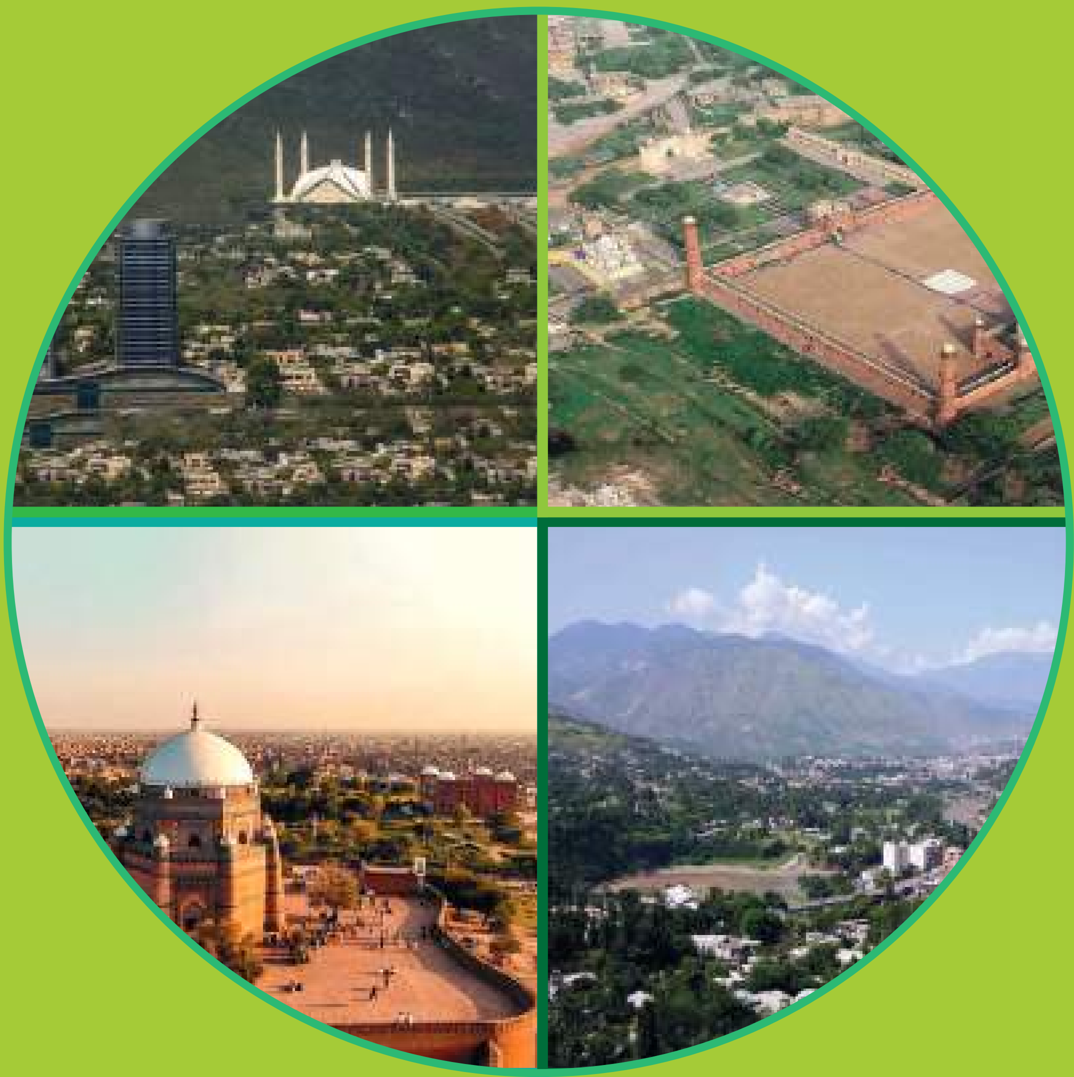
Ministry of Climate Change
and Environmental Coordination
Government of Pakistan

Climate Resilient Urban
Human Settlements Unit

ENHANCING CLIMATE RESILIENCE BY ASSESSING LAND USE LAND COVER CHANGES AND URBAN HEAT ISLAND USING GEOSPATIAL TECHNOLOGIES (FROM 2000 TO 2020)

(A Case Study of Four Metropolitan Cities of Pakistan)



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CLIMATE RESILIENT URBAN HUMAN SETTLEMENTS UNIT
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AURTHOR INFORMATION

TEAM LEAD

Mr. Muhammad Farooq
Sr. Joint Secretary (Env & CC)/NPD (CRUHS) Unit,
Ministry of Climate Change and Environmental Coordination.

AUTHOR

Mr. Zubair Irshad
Technical Officer, (CRUHS) Unit,
Ministry of Climate Change and Environmental Coordination.

CONTRIBUTERS AND SUPPORTING TEAM

i. **Muhammad Azim Khoso**
Director (Urban Affairs)
Ministry of Climate Change and Environmental Coordination.

ii. **Ms. Yasira Kiran**
Manager (Admin & Finance), (CRUHS) Unit,
Ministry of Climate Change and Environmental Coordination.

iii. **Mr. Salman Akbar,**
Urban Planner, (CRUHS) Unit,
Ministry of Climate Change and Environmental Coordination.

iv. **Muhammad Bilal Hafeez**
Office Assistant, (CRUHS) Unit,
Ministry of Climate Change and Environmental Coordination.

REVIEW COMMITTEE

i. **Mr. Arif Goheer**
Principal Scientific Officer/ Head,
Global Climate Change Impact Studies Centre (GCISC), Islamabad.

ii. **Dr. Abdul Waheed (PhD)**
Associate Professor, Department of Urban Regional Planning,
National University of Science and Technology (NUST), Islamabad Pakistan.

iii. **Dr. Irfan Ahmed Rana (PhD)**
Assistant Professor, Department of Urban Regional Planning,
National University of Science and Technology (NUST), Islamabad Pakistan.

EXECUTIVE SUMMARY

Urban Heat Islands (UHIs) are phenomena exacerbated by urbanization, where natural land covers are replaced by dense concentrations of impervious surfaces that absorb and retain heat. This study examines Land Use Land Cover (LULC) changes and their impact on UHI from 2000 to 2020 using geospatial technologies in four metropolitan cities of Pakistan: Islamabad, Lahore, Multan, and Muzaffarabad. A Supervised Classification algorithm was performed on satellite imageries using ArcGIS software for analyzing LULC changes. The study areas were classified into 4 classes such as built-up, barren land, vegetation, and water bodies. Thermal bands from Landsat satellites were employed to derive Land Surface Temperature (LST) and assess UHI intensities. Key findings reveal significant urban expansion across all cities during the study period, with Islamabad, Lahore, Multan, and Muzaffarabad witnessing increases in urban areas by 21.3%, 20.9%, 6.1%, and 15% respectively. Built-up and barren land exhibited the highest LST values, whereas vegetation and water bodies showed lower temperatures. Over the two-decade period, maximum annual LSTs rose in Islamabad (by 1.1°C), Lahore (by 2.1°C), Multan (by 1.9°C), and Muzaffarabad (by 1.5°C). The study underscores the role of expanding built-up areas and decreasing vegetation in exacerbating UHI effects. It highlights the necessity for proactive urban planning and sustainable development strategies to mitigate urban heat and foster resilient cities. This research provides actionable insights for policymakers, urban planners, and environmentalists to formulate effective mitigation strategies against UHI, promoting sustainable urban growth and enhancing the quality of urban living environments.

