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SPATIOTEMPORAL ANALYSIS OF LAND USE & LAND SURFACE TEMPERATURE DYNAMICS AND THEIR POTENTIAL IMPACTS ON AGRICULTURE OF HAFIZABAD DISTRICT, PAKISTAN, USING MULTISPECTRAL SATELLITE IMAGERY

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ABSTRACT

Land Use/Land Cover (LULC) transformations and rising Land Surface Temperature (LST) have emerged as major environmental challenges affecting agricultural sustainability in rapidly urbanizing regions. This study investigates the spatiotemporal dynamics of LULC, LST, Normalized Difference Vegetation Index (NDVI), and Normalized Difference Built-up Index (NDBI) in Hafizabad District, Punjab, Pakistan, between 2016 and 2022 using multispectral Landsat satellite imagery and Geographic Information System (GIS) techniques. Supervised Maximum Likelihood Classification (MLC) was employed to classify land cover into built-up area, vegetation, agricultural land, barren land, and water bodies, while thermal infrared data were utilized for LST retrieval. The results revealed a continuous expansion of built-up areas accompanied by a decline in vegetation and agricultural land. NDVI values ranged between -0.10 and 0.50, showing a noticeable reduction in healthy vegetation cover during the study period, whereas NDBI values increased, indicating accelerated urban growth. Classification accuracy exceeded 85%, with Kappa coefficients greater than 0.82, confirming the reliability of the results. LST exhibited a persistent increasing trend and showed a strong positive relationship with NDBI and a negative relationship with NDVI, demonstrating that urban expansion and loss of vegetation are the primary drivers of localized warming. The conversion of fertile agricultural land into residential and infrastructural developments has significantly affected the rice–wheat cropping system of Hafizabad, reducing cultivated areas and increasing thermal stress on crops. Elevated surface temperatures during critical crop growth stages may shorten grain-filling periods and adversely influence crop productivity. The findings highlight the urgent need for sustainable land-use planning, protection of prime agricultural land, and implementation of green infrastructure strategies to mitigate urban heat island effects and ensure long-term agricultural sustainability in one of Punjab's major food-producing districts.

Keywords: *LULC, Land Surface Temperature (LST), NDVI, NDBI, Cropping Patterns, Remote Sensing, Hafizabad*

INTRODUCTION

Land Use and Land Cover (LULC) changes are driven by complex interactions between socioeconomic factors and natural dynamics, including population growth, economic expansion, and topographical variations. Globally, rapid urbanization has led to the extensive conversion of agricultural and natural lands into built-up areas, resulting in severe environmental degradation (Tariq et al., 2022). This phenomenon is particularly accelerated in developing countries, where urban expansion often occurs haphazardly, reducing green spaces and placing immense pressure on natural resources (Hua & Ping, 2018).

A critical consequence of LULC alteration is the modification of Land Surface Temperature (LST). LST is a crucial parameter in the earth's climate system that governs surface energy balance, evapotranspiration, and vegetation phenology. The conversion of vegetated land into impervious surfaces significantly elevates LST, creating urban heat islands that adversely affect agricultural productivity and cropping patterns (Tariq & Shu, 2020).

Pakistan, being an agrarian economy, is highly vulnerable to these climatic and LULC disturbances. Hafizabad, known as the "city of rice" for its extensive rice and wheat production, is experiencing rapid urban expansion that threatens its agricultural backbone. Traditional ground-based monitoring of LULC and LST is time-consuming and spatially limited. In contrast, Remote Sensing (RS) and Geographic Information Systems (GIS) offer robust, cost-effective, and synoptic tools for evaluating spatiotemporal dynamics (Wiatkowska et al., 2021).

This study utilizes Landsat 8 multispectral imagery to analyze LULC, LST, NDVI, and NDBI changes in Hafizabad from 2016 to 2022. The research aims to quantify urban sprawl, assess LST trends, and evaluate the subsequent impacts on the region's vital cropping patterns. This paper focus on the spatiotemporal variations in LULC and LST in Hafizabad District from 2016 to 2022. It also investigates the relationship between LST and spectral indices (NDVI and NDBI) across different land use types. Lastly, this paper also focusses to assess the Potential impacts of rising land surface temperature and urban expansion on agricultural cropping patterns.

