban Thermal Field Variance Index (UTFVI). The remote sensing tools (NDVI) (NDBI) were used to measure the reduction of plant cover (between fragmented high-NDVI zones and dominant low-NDVI urban cores) in the research. The expansion of built-up areas is 1520 percent, thus the increase of LST in central areas will exceed 40-45 ^{O}C by 2025. The results show a broad variation of UHI intensification as 70 to 80 percent of the city lies within the worst three UTFVI categories, leading to the urban rural thermal increase of 10 to 15 ^{O}C. These changes, provoked by invulnerable surface development and loss of vegetation, worsen ecological stress, risks to health related to heat, and degradation of biodiversity. To reduce the impacts of UHI, as well as to provide more resilience to the cities in South Asia, the findings highlighted the importance of sustainable urban design, including land-use zoning and green alignment. The paper contributes to the Sustainable Development Goal of climate action and sustainable cities in Pakistan by providing a replicable approach to the analysis of UHI in similar urban settings.

Keywords: Urbanization, Urban Heat Intensity, Land use, Sustainable cities

INTRODUCTION

Urbanization can be viewed as one of the most prominent anthropogenic causes of local environmental alteration in the 21st century. Fast urbanization, industrialization and economic growth have changed natural landscapes into megalopolises, which change terrains and alter atmospheric climatic conditions and creating localized climate effects (Oke, 1982; Arnfield, 2003). The impact of urban climatic perturbation is by far the most pronounced effect on the level of microclimatic perturbation, which is the Urban Heat Island (UHI) phenomenon, where cities are characterized by a higher air temperature compared to rural areas. The primary cause of this process is the substitution of natural vegetation with absorptive substances, such as concrete and asphalt, which absorb and accumulate thermal energy (Voogt & Oke, 2003; Santamouris, 2015).

Increased UHI is causing significant problems to the sustainable urban life, such as a rise in energy consumption to cool the city, poor air quality, health hazards (e.g., heat-related diseases) and worsening of the ecosystem (Imran et al., 2015; Weng, 2009). The problem is compounded by urbanization, low green infrastructure and poor awareness of the people especially in developing countries such as Pakistan. As a major industrial city in Pakistan, Faisalabad is the third-largest city in the country to experience a rapid urbanization since 1980s through the growth of the economy. The result of this change has been a large-scale cover of land, loss of vegetation, and the spread of impervious surfaces, which increase the UHI effect (Shahid et al., 2012).

Although Faisalabad has developed into an industrial metropolis, changing an agrarian town, its urban planning and environmental protection has been trailing behind in the development. The expansion of residential, commercial and transportation areas has had an intense effect on the urban microclimate due to extreme changes in (LULC). Previously watered green areas, canals and farmland have been transformed into shrubberies and hedges along the streets. As a result, the land surface temperatures (LST) are significantly increased in high-density populated and industrialized areas at the expense of thermal comfort, biodiversity, water resources, and general livability in urban areas.

The existing literature on UHI in Pakistan has concentrated more on megacities (e.g., Lahore and Karachi) in the context of increased interest in the topic of climate variation and urban resilience (Imran et al., 2015; Iqbal et al., 2019). Nevertheless, mid-sized cities such as Faisalabad are under investigated in the context of UHI spatial variability and ecological effects, which makes it impossible to rely on evidence-based planning and stay consistent with Sustainable Development Goals, namely SDG 13 (Climate Action). In this paper, the authors have bridged these gaps through an evaluation of the spatial distribution of UHI in Faisalabad using geospatial and remote sensing methods. It recognizes UHI hotspots using multi-temporal satellite images and environmental indices and evaluates their association with the changes in LULC and suggests ecologically informed mitigation measures.

The study uses thermal remote sensing, NDVI mapping, and NBDI as methods to explain relationships between the structure of cities and surface temperatures. Findings are put in perspective with the socio-demographic profile of Faisalabad to determine the implications of the findings for the health and sustainability of urban areas. This work will offer a replicable framework on the UHI analysis in other fast urbanizing middle-tier cities by making contributions to the urban climatology literature in South Asia. Finally, the results will be used to enlighten local authorities, urban designers, and policymakers to include green infrastructure and strategic spatial planning to reduce the effects of UHI.

This study uses geospatial technologies and an ecological monitoring environment to evaluate the intensity of the Urban Heat Island (UHI) and the variance of the thermal field in Faisalabad. The goals consist of: To find out about the differences in land surface temperature (LST) over time and space. To examine the surface cover conditions and the impacted areas by urban heat islands (UHI). To use the Urban Thermal Field Variance Index (UTFVI) to look at Lahore's ecological and thermal conditions.

1.1. Literature Review

The unprecedented rate of global urbanization has triggered radical changes in land use/land cover (LULC), the encroachment of the impervious surfaces at the cost of urban green spaces (UGS) and thus aggravating the urban heat island (UHI) effect and raising land surface temperature (LST). The review is an empirical synthesis of literature on UGS mitigation of LST/UHI through remote sensing in Asia (China, Pakistan, India, Malaysia, Turkey, Bangladesh, Indonesia, Ethiopia, Iran), and also Singapore, Chile, Serbia, and Australia with respect to satellite imagery (Landsat, MODIS, Sentinel-2, Gaofen-1) and indices (NDVI, NDBI, LST algorithms). Scope narrows down to pre-2017, non-urban, or non-quantitative studies. Aggregate results indicate a negative NDVI-LST and positive NDBI-LST correlation, with cooling being strengthened by UGS area, complexity, aggregation, and the presence of water; there is strong literature development in the regions but weak in scale/seasonal disparities and absent socioeconomic factors.

The sources are systematically arranged in terms of their theme: (1) UGS cooling mechanisms/configuration, (2) LULC-LST spatiotemporal dynamics, (3) methodological/policy advances. Du et al. (2017) defined Shanghai Green Space Cooling Islands (GCI) based on Landsat 8 temperature amplitude/gradient, which conforms to thermal conduction and suggests bigger/complicated patches, minimized imperviousness, and water bodies, strong yet seasonally constrained. Yang et al. (2017) demonstrated seasonal Changchun cooling (non-winter) based on NDVI-area correlation with Landsat 8 TIRS composition vital, but validation sparse. Naeem et al. (2018) observed that Beijing/Islamabad vegetation makeup marginally outmuscles configuration in the LST reduction (Gaofen-1/Landsat-8), which recommends homogenous patches. Methods According to Aram et al. (2019), the meta-analysis approach resulted in the selection of over 10 ha parks with maximum cooling and regulated by natural/climatic factors. Masoudi and Tan (2019) linked Singapore UGS metrics (PLAND, SHAPE_AM, PD, ENN_AM; 1973–2015 Landsat) to lower LST via size/complexity/aggregation. Terfa et al. (2020) favored compact/connected Addis Ababa patches for LST minimization (Landsat fragmentation indices), scale sensitive. Masoudi et al. (2021) integrated Singapore land-use (2005–2015), showing pattern-cooling contingencies. Wang et al. (2021) introduced GEBI for multi-scale China UGS-LST assessment, prioritizing intra-urban greening.

Kim et al. (2017) linked Texas NDVI (MODIS) to reduced runoff/flooding via regression. Zaidi et al. (2017) validated NDVI vs. semi-supervised classification (80–82% accuracy) for Malaysia sprawl. Kumari et al. (2018) tracked Delhi vegetation decline/LST rise (2003–2017 Landsat; mono-window optimal). Atasoy (2018) projected Osmaniye fragmentation/45% urbanization by 2030 (NDVI/ULR). Pervaiz et al. (2019) exposed Lahore green loss (NDVI/TNDVI/DVI). Waseem and Khayyam (2019) correlated Islamabad 22–51% vegetation loss with 13–43°C/year LST (1992–2017). Nasar-u-Minallah (2020) affirmed Lahore NDBI-LST positivity/1.98°C warming (1990–2015). Rahaman et al. (2020) reported Mumbai green plummet (46.42% to 26.67%; LST hotspots 5,232–14,339 ha, 1988–2018). Moreno et al. (2020) assessed Temuco corridors (Sentinel-2 NDVI). Dutta et al. (2021) attributed Delhi NDVI decay to anthropic forces (1998–2013). Markovic et al. (2021) tied Belgrade NDVI/NDWI declines to LST (1991–2019). Guha et al. (2021) seasonalized Raipur NDBI-LST (r=0.72 post-monsoon; 1991–2018). Batool et al. (2021) noted Karachi suburban gains/core losses (2000–2016). Lotfata (2021) highlighted Qorveh green deficits. Dilawar et al. (2021) correlated Faisalabad indices with LST rise. Javid et al. (2021) tracked Lahore 42.21–49.51°C escalation (2015–2020). Aryal et al. (2022) mapped Victorian UGS hierarchically (Sentinel-2A; UGSI/PCGS). Jabbar and Mohd Yusoff (2022) quantified Lahore 392.78 km² loss/113.85% built-up (1990–2020). Halder et al. (2022) linked Kolkata-Howrah 8.62% decay to NDVI-LST weakening. Baqa et al. (2022) applied GWR to Karachi SUHII-LULC (2000–2020). Arshad et al. (2022) detailed Lahore union-scale reversals/SUHI hotspots. Sumarmi et al. (2022) tied Batu tourism shifts to temperature (2015–2020). Hasan et al. (2022) confirmed Mymensingh NDVI-LST negativity/seasonal peaks. Degefu et al. (2023) modeled Ethiopian UGS morphology-conditional cooling (1990–2020). Przeździek and Zawadzki (2023) innovated Warsaw soil moisture (TVDI). Miah et al. (2023) noted Chittagong greening amid 0.95°C warming. Patel et al. (2024) reviewed LULC-LST-thermal comfort, endorsing vegetation/albedo. Tahir et al. (2025) documented Multan 130.54% built-up/3.5°C LST rise (1994–2024; UTFVI stress). Ghiasvand Nanji (2025) correlated Qom UHI with NDVI (-0.801)/residential (0.719).