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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

Climate change refers to significant and lasting alterations in Earth's climate patterns and conditions (Wu et al. 2016). These changes may be natural or man-made, but human activities have been considered the primary driver of climate change since the 1800s. The majority of the global population, exceeding 50%, resides in urban areas today (Nation 2022). By the year 2045, the worldwide urban population is expected to surge to 6 billion, marking a 1.5-fold increase with cities accounting for two-thirds of global energy usage and more than 70% of greenhouse gas emissions (Kummu et al. 2011) (Bank Oct 06,2022).

Human activities that lead to changes in LULC result in observable alterations in land surface albedo, atmospheric aerosol levels, the exchange of latent and sensible heat, and concentrations of greenhouse gases (Hibbard et al. 2017). This means that buildings and other urban structures tend to be warmer than the air temperature, unlike their rural surroundings (Oke 1982) this is how a UHI is formed.

02 INTRODUCTION

Urbanization has significantly changed the land use and land cover (LULC) in urban areas, leading to a substantial increase in the urban heat island (UHI) effect. The UHI effect is a phenomenon in which urban areas are significantly warmer than surrounding rural areas. This is mainly due to the replacement of natural vegetation with impervious surfaces, such as buildings, roads, and pavements, which absorb and retain heat (Hibbard et al. 2017).

In the GIS field, LULC change detection is an area of holistic analysis (Yadav et al. 2012). Time-series analysis of LULC is critical for considering the connection between human activities and natural phenomena to endorse better policymaking (Lu et al. 2004). The population is increasing rapidly with time. Along with this change, the following natural phenomena are also changing such as an increase in Built area, change in global temperature (global warming), and decrease in vegetation cover deforestation, degradation). UHI phenomena will greatly increase energy consumption, increase urban temperatures, and further deteriorate the quality of life (Almusaed and Almusaed 2011). UHI is recognized as a significant contributor to the phenomenon of global warming, increased heat-related mortality rates, and the emergence of unpredictable climate patterns (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).

Communities around the world are dealing with increasing environmental risks and climate risks as a result of climate change and LULC change (Roy et al. 2022). In South Asia water scarcity and rising temperatures are expected to continue to rise rapidly (Hijioka et al. 2014). 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 and inform approaches to enhancing resource capacity (Wang et al. 2020).

Urbanization and population growth in cities are factors contributing to LULC changes (Alphan 2003). About 3% of the land surface is used for urban purposes (Kamran et al. 2023). Urbanization involves LULC changes, such as the conversion of green space or barren land into impervious surfaces, and commercial and industrial activities. These changes can affect the surface energy (Pal and Ziaul 2017). Such abrupt shifts have a considerable impact on LST and local air temperature (Wang et al. 2018). Urban planners and decision-makers will benefit from the assessment of LULC changes by obtaining useful information.

2.1 Problem Statement

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 built-up areas increased rapidly from 1990 to 2020 in Lahore. Correspondingly, the UHI intensity also rose during this period. Similarly, (Nasar-u-Minallah et al. 2021) and (Hassan et al. 2016) investigated LULC changes in urban centers like Lahore and Islamabad, documenting a notable increase in urban sprawl and built-up areas over time. 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 in developing countries compared to developed countries. 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. This study takes a new approach by examining cities with different climates, geographical features, and topography like Islamabad, Lahore, Multan, and Muzaffarzbad from 2000 to 2020. The aim is to explore how climate conditions interact with land use patterns to shape heat islands over different selected cities and to provide a comprehensive understanding of urban temperature dynamics. This will enhance our understanding of the UHI problem in each city and enable us to present a comprehensive comparison of the changes in UHI for 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 study assesses the ability of four metropolitan cities of Pakistan Islamabad, Lahore, Multan, and Muzaffarabad to understand LULC changes and their impact on UHI in Pakistan. It aims to find how diverse climates, geographical features, and topographies affect UHI formation. Islamabad has a hilly terrain and green spaces, Lahore, is characterized by its flat plains and extensive urbanization, Multan is situated within an arid environment, and Muzaffarabad's mountainous landscape offers unique insights into temperature dynamics. By examining these cities, the research explores the interplay between land use patterns and climate conditions, providing valuable information for urban planning and climate resilience efforts. The geographic location of each of the cities is shown in Figure 1 (a, b, c, d) and the details are discussed below;

Islamabad serving, as Pakistan's capital city, is under the jurisdiction of the federal government of Pakistan as an integral part of the Islamabad Capital Territory (Figure 1(a)). It ranks as the ninth-largest city in Pakistan, with a population of about 2.007 million (PBS 2017) people. Its geographical coordinates are 33.6844°N and 73.0479°E, situated on the periphery of the Pothohar Plateau, adjacent to the Margalla hills within the Islamabad Capital Territory.
Lahore, the capital of Punjab, Pakistan, is the country's second-largest city, following Karachi, with a population of approximately 11.13 million people (PBS 2017). It is situated in the geographical coordinates between 31°15′—31°45′ N and 74°01′—74°39′ E (Figure 1(b).

Multan is a city located on the banks of the Chenab River in the Punjab region. It holds the position as Pakistan's seventh-largest city, boasting a population of approximately 1.872 million residents (PBS 2017) and the major cultural, religious, and economic center of southern Punjab. It is located 30° 11′ 52″ North, 71° 28′ 16″ East (Figure 1(c).

Muzaffarabad as the capital and largest city of Azad Kashmir, holds the 60th position in the list of Pakistan's largest cities with a population of about 149,913 people (PBS 2017). Latitude and longitude coordinates are 34.359688, 73.471054 (Figure 1(d).

Table 1: Climatic and demographic information of selected study areas

City	Min Temperature (°C)	Max Temperature (°C)	Average Rainfall (mm)	Average Relative Humidity (%)	Elevation from Sea Level (m)	Current Population Density (persons/km²)
Islamabad	5	38	100	55	507	1500
Lahore	7	39	600	60	217	2500
Multan	6	42	300	45	122	3500
Muzaffarabad	2	36	1500	70	737	1000