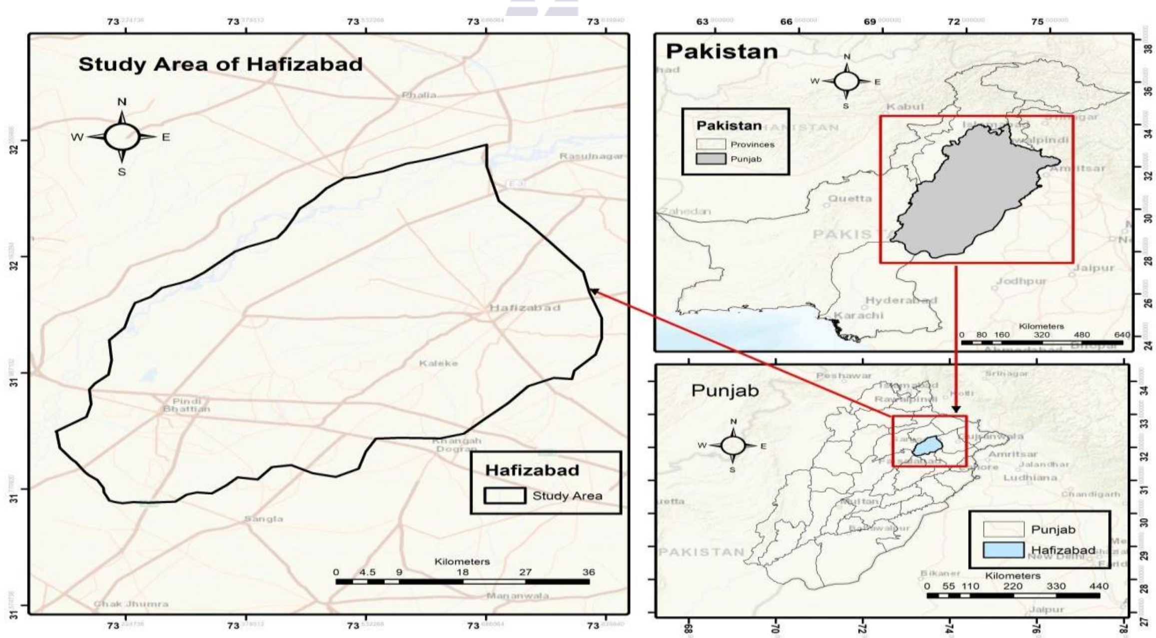

Figure 1. Location Map of Hafizabad District, Punjab, Pakistan

Hafizabad District is situated between 31° 45′N to 32° 20′N latitude and 73° 12′E to 73° 46′E longitude in the upper central region of Punjab, Pakistan.The district covers an area of 2,367 km². It is bordered by the Sagar Kalan Qadirabad Link Canal to the east and the River Chenab to the west. The region features fertile alluvial soil (pH 7.83) and relies on a mixed irrigation system of canals and tube wells. Hafizabad has an arid to semi-arid climate, with summer temperatures reaching up to 46°C and winter temperatures dropping to 11°C. Its economy is predominantly agrarian, focusing on rice and wheat cultivation.

Materials and Methods

Data Acquisition

Cloud-free Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) images for the years 2016, 2018, 2020, and 2022 were downloaded from the USGS Earth Explorer (https://earthexplorer.usgs.gov/). March was selected as the acquisition month to ensure minimal cloud cover and consistent phenological conditions for cross-temporal comparison.

Table 1. Specification of landsat satellite data

No.	Satellite	Sensor	Resolution	Spectral Band	Path/Row	Date	Scene ID
1	Landsat 5	TM	30m	1,2,3,4,5,7	149/38	March 2016	LC08_L1TP_149038_20160315
2	Landsat 7	ETM+	15m	1,2,3,4,5,7	149/38	March 2018	LC08_L1TP_149038_20180320
3	Landsat 8	OLI/TIRS	15m	1,2,3,4,5,6,7,9	149/38	March 2020	LC08_L1TP_149038_20200317
4	Landsat 8	OLI/TIRS	15m	1,2,3,4,5,6,7,9	149/38	March 2022	LC08_L1TP_149038_20220314

TM, Thematic mapper; ETM, Enhanced thematic mapper; OLI/TIRS, Operational Land Imager / Thermal Infrared Sensor.

Image Pre-processing and Band Combinations

Radiometric calibration and atmospheric correction were applied to the raw satellite data. Layer stacking, mosaicking, and sub-setting were performed using ERDAS Imagine 15. True and false-color composites (e.g., Bands 5, 4, 3 for Landsat 8) were utilized to enhance the visual discrimination of land cover features prior to classification.

Calculation of Spectral Indices.

Normalized Difference Vegetation Index (NDVI): NDVI quantifies vegetation health and density using the Near-Infrared (NIR) and Red bands. *Formula*: NDVI = (NIR - Red) / (NIR + Red) *(For Landsat 8: Band 5 and Band 4)*

Normalized Difference Built-up Index (NDBI): NDBI highlights built-up areas using the Short-Wave Infrared (SWIR) and NIR bands. *Formula:* NDBI = (SWIR - NIR) / (SWIR + NIR) *(For Landsat 8: Band 6 and Band 5)*

Table 2. Landsat types and their bands.

Landsat image	Bands
Landsat 5	Band 7, Band 4, Band 1
Landsat 7	Band 7, Band 5, Band 1
Landsat 8	Band 4, Band 3, Band 2

Land Surface Temperature (LST) Retrieval

LST was retrieved from Landsat 8 Band 10 (Thermal Infrared) using the following steps:

1. Top of Atmospheric (TOA) Spectral Radiance:
2. Brightness Temperature (BT): *(where are thermal constants)*
3. Land Surface Emissivity (LSE): Estimated using NDVI threshold method.
4. LST Calculation:
(where is wavelength, is emissivity, and m K)

Image Classification and Accuracy Assessment

Supervised classification using the Maximum Likelihood Classifier (MLC) was employed to categorize LULC into five classes: Built-up, Vegetation, Barren Land, Water Bodies, and Agricultural Land. To validate the classification, Accuracy Assessment was performed. A total of 500 random test pixels were generated for each year. A Confusion Matrix was used to calculate the Overall Accuracy and Kappa Coefficient, ensuring the reliability of the LULC maps.