Early works establish correlations, mid-period configuration, recent projections/indices (e.g., GEBI, hierarchical classification)—evidencing UGS reversal of urbanization's thermal cascade; policies urge corridors, afforestation, zoning, though economic gaps persist.

UGS unequivocally dampens LST/UHI via expansive/connected configurations, countering impervious-driven 1–5°C escalations and 20–50% green losses; NDVI-LST negativity and NDBI positivity consistent. This justifies proposing multicity longitudinal research with high-resolution imagery, machine learning, and socioeconomic integration to model scalable interventions, addressing cost-equity-governance gaps for resilient urban planning.

2. MATERIAL AND MEATHODS

2.1. Study Area

The city of Faisalabad is situated in the Rechna Doab upland, in the east-central region of Pakistan's Punjab province. It serves as the district's headquarters and is one of Punjab Plain's primary distribution hubs, with easy access to Multan, Lahore, and Karachi via air, rail, and road (Fig.1).

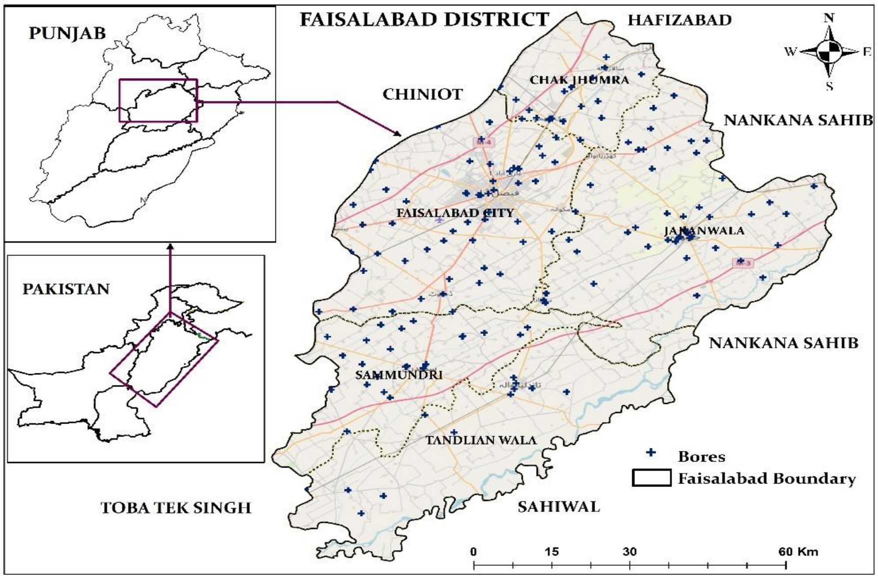

Figure 1: Area of Interest Map of Faisalabad

2.2. Research Design

This study adopted a quantitative, spatio-temporal approach using multi-temporal remote sensing data for the years 2015, 2020, and 2025. All analyses were performed using ArcGIS Pro 3.2 and Landsat 8 OLI/TIRS Collection 2 Level 1 and Level 2 data.

2.3. Satellite Data Acquisition

Three cloud-free (<5% cloud cover) Landsat 8 OLI/TIRS scenes (Path 150/Row 37) acquired during the peak summer months (June–July) were selected to ensure comparability and to capture maximum thermal contrast (Table 3.1).

Year	Acquisition Date	Satellite/Sensor	Cloud Cover (%)	Data Type
2015	29 June 2015	Landsat 8 OLI/TIRS	1.24	Collection 2 Level 1 & Level 2
2020	24 June 2020	Landsat 8 OLI/TIRS	0.86	Collection 2 Level 1 & Level 2
2025	17 June 2025	Landsat 8 OLI/TIRS	2.13	Collection 2 Level 1 & Level 2

All images were downloaded from USGS Earth Explorer.

2.4. Pre-Processing

- Multispectral bands (2–7) were used as Collection 2 Level 2 surface reflectance products (already atmospherically corrected using LaSRC).
- Thermal Band 10 was used as Collection 2 Level 1 thermal data.
- All bands were layer-stacked, re-projected to UTM Zone 42N (WGS84), and clipped to the Faisalabad District boundary.
- Image enhancement (2% linear contrast stretch) was applied for visual interpretation.

2.5. Derivation of Normalized Difference Vegetation Index

NDVI was calculated using surface reflectance bands (Rouse et al., 1974):

$$NDVI = \frac{\rho_{Band\,5} - \rho_{Band\,4}}{\rho_{Band\,5} + \rho_{Band\,4}}$$

where ρ Band5 and ρBand4 are surface reflectance of near-infrared and red bands, respectively.

2.6. Derivation of Normalized Difference Built-Up Index

Built-up areas were mapped using (Zha et al., 2003):

$$NDBI = \frac{\rho_{Band\,6} - \rho_{Band\,5}}{\rho_{Band\,6} + \rho_{Band\,5}}$$

2.7. Land Surface Temperature (LST) Retrieval

LST was retrieved from Thermal Infrared Sensor (TIRS) Band 10 using the Single-Channel (SC) algorithm (Jiménez-Muñoz et al., 2014; USGS, 2021; Malbéteau et al., 2017). The detailed steps are as follows:

Step 1: Conversion of DN to Top-of-Atmosphere Spectral Radiance

$$L_\lambda = M_L \times DN + A_L$$

where M_L= 3.3420 × 10^{-4} and A_L= 0.10000 (values from metadata).

Step 2: Conversion to At-Sensor Brightness Temperature (TB)

$$T_B = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda} + 1\right)}$$

For Landsat 8 Band 10: K_1= 774.8853 W/(m²·sr·µm), K_2= 1321.0789 K.

Step 3: Estimation of Land Surface Emissivity (ε) using NDVI Thresholds Method (Sobrino et al., 2004) Proportion of vegetation (P_v):

$$P_v = \left[\frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}}\right]^2$$

where $NDVI_{min} = 0.2$and $NDVI_{max} = 0.5$.

Land surface emissivity was assigned as:

$$\varepsilon = \begin{cases} 0.973 & NDVI < 0.2 \\ 0.004 \times P_v + 0.986 & 0.2 \leq NDVI \leq 0.5 \\ 0.990 & NDVI > 0.5 \end{cases}$$

Water bodies (manually masked) were assigned ε = 0.995.

Step 4: Final LST calculation

$$LST = \frac{T_B}{1 + \left(\frac{\lambda \times T_B}{\rho}\right)\ln(\varepsilon)} - 273.15$$

where λ = 10.895 µm (central wavelength of Band 10) and ρ = h × c / σ = 1.4388 × 10^{-2} m·K. LST is expressed in °C.

2.8. Urban Heat Island (UHI) Intensity

Urban areas were defined as pixels with NDBI > 0. Rural/reference areas were selected as high-vegetation zones (NDVI > 0.6) located outside the main urban continuum.

2.9. Urban Thermal Field Variance Index (UTFVI)

The Urban Thermal Field Variance Index was used to quantitatively evaluate urban ecological quality (Zhang et al., 2006; Liu & Zhang, 2011):

$$UTFVI = \frac{LST - T_{mean}}{T_{mean}}$$

3. RESULTS

3.1. Dynamics of Land Surface Temperature Change

3.1.1. LST Variation in 2015

The Faisalabad region is depicted on Figure 2, which shows the regional distribution of Land Surface Temperature (LST) derived from the 2015 Landsat data analysis. Large patches of red indicate higher LST, which is highest in the central and southern parts of Faisalabad. This suggests increased UHI impacts, which may be brought on by limited vegetation cover and high levels of urban growth. A transition zone between urban and rural areas is indicated by the orange-colored middle LST values that are dispersed around the city.