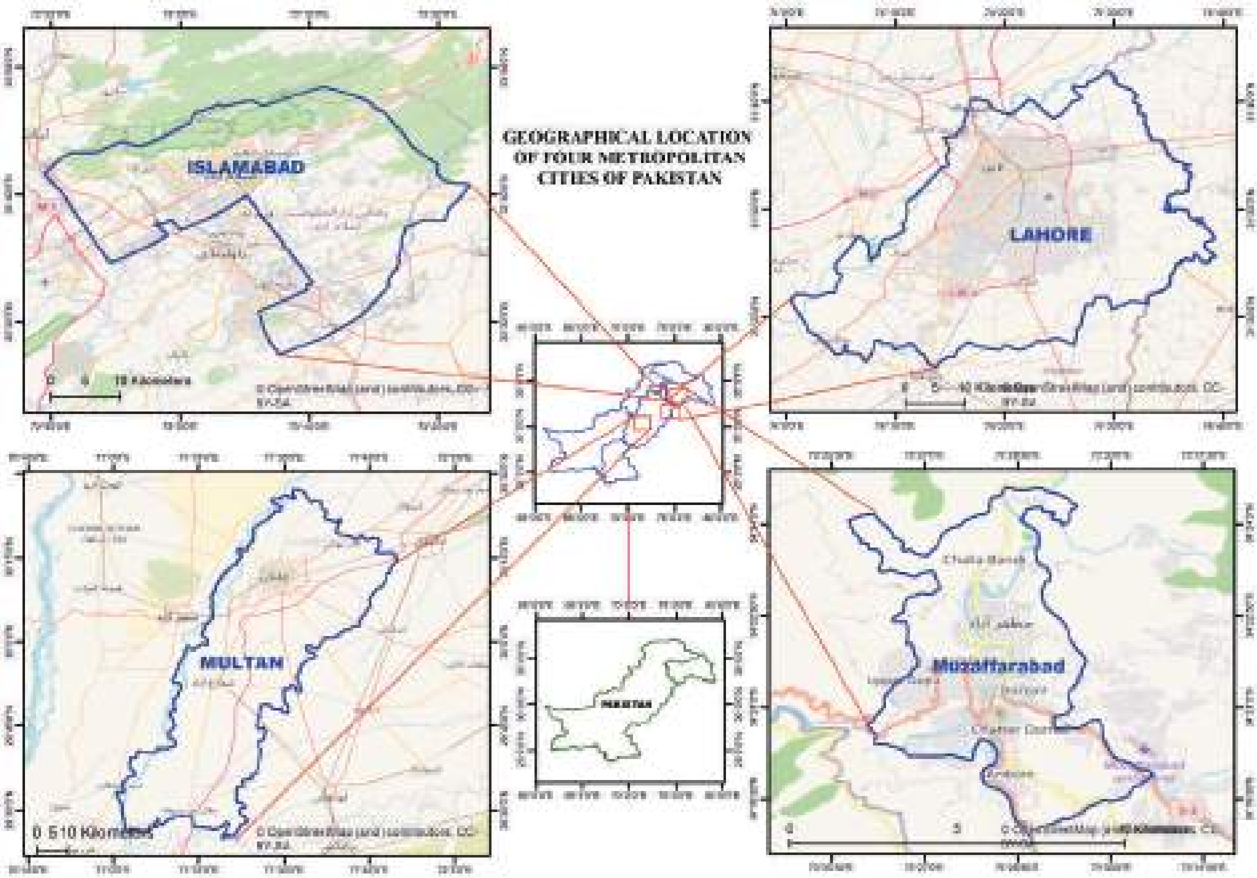


Figure 1: Geographical Location of four metropolitan cities of Pakistan i.e. (a) Islamabad, (b) Lahore, (c) Multan and (d) Muzaffarabad

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 Islamabad, Lahore, Multan and Muzaffarabad 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;

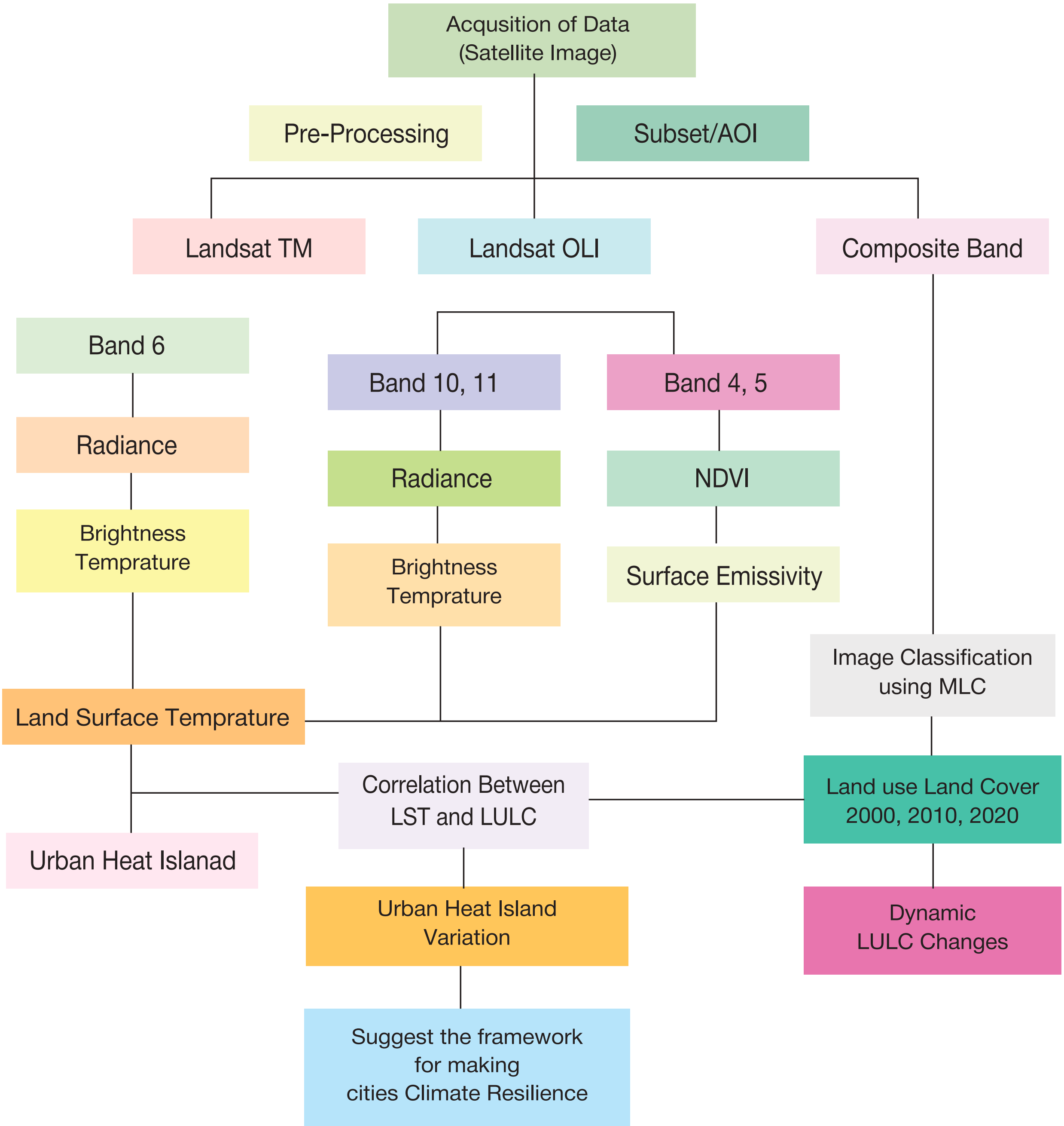


Figure 2: Methodology Flow Chart

3.3 Satellite Data Collection and Processing

Landsat 4-5 and Landsat-8 satellite imageries of 2000, 2010 and 2020 were collected from the United States of Geological Survey website. The imageries were processed in ArcGIS 10.7.0 software and Google Earth Engine Platform. Pre-processing techniques were applied i.e. mosaicking, cloud removing, and clipping to all imageries. The vector boundaries of Islamabad, Lahore, and Multan were used for extracting the Area of Interest (AOI) from tiles. False Colour bands (4, 3 and 2 for Landsat 4-5) and (5, 4 and 3 for Landsat 8) combination was used for LULC classification. The detailed description (Spatial Resolution, Date, path, and rows used for the images) of all the images used in the study are shown in Tables 2 and 3.