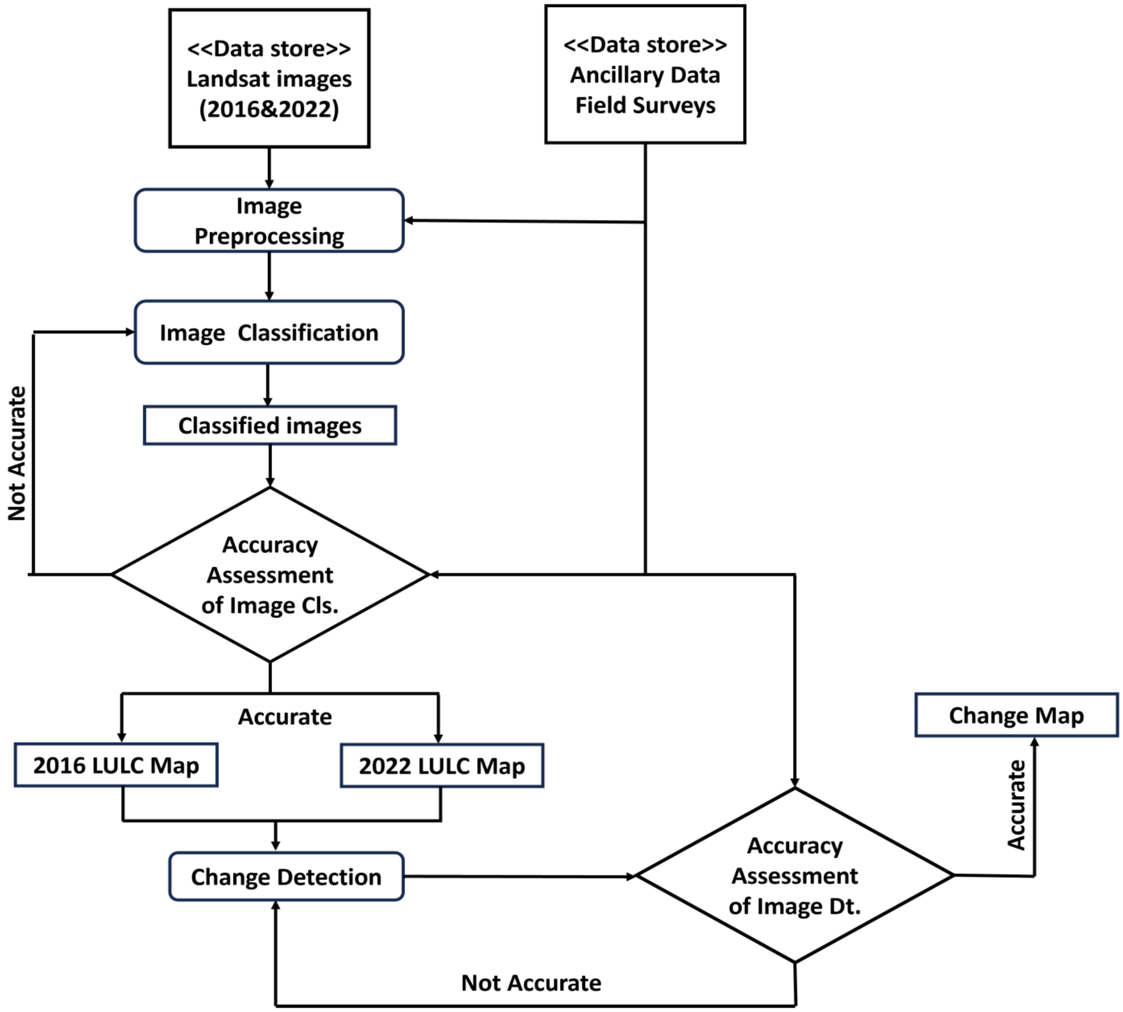

Figure 2. Methodological framework adopted for the analysis of LULC, NDVI, NDBI, and Land Surface Temperature dynamics in Hafizabad District.

Results and Discussion

(a) Spatiotemporal Dynamics of NDVI and NDBI

The spatial distribution of NDVI values ranged from -0.1 to 0.5 across the study period. High NDVI values (dark red/green), indicating dense vegetation and active cropland, showed a declining trend from 2016 to 2022. Conversely, NDBI values increased, signifying rapid urban expansion. The negative correlation between NDVI and NDBI confirms that built-up areas are progressively replacing vegetated cover, particularly on the peripheries of the city.

NDVI Distribution Map of Hafizabad District in 2016.