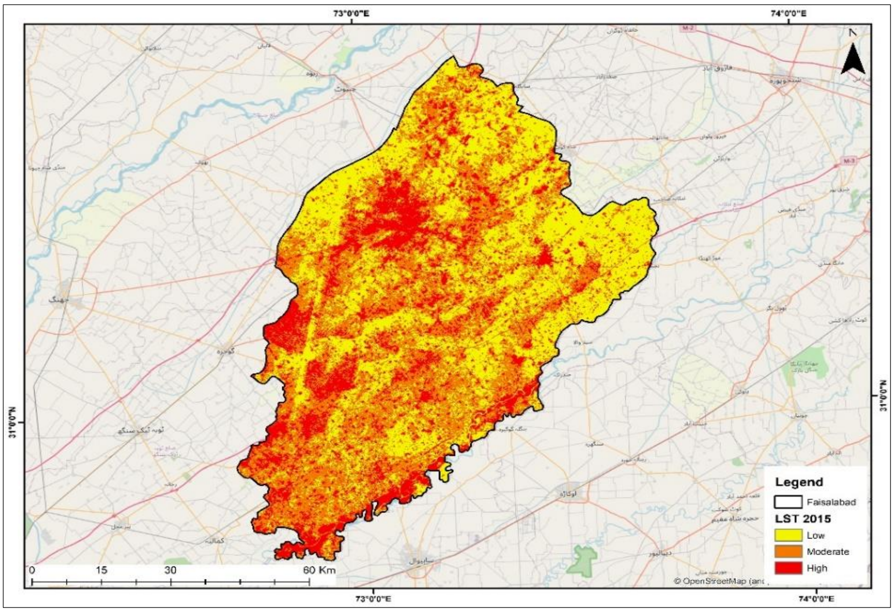

Figure 2: LST map of Faisalabad, 2015

The low LST values that are depicted by the yellow color are mainly found in the north and west periphery that are the areas of agricultural land and water bodies that contribute to the cooling of the temperatures. The rural regions surrounding the city boundaries exhibit the least values of LST that depict the cooling influence of natural environments. This trend indicates the influence of land cover on LST, with metropolitan regions having higher temperature than the vegetated or irrigated ones.

4.1.2. LST Variation in 2020

Figure 3, which is based on the Landsat thermal band, shows how the Land Surface Temperature (LST) was spread out in Faisalabad in 2020 at the regional level. Most of the city center and southern parts have very high LST values, as shown by the large number of red areas. This shows that there is a big urban heat island (UHI), which is probably caused by a lot of dependence on city infrastructure and not enough green space. The intermediate LST is depicted by the orange value that forms a transition zone between the center of the high-temperature zones and an area where the land use of the urban and semi-urban regions intersects.

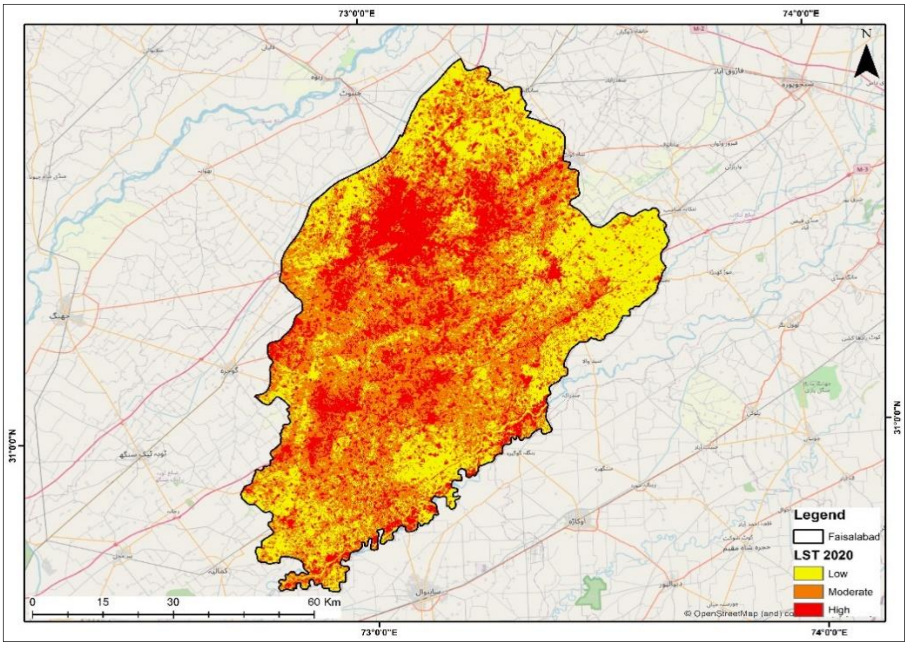

Figure 3: LST map of Faisalabad, 2020

This is because there would be some vegetation or open space to cool things down. The yellow LSTs are the lowest to the north and west. This implies that the cooling effect is assisted by the country side, the place of agriculture land, and water bodies such as the Chenab River. UHI effect is the most effective near the center of the city and the least at the edges.

The LST is the lowest in the rural territories beyond the city boundaries, which demonstrates the difference between cities and the natural environment surrounding them.

3.1.3. LST Variation in 2025

The map of Faisalabad 2025 relies on the Landsat thermal band to demonstrate the distribution of the Land Surface Temperature (LST). The central, southern, and eastern regions are huge as indicated by the red numbers. It is very likely that these regions have a high number of urban houses and thus the temperature might be over 40 to 45 degrees Celsius. Between 35 and 40 C, orange mild LST bands are observed with a lower transition zone around the core. In this belt, there are some green spaces, and the belt comprises of other kinds of land use. Yellow lower LST may also occur in certain areas (in the north and northwest) which are near to farmland, and the temperature is below 35C. This makes the Chenab River cooler, but not as much as it used to because more people are moving to cities. The temperature difference between the city and the countryside is 5–10 C, making the countryside the coolest place. This shows that the temperature is very different in cities and the country. The fact that 70–80 percent of the city has high LST growth shows that urban heat islands have a bigger effect because there are a lot of surfaces that can't be penetrated and plant roots. This poses an ecological risk of heat stress to inhabitants and biodiversity, reducing agricultural land, and necessitating the implementation of green measures to mitigate the impact.

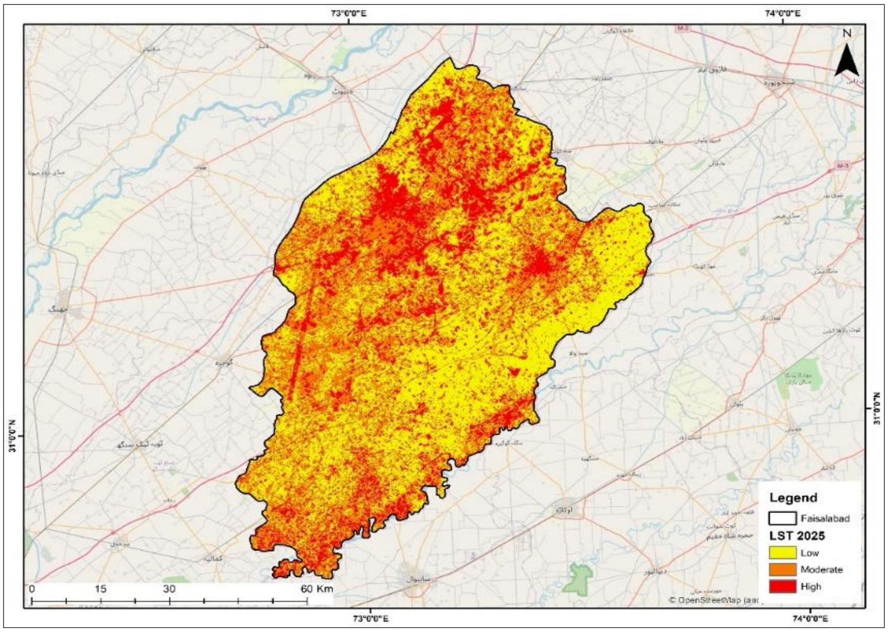

Figure 4: LST map of Faisalabad, 2025

4.2. Land Use Indices

Figure 4 shows a land-use indicators analysis between 2015 and 2025. This is to see how the land cover in Faisalabad has changed over time and space. The NDVI and NDBI have been used to track how much vegetation has grown and how cities have grown. The NDVI was used to figure out how much greening there was and where the dense vegetation was. The NDBI was used to figure out how much urbanization there was and how hard surfaces spread. All these numbers show how fast cities are growing and how that makes LST and UHI worse. The results show some interesting geographical patterns that are very important for environmental analysis and sustainable urbanism. These results show that there are some important spatial patterns that can be used in environmental management and sustainable urban development.