Table 2: Satellite Images used to obtain LULC

Sr.No	Sensor	Date	Path/Row	Path/Row	Path/Row	Path/Row	Spatial Resolution
1	TM	2000	150/037	149/038	150/039	150/036	30 meter
2	TM	2010	150/037	149/038	150/039	150/036	30 meter
3	OLI	2020	150/037	149/038	150/039	150/036	30 meter

Table 3: Satellite Images used to obtain LST

Sr.No	Sensor	Monthly Data	Thermal Band	No. of Images
1	Landsat 5 TM	2000	6	12
2	Landsat 5 TM	2010	6	12
3	Landsat 8 OLI	2020	10,11	12

3.4 Land Use Land Cover Classification

LULC is the categorization of both human activities and natural elements present on a landscape during a specific timeframe based on recognized statistical and scientific techniques of analysis of suitable source materials. LULC classification maps were produced from satellite imagery. Training samples were gathered for each of the four classes i.e. barren land, built-up area, water bodies and vegetation area (Table 4). Then Maximum Likelihood Classification (MLC) algorithm was employed to create the LULC map. The maps with the area covered by each class were created for the years 2000, 2010 and 2020.

Table 4: 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

The accuracy of LULC classification is one of the important parts that can be determined by user and producer accuracy, overall accuracy, and kappa coefficient in the confusion matrix to obtain reliable results. If errors are not investigated, the LULC map will lose its reliability for decision-making (Shao and Wu, 2008). A total of 240 random ground points, with 60 points for each class have been marked in Google Earth for the study period. LULC accuracy assessment was done in ArcGIS by comparing classified images with high-resolution Images.

3.6 Land Surface Temperature Calculations

LST has been derived from the thermal band of Landsat 4-5 and Landsat 8. Band 6 of Landsat 4-5 and bands 10 and 11 of Landsat-8 were used to calculate LST for the years 2000 and 2010 using ArcGIS 10.7, while LST for the year 2020 was mapped using the Google Earth Engine platform. The Top of Atmospheric (TOP) spectral radiance, Brightness Temperature (BT), NDVI, Proportion of vegetation (Pv), and emissivity were obtained, and subsequently, Land Surface Temperature was computed using these factors. The thermal bands are represented as digital numbers (DN), and to transform these DN values from the thermal band into spectral radiance (Lλ), we applied Equation 1. Spectral radiance is quantified in units of watts / (m^2 × ster × 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 (°C). 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 5: 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 Urban Heat Island 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 Urban Heat Island maps. For the particular satellite images.

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

μ is the mean LST and σ is the standard deviation.

04 RESULT

4.1 Spatial-Temporal Land Use Land Cover Changes

In line with the research focus on LULC, four categories have been generated. LULC maps were produced with 10-year differences (2000, 2010 and 2020) for the study areas (Islamabad, Lahore, Multan, and Muzaffarabad). During the study period, there was a noticeable gradual increase in the extent of built-up areas within the study area. LULC results are shown in Table 6. The details of the changes in LULC classes in all cities are discussed below;

4.1.1 Islamabad

The findings indicate the changes in the built-up area between 2000 and 2020 in Islamabad have increased by 21.3 % from 46.9 km2 to 239.7 km2 (Table 6 and Figure 3). Overall, the vegetation area and barren land decreased significantly over the same period. The vegetation area was decreased by 2% from 271.9 km2 to 253.6 km2 and the barren land was decreased by 19.1% from 579.4 km2 to 406.4 km2 between 2000 and 2020. Whereas water bodies have also faced a decreasing trend in the area i.e. 0.1% from 7.5 km2 to 6.0 km2 between 2000 and 2020. A total of 173.0 km2 of barren land and 18.3 km2 of vegetation was transformed into other LULC classes during the study period (Figure 3).

The LULC results show that the built-up area has been growing continuously every year during the study period as shown by the red colour in Figure 3. The analysis further revealed that the barren land and vegetation areas were most affected by this rapid urbanization. Previous research conducted by (Shah et al. 2022) has demonstrated a substantial increase in built-up area in Islamabad from 1979 to 2019. (Hassan et al. 2016) Utilizing object-based classification with eCognition Developer 64 software on SPOT 5 imagery from 2012 revealed significant increases in built-up and impervious surface areas, while vegetation cover declined. The Islamabad city population was 529,180 according to the 1998 census and now it is 1,014,825 according to the 2017 census, showing a 91.9% increase in the last twenty yeas period and can be called the main reason behind the expansion of the urban areas (PBS, 2017).