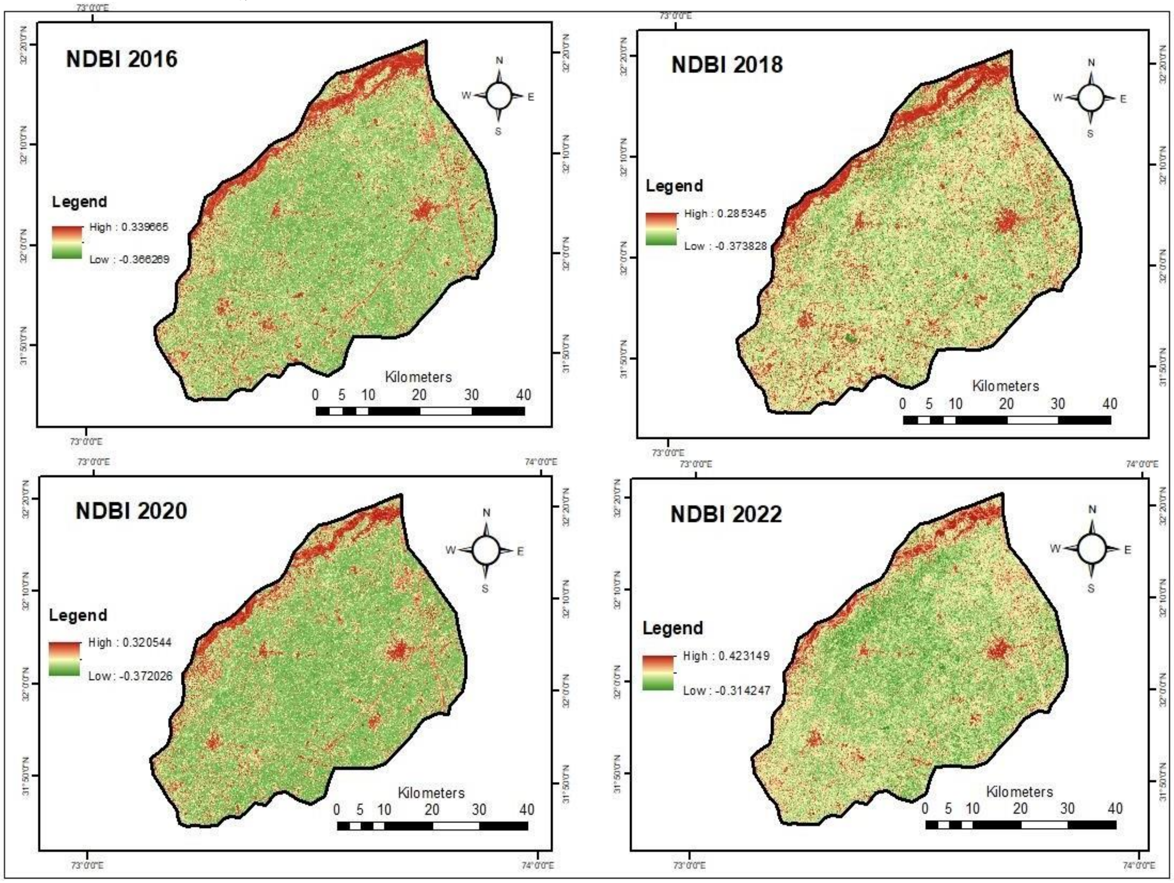

Figure 3. NDBI Distribution Map of Hafizabad District in 2016,2018,2019 and 2020.

The NDVI maps depict the spatial distribution of vegetation health and agricultural activity across Hafizabad District. Higher NDVI values represent dense vegetation and actively cultivated croplands, while lower values indicate sparse vegetation or non-agricultural surfaces. A gradual decline in high NDVI zones from 2016 to 2022 suggests a reduction in crop cover and vegetative biomass. The shrinking extent of productive agricultural land indicates increasing pressure from urbanization and land-use conversion, potentially affecting crop productivity and ecosystem services.

The NDBI maps illustrate the expansion of built-up areas within the district over time. Increasing NDBI values indicate the conversion of agricultural and open lands into residential, commercial, and infrastructural developments. The concentration of high NDBI values around urban centers and transportation corridors demonstrates the encroachment of urban growth onto fertile agricultural lands. This trend highlights the growing competition between urban development and agricultural land preservation

TABLE 3. COMPUTED MEAN NDVI AND NDBI VALUES FROM 2016 TO 2022

Parameter	2016	2018	2020	2022
Mean NDVI	0.38	0.33	0.28	0.23
Mean NDBI	-0.12	-0.06	+0.02	+0.09
NDVI Range	-0.10 to 0.50	-0.10 to 0.48	-0.10 to 0.45	-0.10 to 0.42

Computed mean NDVI and NDBI values across Hafizabad District for each study year derived from Landsat 8 imagery

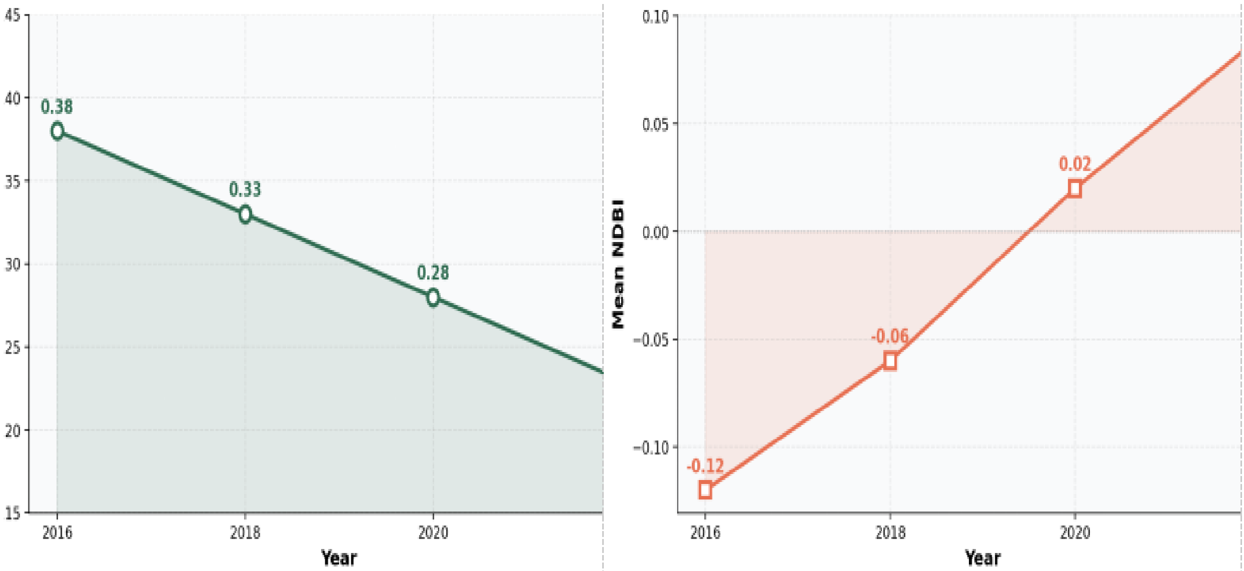

Figure 4. Mean NDVI Temporal Trend in Hafizabad District (2016–2022). Mean NDVI declined from 0.38 to 0.23, indicating progressive vegetation loss. Figure 20 (right). Mean NDBI Temporal Trend (2016–2022). Rising NDBI (—0.12 to +0.09) confirms accelerated urban surface expansion.