32.1 Analysis of vegetation distribution and cover patterns in 2015

The 2015 NDVI spatial distribution in Faisalabad, which represents differences in vegetation density throughout the study region, is displayed in Figure 5. The map's high-vegetation areas (shown in dark green) are primarily found in the northern and southern edges, which are the primary indicators that most of the land is made up of agricultural land with a little amount of green space. Between these agricultural areas, there is a reasonable amount of vegetation (light green), while the parts that are semi-urban have less vegetation (yellow).

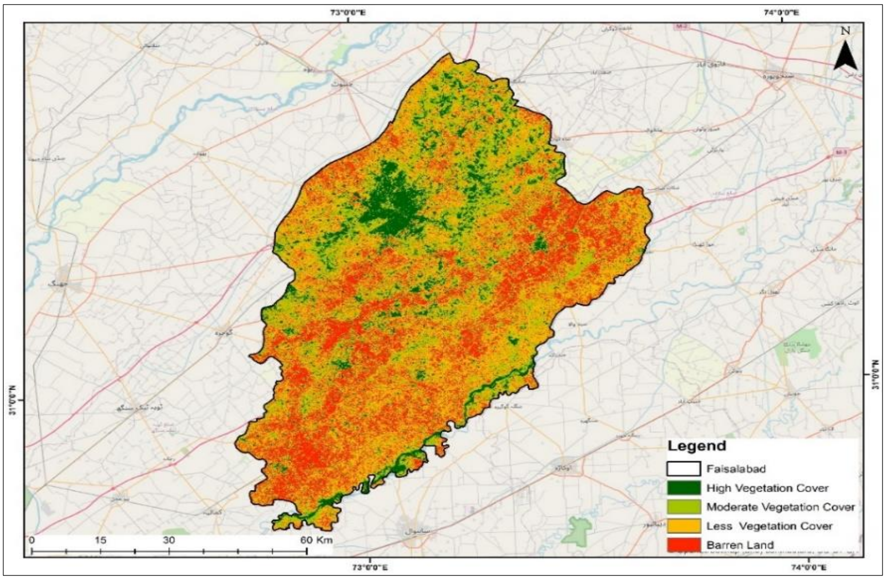

Figure 5: Spatial distribution of NDVI in Faisalabad, 2015

The city center's extremely low NDVI, which is represented by the color's orange and red, indicates that there is a lot of built-up area and little vegetation. These small NDVI areas are associated with large population centers, commercial centers and industries and reduce green areas. The general trend indicates that there is a high vegetation gradient between the peripheral rural regions and urban centre and therefore the processes of urbanization and land shifting will have the effect of ensuring that the vegetative covering process will gradually reduce.

3.2.2 Analysis of vegetation distribution and cover patterns in 2020

A map of Faisalabad's (NDVI) in 2020 is displayed in Figure 6, and it is evident that the vegetation cover has degraded from 2015. The NDVI (dark green) values on the northern side of the study region are rather high, indicating the presence of agricultural fields and healthy vegetation. However, these green spaces are perceived as being smaller and more fractured. A further indication that agricultural and open lands are transitioning to urban and semi-urban areas is the decrease in light green areas of moderate vegetation, particularly near the urban fringe. There has been a significant increase in the non-green area, which denotes drier ground and decreased vegetation cover, especially in the central and southern metropolitan centers.

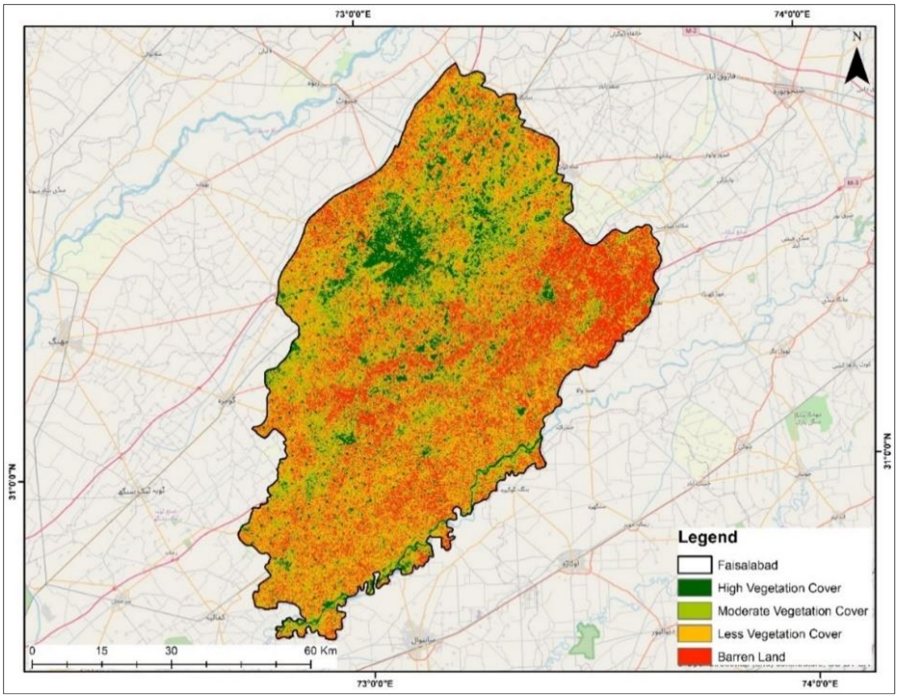

Figure 6: Spatial distribution of NDVI in Faisalabad, 2020

3.2.3 Analysis of vegetation distribution and cover patterns in 2025

In 2025, Figure 7 shows how the Normalized Difference Vegetation Index (NDVI) is spread out in Faisalabad. This shows that the amount of vegetation cover has changed a lot over the years. The picture shows that the dark green high vegetation cover at the first two points is still mostly on the northern edge and a few small areas in the south. But it's clear that the area it covers has gotten a lot smaller since the study began. The light green areas with some plants have been broken up, which means that construction sites have taken over semi-natural and agricultural fields. But as cities get bigger and their infrastructure gets better, there is a lot barer land and poor vegetation cover (orange and red) in and around the city center. The upward trend shows that Faisalabad's green spaces will keep getting smaller from 2015 to 2025. This is probably because rising temperatures are affecting the land's surface, the loss of ecological stability, or the severity of urban heat islands. The spatial pattern shows that the city has grown too big for the plants to keep up with, especially on the east and central sides.

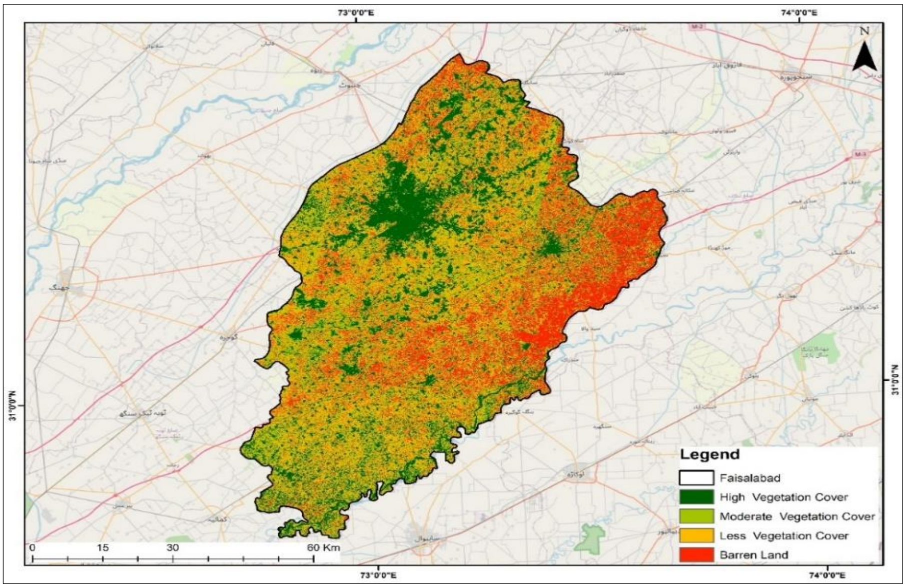

Figure 7: Spatial distribution of NDVI in Faisalabad, 2025

4.3. Trend Analysis of Built-up Expansion

According to the general tendencies in the evolution of NDBI in the period of 2015 to 2025, it is characterized by the rapid urbanization process and the active migration of natural land surfaces into non-porous built-up infrastructure. This trend is very appropriate for the observed rises in UHI levels and land surface temperatures. With increasing surface constructions, the surface can store more heat, and this reduces the evapotranspiration and alters the local thermal field. The outcomes indicate the role of green spaces and sustainable city planning in supporting the heat stress in Faisalabad in the short term.