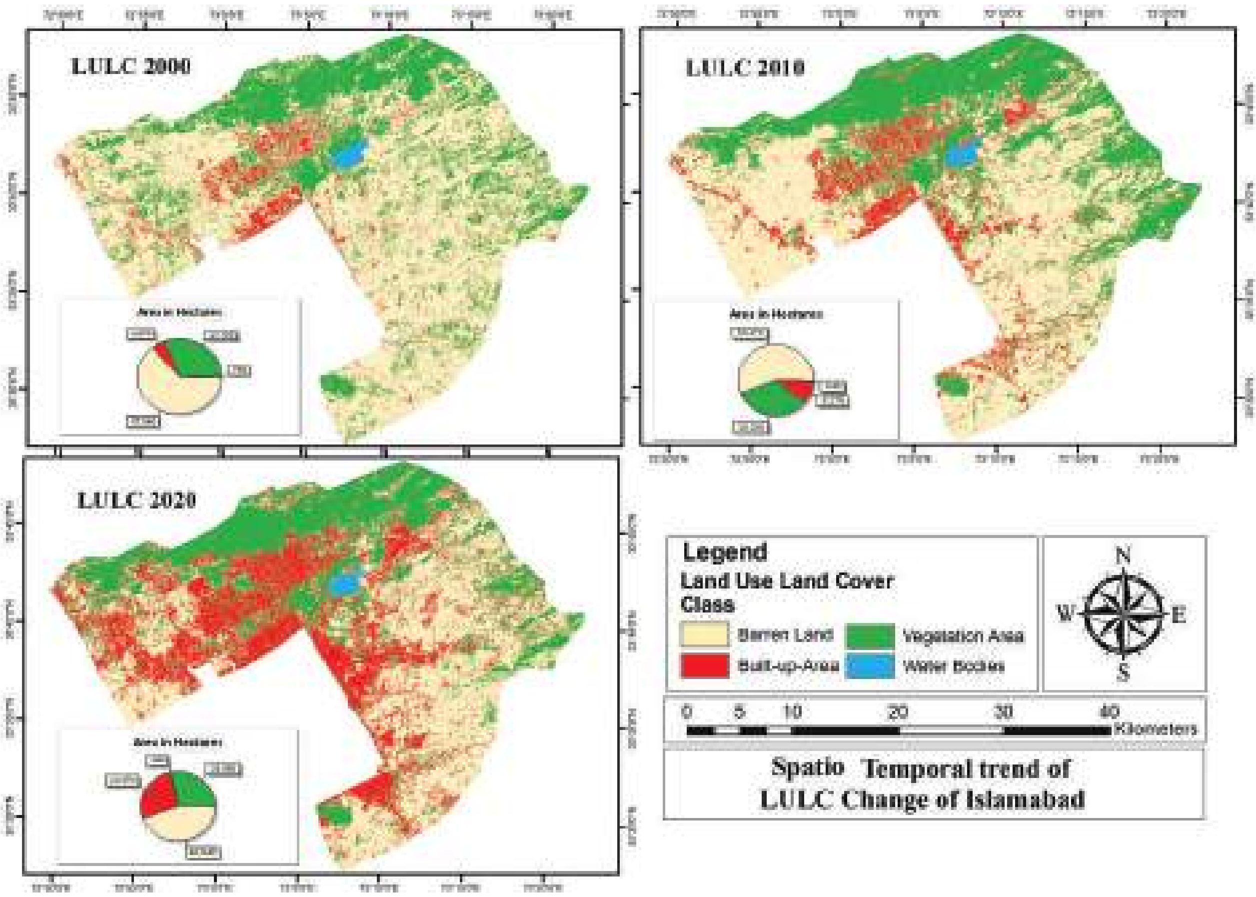


Figure 3: Land Use Land Cover Maps of Islamabad for 2000, 2010 and 2020

4.1.2 Lahore

The LULC maps for the Lahore district are shown in Figure 4. The figure illustrates a gradual growth in the urban area from 2000 to 2020. The built-up area was 364.6 km2, 614.0 km2, and 717.1 km2 in 2000, 2010 and 2020. This shows the built-up area has expanded by 352.5 km2 between 2000 and 2020. The population of Lahore city was 5,143,495 according to the 1998 census and now it is 11,126,285 according to the 2017 census, which shows that the population of Lahore from 1998 to 2017 increased by 116.3% which has caused the expansion of the urban areas (PBS, 2017).

The vegetation area in the Lahore district has decreased rapidly between 2000 and 2020. It is noted that the vegetation-covered areas were 890.9 km2, 890.6 km2, and 579.8 km2 of the total land area during the years 2000, 2010 and 2020. However, vegetation area decreased by 311.1 km2 during the study period. Similarly, it has been found that barren land and water bodies also decreased by 370.4 km2 and 7.1 km2 of its total area of land respectively during the last 20 years (Figure 4). This finding is similar to other research findings (Tariq and Mumtaz 2022) that analyzed Landsat data from 1990 to 2018, revealing significant increases in built-up areas alongside decreases in barren land, water, and vegetation.

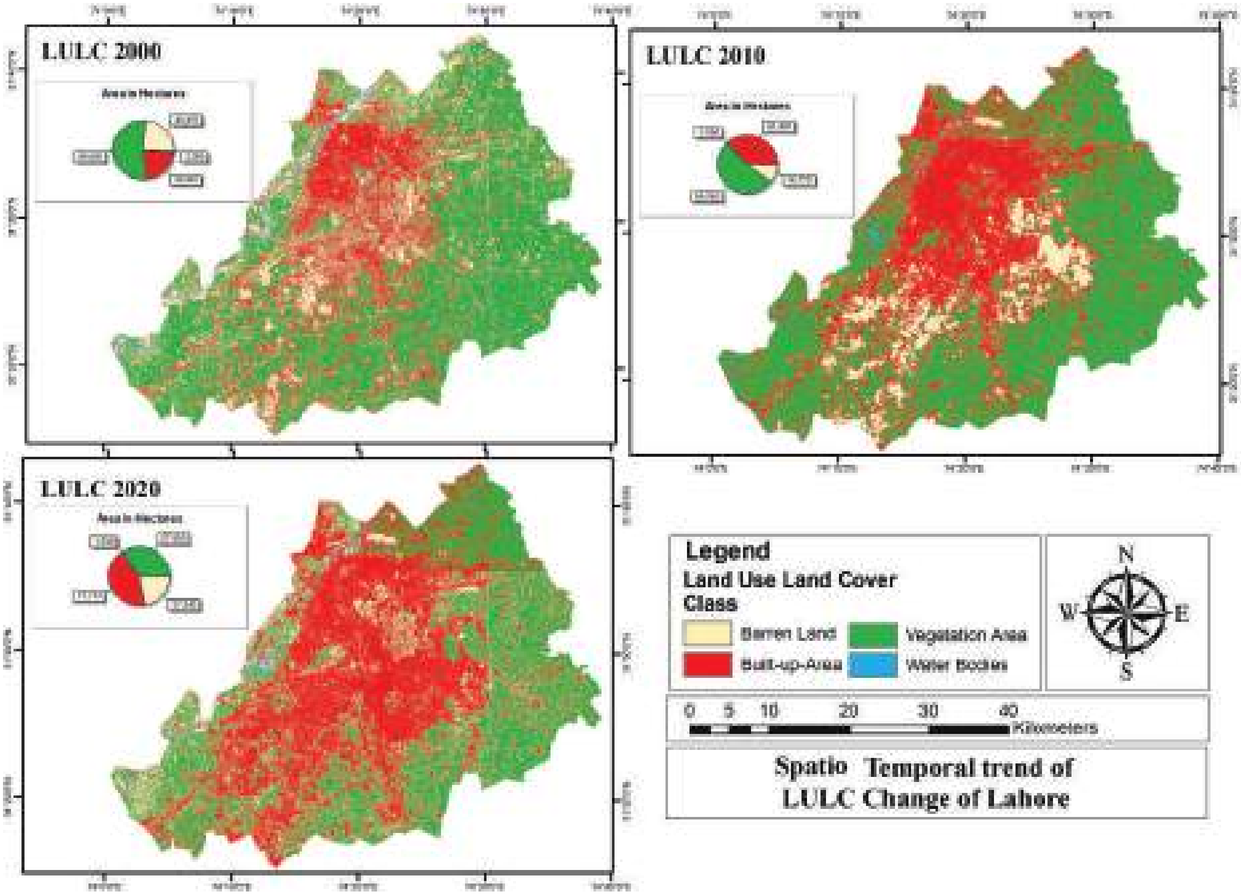


Figure 4: Land Use Land Cover maps of Lahore for 2000, 2010 and 2020

4.1.3 Multan

Figure 5 shows the LULC classification maps of district Multan. The results (Table 6) show the built-up area has shown an increase of 225.7 Km2 (6.1%) during the last 20 years (2000 to 2020). According to the Pakistan Bureau of Statistics (2017) report the population of Multan city increased from 1,182,441 to 1,197,384 between 1998 and 2017. From 2000 to 2020 the vegetation area and barren land faced a decreasing trend of 3% and 3.8% respectively, while water increased by 0.6% (Table 6 and Figure 5). Therefore, this finding is similar to other research findings (Hussain et al. 2021; Hussain et al. 2019), (Hussain et al. 2021).