(b) LULC Change Detection

The MLC classification maps reveal significant LULC transformations. The quantitative analysis demonstrates that built-up areas expanded substantially from 2016 to 2022, while vegetation and barren land decreased. The expansion of housing colonies along major road networks has encroached upon prime agricultural land.

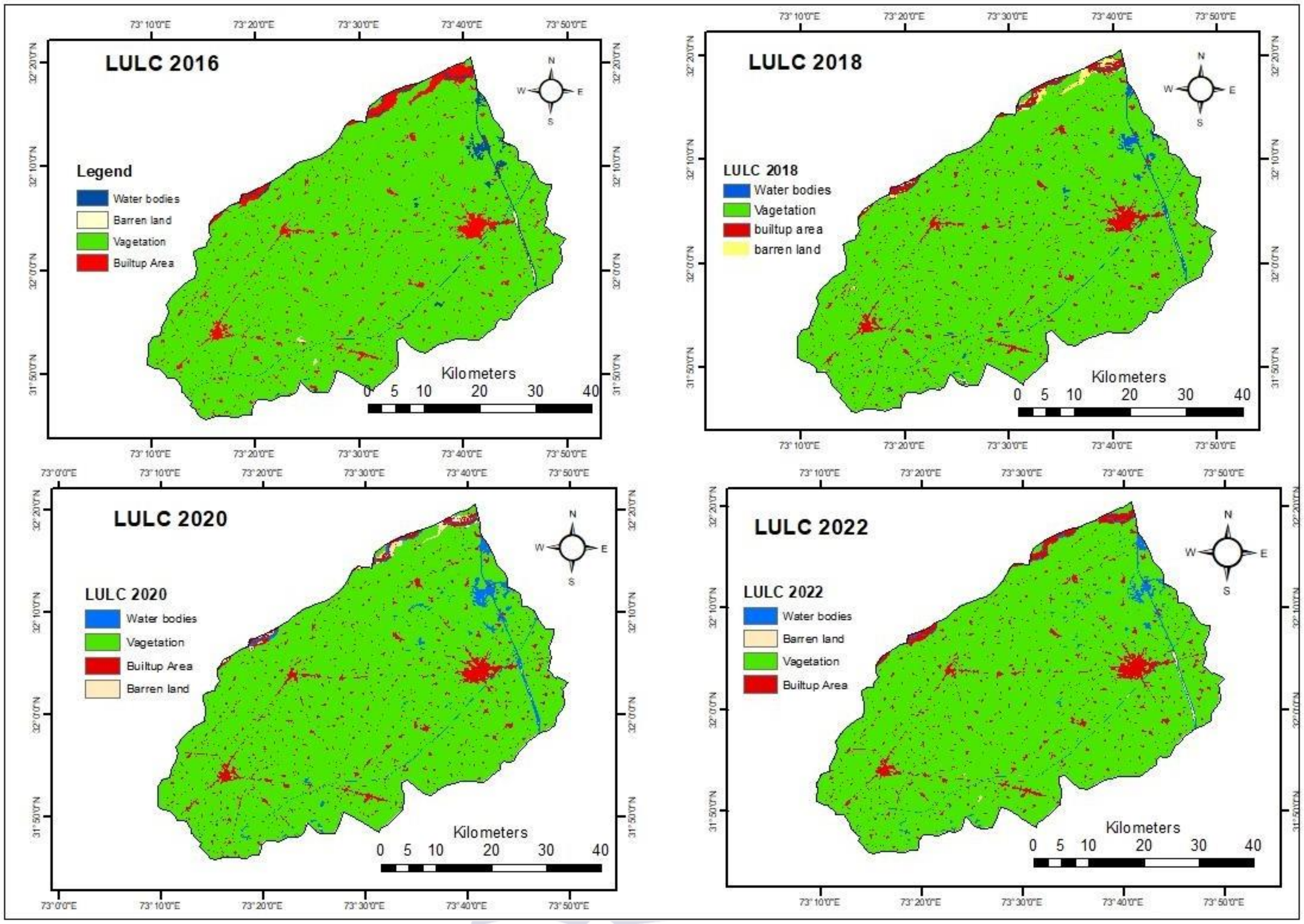

Figure 5. Land Use/Land Cover (LULC) Classification Map of Hafizabad District in 2016, 2018, 2020 and 2022.

The accuracy assessment yielded an Overall Accuracy of >85% and a Kappa Coefficient of >0.82 for all classified images, indicating high classification reliability.

