Ministry of Climate Change
Government of Pakistan

Climate Resilient Urban
Human Settlements Unit

SPATIOTEMPORAL CHANGES IN LULC AND ASSOCIATED IMPACT ON URBAN HEAT ISLANDS OVER PAKISTAN USING GEOSPATIAL TECHNIQUES

A Case Study of Six Metropolitan Cities of Pakistan

Karachi - Hyderabad - Quetta - Faisalabad - Peshawar - Mardan

2025

REPORT CRUHS UNIT

CLIMATE RESILIENT URBAN HUMAN SETTLEMENTS UNIT
MINISTRY OF CLIMATE CHANGE & ENVIRONMENTAL COODINATION
GOVERNMENT OF PAKISTAN - 2025

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Executive Summary

Urban Heat Islands (UHIs) are phenomena intensified by urbanization, characterized by the replacement of natural land covers with dense, heat-retaining impervious surfaces. This study investigates Land Use Land Cover (LULC) changes and their impact on UHI from 2000 to 2020 across six metropolitan cities in Pakistan i.e. Karachi, Hyderabad, Faisalabad, Quetta, Peshawar and Mardan. Geospatial technologies were employed to analyze these changes, with a Supervised Classification algorithm applied to satellite imagery using ArcGIS software. The study areas were classified into four categories: built-up areas, barren land, vegetation, and water bodies. Thermal bands from Landsat satellites were used to derive Land Surface Temperature (LST) and assess UHI intensities. The findings reveal substantial urban expansion in all cities during the study period, with increases in urban areas as follows Karachi, Hyderabad, Faisalabad, Quetta, Peshawar and Mardan has increased bsy 25.7%, 13.9%, 18.7%, 21.2%, 26.3% and 26.2% respectively during 2000-2020. Built-up and barren land exhibited the highest LST values, while vegetation and water bodies had lower temperatures. Over the two-decade period, maximum annual LSTs increased in Karachi rose by 2.1°C, Hyderabad by 1.9°C, Faisalabad by 2.0°C, Quetta by 2.2°C, Peshawar 2.0°C, and Mardan 2.0°C. This study highlights the significant role of expanding built-up areas and diminishing vegetation in exacerbating UHI effects. It emphasizes the need for proactive urban planning and sustainable development strategies to mitigate urban heat and promote resilient cities. The research offers valuable insights for policymakers, urban planners, and environmentalists to develop effective strategies for combating UHI, fostering sustainable urban growth, and improving urban living conditions.

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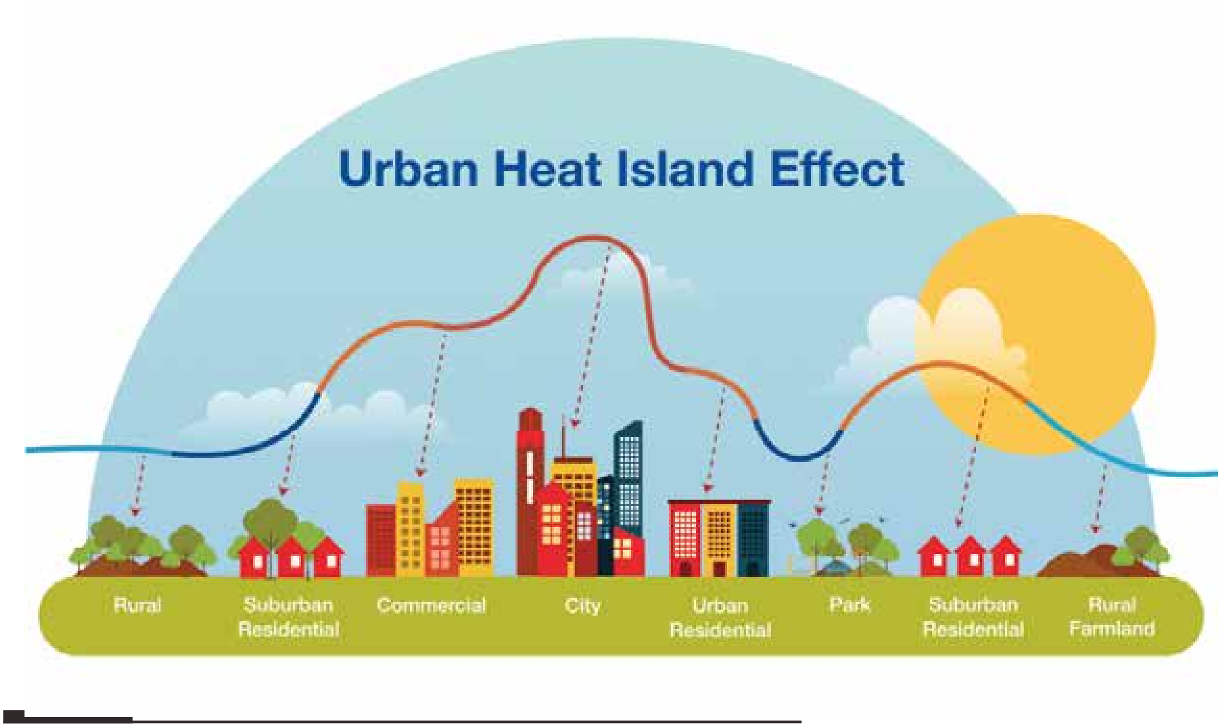
List of Abbreviations

LULC	Land Use Land Cover
UHI	Urban Heat Island
GIS	Geographic Information System
RS	Remote Sensing
LST	Land Surface Temperature
AOI	Area of Interest
GEE	Google Earth Engine
MLC	Maximum Likelihood Classification
TOP	Top of Atmospheric
BT	Brightness Temperature
Pv	Proportion of vegetation
DN	Digital Numbers
NDVI	Normalized difference vegetation index
NDBI	Normalized difference Built-up index
PBS	Pakistan Bureau of Statistics
Min	Minimum
Max	Maximum



01 Background

Urban Heat Islands (UHIs) are a well-documented consequence of rapid urbanization, driven by the transformation of natural landscapes into heat-retaining built environments. The replacement of vegetation areas and water bodies with impervious surfaces such as concrete and asphalt significantly change local climate conditions, leading to increased Land Surface Temperatures (LST) and exacerbating heat stress in urban areas. This phenomenon poses severe environmental and socio-economic challenges, including increased energy consumption, deteriorated air quality, and heightened risks to public health.

Recent studies (Irshad et al. 2024) utilizing geospatial technologies have demonstrated that changes in Land Use and Land Cov er (LULC) play a crucial role in the intensification of UHI effects. By utilizing multi-temporal satellite imagery, researchers have quantified the extent of urban expansion and its thermal impact over time. Similar studies conducted in various metropolitan regions, such as Islamabad, Lahore, Multan and Muzaffarabad have revealed significant increases in built-up areas and corresponding rises in LST over the past two decades. The findings emphasize that barren land and urbanized zones exhibit the highest LST values, while vegetated and water-covered areas contribute to urban cooling.

Building upon these insights, the present study focuses on assessing UHI dynamics in the metropolitan cities of Karachi, Hyderabad, Faisalabad, Quetta, Peshawar, and Mardan, using advanced geospatial techniques. By analyzing LULC changes from 2000 to 2020, this research aims to quantify the spatial and temporal variations in UHI intensity. Landsat-derived thermal bands, combined with supervised classification algorithms in GIS-based environments, will facilitate a comprehensive evaluation of urban expansion and its impact on surface temperatures. This study seeks to provide valuable knowledge for urban planners, policymakers, and environmental stakeholders to formulate sustainable urban development strategies that mitigate UHI effects, enhance climate resilience, and promote sustainable land use management.

02 INTRODUCTION

Climate change refers to significant and lasting changes in Earth's climate patterns and has emerged as a critical global challenge, with human activities identified as the primary driver since the 1800s (Wu et al. 2016). Urbanization, marked by the rapid growth of cities worldwide, has exacerbated this issue, with over 50% of the global population now residing in urban areas (Zhao et al. 2017). Future Projections suggest that by 2045, the urban population will increase to 6 billion (Kummu et al. 2011), with cities accounting for a disproportionate share of global energy usage and greenhouse gas emission (Hoornweg et al. 2020). Urbanization and population growth in cities are the main factors that contribute to LULC changes (Alphan 2003). Pakistan is experiencing rapid urbanization, with an annual growth rate of 3%, the most substantial in South Asia (Kamran et al. 2023). Urbanization brings about significant alterations in LULC, including the conversion of green spaces or barren land into impervious surfaces, along with the establishment of commercial and industrial activities such changes can affect the surface energy (Pal and Ziaul 2017). Such abrupt shifts have a considerable impact on land surface temperature (Wang et al. 2018).

Human activities, particularly changes in LULC, have profound impacts on environmental factors such as land surface albedo, atmospheric aerosol levels, heat exchange, and greenhouse gas concentrations (Hibbard et al. 2017). These alterations contribute to the formation of UHIs, where urban areas experience higher temperatures than their rural surroundings (Oke 1982). Human activities and lack of vegetation are the primary contributors to the UHI effect (Hassan et al. 2021a). Similarly, green spaces in metropolitan areas of developing countries were replaced by built-up areas between 2003 and 2016 (Girma et al. 2019). This underscores the importance of studying LULC in developing countries and its implications, particularly concerning the UHI effect. Addressing these issues proactively is crucial to mitigate their effects before they become irreversible. Comprehensive research has been conducted on the UHI effect in recent decades, and it is noted in numerous major urban centre worldwide.

Cities have different surface characteristics, affecting how they absorb and release heat, materials like asphalt and concrete reduce evaporation, influencing the local climate (Bokaie et al. 2016; Estoque et al. 2017). The UHI effect exacerbates temperature changes in urban areas, impacting both humans and nature (Ellis and Roberts 2016). Its negative effects on health and the environment have drawn attention from various stakeholders. Therefore, studying UHI is needed to mitigate its effects and recommend solutions for the current heat island issues. Many UHI studies have been conducted in the largest cities worldwide. However, developing countries are still lagging in such studies and therefore not planning accordingly for their future metropolitan cities.

2.1 Problem Statement

Communities around the world are dealing with increasing environmental and climate risks as a result of climate change and LULC change (Roy et al. 2022), including water scarcity and rising temperatures, particularly pronounced in regions like South Asia (Hijioka et al. 2014). The rapid urbanization in Pakistan may be attributed to both natural population growth and migration to metropolitan areas (Jabeen et al. 2017). The urban population of Pakistan, which accounted for 32.5% of the total in 1998, is anticipated to rise to 50% by the year 2030 (Jan and Iqbal 2008). Pakistan is facing urban development challenges such as increased emission of greenhouse gas (GHG), level of pollution, increased electricity, urban flooding, consistent rise in local temperatures, increase in built-up areas, and reduced vegetation cover (Aslam et al. 2021). In response to these concerns, assessment and evaluation of communities' climate resilience is important for research and policy-making because of its potential to inform approaches to enhancing resource capacity (Wang et al. 2020).

The application of Geographic Information Systems (GIS) facilitates the analysis of LULC changes, enabling a comprehensive understanding of the relationship between human activities and natural phenomena to inform policymaking (Yadav et al. 2012); (Lu et al. 2004). As populations continue to increase, coupled with changes in built-up areas, global temperatures, and vegetation cover, UHI phenomena pose significant challenges, including increased energy consumption, elevated urban temperatures, and adverse impacts on quality of life (Almusaed and Almusaed 2011) (He 2019). A thorough investigation of the factors influencing the effect of UHI is necessary for formulating sensible urban planning policies and mitigating the consequences of UHI (Tian et al. 2021). For instance, research conducted by (Farid et al. 2022) measured that vegetation cover declined significantly, dropping from 60.5% to 47.7%, largely due to urbanization. Meanwhile, built-up land expanded by 23.52% over the same period. Correspondingly, the UHI intensity also rose from 1.72°C in 1990 to 2.41°C in 2020 during this period. Similarly, (Nasar-u-Minallah et al. 2021) investigated that during the past five decades (1973 to 2020), the built-up area of Lahore city has expanded by 532 km2. (Hassan et al. 2016) investigated LULC changes in urban centers of Islamabad, revealing significant urban sprawl and the expansion of built-up areas over the period from 1992 to 2012. The built-up areas increased from 18.09 % (16,281 ha) in 1992 to 56.73 % (51,039 ha) in 2012. (Sadiq Khan et al. 2020) found that impervious surfaces increased by 11.9% over 26 years (1993 to 2018), reducing barren land, forests, grass/agriculture land, and water bodies. This Land Use and Land Cover (LULC) change contributed to warming, with converted areas adding 1.52°C. These measurements highlight the substantial influence of urbanization on increasing temperatures within urban areas.

As previously stated, there is considerable interest in studying the UHI phenomenon globally. The existing literature highlights the lack of comparative and detailed analysis studies specifically focusing on major cities, which this study aims to fulfill. The current study focuses on the LULC and its impact on UHI by using remote sensing data to provide a comparative and detailed analysis of the subject problem. The focus is on different cities of Pakistan such as Karachi, Hyderabad, Faisalabad, Quetta, Peshawar and Mardan spanning from 2000 to 2020. The aim is to explore how land use patterns contribute to the formation of heat islands in various selected cities and to develop a comprehensive understanding of urban temperature dynamics.

This research will advance our comprehension of the UHI problem in each city and allow us to conduct a comprehensive comparison of UHI changes over the past twenty years. The main objectives of the study are, a) to assess climate resilience in Pakistan's metropolitan areas through an integrated approach that includes analyzing LULC changes, b) Comprehensive analysis of the spatial distribution of LST, c) to identify UHIs effects and explore their correlations with LULC patterns d) to explore the impact of elevation and geographic factors on the UHI effect, and to propose sustainable solutions for mitigating. The results of this study will provide valuable insights for urban planning and policy development aimed at enhancing climate resilience in Pakistan's metropolitan areas.

03 MATERIAL & METHOD

3.1 Study Area

The research extends to six additional Pakistani cities, each with their own unique geographical and climatic characteristics. Detailed below are the descriptions of Karachi, Hyderabad, Faisalabad, Quetta, Peshawar, and Mardan, which further contribute to understanding the interplay between land use patterns and climate conditions.

Karachi, the largest city and economic hub of Pakistan, is the capital of the Sindh province. It is the most populous city in the country, with an estimated population of over 14.91 million people according to the PBS 2017 census. Located at 24.8607°N latitude and 67.0011°E longitude, Karachi is situated along the Arabian Sea coastline. This coastal location influences its climate, resulting in hot and humid conditions for most of the year. The city experiences mild winters and moderate monsoon rains, with urbanization contributing to the urban heat island effect.

Hyderabad, also in the Sindh province, is the eighth-largest city in Pakistan, with a population of approximately 1.733 million people (PBS 2017). It is positioned at 25.3960°N latitude and 68.3578°E longitude. The city's flat plains and proximity to the Indus River impact its climate, which is characterized by hot summers, mild winters, and moderate monsoon rainfall. Hyderabad's extensive urban development also affects its local climate, often resulting in elevated temperatures and localized air pollution.

Faisalabad, the third-largest city in Pakistan, is located in the Punjab province. It has a population of about 3.204 million residents according to PBS 2017. Geographically, it is situated at 31.4504°N latitude and 73.1350°E longitude. The city lies within a flat, agricultural region, which influences its climate. Faisalabad experiences hot summers and cool winters, with significant seasonal variations. The extensive agricultural activities and industrial growth contribute to localized climate changes and pollution.

Quetta, the capital of Balochistan province, is the tenth-largest city in Pakistan, with a population of around 1.001 million people (PBS 2017). It is located at 30.1798°N latitude and 66.9750°E longitude. Quetta is situated in a mountainous region, leading to a unique climate characterized by cold winters, with occasional snowfall, and mild summers. The high-altitude environment significantly influences the temperature dynamics and precipitation patterns in the city, distinguishing it from the more temperate and arid regions of Pakistan.

Peshawar, the capital of Khyber Pakhtunkhwa province, is the sixth-largest city in Pakistan, with a population of approximately 1.970 million people according to PBS 2017. It is positioned at 34.0151°N latitude and 71.5249°E longitude. The city's geographical location in the Peshawar Valley influences its climate, which features hot summers, mild winters, and moderate rainfall during the monsoon season. Peshawar's urbanization and historical significance impact its local environment and climate.

Mardan, also in the Khyber Pakhtunkhwa province, is the 19th largest city in Pakistan, with a population of about 358,604 people (PBS 2017). It is situated at 34.1988°N latitude and 72.0451°E longitude. The city is located in a fertile plain, contributing to its agricultural prominence. Mardan's climate is characterized by hot summers, mild winters, and moderate monsoon rainfall. The agricultural activities and urban expansion influence its local climate conditions.