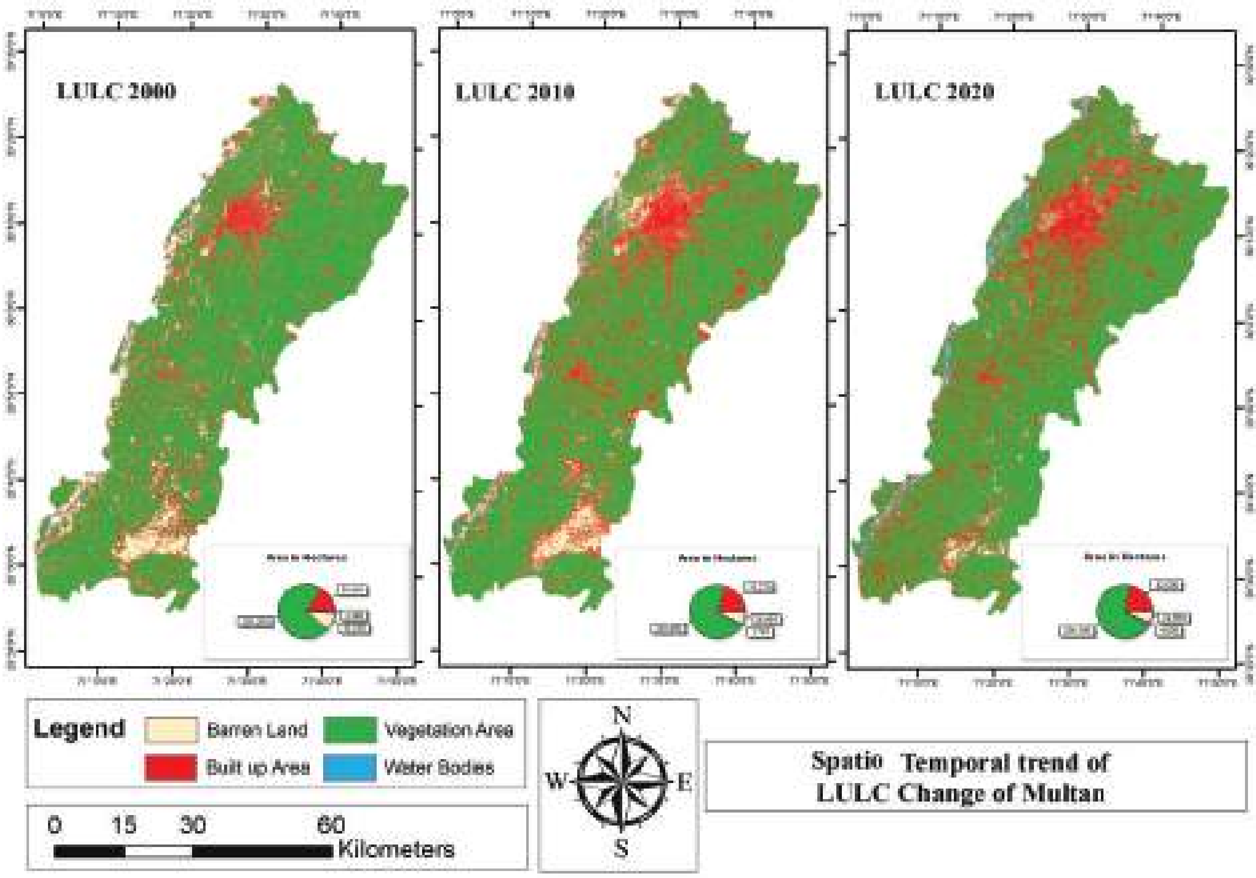


Figure 5: Land Use Land Cover maps of Multan for 2000, 2010 and 2020

4.1.4 Muzaffarabad

The spatiotemporal maps and the land use statistics of Muzaffarabad city are shown in Figure 6 and Table 6. The result shows that the built-up area has increased by 6 km2 from 2000 to 2020, while the barren land decreased significantly over the same period by 27.7 km2. An increasing trend has been noted in the vegetation area and water bodies i.e. 20% and 1.3% between 2000 and 2020 respectively. The population of Muzaffarabad city increased from 85,462 in 1998 to 149,913 in 2017, which shows an increasing trend of 75% (PBS, 2017). A small change in the population has been noted as compared to other districts, therefore little increase within urban areas.