4.3.1. Spatio-Temporal Dynamics of Built-Up Areas, 2015

The satellite information generated a map of Faisalabad that was utilized in 2015 to show the NDBI value on the map shows that the central and southern parts of the city have a lot of high NDBI value. This is because there is a great number of cities and surfaces that do not permit any water to reach through them like houses and factories. To some extent there is already some urban development in these regions as they are close to the major roads like M-3 motorway. Along the north, west and eastern borders, it has green areas such as moderate and low NDBI (as low as -0.242367). They have an open space; agricultural land and effects of Chenab river that make them look like an illustration of mixed land use (more natural surfaces). NDBI has the lowest values in rural areas (Figure 8) not around cities where there are small populations and large farms**.**

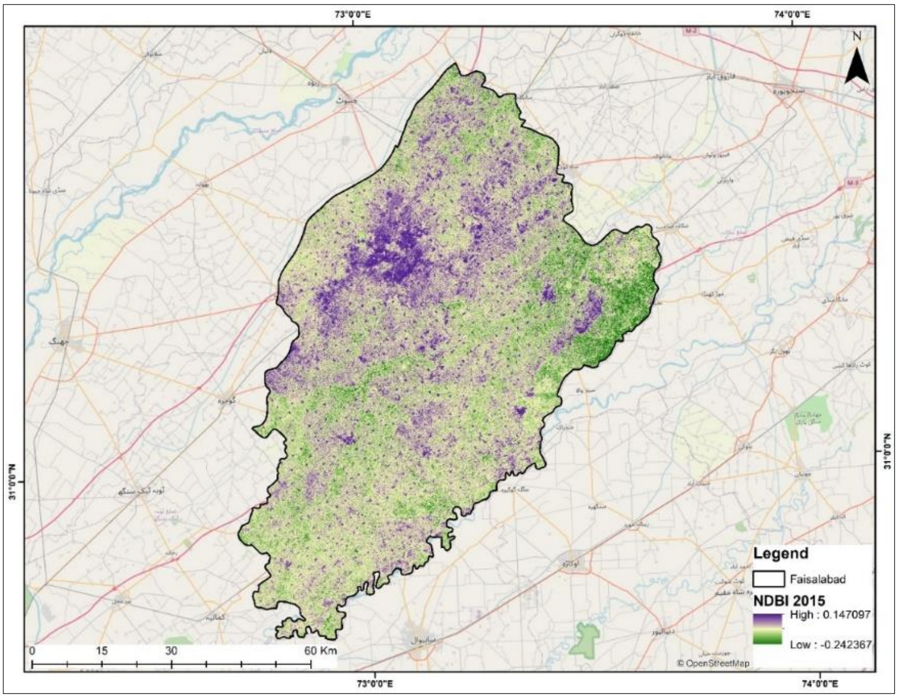

Figure 8: Spatio-Temporal distribution of NDBI in Faisalabad, 2015

3.3.2. Spatio-Temporal Dynamics of Built-Up Areas, 2020

A more geographical picture of the expansion of built-up regions may be found in the 2020 Faisalabad satellite image map, also known as the

Normalized Difference Built-up Index (NDBI) map (Fig. 9). The data shows that the coverage of impervious surfaces has significantly increased, with the center, south, and east having the highest NDBI values (reaching 0.230502). These zones, which are identified by their purple color coding, are characterized by increased urbanization, whether it be residential, commercial, or industrial, and they have substantial extensions towards important transportation networks like the M-2 and M-3 motorways. The built-up area has increased by 10–15% since 2015, which is a sign of significant urban sprawl brought on by population growth and economic activity. The moderate to low NDBI scores are shown in green, while the high NDBI center (with a score of -0.273823) is progressively confined to the north, west, and a few regions in the east. These regions, which are linked to the Chenab River's cooling effects, open spaces, and agricultural lands, indicate a decline in natural and vegetated areas as compared to 2015. Urbanization is strongly encroaching on the already ruralized environment, as seen by the narrowing of this transitional zone. The city still has the lowest NDBI values, although rural areas—which are mostly made up of farmlands and sparsely populated areas—still differ greatly from the urban core.

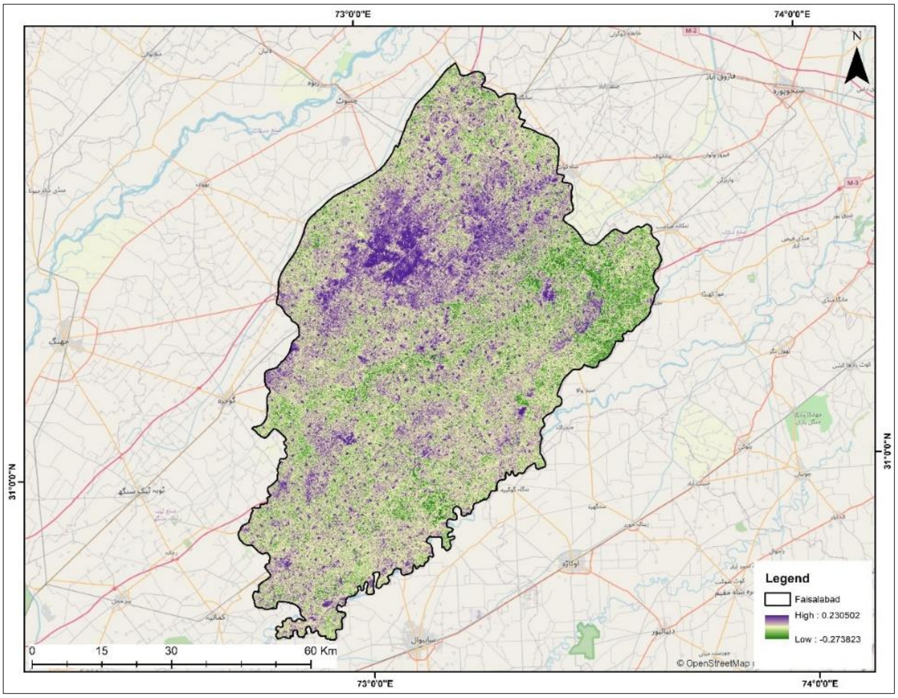

Figure 9: Spatio-Temporal distribution of NDBI in Faisalabad, 2020

3.3.3. Spatio-Temporal Dynamics of Built-Up Areas, 2025

The Built-up Index Normalized Difference figure for Faisalabad shows a satellite view of the city as of 2025. The Built-up Index (NDBI) map (Fig. 10) shows comprehensive satellite data about the expansion of built-up areas in the city. The stark extent of urbanization and its effects on local land use and heat activities are described in this debate. The NDBI values up to 0.210585 are widely distributed across Faisalabad, particularly in the eastern, southern, central, and some western regions. The impervious built-up landmass, residential, commercial, and industrial areas have significantly increased in these locations, and the major thoroughfares such as the M-2 and M-3 motorway are giving priority to this growth. The fact that the purple areas are now noticeably denser than they were in 2020 suggests that the area solid will rise by about 15–25%, which supports the results of urban sprawl brought on by economic and demographic drivers.

The moderate to lower NDBI values are gradually pushed to the north and northwest margins surrounding the high NDBI core, reaching their lowest of -0.252699 and shown in green. These areas, which are connected to open spaces, agricultural areas, and the Chenab River's buffer effect, suggest that natural and vegetated surfaces have continued to decline since 2020. This green belt's shrinkage demonstrates how unregulated rural landscapes gradually transform into urban landscapes, leaving behind only fragments of nature.