Table 1 : Climatic and demographic information of selected study

City	Min Temperature (°C)	Max Temperature (°C)	Average Rainfall (mm)	Average Relative Humidity (%)	Elevation from Sea Level (m)	Current Population Density (persons/km²)
Karachi	15	35	250	70	8	6000
Hyderabad	10	40	125	60	13	4500
Fasialabad	4	40	375	50	186	4000
Quetta	-2	34	260	40	1680	2000
Peshawar	6	38	400	55	359	2300
Mardan	5	39	450	60	283	3200

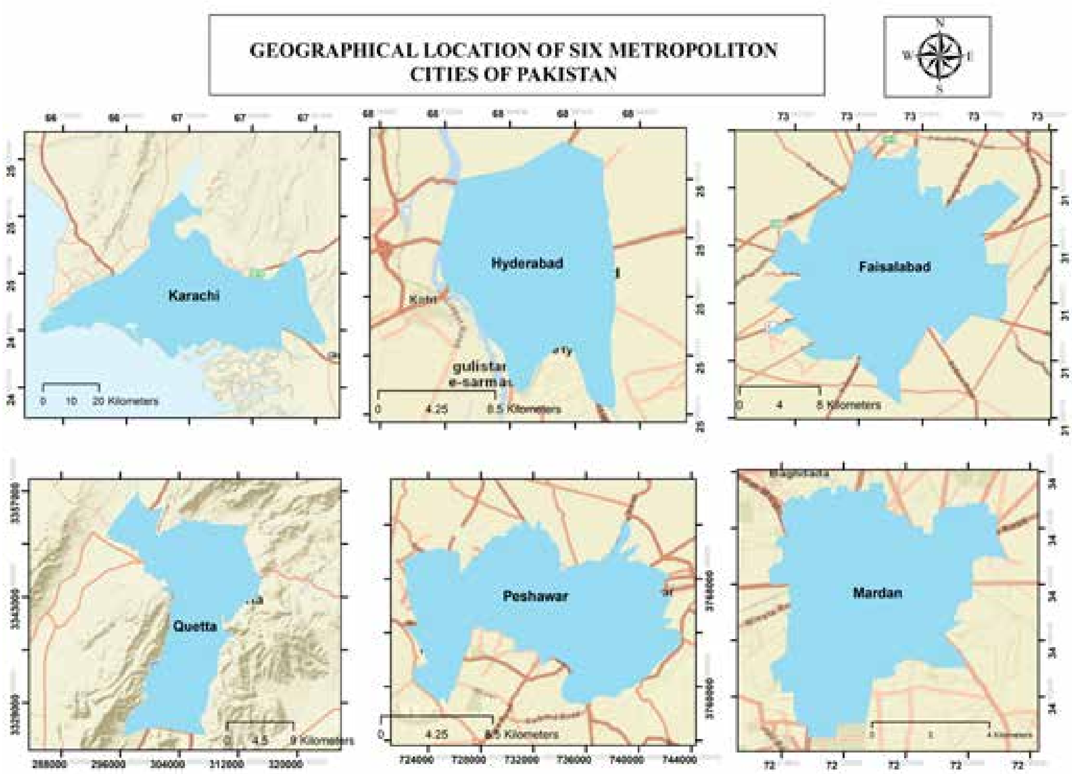


Figure 1: Geographical location of six metropolitan cities of Pakistan i.e. (a) Karachi, (b) Hyderabad, (c) Faisalabad, (d) Quetta, (e) Peshawar, and (f) Mardan

3.2 Data Collection & Processing

This study will mainly depend on satellite data. satellite data as the primary source for its analysis and research. Landsat satellite imageries are used for this research due to continuous observation provides a long-term record, moderate spatial resolution, and multispectral bands enable a detailed study of land surface characteristics. Classification of LULC, LST, and UHI were produced from Landsat data. These data were collected from the United States Geological Survey (USGS) and Google Earth Engine for four cities in Pakistan such as Karachi, Hyderabad, Faisalabad, Quetta, Peshawar and Mardan for 2000, 2010 and 2020. The complete methodology flow chart has been shown in Figure 2. The methodology taken on in the study is discussed below;

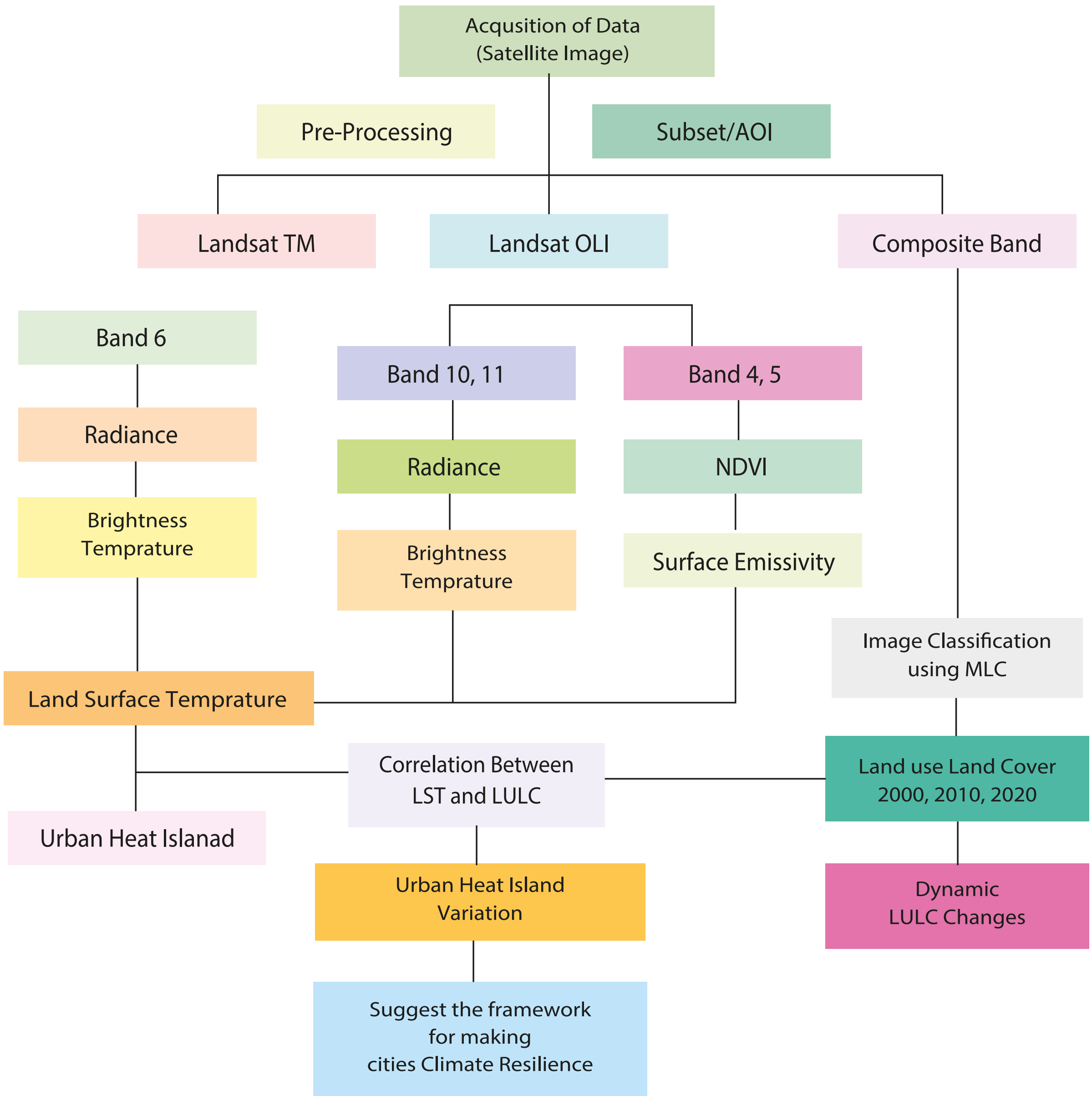


Figure 2: Methodology Flow Chart

3.3 Satellite Data Collection and Processing

In response to the increasing trend of urbanization and UHI effects, this study conducts various analyses to produce specific outputs. Initially, utilizing Landsat data to extract Land Use and Land Cover (LUCL) maps, Dynamic changes in LULC classes maps, and retrieve LST for the years 2000, 2010, and 2020, enabling the identification of urban cores and other land cover classes essential for studying the UHI phenomenon within urban areas. Moreover, the study area enhances the spatial-temporal analysis of UHIs and their correlation with built-up areas, vegetation cover, water bodies, and barren land.

LST in °C values are obtained using the Google Earth Engine (GEE) algorithm. Google Earth Engine (GEE) is an online platform created to allow remote sensing users to easily perform big data analyses without increasing the demand for local computing resources (Ermida et al. 2020). Subsequently, the raw data undergoes processing, including clipping/mosaicking to match the study area boundaries and prepared map layouts with the help of ArcGIS. The detailed description (spatial resolution, date and rows used for the images) used in the study are shown in Table 2

Table 2: Satellite Images used to obtain LULC and LST

Sr.no	Sensor	Date	Spatial Resolution
1	Landsat TM	2000	30 meter
2	Landsat TM	2010	Lorem ipsum 30 meter
3	Landsat OLI	2020	30 meter

3.4 Land Use Land Cover Classification

LULC classification maps were generated using the Maximum Likelihood Classification (MLC) algorithm. The MLC is the primary parametric classifier, forming decision boundaries based on class mean and covariance (Srivastava et al. 2012). It utilizes a neighborhood function to make classification decisions (Mushtaq et al. 2021). Training samples were collected, for four classes such as barren land, built-up area, water bodies, and vegetation area (Table 3). Classification was then conducted using training samples, and validation techniques were applied to assess the accuracy and reliability of the classification results. The four LULC classifications are based on the research findings of (Al-Aayedi et al. 2023; Faqe Ibrahim 2017; Feng and Flewelling 2004). The classification maps delineating the area covered by each class were produced for each of the study years 2000, 2010 and 2020.

Table 3: Detail of LULC Classes

Sr. No	Classes	Detail
1.	Built-up-Area	The built-up Area includes the commercial and residential areas, roads, and pavement areas.
2.	Vegetation Area	The definition of vegetation in this research work denotes land grassland, forest Area, and agricultural area.
3.	Water Bodies	It includes rivers, Streams, lakes, ponds etc.
4.	Barren Land	Barren land denotes land without shrubs, sandy areas, dry areas, barren land, and dry grasses.

3.5 LULC Accuracy Assessment

Accuracy assessment involved evaluating user and producer accuracy, overall accuracy, and the kappa coefficient using a confusion matrix. A total of 240 random ground points, with 60 points for each class, were marked on Google Earth for the study period. LULC accuracy assessment was performed in ArcGIS by comparing classified images with high-resolution images. Accuracy assessment not only evaluates the quality of a map but also deals with a way to improve its utility (Dong et al. 2022).

3.6 Land Surface Temperature Calculations

LST retrieval using remote sensing, especially Landsat data, has become a prominent topic in environmental studies over the last few decades (Hakan 2016). Land Surface Temperature (LST) has been derived from the thermal bands of Landsat using ArcGIS 10.7 for the years 2000 and 2010, and the Google Earth Engine platform for 2020. The calculation involved obtaining the Top of Atmospheric (TOA), spectral radiance, Brightness Temperature (BT), NDVI, Proportion of vegetation (Pv), and emissivity followed by computation of LST using these factors (Barsi et al. 2014).

For Landsat 4-5 TM:

The thermal bands are represented as digital numbers (DN), and to transform these DN values from the thermal band into spectral radiance (L λ), There are two Equations (1) and (2) we applied Equation (1). Spectral radiance is quantified in units of watts / ($m^2 \times$ ster $\times$ μm).

$$L\lambda\,[\frac{LMAX\lambda - LMIN\lambda}{QCALMAX - QCALMIN}] \times [QCAL - QCALMIN] + LMIN\lambda]\ \ldots\ldots\ldots(1)$$

Eq. 2 was employed to transform the spectral radiance into satellite brightness temperature

$$T = \frac{K2}{In\,(\frac{K1}{L\lambda} + 1)} - 273.15\ \ldots\ldots\ldots(2)$$

T is the temperature in degrees Celsius ( ). For Landsat 4-5 TM, the constants K1 and K2 have been defined as 607.76 and 1,260.56, respectively, and Lλ has been determined in the above step. A higher LST value indicates more intense heat and poorer conditions and a lower value indicates good condition. Table 5 shows the LST ranges for different conditions.

For Landsat 8 OLI/TIRS:

Top of Atmosphere (ToA) values were determined using the following equations:

$$0.0003342 \times Band10 + 0.1\ \ldots(1)$$

Brightness Temperature value calculated:

$$(\frac{1321.0789}{Ln\,(\frac{774.8853}{TOA})} - 273.15\ \ldots(2)$$

NDVI and NDBI are calculated following equations:

$$NDVI = Float\,(Band5 - Band4)/Float(Band5 + Band4)\ \ldots(3)$$
$$NDBI = Float\,(Band6 - Band5)/Float(Band6 + Band5)\ \ldots(4)$$

To compute Land Surface Temperature (LST), firstly determine the Proportion of Vegetation Index (PV) using Equation 6 and Emissivity (Equation 7), and then extract the LST through the following process:

$$PV = Square(NDVI - NDBImin\ )/(NDVImax - NDVImin) \ldots (5)$$

$$\varepsilon = 0.004 \times PV + 0.986 \ldots \ldots \ldots (6)$$

$$LST = \left(\frac{BT}{1 + (0.00115 \times \frac{BT}{1.4388}) \times Ln(\varepsilon)}\right) \ldots (7)$$

Table 4: Description of Land Surface Temperature The lower value shows good condition and the worst condition is high (Lobaccaro et al. 2019)

Sr. No.	LST In Celsius	Detail
1.	18–23 ◦C	No Thermal Stress
2.	23–29 ◦C	Slight Heat Stress
3.	29–35 ◦C	Moderate Heat Stress
4.	35–41 ◦C	Strong Heat Stress
5.	>41 ◦C	Extreme Heat Stress

3.7 Urban Heat Island

The UHI maps have been created from the Landsat 4-5 and Landsat 8 imageries for each year 2000, 2010 and 2020. ArcGIS software is used to derive UHI maps. For the particular satellite images, The UHI has been calculated using the following equation

$$UHI = \mu + \frac{\sigma}{2} \ldots \ldots \ldots (8)$$

μ is the mean LST and σ is the standard deviation (Kaplan et al. 2018).

04 RESULT

4.1 Spatial-Temporal Land Use Land Cover Changes

The research emphasis on Land Use and Land Cover (LULC), four distinct categories have been recognized such as built-up area, barren land, vegetation area and water bodies. LULC maps were generated, clarifying changes over 10-year intervals (2000, 2010, and 2020) across six cities of Pakistan such as Karachi, Hyderabad, Faisalabad, Quetta, Peshawar and Mardan. Over the study period, a noticeable gradual expansion was observed in the coverage of built-up areas within the designated study area. The findings on LULC are followed by a comprehensive discussion on the specific changes in LULC classes across all six cities, as provided below:

4.1.1 Karachi

Karachi city experienced significant changes in land use land cover between 2000 and 2020. The built-up area has increased notably, growing from 11.16% to 25.70% of the total land area, which corresponds to an addition of 379 hectares. This expansion highlights substantial urban growth over the past two decades. In contrast, vegetation area has decreased from 14.65% to 11.24%, a reduction of 89 hectares, indicating a loss of green spaces, likely due to urban development. Water bodies have slightly decreased from 3.26% to 3.15%, with a minimal reduction of 3 hectares, suggesting relatively stable water resources but still requiring attention. Barren land, once accounting for 70.92% of the area in 2000, has decreased to 59.92% by 2020, reflecting a shift from undeveloped land to other uses, such as urban or agricultural purposes. Overall, these changes point to a trend of increasing urbanization at the expense of natural and undeveloped areas, with implications for future urban planning and environmental management (Figure 3).

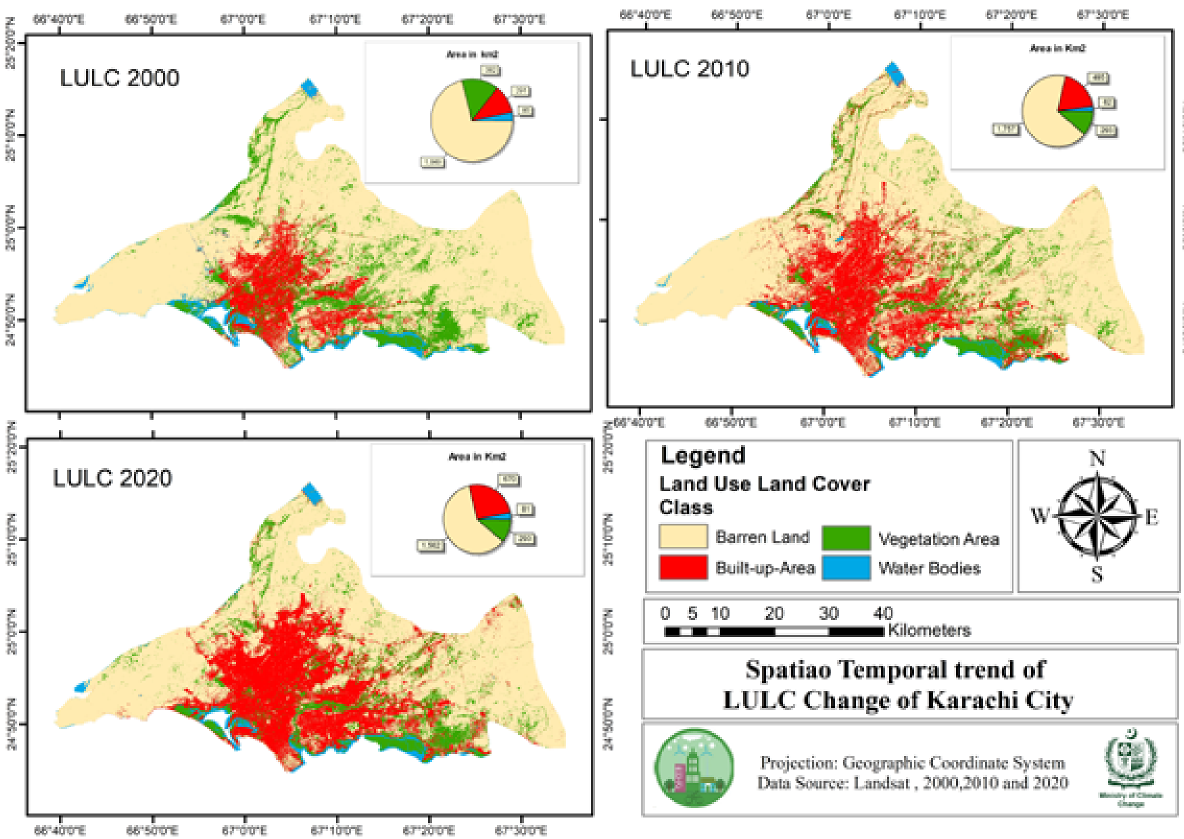


Figure 3: Land Use Land Cover Maps of Karachi for 2000, 2010 and 2020

4.1.2 Hyderabad

The result show in the figure the Land Use and Land Cover (LULC) dynamics changes observed in Hyderabad from 2000 to 2020, describing variations across different land use categories. Especially, the built-up area expanded notably, increasing from 39 km^2 in 2000 to 62 km^2 in 2020. This growth comprised a substantial 30.8% increase from 2000 to 2010, followed by an additional 21.6% increase from 2010 to 2020, rising the percentage of built-up areas from 23.6% in 2000 to 37.6% in 2020.