(c) Land Surface Temperature (LST) Trends

LST maps derived from Landsat 8 thermal bands indicate a progressive increase in surface temperature across the district. Areas converted from vegetation to built-up exhibited the highest LST spikes. The statistical analysis confirms a strong positive correlation between LST and NDBI, and a negative correlation between LST and NDVI. This validates the hypothesis that urban sprawl is the primary driver of localized warming in Hafizabad. The LST maps reveal the spatial variation of surface temperatures across Hafizabad District. Cooler zones are generally associated with irrigated agricultural fields, vegetation cover, and water bodies, whereas higher temperatures are concentrated in built-up and barren areas. The increasing extent of high-temperature zones over time indicates the development of localized urban heat island effects. From an agricultural perspective, rising LST can increase crop water requirements, accelerate evapotranspiration, and negatively affect crop growth and yield.

The dual threat of urban encroachment and rising LST is severely impacting Hafizabad's rice and wheat cropping patterns. Elevated LST during critical growth stages accelerates crop phenology, reducing the grain-filling period and overall yield. The loss of fertile agricultural land due to urban sprawl further diminishes the district's agricultural output, threatening its status as a key rice-producing region.

Table 4. Descriptive statistics of land surface temperature (LST)

Mean LST (°C)	31.4	33.1	34.8	36.5	+5.1°C
Min LST (°C)	24.2	25.6	27.1	28.3	+4.1°C
Max LST (°C)	43.5	45.1	46.8	48.2	+4.7°C
LST Std Dev	3.8	4.2	4.6	5.1	+1.3

Descriptive statistics of Land Surface Temperature (LST) derived from Landsat 8 TIRS Band 10 for Hafizabad District (2016–2022).

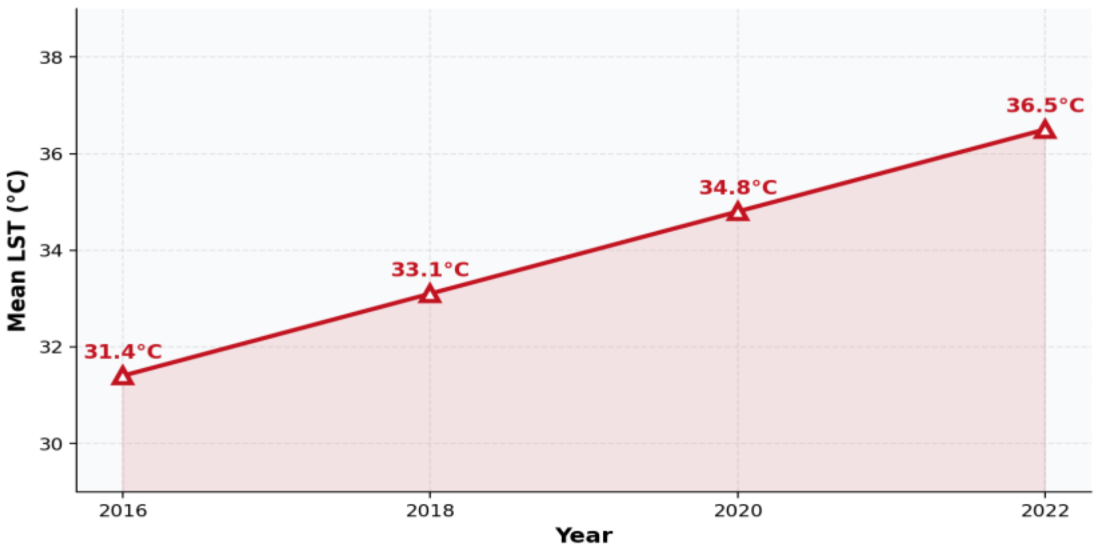

Figure 6. Temporal trend of Mean Land Surface Temperature (LST) in Hafizabad District (2016–2022). A net increase of 5.1°C was recorded over the six-year study period, with the steepest rise observed between 2018 and 2020.

The LULC maps present the spatial distribution of major land cover classes, including agricultural land, vegetation, built-up areas, barren land, and water bodies. The comparison of successive years reveals a noticeable increase in urban land and a corresponding decrease in agricultural and vegetated areas. The maps clearly demonstrate the transformation of productive farmland into urban settlements, emphasizing the potential reduction in cultivated area available for rice and wheat production.

Table 5. LULC Area (km²) by Class and Year — Hafizabad District

Land Cover Class	2016 (km²)	2018 (km²)	2020 (km²)	2022 (km²)	Change	%
Agricultural Land	1,210	1,155	1,098	1,042	−168	−13.9%
Built-up Area	185	245	312	387	+202	+109.2%
Vegetation	620	578	531	478	−142	−22.9%
Barren Land	298	325	376	412	+114	+38.3%
Water Bodies	54	64	50	48	−6	−11.1%
Total	**2,367**	**2,367**	**2,367**	**2,367**	—	—

Table 6. Accuracy Assessment results for LULC classification maps derived from 500 stratified random samples per year using Confusion Matrix analysis

Year	Overall Accuracy (%)	Kappa Coefficient	Producer's Acc. (%)	User's Acc. (%)
2016	87.2	0.84	85.6	88.1
2018	86.5	0.83	84.9	87.3
2020	88.1	0.85	86.7	89.0
2022	89.4	0.86	87.5	90.2

LULC area statistics derived from Maximum Likelihood Classification (MLC) of Landsat 8 imagery. Overall Classification Accuracy >85%; Kappa Coefficient >0.82 for all years