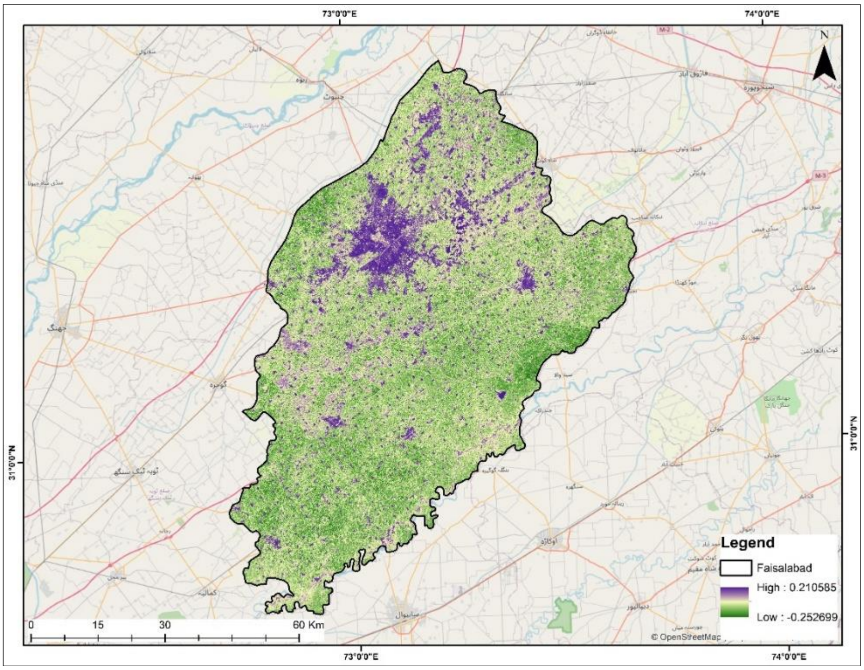

Figure 10: Spatio-Temporal distribution of NDBI in Faisalabad, 2025

3.4. Urban heat island intensity

3.4.1. Spatio-Temporal Variation of UHI Intensity, 2015

The 2015 Faisalabad Urban Heat Island (UHI) intensity map shows how hot it is and gives comments on the city's thermal situation and its effects on the environment. The orange and red zones in the middle and southern parts of Faisalabad, respectively, show that UHI will be high and very high there (Fig. 11). These areas, which include the city center, have a lot of buildings, little greenery, and concrete or asphalt coverings, all of which help them hold onto heat. These areas of extreme heat are found along major transport corridors such as the M-3 motorway. They demonstrate how the growth of cities increases temperatures in the region. There are yellow moderate areas of UHI where there is moderate heat. These areas are distributed at and around the city center. More likely to be mixed-use, containing a few plants or not, these places allow the heat to remain low. The blue and green colors with the least UHI are in the north and west periphery which are associated with farming, open spaces and cooling of the Chenab River. Although they are smaller than the territory of the warmer city, they are colder, and this implies that it is a superior thermal situation. Outside urban areas, there are large farmlands with low density community and very low to low intensity UHI. They are colder there, as there are more plants, and fewer surfaces that do not permit water to pass.

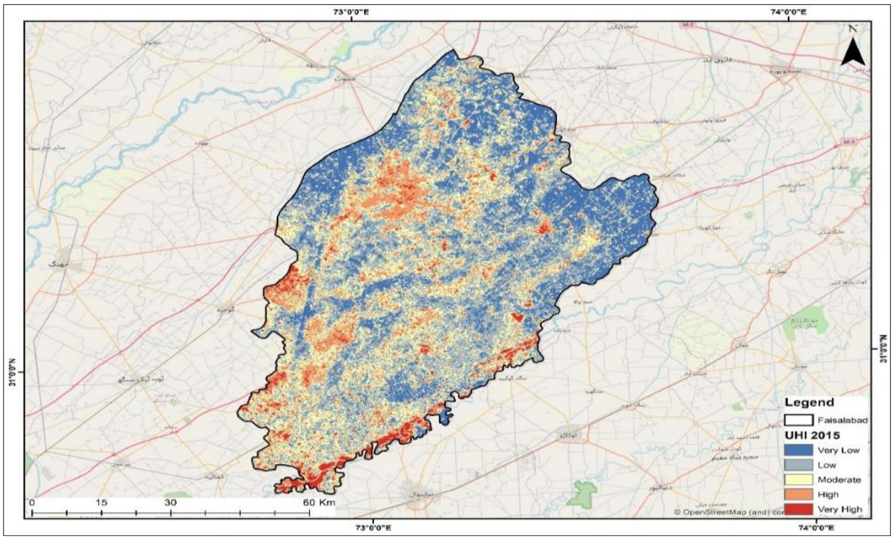

Figure 11: UHI Intensity Patterns in Faisalabad, 2015

4.4.2. Spatio-Temporal Variation of UHI Intensity, 2020

The 2020 Urban Heat Island (UHI) intensity map of Faisalabad looks at how heat is spread across the city. This has ecological effects and gives us clues about how the thermal landscape is changing in cities. The orange and red areas, which show high and very high levels of UHI, are what make up the main, southern, and eastern parts of Faisalabad (Fig. 12). These areas, which include the core city and the surrounding areas, have a lot of built-up surfaces, little vegetation, and a lot of impermeable surfaces, like roads and buildings. This means they have a lot of heat. The growth of these hot spots since 2015, especially along major roads like the M-3 motorway, suggests that cities are growing more quickly and that thermal stress is rising as a result. The city center is surrounded by transitional belts with yellow mild UHI zones. These zones show the average temperature and are most likely caused by mixed land use zones with open areas or partial vegetation cover that help reduce the effects of heat. The loss of blue and green areas, which can be seen as very low and low UHI intensity, is linked to farmland, open space, and the cooling effect of the Chenab River. This happens in the north and west. The fact that these colder areas are now smaller than they were in 2015 shows that cities are still growing into rural areas. Rural areas usually have very low, low, or even lower UHI intensities than cities because they have a lot of farmlands, few settlements, more vegetation cover, and fewer areas that can't be penetrated. The central and eastern zones have the worst temperature conditions. The difference in temperature between the city center and the rural edge shows how strong the UHI effect is.

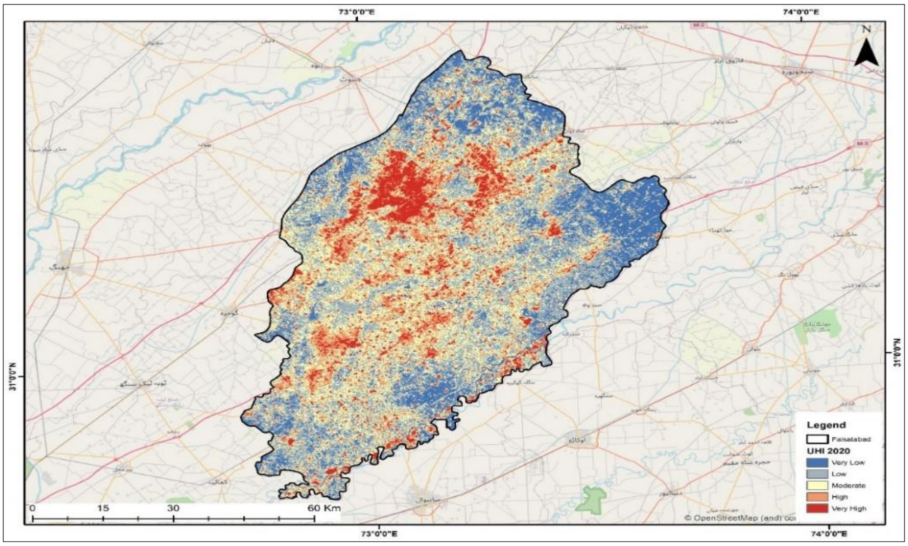

Figure 12: UHI Intensity Patterns in Faisalabad, 2020

3.4.3. Spatio-Temporal Variation of UHI Intensity, 2025

The Urban Heat Island (UHI) intensity map of Faisalabad in 2025 shows how heat intensity changes over time. This is important for understanding the city's thermodynamic environment and its effects on the environment. The main, southern, eastern, and some western parts of Faisalabad are mostly orange and red, which means that the UHI is very high and high (Fig. 13). The areas, which include the city center and the much larger outskirts, show a high level of heat energy concentration because there are a lot of built-up surfaces, no plants, and a lot of non-porous materials like concrete and asphalt. About 70–80% of the city's limits are cat-critical areas. Their strong effect on these hot spots, especially on important roads like the M-2 and M-3 motorways, shows a big increase in urban growth and thermal nuisance compared to the past. There are yellow areas around the urban core that show moderate UHI and make a much narrower transition zone. This means that the mixed land use zones are only moderately hot because they still have some plants or open areas that can be used to cool down the space. Bluish green and green segments that show very low and low levels of UHI are becoming less common in the north and northwest, in line with the Chenab River's cooling, open spaces, and remaining farmland. The big loss of these colder areas since 2020 shows how quickly urban growth is taking over rural areas. Rural areas outside of cities still have very low to low UHI intensities because there aren't many settlements, there is a lot of farmlands, there are a lot of plants, and there aren't many surfaces that can't be penetrated. The central and eastern regions have the worst thermal conditions, so the UHI effect is even stronger because the temperature difference between the city and the countryside is so great.