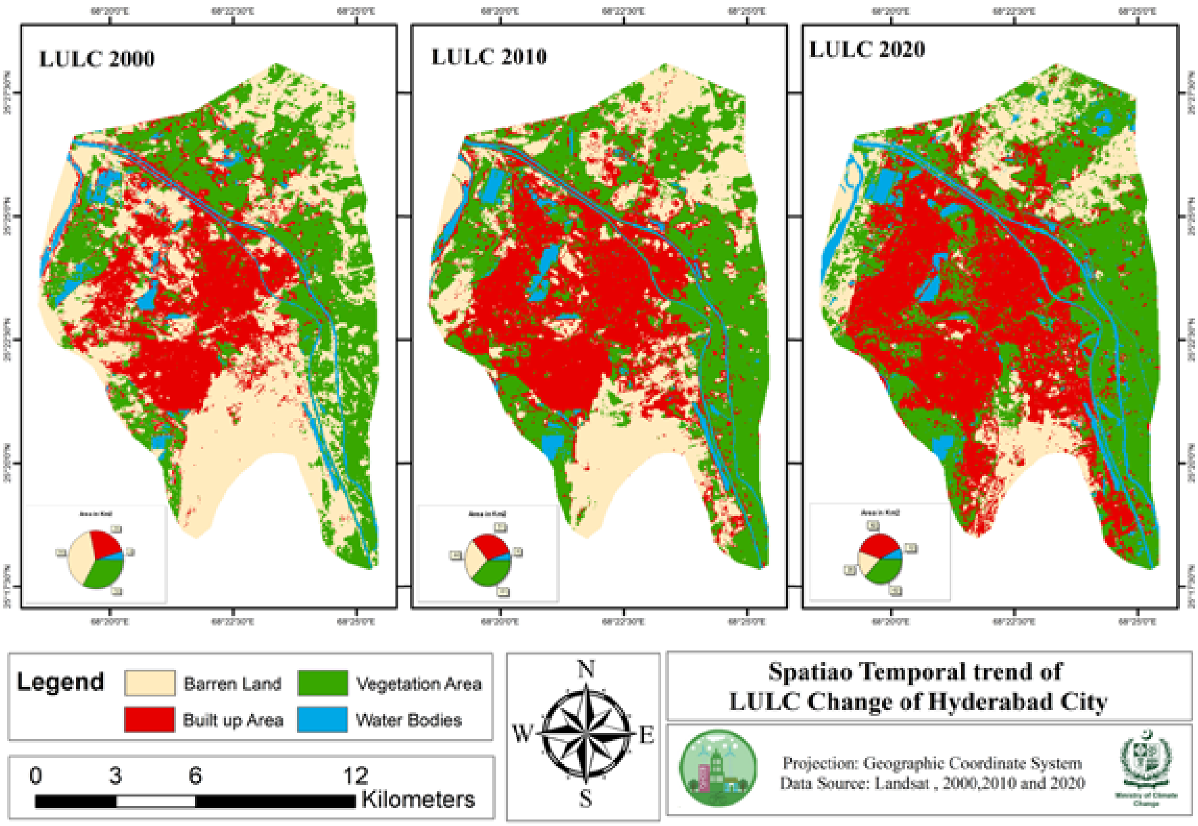


Figure 4: Land Use Land Cover maps of Hyderabad for 2000, 2010 and 2020

In contrast, barren land observed a decline, shrinking from 64 km^2 in 2000 to 29 km^2 in 2020. This decline consisted of a 29.7% reduction from 2000 to 2010 and a further decrease of 35.6% from 2010 to 2020, leading to a drop in barren land percentage from 38.8% in 2000 to 17.6% in 2020. The vegetation area showcased an overall increase, from 54 km^2 in 2000 to 62 km^2 in 2020, maintaining a consistent 37.6% from 2010 to 2020 despite a slight rise of 1.6% from 2010 to 2020. Water bodies experienced a minimal increase from 8 km^2 in 2010 to 12 km^2 in 2020, reflecting a 50% rise, indicating a consistent 7.3% coverage in 2020. These changes indicate significant changes in Hyderabad LULC pattern.

4.1.3 Faisalabad

The Map shows the changes from 2000 to 2020 reveals significant variations across various land use categories. Notably, the built-up areas in Faisalabad expanded conspicuously, expanding from 118 km² in 2000 to 182 km² in 2020. This growth reflects a substantial 44 km² increase (37.3%) from 2010 to 2020, following a previous growth of 20 km² (14.5%) from 2000 to 2010, resulting in an elevation of built-up areas from 34.4% in 2000 to 53.1% in 2020. Conversely, barren land seen a stark decline from 52 km² in 2000 to 13 km² in 2020, showcasing a sharp 47 km² decrease (78.3%) from 2010 to 2020, subsequent to an 8 km² reduction (15.4%) from 2000 to 2010. The percentage of barren land reduced significantly from 15.2% in 2000 to 3.8% in 2020. Variations were observed in the vegetation areas, declining from 171 km² in 2000 to 146 km² in 2020, representing a decrease of 28 km² (19.7%) from 2000 to 2010 and a marginal rise of 3 km² (2.1%) from 2010 to 2020, resulting in a decrease in the vegetation area percentage from 49.9% in 2000 to 42.6% in 2020. Conversely, water bodies remained relatively stable, consistently covering 2 km² across the three observed years, indicating minimal changes in this specific land cover category. These transformations of LULC pattern underscore substantial shifts, including notable growth in built-up areas, a significant reduction in barren land, variations in vegetation areas, and the stability of water bodies. Understanding these changes is imperative for effective urban planning, environmental preservation, and strategic resource management in Faisalabad.

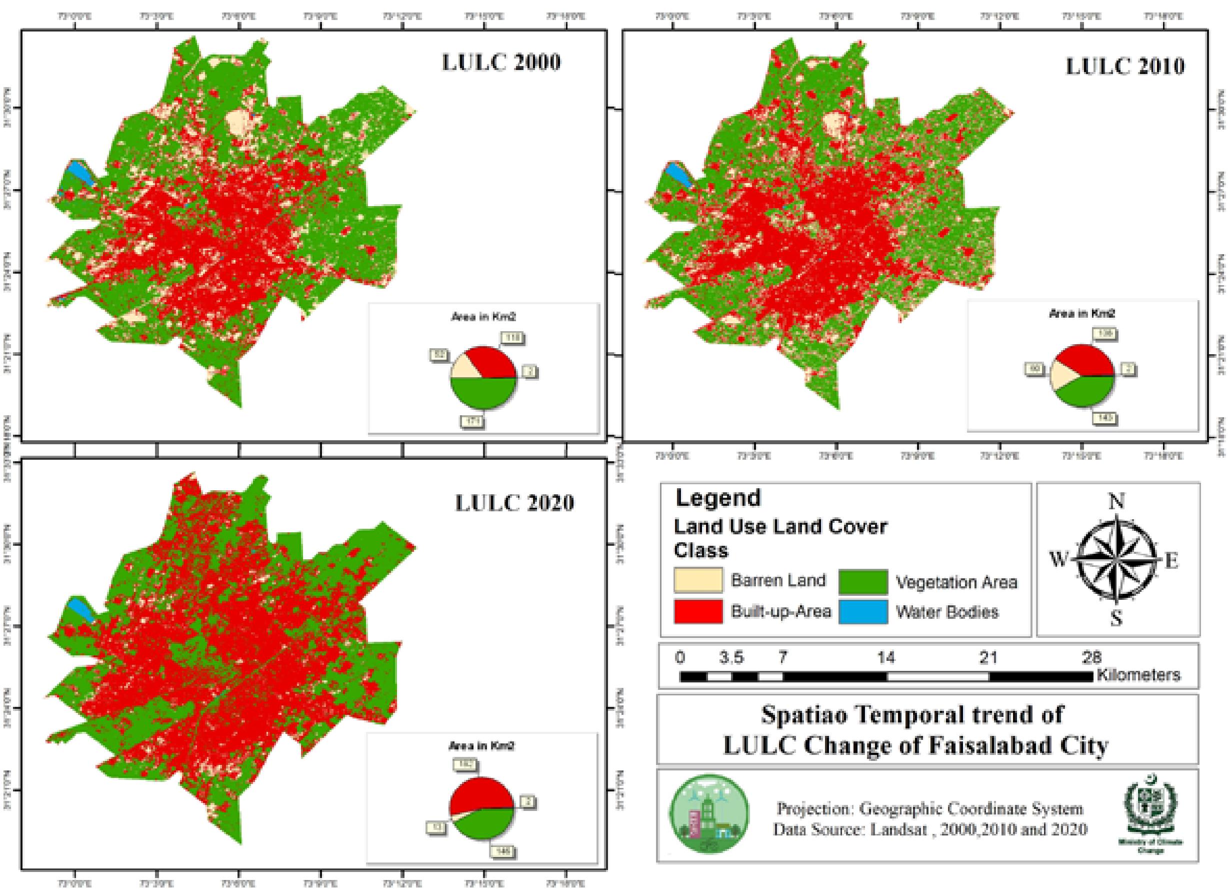


Figure 5: Land Use Land Cover maps of Faisalabad for 2000, 2010 and 2020

4.1.4 Quetta

The result show in the figure (6) changes during three distinct periods: 2000, 2010, and 2020. It shows shifts across diverse land use categories within this time period. Notably, Quetta experienced a remarkable increase in built-up areas, expanding from 47 km² in 2000 to 126 km² in 2020. This development indicated a significant 103 km² increase (146.8%) from 2010 to 2020, following an initial growth of 23 km² (48.9%) from 2000 to 2010. Consequently, the proportion of built-up areas increased from 12.6% in 2000 to 33.9% in 2020. Conversely, the region saw a noteworthy decline in barren land, shrinking from 306 km² in 2000 to 195 km² in 2020. This showcased a considerable reduction of 46 km² (15%) from 2000 to 2010, followed by a substantial decline of 241 km² (92.7%) from 2010 to 2020. This led to a significant drop in barren land from 82.3% in 2000 to 52.4% in 2020.

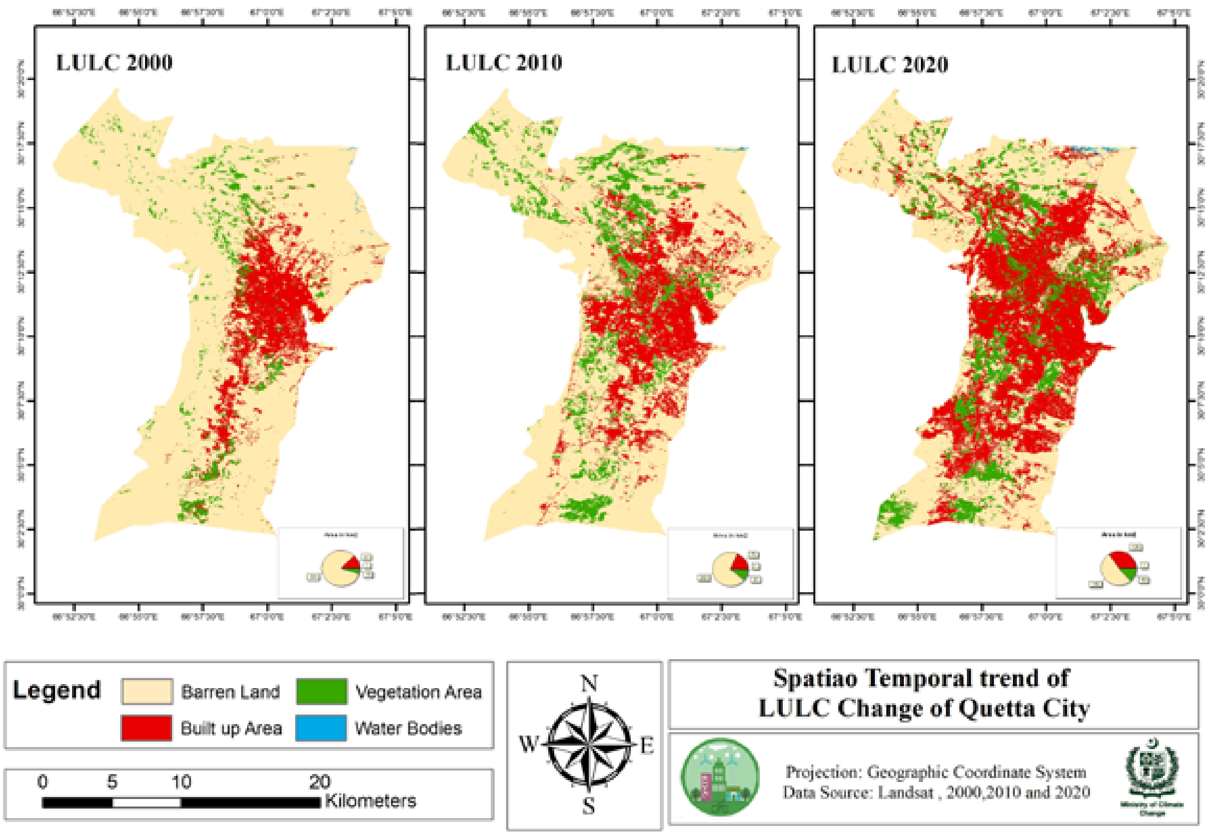


Figure 6: Land Use Land Cover maps of Quetta for 2000, 2010 and 2020

Furthermore, vegetation area exhibited fluctuations, rising from 18 km² in 2000 to 50 km² in 2020. This included an increase of 23 km² (127.8%) from 2000 to 2010 and a subsequent rise of 27 km² (65.9%) from 2010 to 2020. Despite these variations, the percentage of vegetation area experienced an upward trajectory from 4.8% in 2000 to 13.4% in 2020. Meanwhile, water bodies in Quetta remained relatively stable, consistently encompassing an area of 1 km² from 2000 to 2020, signifying minimal alterations within this specific land cover category.

4.1.5 Peshawar

The result examines the Land Use and Land Cover (LULC) changes perceived in Peshawar across three defined periods 2000, 2010, and 2020, spotlighting shifts in various land use categories. Peshawar underwent noteworthy alterations, notably in its built-up areas, which expanded substantially from 62 km^2 in 2000 to 118 km^2 in 2020. This expansion indicated a substantial 96 km^2 increase (114.5%) from 2010 to 2020, following an initial growth of 22 km^2 (35.5%) from 2000 to 2010. Consequently, the percentage of built-up areas increase from 29.1% in 2000 to 55.4% in 2020. Conversely, the barren land witnessed a striking decrease from 65 km^2 in 2000 to 33 km^2 in 2020, marking a reduction of 20 km^2 (30.8%) from 2000 to 2010, followed by a substantial decline of 53 km^2 (117.8%) from 2010 to 2020. This resulted in a significant drop in barren land from 30.5% in 2000 to 15.5% in 2020.