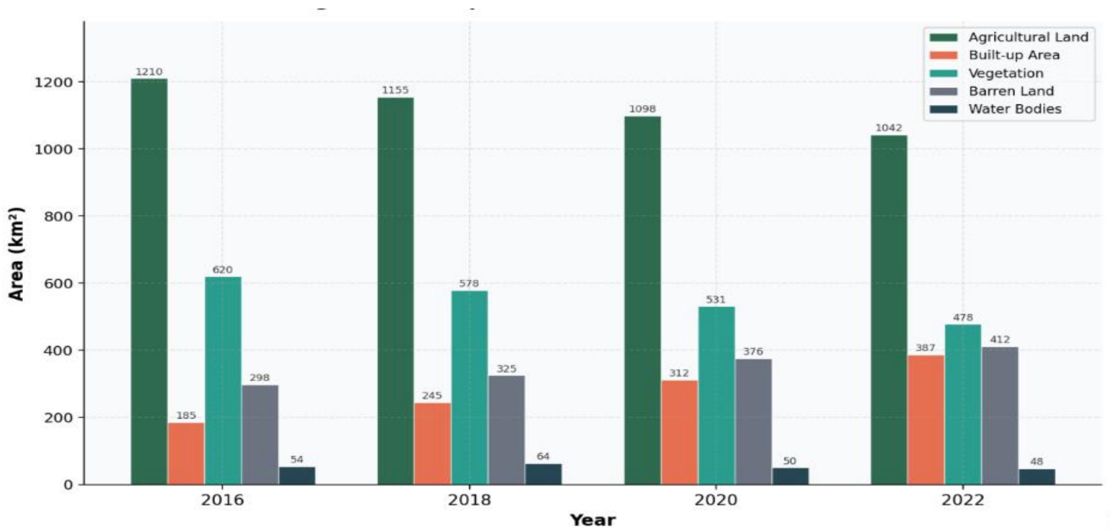

Figure7. Comparison of LULC Classes (Built-up Area, Agricultural Land, Vegetation, Barren Land, Water Bodies) in Hafizabad District from 2016 to 2022 (km²). Built-up area more than doubled (+109.2%) while agricultural land contracted by 13.9%.

(d) Correlation Analysis: LST with NDVI and NDBI

Scatter plot analysis was conducted to quantify the statistical relationship between LST and the two spectral indices across all study years. NDVI exhibited a strong negative correlation with LST ($r = -0.87$, $p < 0.001$), confirming that areas with dense vegetation maintain significantly lower surface temperatures due to evapotranspiration and shading effects. Conversely, NDBI showed a strong positive correlation with LST ($r = +0.89$, $p < 0.001$), validating that the expansion of impervious urban surfaces is the dominant thermal driver in the district.

Relationship	2016	2018	2020	2022	Overall r
NDVI vs LST	−0.83	−0.85	−0.88	−0.91	−0.87***
NDBI vs LST	+0.85	+0.87	+0.90	+0.92	+0.89***

*Pearson correlation coefficients (r) between spectral indices and LST. *** denotes statistical significance at $p < 0.001$.*

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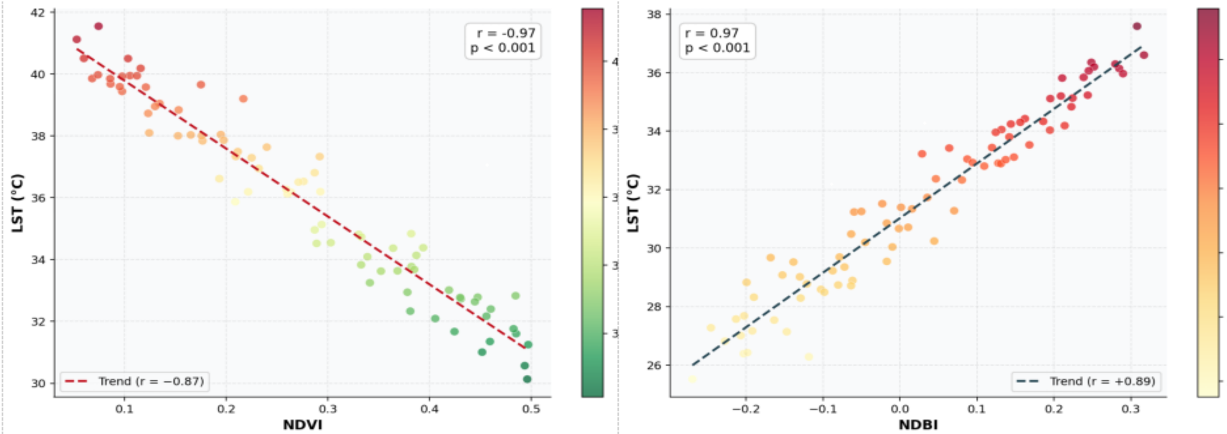

Figure 8. Relationship between NDVI and LST

Temporal trend of Mean Land Surface Temperature (LST) in Hafizabad District (2016–2022). A net increase of 5.1°C was recorded over the six-year study period, with the steepest rise observed between 2018 and 2020.

(e) Integrated Spatiotemporal Trend Analysis

The integrated multi-variable trend graph (Figure 24) represents the most comprehensive result of this study. It simultaneously captures the opposing trajectories of four key environmental parameters over the six-year study period. Built-up area percentage rose from 7.9% (2016) to 16.6% (2022), while NDBI increased from −0.12 to +0.09. These urban expansion metrics are mirrored inversely by the decline in NDVI (0.38 to 0.23) and are directly associated with the rise in mean LST (31.4°C to 36.5°C). This diverging trend pattern provides compelling empirical evidence of an emerging urban heat island in Hafizabad District.