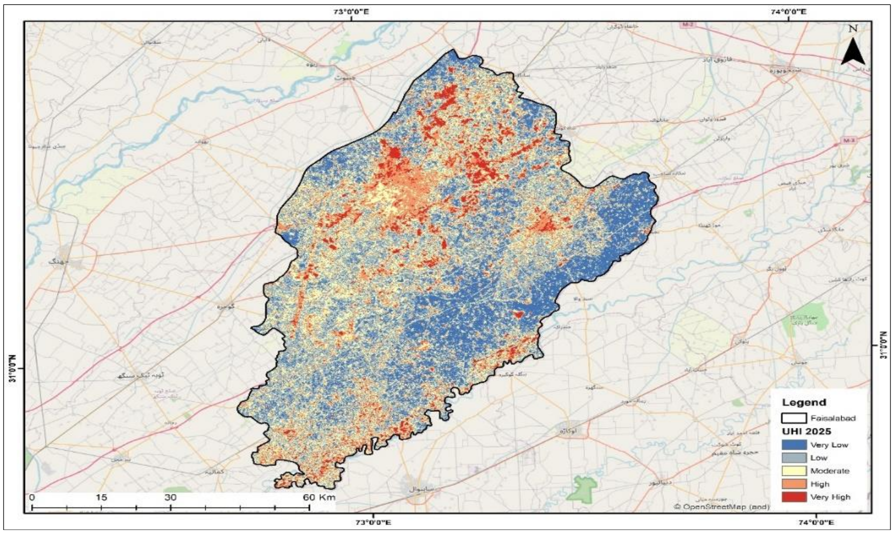

Figure 13: UHI Intensity Patterns in Faisalabad, 2025

3.5. Ecological assessment of UTFVI

3.5.1. Spatio-Temporal Distribution of UTFVI in 2015

Figure 14 displays the map of Urban Thermal Field Variance Index (UTFVI) of Faisalabad in 2015. It provides a geographical image of the biological and thermal environment of the study area. The following discussion analyzes the allocation of thermal field change, explaining the impact of urban heat island (UHI) and its ecological implication. The red and orange patches in the central and the southern part of Faisalabad are very critical as they depict the worst and poor UTFVI. Such areas that constitute a great portion of the urban center exhibit great overheating and deficiency of ecological quality since they contain numerous amounts of heat and already occupied area and cultivated vegetation are saturated. The fact that these high-stress areas are adjacent to major transport infrastructure such as M-3 motorway is due to the early urban development that altered the dynamics of heat. The blue and gray areas indicating the good and normal UTFVI types are distributed throughout the middle of the city and more so on the northern and western sides.

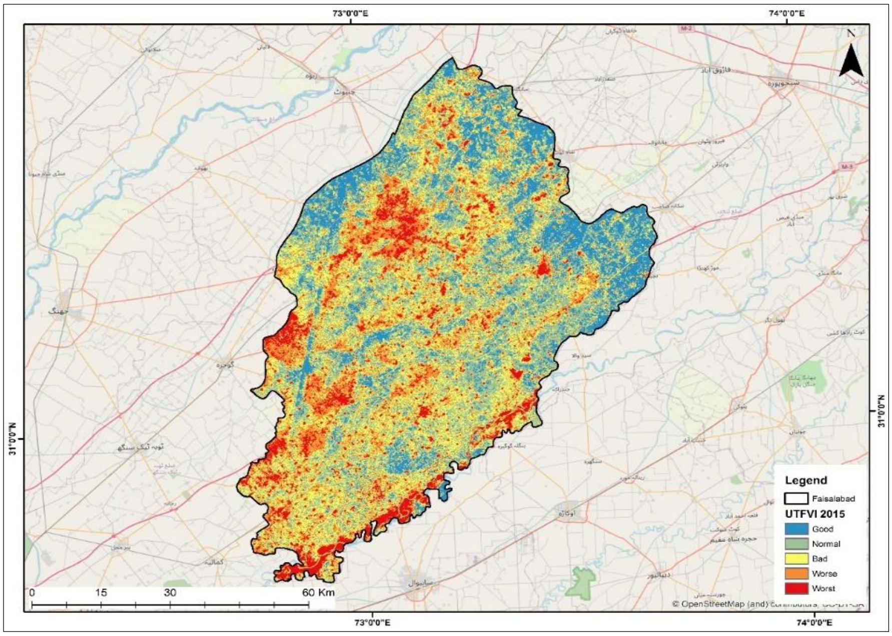

Figure 14: Spatio-Temporal Distribution of UTFVI in Faisalabad, 2015

The thermal gradient variance in these areas is also less and is attributed to large open spaces, agricultural land and cooling of the Chenab River and its tributaries. They are smaller cooler patches that indicate that the heat stress is slightly lower, but the more highly stressed areas conceal it. The central high-stress areas are enclosed by the yellow bad UTFVI zone of transition. It demonstrates that there are certain ecological issues of minor nature. The greatest thermal variance is the least outside the city areas. The reason behind this is that there are numerous farms and few people hence this ensures that the ecology is content with improved conditions. Such spread proves that the power of the city upon the periphery is gradually dwindling.

4.5.2. Spatio-Temporal Distribution of UTFVI in 2020

Based on satellite data, the 2020 Urban Thermal Field Variance Index (UTFVI) map for Faisalabad (Fig. 15) provides a regional evaluation of the thermal and ecological conditions throughout the research area. In addition to presenting data on the shifting impact of urban heat islands (UHIs) and their environmental implications, this study investigates the distribution of thermal field variance. The central, southern, and eastern regions of Faisalabad are dominated by red and orange sections, which represent the worst and bad UTFVI, respectively. Due to an increase in built-up areas, a decrease in greenery, and an increase in heat-reflecting surfaces, these spaces—including the urban center and the surrounding peripheral areas—imply an ecologically poorer environment and an intensification of thermal pressure. Compared to 2015, their expansion in high-stress locations along important corridors with the M-3 motorway is an indication of accelerated urban sprawl.

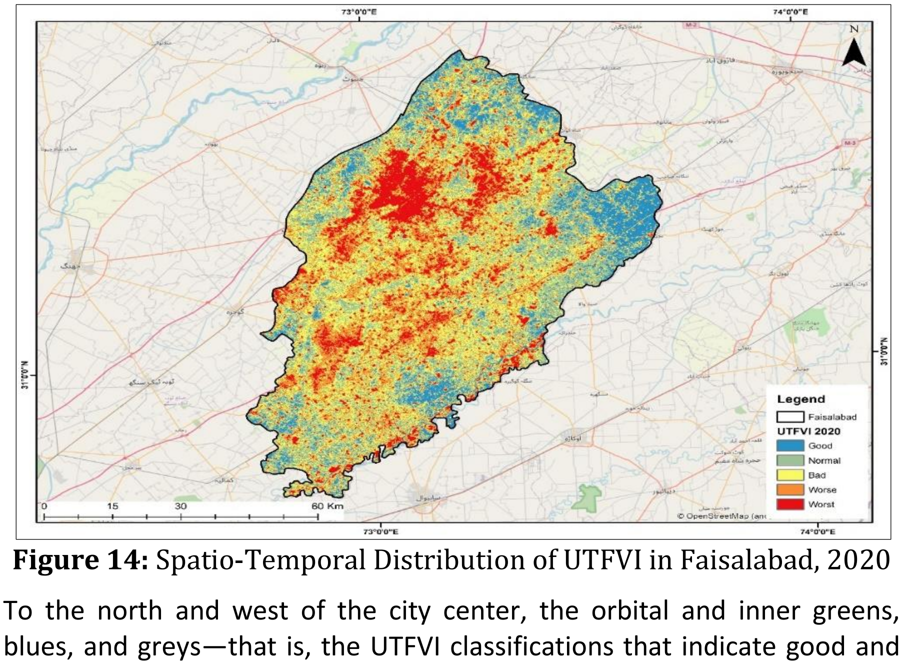

Figure 14: Spatio-Temporal Distribution of UTFVI in Faisalabad, 2020

To the north and west of the city center, the orbital and inner greens, blues, and greys—that is, the UTFVI classifications that indicate good and normal—become cleared out. The Chenab River's cooling impact, open spaces, and agricultural areas are associated with minimal thermal variance. The fact that there are fewer of these cooler places now than there were in 2015 suggests that people are less able to withstand heat stress as urbanization supplants natural landscapes. Yellow patches that form a more constrained transition band around the high-stress zone indicate bad UTFVI, which indicates moderate difficulties with ecological and thermal issues. This tendency highlights a gradient where urban thermal influence gradually decreases at the city's edges. With their vast agricultural grounds and sparse populations, rural locations outside of metropolitan areas have the least amount of thermal variance, which leads to more favorable ecological circumstances.