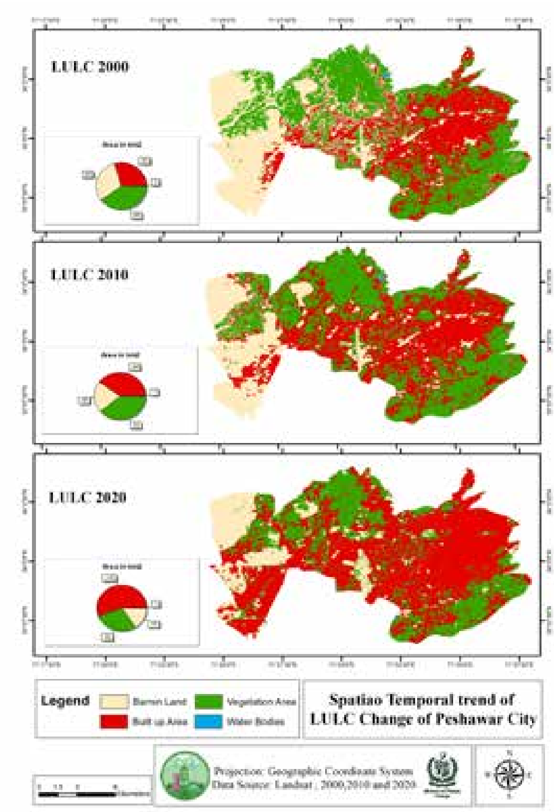


Figure 7: Land Use Land Cover maps of Peshawar for 2000, 2010 and 2020

Moreover, the vegetation area in Peshawar portrayed fluctuations, slightly declining from 85 km^2 in 2000 to 61 km^2 in 2020. This showcased a decrease of 2 km^2 (2.4%) from 2000 to 2010, followed by a more notable decline of 22 km^2 (26.5%) from 2010 to 2020. Consequently, the percentage of vegetation area decreased from 39.9% in 2000 to 28.6% in 2020. Meanwhile, water bodies remained relatively stable, consistently covering 1 km^2 from 2000 to 2020, signifying minimal changes within this specific land cover category.

4.1.6 Mardan

The LULC Map scrutinizes the Land Use and Land Cover (LULC) changes in Mardan over the periods of 2000, 2010, and 2020, delineating shifts in various land use categories. The built-up areas in Mardan saw substantial expansion, growing from 11 km² in 2000 to 22 km² in 2020, with a remarkable increase of 7 km² (63.6%) from 2010 to 2020 and an initial growth of 4 km² (36.4%) from 2000 to 2010. This increase led to a grown in the percentage of built-up areas from 26.2% in 2000 to 52.4% in 2020. Conversely, while barren land experienced a slight decline from 4 km² in 2000 to 3 km² in 2020, it showcased fluctuations, including a 25% reduction from 2000 to 2010, followed by a 100% increase from 2010 to 2020.

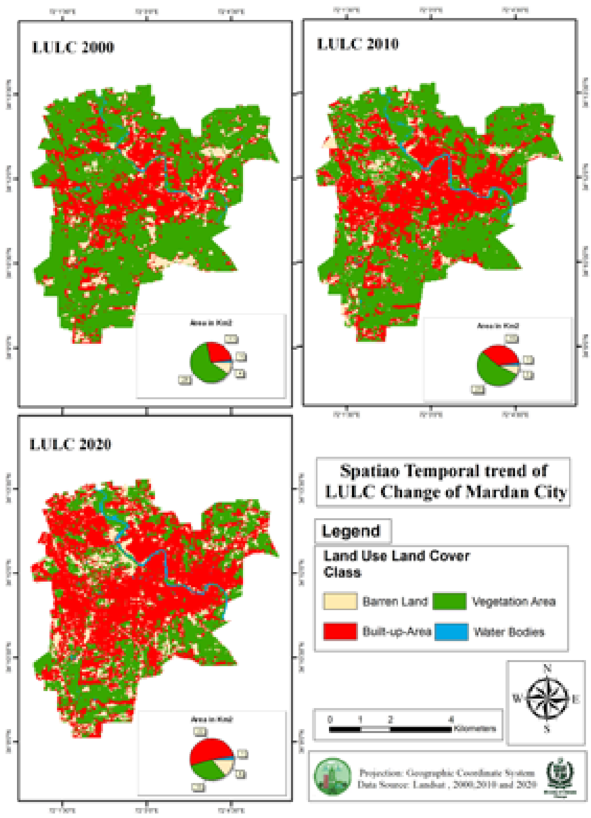


Figure 8: Land Use Land Cover maps of Mardan for 2000, 2010 and 2020

The percentage of barren land decreased from 9.5% in 2000 to 7.1% in 2010 and then rose to 14.3% in 2020. Additionally, the vegetation area in Mardan fluctuated significantly, declining from 26 km² in 2000 to 13 km² in 2020, marking a reduction of 3 km² (11.5%) from 2000 to 2010 and a subsequent decline of 10 km² (43.5%) from 2010 to 2020. Consequently, the percentage of vegetation area decreased from 61.9% in 2000 to 31.0% in 2020. In contrast, the water bodies remained relatively constant, covering 1 km² consistently from 2000 to 2020, indicating minimal changes within this particular land cover category. These insights underscore the substantial growth in built-up areas, marginal shifts in barren land, a considerable decrease in vegetation areas, and the stability of water bodies in Mardan.

4.2 Dynamic Changes in LULC Classes

The LULC classification results show that all four classes in each of the six metropolitan cities have undergone various changes in terms of area from 2000 to 2020. Figure 9 to 14 illustrates the dynamic changes in each class within the study area. The map indicates a significant increase in built-up areas from 2000 to 2020, while vegetation areas and barren land have decreased. These changes are attributed to urbanization, which has led to the construction of new built-up areas such as settlements, road networks, and paved areas to accommodate the growing community.

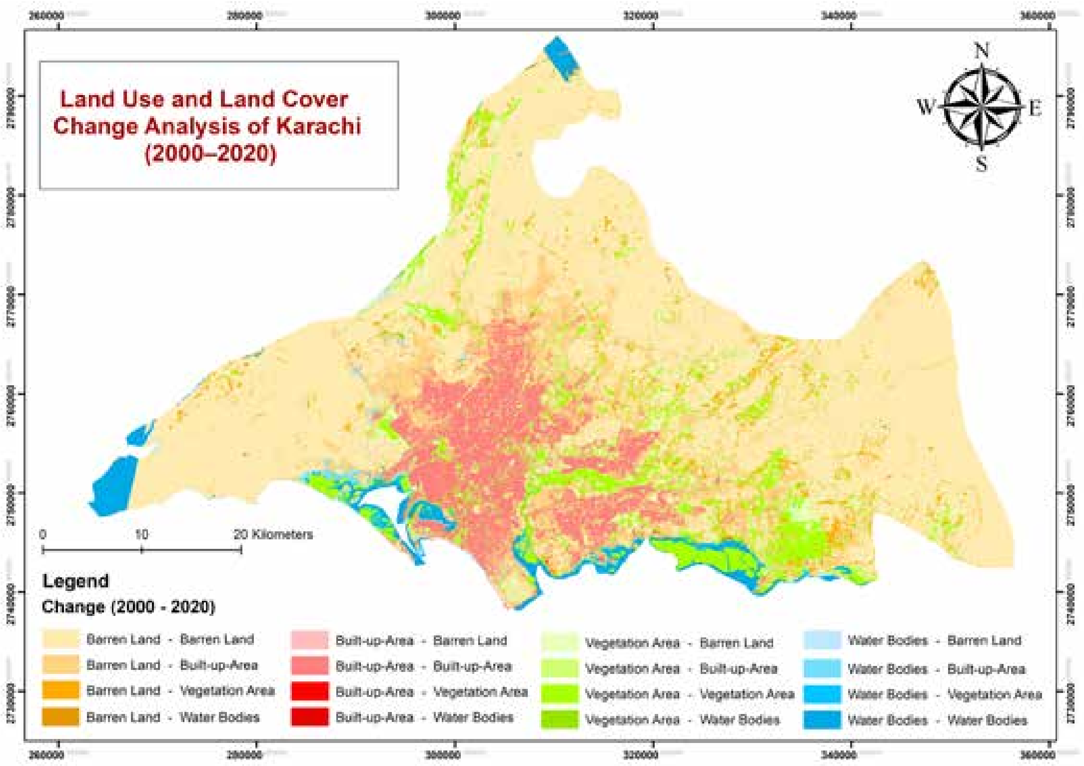
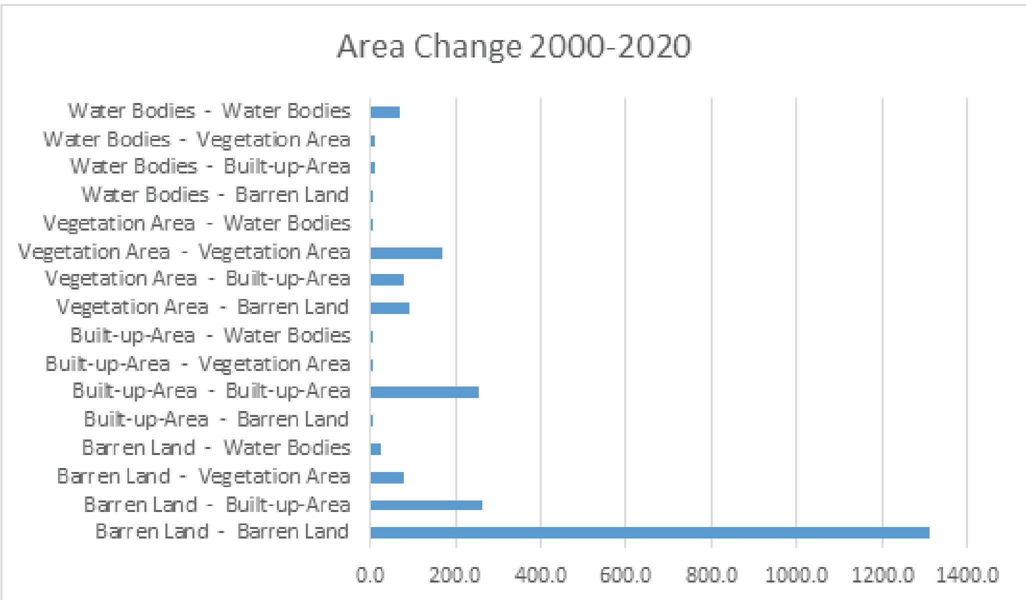


Figure 9: Karachi Map Show Conversion of LULC Class into Other Class



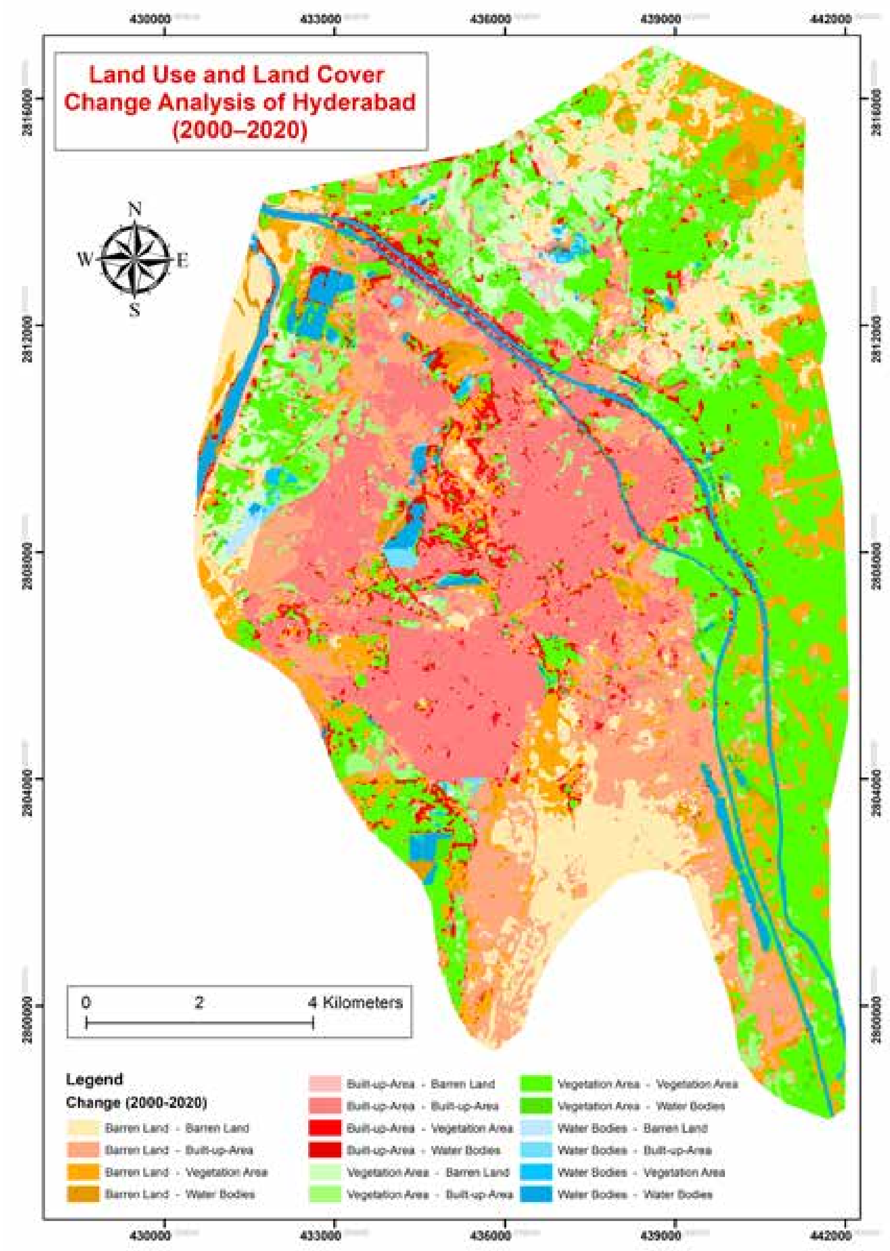
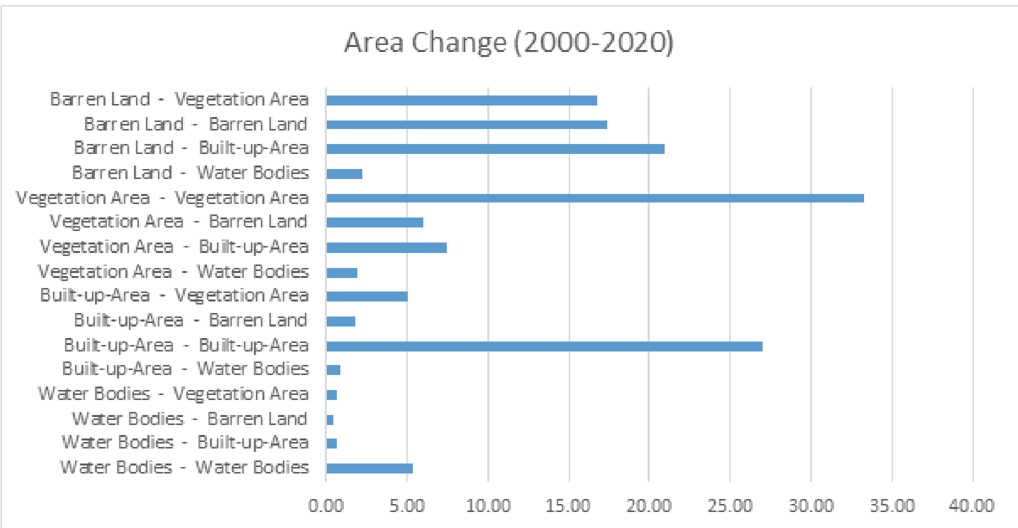


Figure 10: Hyderabad Map Show Conversion of LULC Class into Other Class



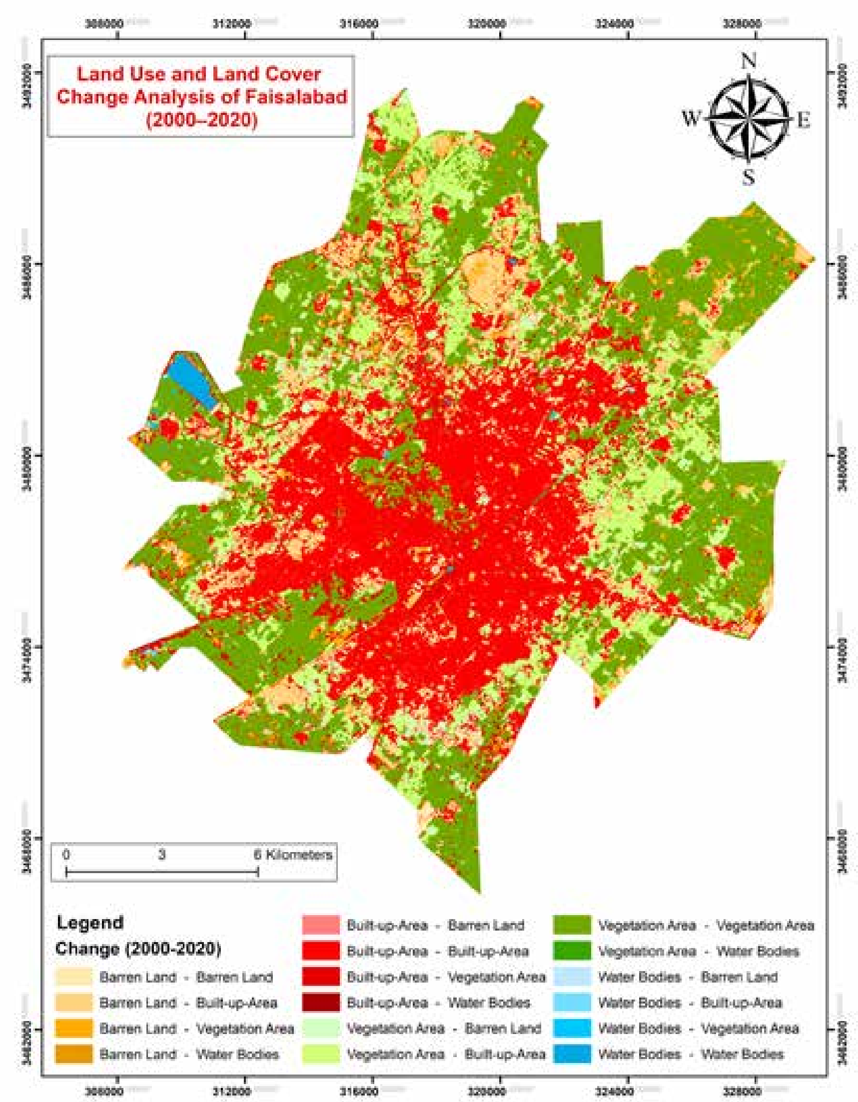
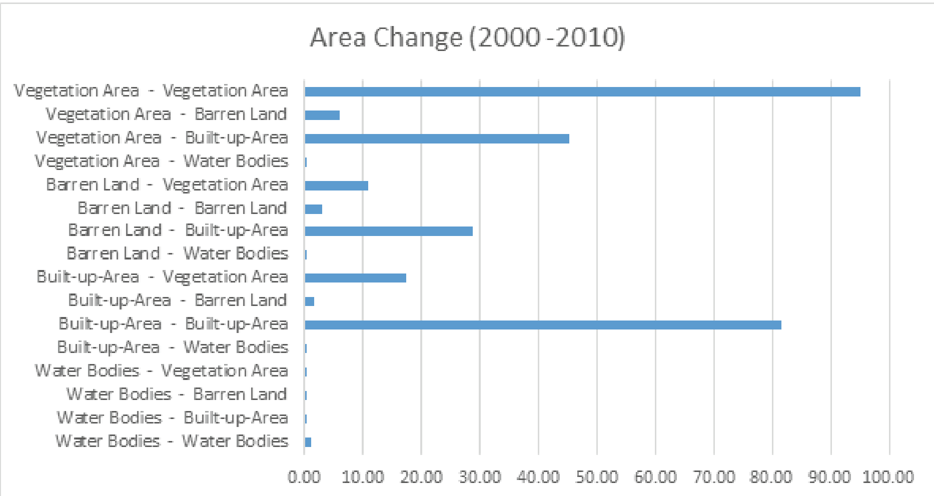