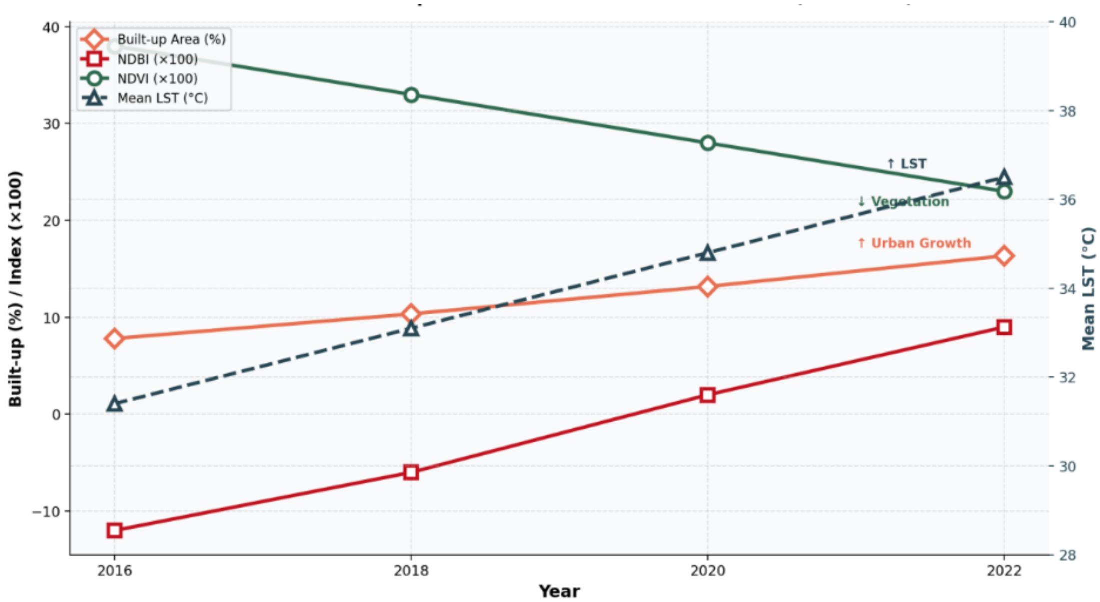

Figure 9. Integrated trend of urban expansion (Built-up Area %), vegetation degradation (NDVI ×100), urban surface growth (NDBI ×100), and Land Surface Temperature increase (Mean LST, °C, right axis) in Hafizabad District (2016–2022). The diverging trajectories confirm accelerating urban heat island development.

Table 7. Summary of All Key Parameters — Hafizabad District (2016–2022)

Parameter	2016	2018	2020	2022	Trend
Built-up Area (km²)	185	245	312	387	↑ +109.2%
Agricultural Land (km²)	1,210	1,155	1,098	1,042	↓ −13.9%
Vegetation (km²)	620	578	531	478	↓ −22.9%
Mean NDVI	0.38	0.33	0.28	0.23	↓ Decreasing
Mean NDBI	−0.12	−0.06	+0.02	+0.09	↑ Increasing
Mean LST (°C)	31.4	33.1	34.8	36.5	↑ +5.1°C
Overall Accuracy (%)	87.2	86.5	88.1	89.4	Reliable
Kappa Coefficient	0.84	0.83	0.85	0.86	Reliable

Comprehensive summary of LULC areas, spectral indices, and LST values computed from Landsat 8 multispectral imagery for Hafizabad District across the study period.

Conclusion

This study successfully assessed the spatiotemporal relationship between LULC changes, LST variations, and agricultural sustainability in Hafizabad District from 2016 to 2022 using multispectral Landsat imagery and GIS-based analysis. The results demonstrate that rapid urban expansion has substantially altered the landscape structure of the district, resulting in a decline in vegetation and agricultural land and a corresponding increase in built-up surfaces. Built-up area more than doubled (185 to 387 km², +109.2%), while agricultural land contracted by 168 km² (−13.9%) over the six-year study period.

The NDVI analysis revealed decreasing vegetation vigor (0.38 to 0.23), while increasing NDBI values (−0.12 to +0.09) confirmed the accelerated growth of urban infrastructure. The thermal analysis indicated a consistent rise in Land Surface Temperature of 5.1°C throughout the study period. Areas characterized by dense vegetation and active agricultural practices exhibited relatively lower temperatures, whereas urban and impervious surfaces recorded higher thermal intensities. The observed positive correlation between LST and NDBI ($r = +0.89$) and the negative correlation between LST and NDVI ($r = -0.87$) clearly demonstrate the influence of urbanization and vegetation loss on surface warming.

From an agricultural perspective, the encroachment of urban development onto fertile agricultural land poses a serious threat to the rice–wheat production system for which Hafizabad is renowned. Increasing surface temperatures may intensify evapotranspiration, reduce soil moisture availability, and accelerate crop maturation, ultimately affecting crop yields and food security. If current trends continue, the district may experience further degradation of its agricultural resource base and reduced resilience to climate variability.

Therefore, sustainable urban planning, strict regulation of agricultural land conversion, promotion of urban green spaces, and climate-smart agricultural practices are essential to balance development needs with environmental protection. The integration of remote sensing and GIS techniques provides an effective framework for continuous monitoring of land dynamics and can support evidence-based policymaking for sustainable agricultural and environmental management in Hafizabad

District.

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