3.5.3. Spatio-Temporal Distribution of UTFVI in 2025

According to satellite data, the Urban Thermal Field Variance Index (UTFSI) map of Faisalabad in 2025 offers a geographical analysis of the thermal and ecological situation in the area of the research (Fig 16). This method allows analyzing the ecological implications of urban heat island (UHI) aggravation by evaluating the heat variance distribution. The red and orange areas are the worst and bad UTFVI areas that are mostly located in the central, southern, eastern, and part of the western parts of Faisalabad. The areas, including the center city and its highly extended periphery, have severe heat stress and poor environmental conditions, presumably due to the highly dense surfaces, scarce plant life, and increased heat islands.

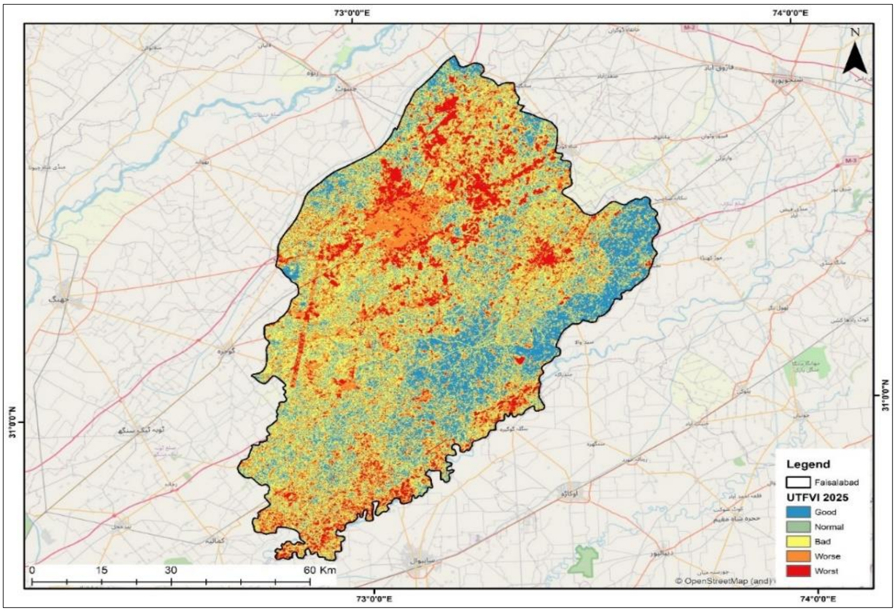

Figure 16: Spatio-Temporal Distribution of UTFVI in Faisalabad, 2025

When the affected regions currently cover approximately 70-80 percent of the municipal boundaries, the massive coverage of these stress-prone regions that run along major arteries such as the M-2 and M-3 highways demonstrate that the urban development is increasing tremendously than it was previously. The blue and Gray regions, respectively the "good" and "normal" category of UTFVI are increasingly pushed to the north and northwest of the metropolitan core. These zones can be associated with lower thermal variance as well as the cooling effect of the Chenab River, open spaces, and remaining agricultural lands are correlated with these areas. Since 2020, these cooler areas have reduced greatly, which highlights how fast urbanization is ruining natural scenery and reducing its capacity to tolerate heat stress.

The yellow “bad" UTFVI regions surrounded the main high-stress places and give a significantly less pronounced transitional strip, which also indicates significant ecological and thermal challenges. This decreasing gradient describes a less buffer separating the cooler periphery and the metropolitan heat center. The thermal variance beyond cities is lowest in rural areas which are characterized by large tracts of farmlands and sparse population.

4. DISCUSSION

4.1. Reduction in Vegetation Cover and Its Ecological Impact

According to the NDVI analysis, the plant cover significantly decreased during the research period, and by 2025, the high NDVI values (dark green) would be shifted to the north and northwest margins. It symbolizes the conversion of semi-natural and agricultural lands into built-up regions since it is typified by the enlargement of low vegetation (orange and red) and the shrinkage of moderate vegetation areas (green light). This statistic is consistent with the findings of Ahmed et al. (2013), who noted that urban development has resulted in vegetation loss in the Dhaka area, attributing this to land conversion and population pressure. Another illustration of how urban-based population density, commercial, and industrial presence limit accessible green space is the city suburban areas and the lack of greenery in the center and eastern areas (Li et al., 2017). The loss of ecosystem services, such as traditional carbon sequestration and air purification, retaining the necessary heat in the urban environment, and maintaining biodiversity, is reflected in this gradient in vegetation from rural to urban areas (Seto et al., 2012). According to Imran et al. (2000), the continuous loss of green spaces, which outpaces regeneration, is endangering ecological resilience and raising exposure to climate stressors in Pakistani urban areas.

4.2. Growth of Built-Up Areas and Thermal Implications

The NDBI maps show that the built-up area has grown significantly, with high NDBI values rising from 0.147097 in 2015 to 0.210585 in 2025, particularly in the central, southern, and eastern regions. The urban corridor in Punjab is a prime example of this growth, which has increased to 15-20% since 2020 and is marked by rapid urban development under its demographic and economic effect (Hassan et al., 2016). The expansion of impermeable surfaces, such as asphalt and concrete, increases heat absorption and retention, reduces evapotranspiration, and intensifies the impact of UHIs (Oke, 1982). According to Weng et al. (2004)'s research on UHI, the loss of medium landscapes—a crucial transitory area that serves as a barrier to heat intensification—is shown by the reduction of broad band NDBI areas. The potential of urbanization in producing thermal anomalies is highlighted by the close correlation between rising NDBI and high LST values, as well as the observation that 70–80% of Faisalabad will have high LST zones by 2025 (Fig 4.3). The observation is consistent with data on built-up growth to increased LST and UHI measures at the global scale (Zhou et al., 2016).

4.3. Escalation of Urban Heat Island Effects

By 2025, the bulk of the urban core will be represented by the worst and bad thermal categories on the UTFVI and LST maps, which are powerful indications of worsened UHI consequences. A thermal gradient of 10 to 15 degrees Celsius between urban and rural areas indicates intense stress heat, particularly in the central and eastern regions where natural cooling buffer systems have been pushed away by urban sprawl. This pattern is consistent with the findings of Estoque et al. (2017), who found that the effects of UHI are amplified in Southeast Asian megacities due to changes in landscape composition. According to study on riverine urban systems, the Chenab River and agricultural lands are linked to the contraction of low LST and UTFVI areas. This is a weakness of these environmental resources to the influence of urbanization (Patz et al., 2005). The economic impact of the 2022 floods, which caused $30 billion in damages to Pakistan's economy and increased its sensitivity to climate change, supports the health implications, including increased susceptibility to respiratory illnesses and heatstroke (World Bank, 2023)).

4.4. Ecological and Socioeconomic Consequences

Such changes in land use have a significant negative influence on the environment, particularly the reduction of agricultural areas in Faisalabad, one of the main breadbaskets (Qureshi et al., 2014). Food security is threatened by the encroachment of arable land into urban areas, which is made worse by the prediction that 50% of the population would live in cities by 2030 (UN-Habitat, 2016). In addition to the dropped air quality and fragmented habitat that endanger the local biodiversity, the decreased evapotranspiration in the form of less green cover exacerbates the LST and UHI (Gill et al., 2007). Socioeconomically, vulnerable populations are disproportionately affected by the increased heat stress, which is consistent with global results that low-income communities are disproportionately affected by urban heat (Reid et al., 2009). The findings are consistent with national patterns of uncontrolled sprawl, where the pace of urbanization outpaces the planning for sustainable development, necessitating a comprehensive approach to environmental planning.

4.5. Strategies for Sustainable Urban Planning

The conversation suggests specific steps that can be taken to fix the ecological and thermal problems that have been seen. One possible solution for Faisalabad is green cover, which can include things like roof gardens and green corridors. This is because it has been shown to lower LST by 2 to 4 degrees Celsius and make the air better (Akbari et al., 2001). Using water retention schemes in peri-urban farming is a good way to keep the ecology in balance, which is in line with the best practices of resilient urban planning (Gill et al., 2007). According to case studies of green infrastructure in cities like Singapore, thermal equity projects are what make life better (Tan et al., 2017). Furthermore, land use zoning must be prioritized at the legislative level to protect agricultural and riparian areas and facilitate sustainable development, irrespective of population constraints.

5. CONCLUSION

This paper has given comprehensive research of the land use and thermal patterns of land in Faisalabad between 2015 and 2025 using remote sensing modalities and land-related indices, namely the (NDVI), the Normalized Difference Built-up Index (NDBI), the Land Surface Temperature (LST), and the Urban Thermal Field Variance Index (UTFVI). The experiment was conducted on a Thursday, October 09, 2025, and at 11.36 PM PKT. It paid attention to the significant change in ecological and thermal landscape within the city due to the rapid urbanization process providing some valuable insights into the issue of sustainable urban development and the prospects involved. This chapter provides the key findings and broad implications and recommendations of the potential future research and the policy efforts.

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