Figure 11: Faisalabad Map Show Conversion of LULC Class into Other Class



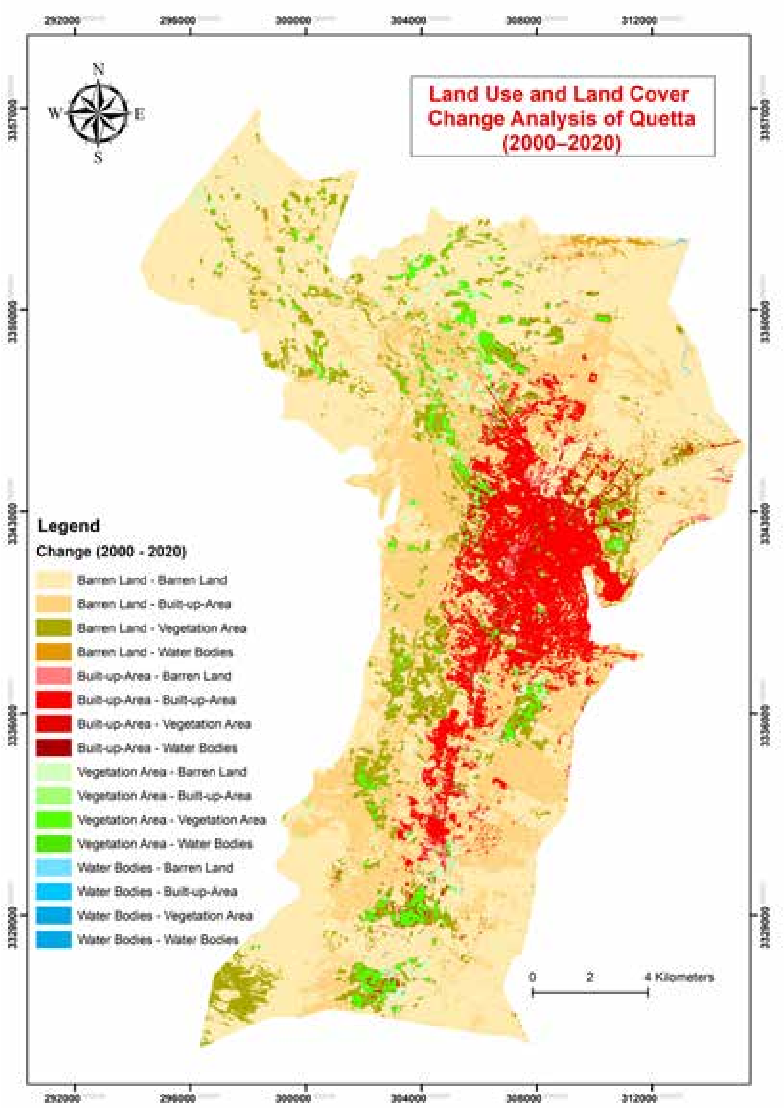
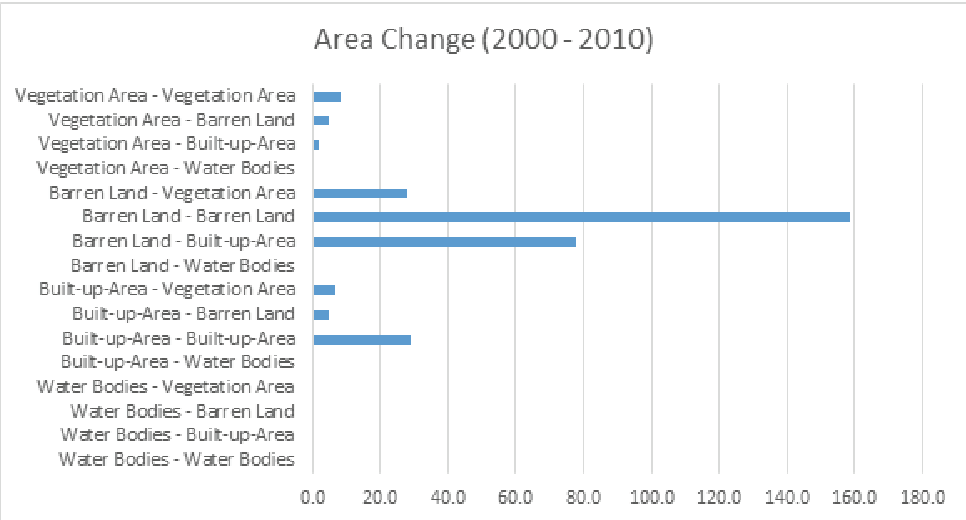


Figure 12: Quetta Map Show Conversion of LULC Class into Other Class



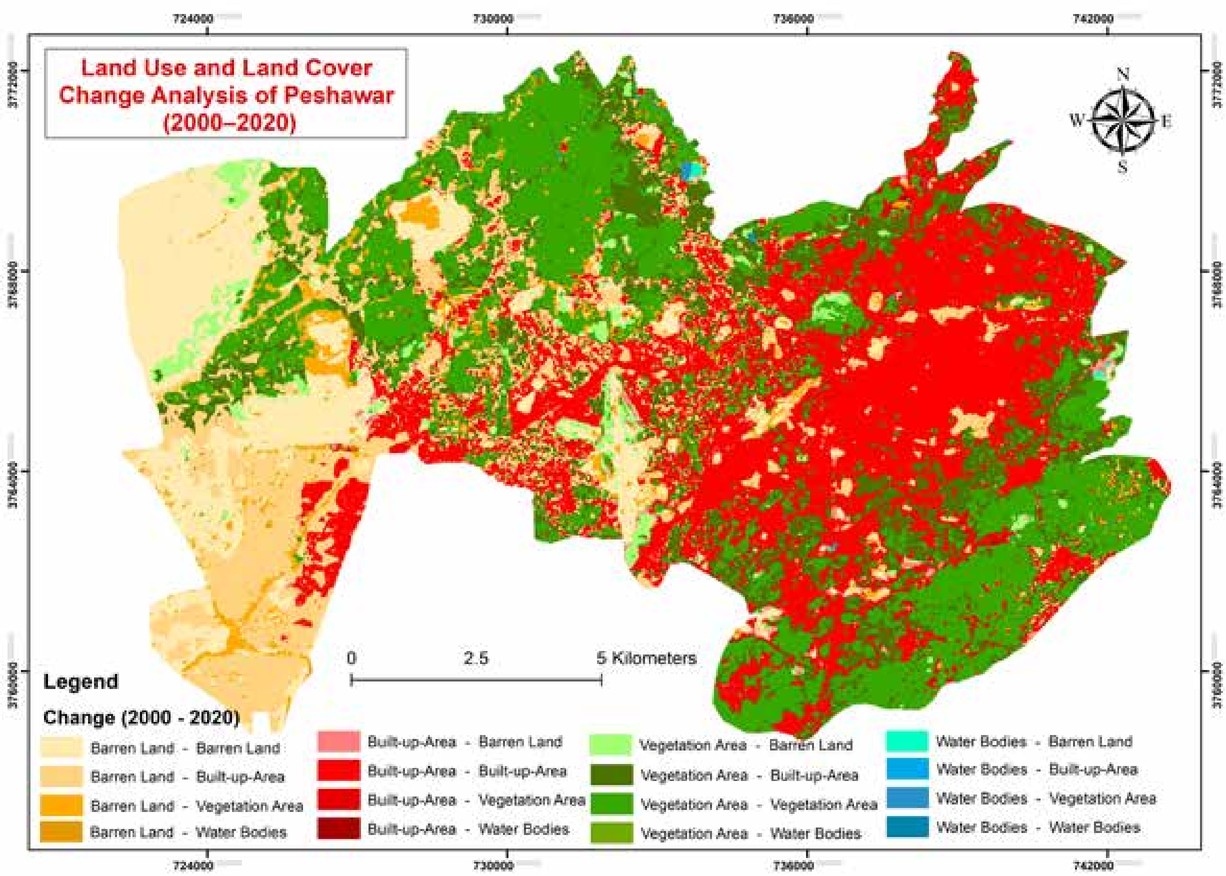
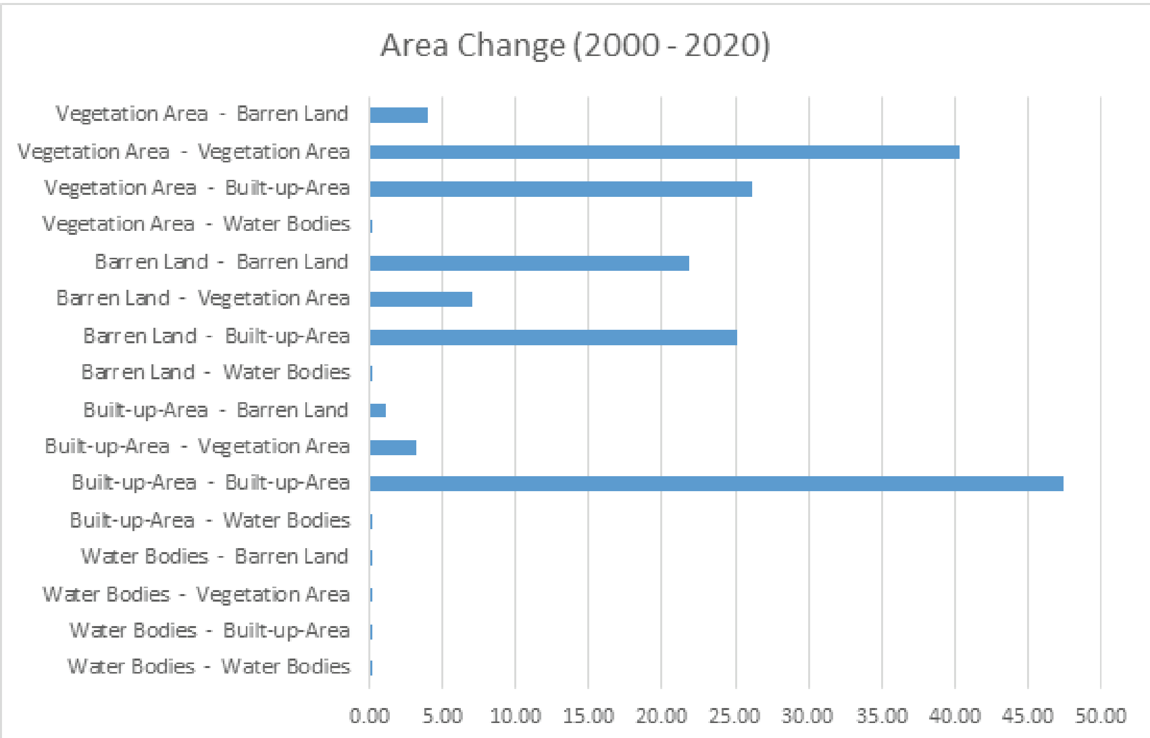


Figure 13: Peshawar Map Show Conversion of LULC Class into Other Class



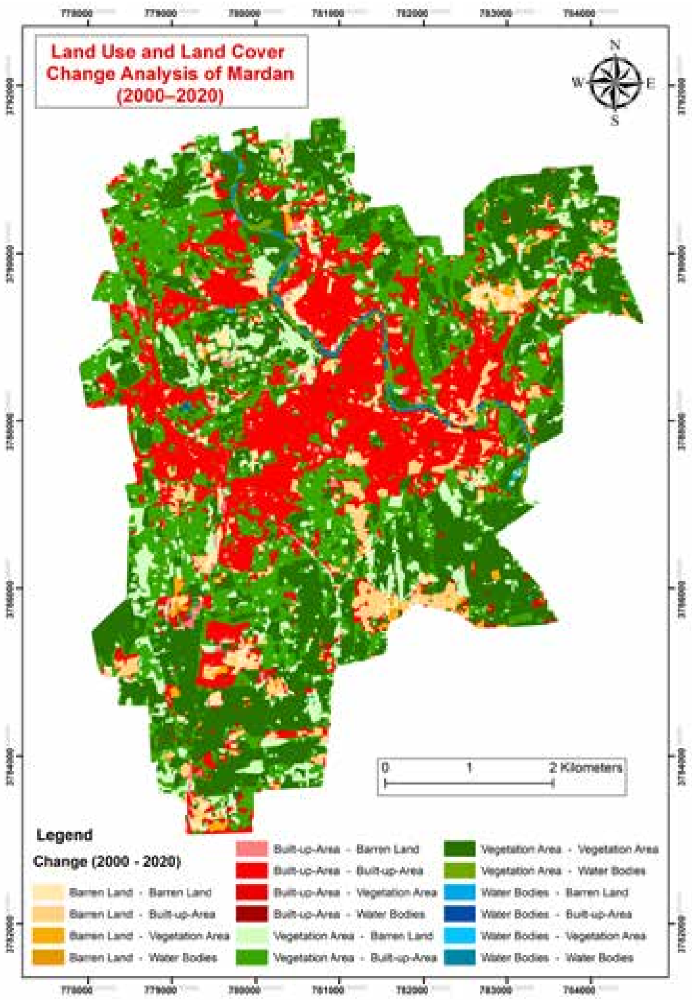
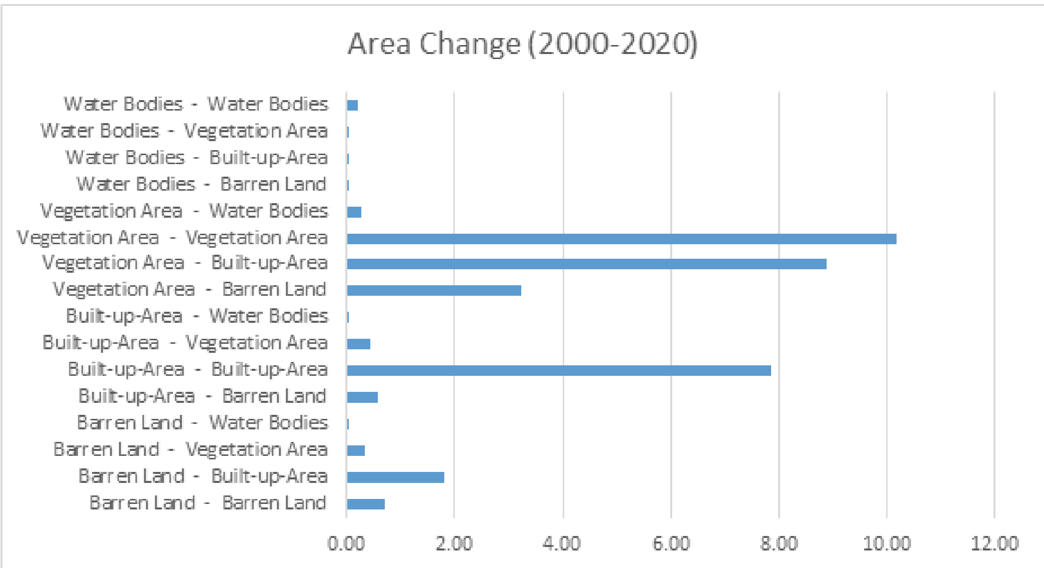


Figure 14: Mardan Map Show Conversion of LULC Class into Other Class



4.3 LULC Accuracy Assessment

Accuracy assessment was conducted using a confusion matrix, which provided satisfactory overall accuracy, considered acceptable for further analysis and change detection (Lea et al., 2010). The confusion matrix includes details about the actual and predicted classifications by the classification system. User accuracy and producer accuracy were calculated for each LULC class. The overall classification accuracy ranged between 85% and 95%, with Kappa coefficient values of 0.94, 0.91, 0.95, and 0.96 for Karachi, Hyderabad, Faisalabad, Quetta, Peshawar and Mardan, respectively. Table 6 presents the detailed accuracy assessment for all Six cities.