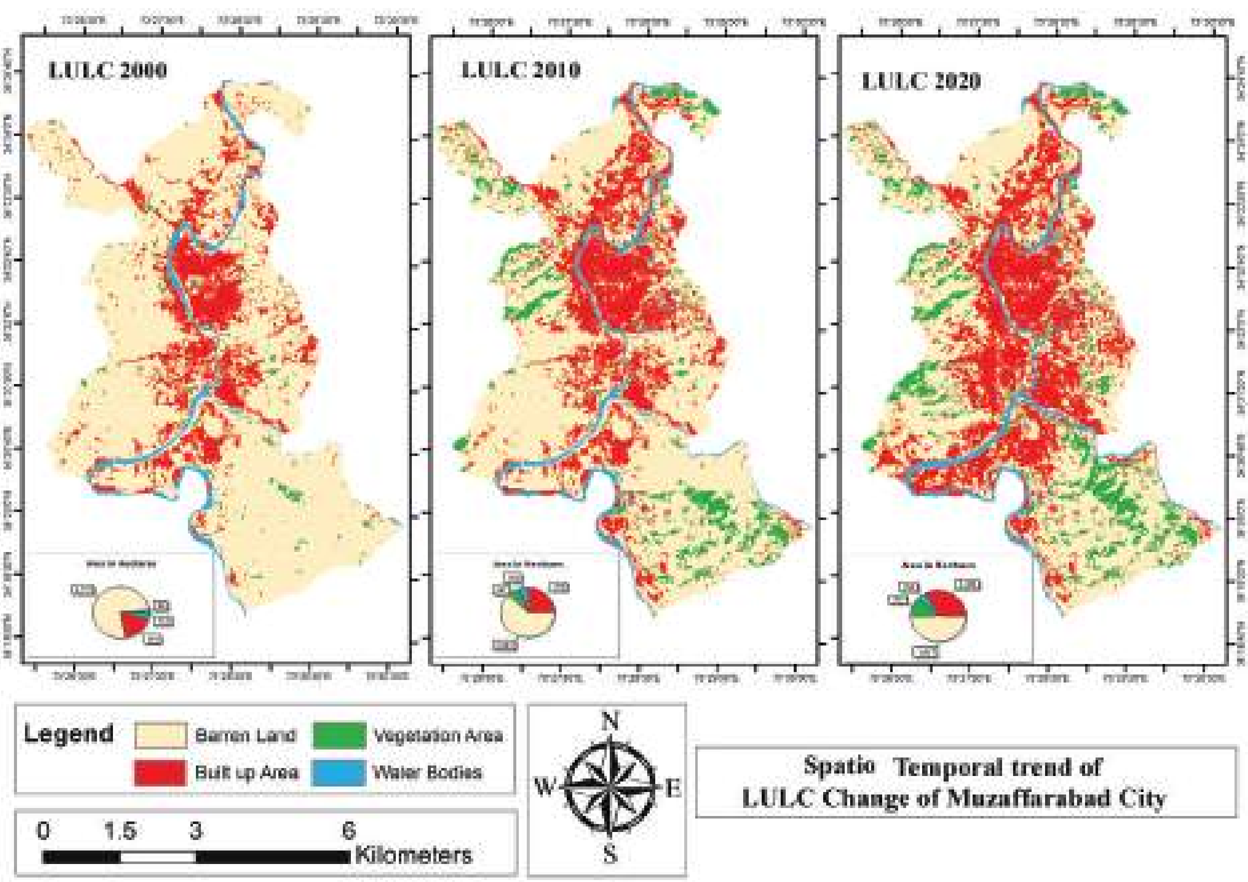


Figure 6: Land Use Land Cover maps of Muzaffarabad for 2000, 2010 and 2020

Table 6: Classification of LULC with area (2000, 2010, 2020)

	Classification of LULC	Area in hectare 2000	%	Area in hectare 2010	%	Area in hectare 2020	%
Islamabad	Built-up Area	4690	5.2	9270	10.2	23970	26.5
	Vegetation Area	27190	30.0	30200	33.3	25360	28.0
	Barren Land	57940	64.0	50470	55.7	40640	44.9
	Water Bodies	750	0.8	640	0.7	600	0.7
Lahore	Built-up Area	36460	21.7	61400	36.5	71710	42.6
	Vegetation Area	89090	52.9	89060	52.9	57980	34.4
	Barren Land	40470	24.0	16770	10.0	37040	22.0
	Water Bodies	2290	1.4	1080	0.6	1580	0.9
Multan	Built-up Area	59430	16.3	74270	20.3	82000	22.4
	Vegetation Area	265200	72.6	260460	71.3	254160	69.6
	Barren Land	38330	10.5	26900	7.4	24560	6.7
	Water Bodies	2380	0.7	3710	1.0	4620	1.3
Muzaffarabad	Built-up Area	662	18.3	919	25.4	1206	33.3
	Vegetation Area	56	1.5	267	7.4	417	11.5
	Barren Land	2771	76.5	2243	61.9	1817	50.2
	Water Bodies	133	3.7	193	5.3	182	5.0

4.2 Dynamic Changes in LULC Classes

The LULC classification results show that all the four classes of all four metropolitan cities have faced different changes in terms of the area from 2000 to 2020. Figures 7-10 shows the dynamic changes in each class of the study area. Uncontrolled urbanization resulting from population growth, rural-to-urban migration, and infrastructure development contributes to the depletion of natural resources, such as agricultural land (Fu and Weng 2018). The map shows that the built-up area extensively increased from 2000 to 2020 whereas vegetation area and barren land decreased. These changes were because of the urbanization which resulted in the construction of new built-up areas such as settlements, road networks, and paved areas to facilitate the community of the area. (Hassan et al. 2016) noted increasing built-up areas alongside decreasing vegetation and barren land from 1992 to 2012, driven by factors including economic growth, climate change, and population expansion, exacerbating habitat degradation through rapid urbanization and deforestation. The constant population growth and the influx of individuals from neighboring areas to urban centers have led to transformations in green spaces, barren lands, and water bodies within urban areas. The details of LULC conversion for these areas are mentioned in Table 7 and Figure 7 below.