Table 6: Accuracy Assessment

Year	2000	2010	2020
Karachi Overall accuracy (%)	95.2	91.3	97.1
Karachi Kappa coefficient (%)	0.94	0.95	0.96
Hyderabad Overall accuracy (%)	89.3	92	92.4
Hyderabad Kappa coefficient (%)	0.91	0.94	0.95
Faisalabad Overall accuracy (%)	91.3	89.3	92.5
Faisalabad Kappa coefficient(%)	0.92	0.91	0.92
Quetta Overall accuracy (%)	85.3	91.3	91.2
Quetta Kappa coefficient (%)	0.9	0.94	0.97
Peshawar Overall accuracy (%)	91.3	89.3	92.5
Peshawar Kappa coefficient (%)	0.92	0.91	0.92
Mardan Overall accuracy (%)	85.3	91.3	91.2
Mardan Kappa coefficient(%)	0.9	0.94	0.97

4.6 Urban Heat Island (UHI) Variations from 2000 to 2020

The UHI phenomenon is examined across all cities revealing clear variations influenced by multiple factors such as water bodies, high-elevation areas with lower temperatures, and the geographical location of cities play significant roles in either enhancing or reducing the UHI effect. The LST maps show spatial temperature differences, with green spots indicating lower temperatures recognized to factors like water bodies and vegetation areas. with red spots indicating higher temperatures in urban areas like built-up areas and orange to blue spots surrounding rural areas or barren land. UHI effects are observed with a continuing increase in LST along the built-up area, resulting in higher surface temperatures than other LULC classes. An increase in surface UHI intensity has been observed. The maps exhibit spatial variations, prominently highlighting the UHI effect in urban areas through distinctive red spots indicating raised temperatures. These results intensely show the temperature contrast between urban and rural regions. The effect of UHI, which is observed in this study, is reflected in variations in LST with continuous changes in the thermal environment. The primary factor contributing to the rise in LST, subsequently leading to the UHI effect, is considered to be urbanization.

The LST shift from 2000 to 2020 shows a clear rise in urban across all cities, while areas with natural features like rivers and vegetation exhibit lighter spots. Urban sprawl extends into rural areas, visible in LULC maps. The trend of UHI is discussed below;

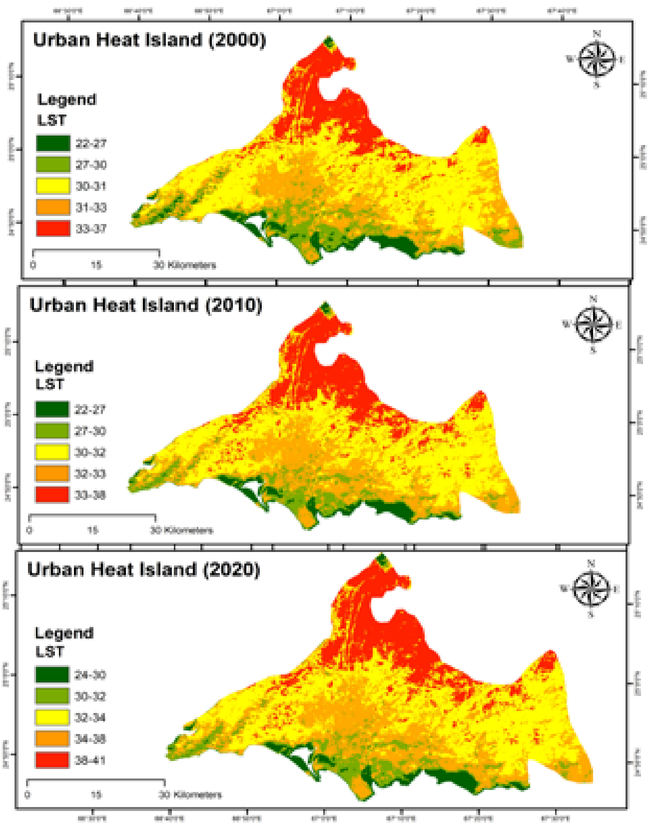


Figure 15: Urban Heat Island Map (Karachi)

Figures 15 and 16 results indicate that the Land surface temperature (LST) varies across different land cover types, influenced by their unique characteristics. In 2000, LSTs were 22°C and 27°C for water, 27°C and 30°C for green areas, 34°C and 38°C for built-up areas, and 37°C and 38°C for barren land / desert areas.

In 2020 the highest LST was observed in desert land (41°C) due to its heat-absorbing nature, while in built-up areas (38°C), likely due to the increasing prevalence of impervious surfaces in urban areas and the release of carbon dioxide into the atmosphere likely contribute to the higher LST observed. Vegetation areas have the third lowest LST while water bodies have the lowest LST. However, the LST for both vegetation areas and water bodies has consistently increased from 2000 to 2020. This consistent rise in LST across all land cover types suggests a potential impact of climate change on urban environments.

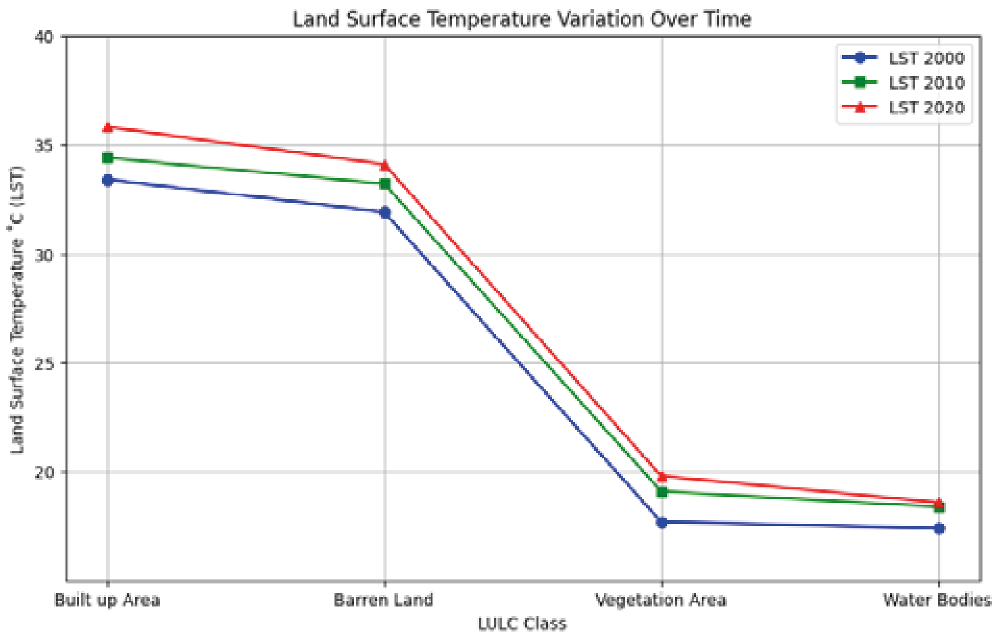


Figure 16: Correlation scatter plot (Karachi) for 2000, 2010 and 2020 LULC and LST

The Urban Heat Island (UHI) maps for Hyderabad, shown in Figures 17 and 18, reveal a notable rise in maximum Land Surface Temperature (LST) in built-up areas, increasing from 37°C in 2000 to 39.8°C in 2020. This trend highlights the growing heat retention in urban areas due to factors such as increased construction and reduced green spaces.

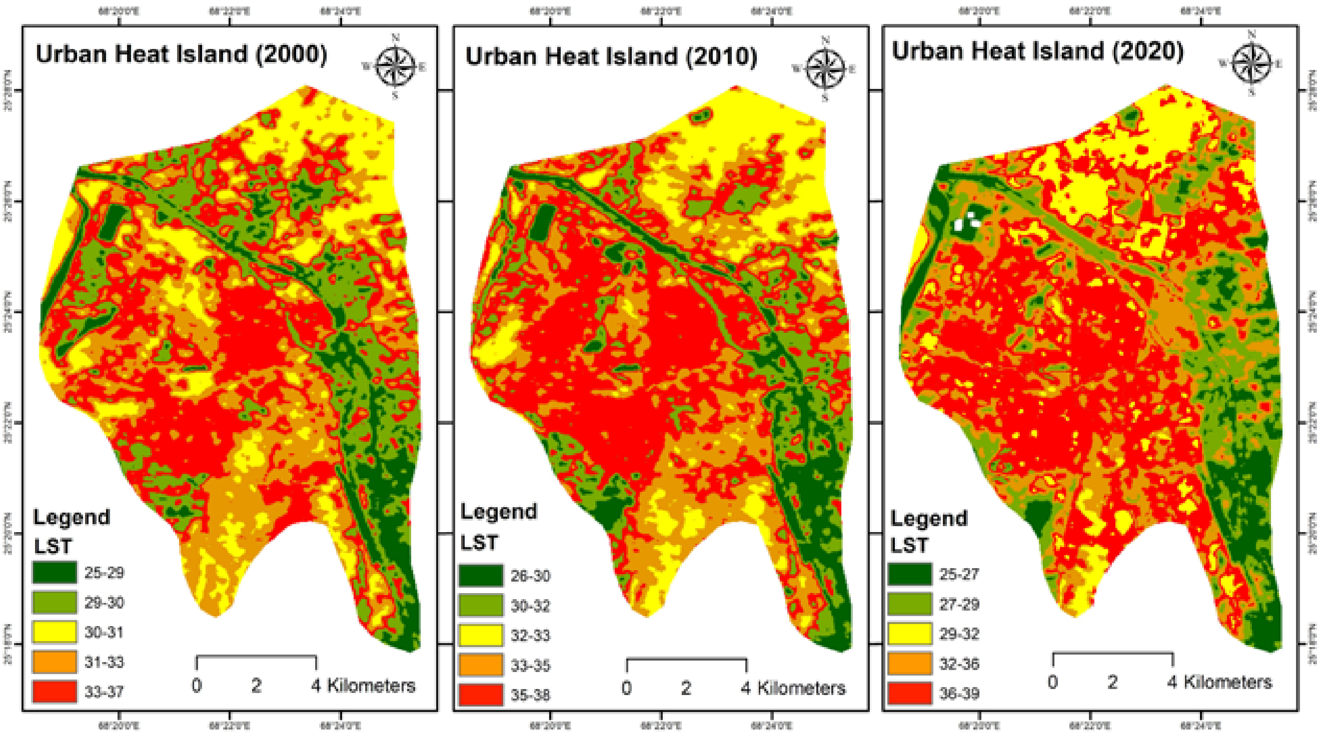


Figure 17: Urban Heat Island Map (Hyderabad)

In contrast, minimum LST in these areas also rose from 25°C to 27°C, over the same period. While regions with water bodies and vegetation experienced a slower temperature increase, they remain cooler compared to urban areas. This disparity illustrates the broader impact of urban heat islands on local climate patterns

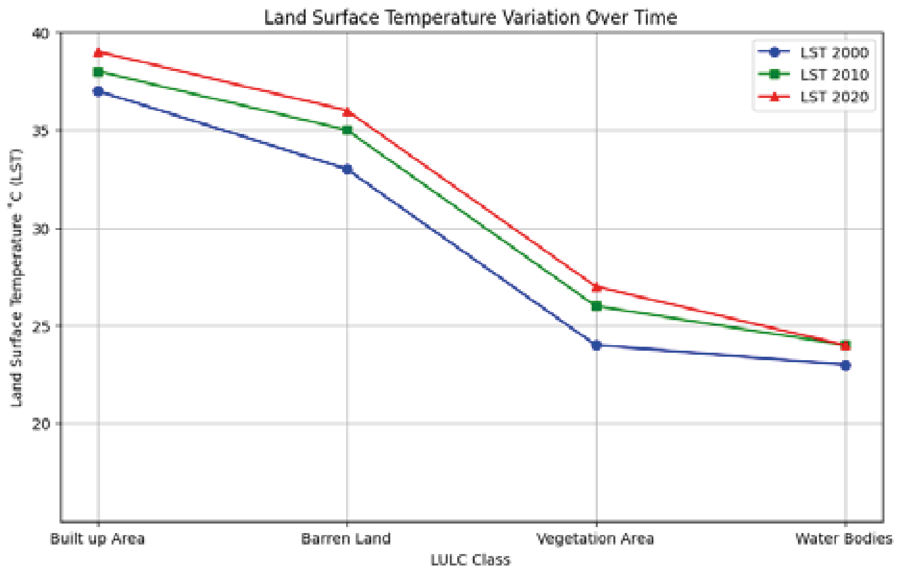


Figure 18: Correlation scatter plot (Hyderabad) for 2000, 2010 and 2020 LULC and LST

The results indicate a significant rise in LST in Faisalabad over the past two decades. In 2000, the maximum LST in the city was 37°C, while the minimum LST was 25°C, as shown in Figures 19 and 20. By 2010, there was a noticeable increase in surface temperatures across different land uses. Specifically, LST in built-up areas rose to 39°C, and in barren lands, it increased to 36°C. Conversely, temperatures in water bodies and vegetation areas saw a smaller increase, reaching 25°C.

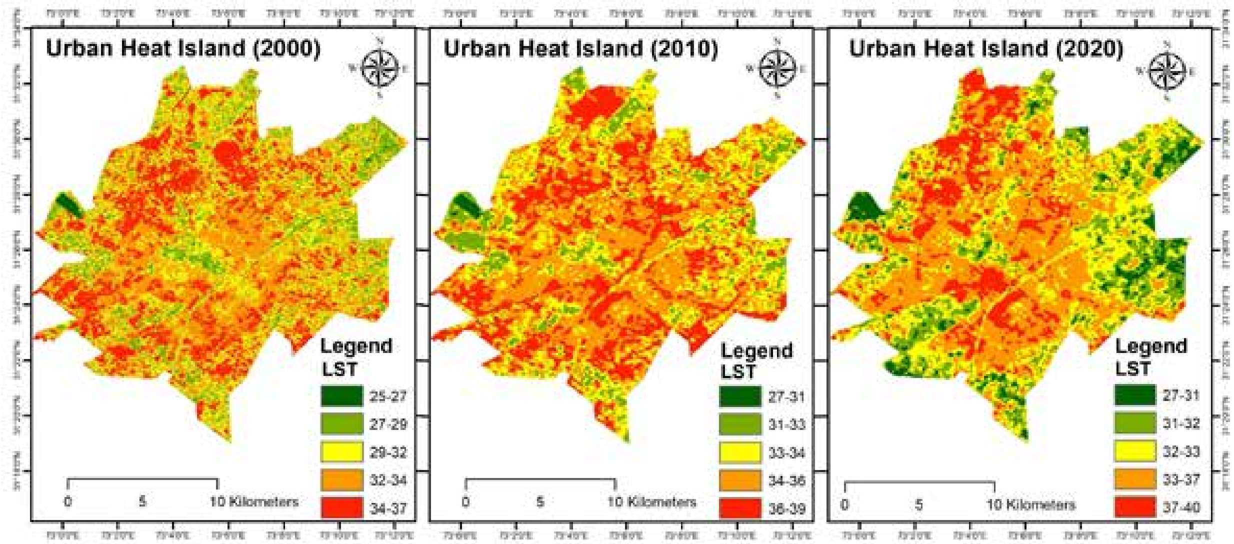


Figure 19: Urban Heat Island Map (Faisalabad)

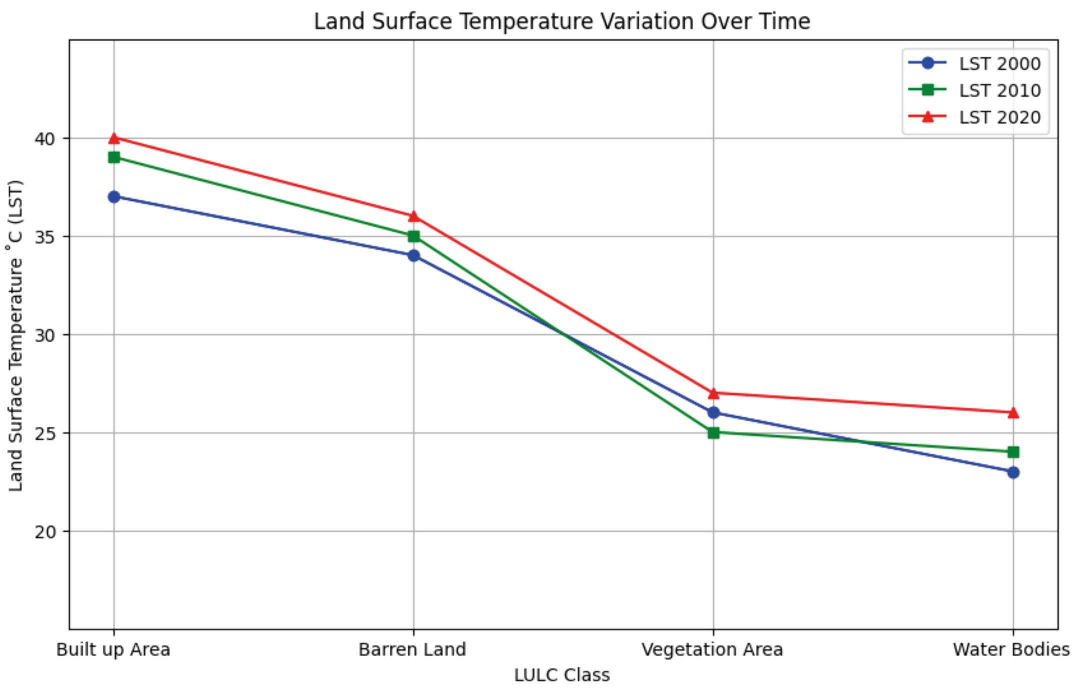


Figure 20: Correlation scatter plot (Faisalabad) for 2000, 2010 and 2020 LULC and LST

The trend of rising temperatures continued through to 2020. In built-up areas, the average LST reached 40°C, marking a significant increase of 3°C from 2000. This continued warming in urban areas reflects the intensification of the heat island effect. Meanwhile, the temperature in water bodies and vegetation areas also rose, reaching 27°C by 2020, indicating a broader impact of urbanization on local temperature patterns.

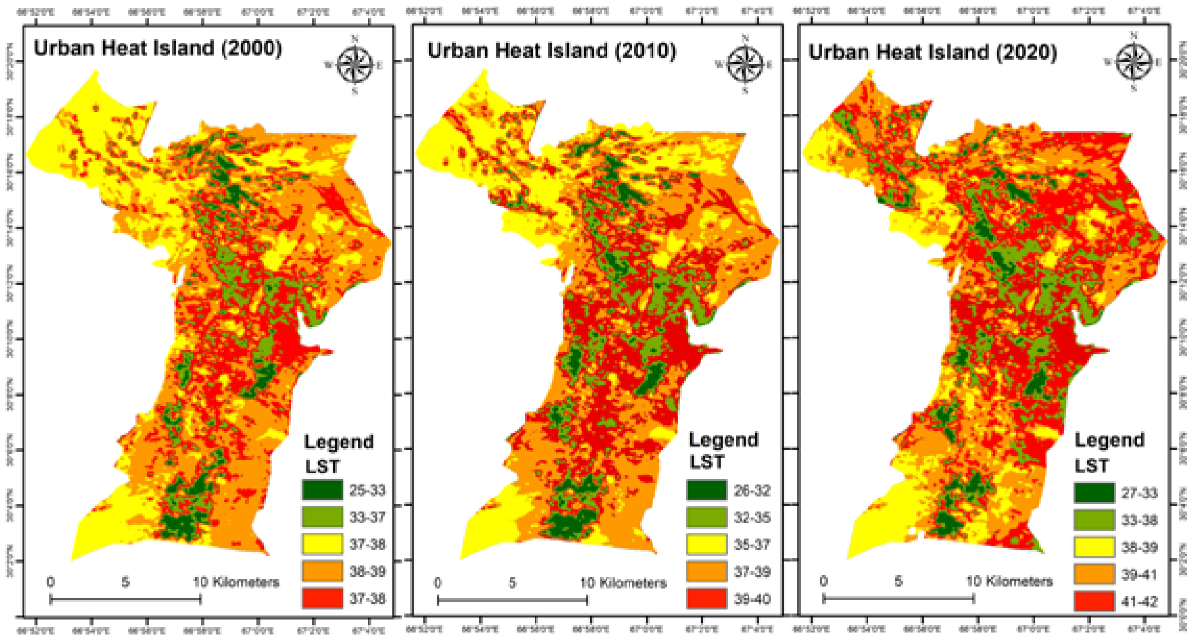


Figure 21: Urban Heat Island Map (Quetta)

Figures 21 and 22 illustrate the temperature dynamics in Quetta over time. In the year 2000, the maximum LST in built-up areas of Quetta was recorded at 38°C, while the minimum LST in areas covered by vegetation was 25°C. This initial data highlights the

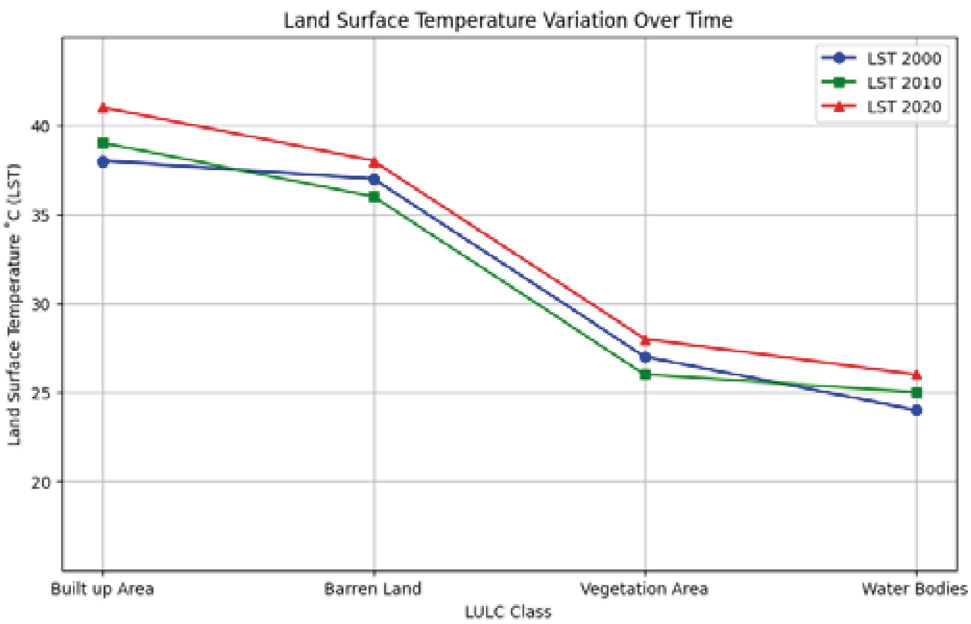


Figure 22: Correlation scatter plot (Quetta) for 2000, 2010 and 2020 LULC and LST

In 2010 the built-up areas saw a significant increase, with maximum temperatures reaching 39°C, up from 38°C in 2000. Barren lands also exhibited an increase, with LST rising to 38°C. Areas with vegetation and bodies of water showed a more moderate temperature increase, reaching 26°C.

In 2020, the trend of rising temperatures continued. Built-up areas rose to 41°C, reflecting an overall increase of 3°C from 2010. In contrast, temperatures in vegetation and water body areas also rose, reaching 27°C.

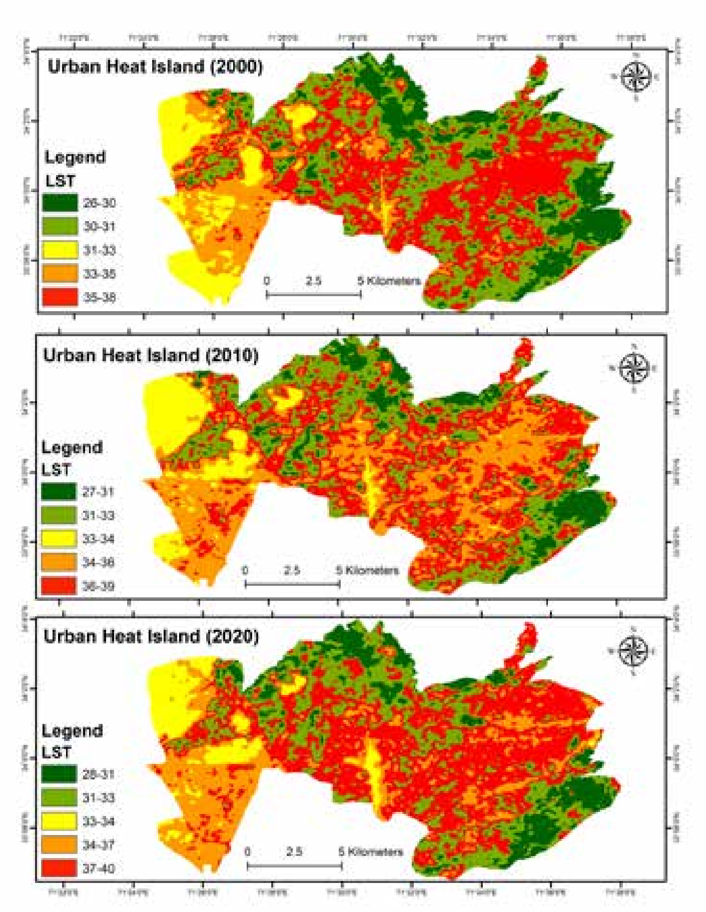


Figure 23: Urban Heat Island Map (Peshawar)

The UHI maps for Peshawar (Figures 23 and 24), reveal a clear upward trend in LST over the past two decades. In 2000, the maximum LST in built-up areas was recorded at 38°C. This increased to 39°C in 2010 and further rose to 40°C by 2020. This represents a 2°C increase from 2000 in built-up areas indicating a continuous intensification of heat in urban areas. Concurrently, the minimum LST in areas with water bodies and vegetation also showed a gradual increase, rising from 26°C in 2000 to 27°C in 2010, and reaching 28°C in 2020.

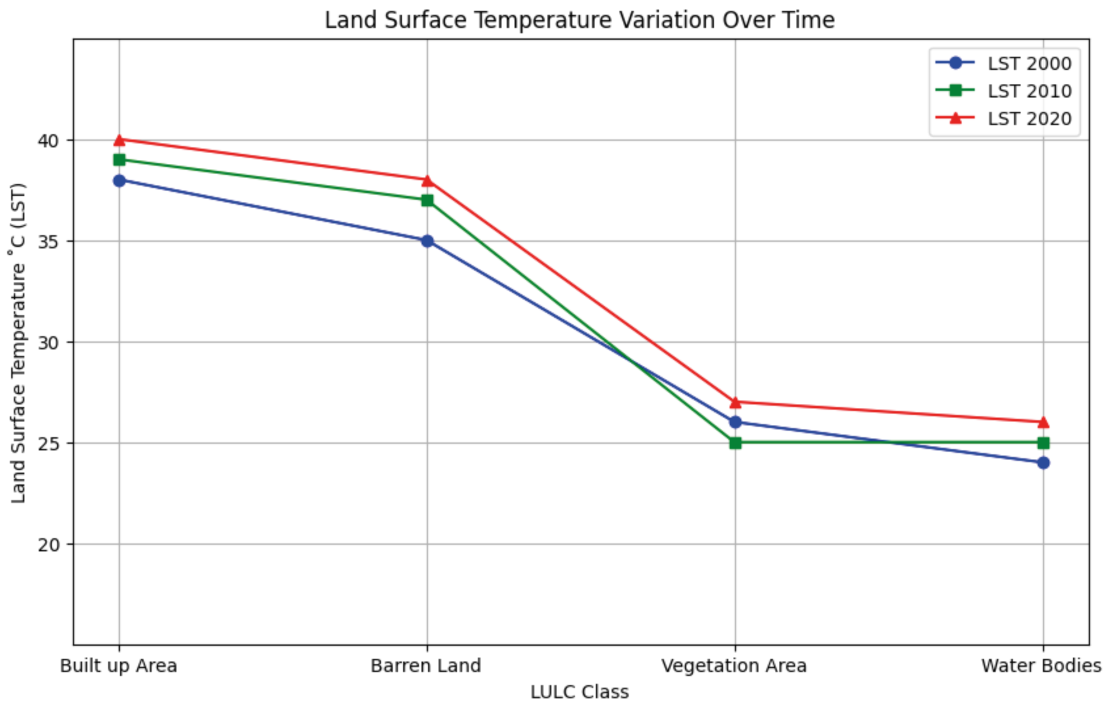


Figure 24: Correlation scatter plot (Pesawar) for 2000, 2010 and 2020 LULC and LST

The results illustrated in Figures 25 and 26, reveal significant changes over the past two decades in Mardan. In 2000, the maximum LST in built-up areas was recorded at 36°C, while the minimum LST was 28°C. This initial data sets a baseline for understanding subsequent temperature trends.

In 2010, there was a noticeable rise in surface temperatures across different land use classes. In built-up areas, the LST increased to 37°C, while barren land indicates a slight rise to 35°C. Meanwhile, LST in water bodies and vegetation areas also increased, reaching 29°C.

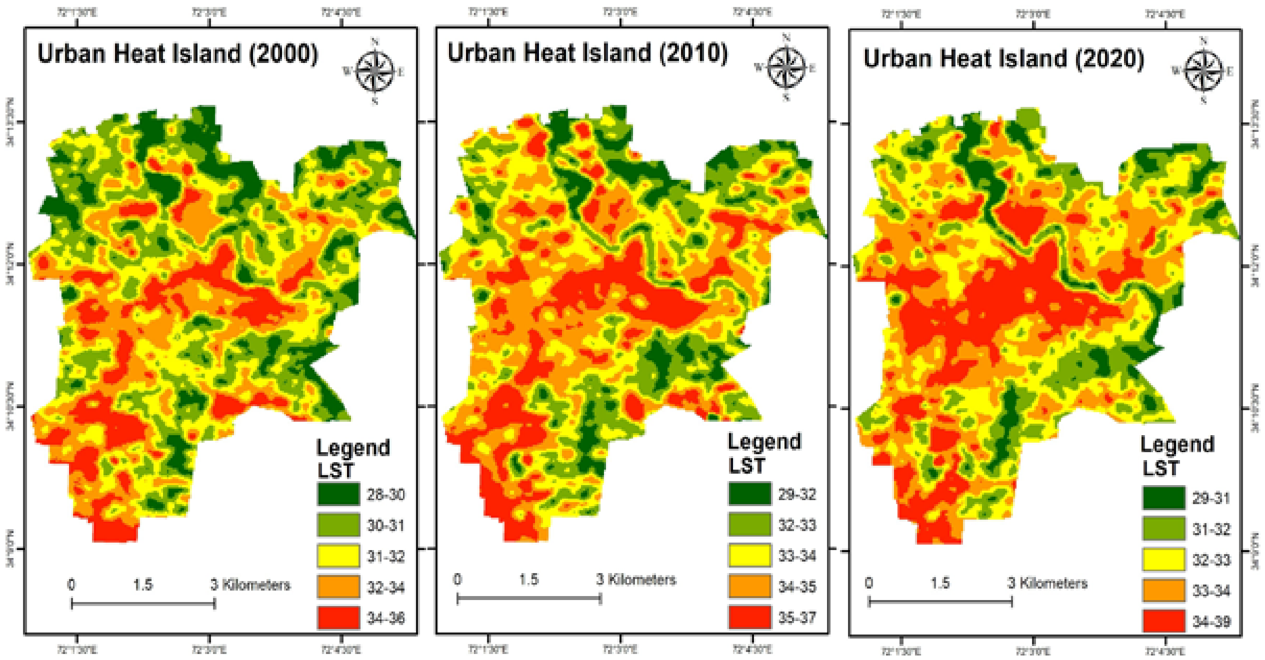


Figure 25: Urban Heat Island Map (Mardan)

In 2020, the trend of rising temperatures continued. Built-up areas experienced a further increase in LST, reaching an average of 39°C, which represents an overall rise of 2.8°C from 2000. This increase highlights the intensification of the urban heat island effect as urban areas continue to expand and develop. Conversely, temperatures in water bodies and vegetation areas rose to 29°C, reflecting a more moderate increase compared to urban areas.

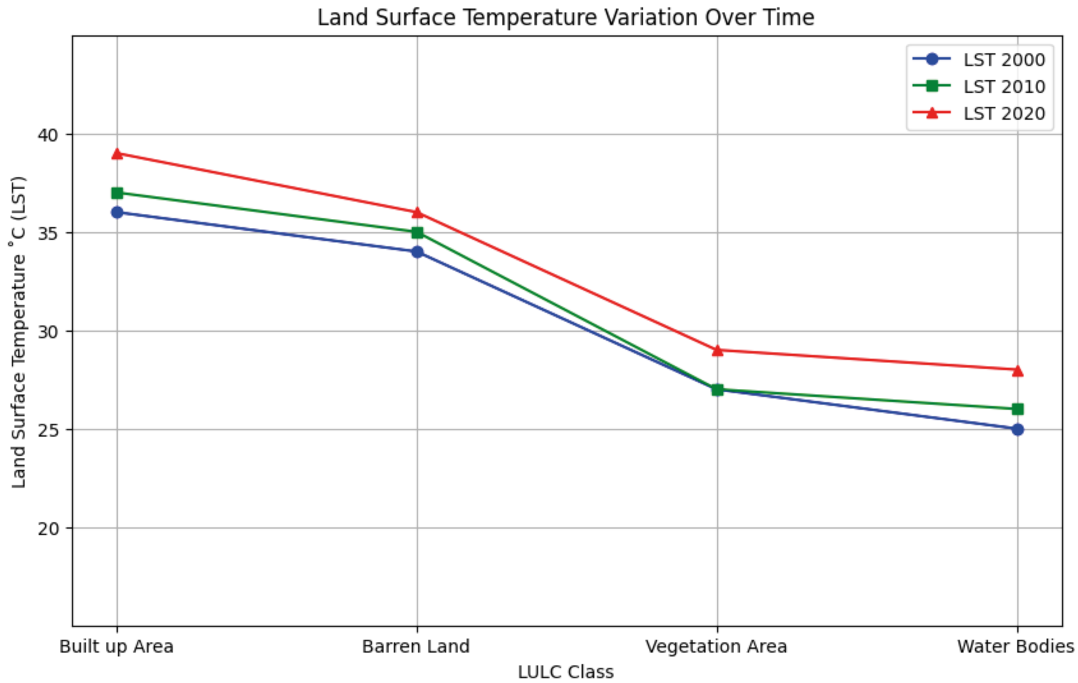


Figure 26: Correlation scatter plot (Mardan) for 2000, 2010 and 2020 LULC and LST

The examination of LST trends across various cities, as showed in Figures 15 through 26, reveals significant patterns in the impact of urbanization on local climatic conditions. In the year 2000, LST varied considerably among different land cover types, with desert regions recording the highest temperatures and water bodies the lowest. Over the subsequent two decades, the data indicate a consistent increase in LST across all land cover categories.

Built-up areas, in particular, have experienced the most substantial rises in temperature, attributed to factors such as increased urban development, expanded impervious surfaces, and diminished green spaces. Conversely, while water bodies and vegetated areas have also exhibited rising temperatures, the increases have been comparatively moderate. This observed trend underscores the escalation of the UHI effect.

05 Discussion

The study highlights the variations and trends of UHI effects, along with urban thermal changes influenced by LULC using satellite data from 2000 to 2020 of four cities i.e. Karachi, Hyderabad, Faisalabad, Quetta, Peshawar and Mardan. The Maximum Likelihood Classification (MLC) algorithm is used for LULC classifications which provide precise results. (Patil et al. 2012) also used MLC algorithm in their study which found accurate results. The findings of this study indicate that the urban area in all four cities i.e. Karachi, Hyderabad, Faisalabad, Quetta, Peshawar and Mardan has increased by 25.7%, 13.9%, 18.7%, 21.2%, 26.3% and 26.2% respectively during 2000-2020, which caused a decline in vegetated areas i.e., parks and green spaces by conversion into built-up areas and barren land. This conversion primarily occurs through the formation of new housing societies, the expansion of road networks, and the development of new buildings and industrial complexes. (Hassan et al. 2021b) also stated that the constant rise in population and migration from surrounding areas to urban areas has caused significant changes in LULC classes within urban environments. Moreover, the analysis depicts that LST is more influenced by changes in LULC such as the development of built-up areas and the presence of barren land. In comparison, vegetation areas and water bodies exert a lesser effect on LST due to the cooling effect, which benefits the ecosystem and can help mitigate climate change. In study areas, the built-up and barren land revealed the highest recorded LST, while vegetation and water bodies showed the lowest measured LST values. This aligns with (Saleem et al. 2020), who found that built-up area and barren land exhibit significantly higher LST than vegetated and water-covered surfaces due to the heat retention of impervious materials and the cooling effects of vegetation and water. From 2000 to 2020, the annual maximum LST in Karachi rose by 2.1°C, Hyderabad by 1.9°C, Faisalabad by 2.0°C, Quetta by 2.2°C, Peshawar 2.0°C, and Mardan 2.0°C, Ullah et al. (2023) and Waseem and Khayyam (2019) conducted separate studies over Islamabad and concluded that significant changes in LST are linked to the changes in land use and land cover patterns, which is in concurrence with our findings. This increase in temperature is attributed to the energy expanded by the urban population., transports, buildings and other absorbing materials in cities such as Karachi, Hyderabad, Faisalabad, Quetta, Peshawar and Mardan. Despite the distinct locations and physiographies of the four cities, their surface temperatures show minimal differences. The expansion of built-up areas and the reduction in vegetation contribute to a favorable contribution to UHI. The study's findings showed that appropriate action plans are required to manage urban heat and promote sustainable city development. The analysis also indicates that as barren land continues to decrease, built-up areas will become the primary factor influencing LST in the future. It has been noted in a few previous studies that the relationship between changes in land use land cover and land surface temperature in small and medium cities in Pakistan.

06 Limitations of the study

In this study, Landsat products were utilized to analyze land use land cover, land surface temperature and urban heat island effects for the years 2000, 2010, and 2020. To improve future research, it is recommended to use datasets with higher temporal and spatial resolutions to reduce uncertainties related to cloud cover and coarse spatial resolution. Future studies should also explore innovative methodologies and techniques. While this research concentrated on urban areas and LULC changes related to UHI, subsequent investigations should incorporate additional factors such as regional climate change and its effects on UHI, as well as the broader impact of urbanization on climate change. Although this study provided a thorough examination of the UHI phenomenon and its correlation with LULC changes, future research could expand to other cities in Pakistan, offering deeper insights into UHI and related issues at both regional and localized scales to better understand andaddress these challenges.

07 Conclusions

This research study utilized geospatial techniques to analyse spatiotemporal changes in land use land cover and their impact on urban heat islands across four metropolitan cities in Pakistan from 2000 to 2020. The major results of this study are given below:

1. A significant increase was observed in urban areas of all six cities, with built-up and barren land revealing the highest LST values. The observed rise in LST, particularly in urban areas, emphasizes the exacerbation of the UHI effect over the study period.
2. The changes detected in LULC from 2000 to 2020 are due to the replacement of vegetation areas with impermeable surfaces which reveals a noticeable shift in the climate of all six cities. This transformation has resulted in the loss of approximately 3% of its original land area in Karachi, 7.3% in Faisalabad, and 11.3% in Peshawar and 31% in Mardan.
3. Considerable variations in LST were observed for the years 2000, 2010, and 2020. The results show that from 2010 to 2020, the LST rose from 38.8°C to 41°C in Karachi, 37°C to 39°C in Hyderabad, 38°C to 40°C in Faisalabad, 38°C to 41°C in Quetta, 38°C to 40°C in Peshawar while for 37°C to 39°C in Mardan. The lowest temperatures were recorded within regions characterized by water bodies and vegetation areas. The results indicate the presence of poor ecological conditions in all urban areas of the cities showing the highest value.

This study will enhance climate change mitigation efforts by refining land use planning systems and reducing impermeable surfaces, with a specific emphasis on understanding their influence on mitigating the UHI effect for the sustainable development of future cities. This study provides useful insight into the long-term changes in LULC and vegetation, which influence variations in LST and UHI using remote sensing data.

08 Recommendations

Based on the analysis and findings of this report, the following measures can be taken to mitigate the urban heat island effect:

1. Increase Vegetation: Promote the expansion of green spaces, urban forests, and vegetated areas within cities. Planting trees, installing green roofs, and creating parks can help absorb heat, provide shade, and enhance biodiversity.
2. Cool Roofs and Surfaces: Encourage the use of cool roofing materials and light-colored pavements to reduce heat absorption and minimize surface temperatures.
Implementing cool pavement technologies and reflective coatings can significantly lower urban heat island effects.
3. Permeable Pavements: Invest in permeable pavement systems that allow rainwater to infiltrate the ground, reducing runoff and surface temperatures. Permeable surfaces also help replenish groundwater and mitigate heat build-up.
4. Heat-Resilient Infrastructure: Design and retrofit buildings and infrastructure with heat-resilient materials and energy-efficient technologies. Implement green building standards, such as LEED certification, to enhance thermal comfort and reduce energy consumption.
5. Community Engagement: Engage residents, businesses, and community organizations in heat island mitigation efforts. Promote awareness, provide education, and encourage participation in tree planting, green space maintenance, and sustainable urban development initiatives.
6. Policy Support: Enact and enforce policies that support heat island mitigation, such as building codes, zoning regulations, and incentives for green infrastructure.
Develop urban heat island action plans and integrate heat mitigation goals into climate resilience strategies.
7. Data Monitoring and Analysis:
Establish monitoring systems to track urban heat island dynamics and evaluate the effectiveness of mitigation measures. Use remote sensing technologies, weather stations, and urban heat mapping to identify hotspots and inform decision-making.
8. Cross-Sector Collaboration: Foster collaboration among government agencies, research institutions, businesses, and community stakeholders to address the complex challenges of urban heat islands. Form partnerships, share resources, and leverage expertise to implement comprehensive solutions.
9. Long-Term Planning and Adaptation: Adopt a holistic and long-term approach to urban heat island mitigation, considering future climate projections and demographic trends. Invest in resilient infrastructure, green infrastructure, and adaptive management practices to build climate-ready cities.

By implementing these recommendations, cities can effectively reduce the urban heat island effect, enhance quality of life, and create more sustainable and resilient urban environments for current and future generations.

09 References

1. Irshad, Z., Hassan, M., Akbar, S., Farooq, M., & Chishtie, F.A. (2024). Spatiotemporal changes in LULC and associated impact on urban Heat Islands over Pakistan using geospatial techniques. Urban Climate, 57, 102112
2. Almusaed, A., & Almusaed, A. (2011). The urban heat island phenomenon upon urban components. Biophilic and Bioclimatic Architecture: Analytical Therapy for the Next Generation of Passive Sustainable Architecture, 139-150
3. Alphan, H. (2003). Land-use change and urbanization of Adana, Turkey. Land degradation & development, 14, 575-586
4. Aslam, A., Rana, I.A., & Bhatti, S.S. (2021). The spatiotemporal dynamics of urbanisation and local climate: A case study of Islamabad, Pakistan. Environmental Impact Assessment Review, 91, 106666
5. Bank, T.W. (Oct 06,2022). Urban Development
6. Farid, N., Moazzam, M.F.U., Ahmad, S.R., Coluzzi, R., & Lanfredi, M. (2022). Monitoring the Impact of Rapid Urbanization on Land Surface Temperature and Assessment of Surface Urban Heat Island Using Landsat in Megacity (Lahore) of Pakistan. Frontiers in Remote Sensing, 3
7. Fu, P., & Weng, Q. (2018). Responses of urban heat island in Atlanta to different land-use scenarios. Theoretical and Applied Climatology, 133, 123-135
8. Hassan, T., Zhang, J., Prodhan, F.A., Pangali Sharma, T.P., & Bashir, B. (2021). Surface Urban Heat Islands Dynamics in Response to LULC and Vegetation across South Asia (2000–2019). Remote Sensing, 13, 3177
9. Hassan, Z., Shabbir, R., Ahmad, S.S., Malik, A.H., Aziz, N., Butt, A., & Erum, S. (2016). Dynamics of land use and land cover change (LULCC) using geospatial techniques: a case study of Islamabad Pakistan. SpringerPlus, 5, 812
10. He, B.-J. (2019). Towards the next generation of green building for urban heat island mitigation: Zero UHI impact building. Sustainable Cities and Society, 50, 101647
11. He, J.F., Liu, J.Y., Zhuang, D.F., Zhang, W., & Liu, M.L. (2007). Assessing the effect of land use/land cover change on the change of urban heat island intensity. Theoretical and Applied Climatology, 90, 217-226
12. Hibbard, K., Hoffman, F., Huntzinger, D., & West, T. (2017). Changes in land cover and terrestrial biogeochemistry
13. Hijioka, Y., Lasco, R., Surjan, A., & Pereira, J. (2014). Climate Change 2014 Impacts, adaptation, and vulnerability. Part B Regional aspects. Contribution of Working Group II to the Fifth Assessment Report of the IPCC.
14. Hussain, S., Mubeen, M., Ahmad, A., Masood, N., Hammad, H.M., Amjad, M., Imran, M., Usman, M., Farid, H.U., Fahad, S., Nasim, W., Javeed, H.M.R., Ali, M., Qaisrani, S.A., Farooq, A., Khalid, M.S., & Waleed, M. (2021). Satellite-based evaluation of temporal change in cultivated land in Southern Punjab (Multan region) through dynamics of vegetation and land surface temperature. Open Geosciences, 13, 1561-1577
15. Hussain, S., Mubeen, M., Akram, W., Ahmad, A., Rahman, M., Ghaffar, A., Amin, A., Awais, M., Hafiz, U., Farid, A., Farooq, W., Amin, A., & Jatoi, W. (2019). Study of land cover/land use changes using RS and GIS: a case study of Multan district, Pakistan
16. Jabeen, N., Farwa, U., & Jadoon, M. (2017). Urbanization in Pakistan: a governance perspective. Journal of the Research Society of Pakistan, 54, 127-136
17. Jan, B., & Iqbal, M. (2008). Urbanization trend and urban population projections of Paki-

stan using weighted approach. Sarhad Journal of Agriculture (Pakistan), 24

18. Kamran, Khan, J.A., Khayyam, U., Waheed, A., & Khokhar, M.F. (2023). Exploring the nexus between land use land cover (LULC) changes and population growth in a planned city of islamabad and unplanned city of Rawalpindi, Pakistan. Heliyon, 9, e13297
19. Karakuş, C.B. (2019). The Impact of Land Use/Land Cover (LULC) Changes on Land Surface Temperature in Sivas City Center and Its Surroundings and Assessment of Urban Heat Island. Asia-Pacific Journal of Atmospheric Sciences, 55, 669-684
20. Khare, V.R., Vajpai, A., & Gupta, D. (2021). A big picture of urban heat island mitigation strategies and recommendation for India. Urban Climate, 37, 100845
21. Kibert, C.J. (2016). Sustainable construction: green building design and delivery. John Wiley & Sons
22. Kummu, M., De Moel, H., Ward, P.J., & Varis, O. (2011). How close do we live to water? A global analysis of population distance to freshwater bodies. PloS one, 6, e20578
23. Lu, D., Mausel, P., Brondízio, E., & Moran, E. (2004). Change Detection Techniques. International Journal of Remote Sensing, 25
24. Mumtaz, F., Tao, Y., de Leeuw, G., Zhao, L., Fan, C., Elnashar, A., Bashir, B., Wang, G., Li, L., Naeem, S., Arshad, A., & Wang, D. (2020). Modeling Spatio-Temporal Land Transformation and Its Associated Impacts on land Surface Temperature (LST). Remote Sensing, 12, 2987
25. Nasar-u-Minallah, M., Zia, S., Rahman, A.-u., & Riaz, O. (2021). Spatio-Temporal Analysis of Urban Expansion and Future Growth Patterns of Lahore, Pakistan. Geography, Environment, Sustainability, 14, 41-53
26. Nation, U. (2022). What is Climate Change
27. Oke, T. (1982). The energetic basis of urban heat island. Quarterly Journal of the Royal Meteorological Society, 108, 1-24
28. Pal, S., & Ziaul, S. (2017). Detection of land use and land cover change and land surface temperature in English Bazar urban centre. The Egyptian Journal of Remote Sensing and Space Science, 20, 125-145
29. PBS, G. (2017). Salient Features - 6th Population & Housing Census 2017
30. Contents (District Tables). In
31. Rehan, R.M. (2016). Cool city as a sustainable example of heat island management case study of the coolest city in the world. HBRC Journal, 12, 191-204
32. Roy, P.S., Ramachandran, R.M., Paul, O., Thakur, P.K., Ravan, S., Behera, M.D., Sarangi, C., & Kanawade, V.P. (2022). Anthropogenic land use and land cover changes—A review on its environmental consequences and climate change. Journal of the Indian Society of Remote Sensing, 50, 1615-1640
33. Sadiq Khan, M., Ullah, S., Sun, T., Rehman, A.U., & Chen, L. (2020). Land-Use/Land-Cover Changes and Its Contribution to Urban Heat Island: A Case Study of Islamabad, Pakistan. Sustainability, 12, 3861
34. Sasmito, B., Suprayogi, A., Awaluddin, M., Darlina, S.P., Andani, N.D., & Kalinda, I.O.P. (2019). Spatial Model of Micro Climate Assessment and Recommendation of Mitigation In Semarang City With Remote Sensing Technology. IOP Conference Series: Earth and Environmental Science, 313, 012037
35. Shah, A., Ali, K., & Syed Moazzam, N. (2022). Spatio-temporal analysis of urban sprawl in Islamabad, Pakistan during 1979–2019, using remote sensing. GeoJournal, 87

36. Tariq, A., & Mumtaz, F. (2022). Modeling spatio-temporal assessment of land use land cover of Lahore and its impact on land surface temperature using multi-spectral remote sensing data. Environmental Science and Pollution Research, 30, 17

37. Tian, L., Li, Y., Lu, J., & Wang, J. (2021). Review on Urban Heat Island in China: Methods, Its Impact on Buildings Energy Demand and Mitigation Strategies. In, Sustainability

38. Voogt, J.A., & Oke, T.R. (2003). Thermal remote sensing of urban climates. Remote Sensing of Environment, 86, 370-384

39. Wang, S., Ma, Q., Ding, H., & Liang, H. (2018). Detection of urban expansion and land surface temperature change using multi-temporal landsat images. Resources, Conservation and Recycling, 128, 526-534

40. Wang, X., Xiao, X., Zou, Z., Hou, L., Qin, Y., Dong, J., Doughty, R.B., Chen, B., Zhang, X., Chen, Y., Ma, J., Zhao, B., & Li, B. (2020). Mapping coastal wetlands of China using time series Landsat images in 2018 and Google Earth Engine. ISPRS Journal of Photogrammetry and Remote Sensing, 163, 312-326

41. Wu, X., Lu, Y., Zhou, S., Chen, L., & Xu, B. (2016). Impact of climate change on human infectious diseases: Empirical evidence and human adaptation. Environment international, 86, 14-23

42. Yadav, P., Kapoor, M., & Sarma, K. (2012). Land use land cover mapping, change detection and conflict analysis of Nagzira-Navegaon Corridor, Central India using geospatial technology. International Journal of Remote Sensing and GIS, 1, 90-98

43. Akomolafe, G.F., & Rosazlina, R. (2022). Land use and land cover changes influence the land surface temperature and vegetation in Penang Island, Peninsular Malaysia. Scientific Reports, 12, 21250

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