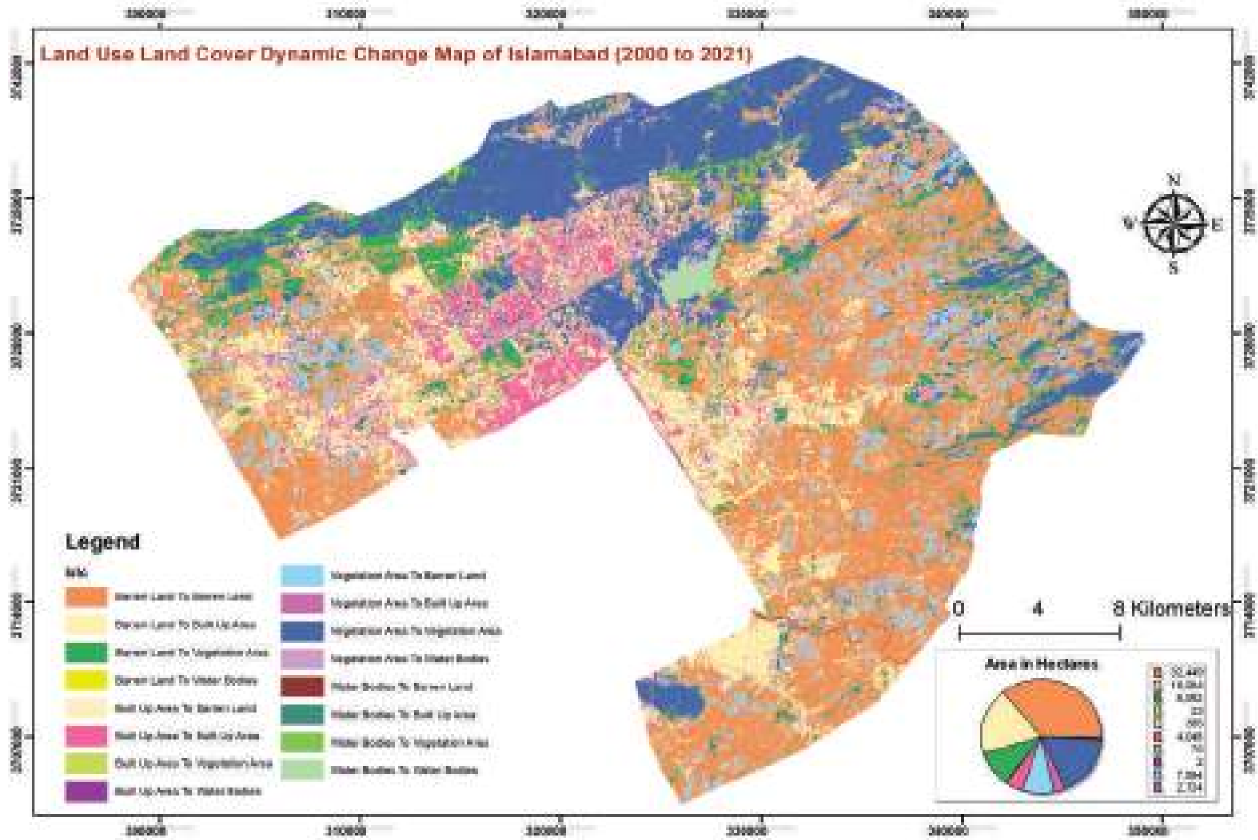


Figure 7: Islamabad Map Show Conversion of LULC Class into Other Class

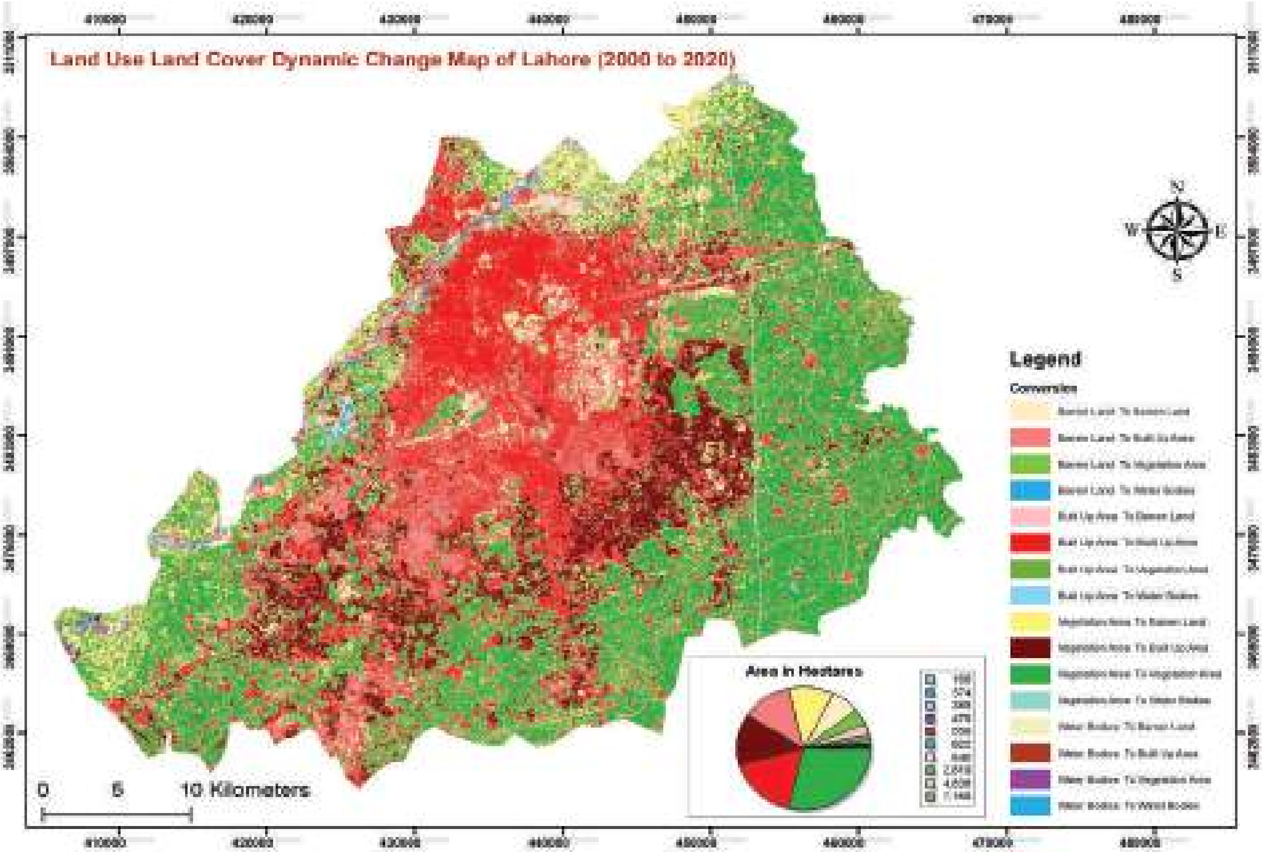


Figure 8: Lahore Map Show Conversion of LULC Class into Other Class

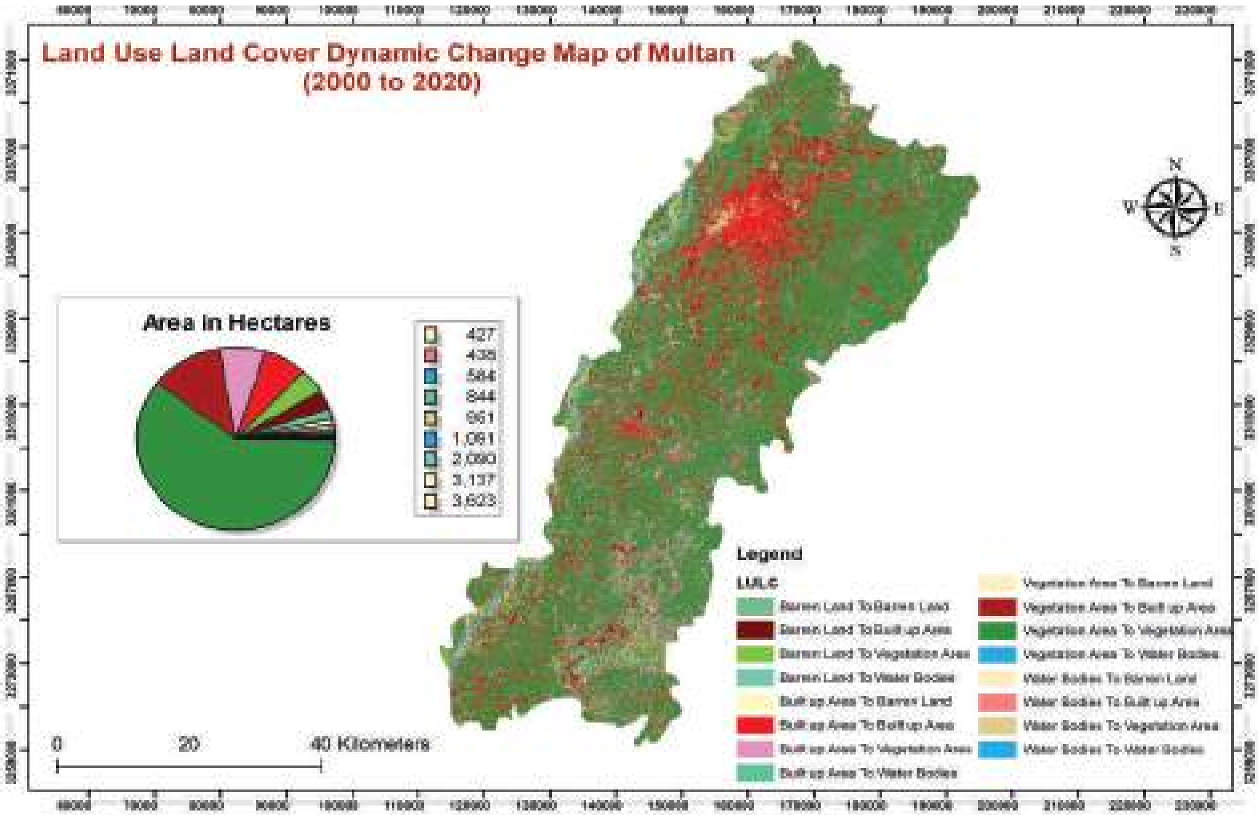


Figure 9: Multan Map Show Conversion of LULC Class into Other Class

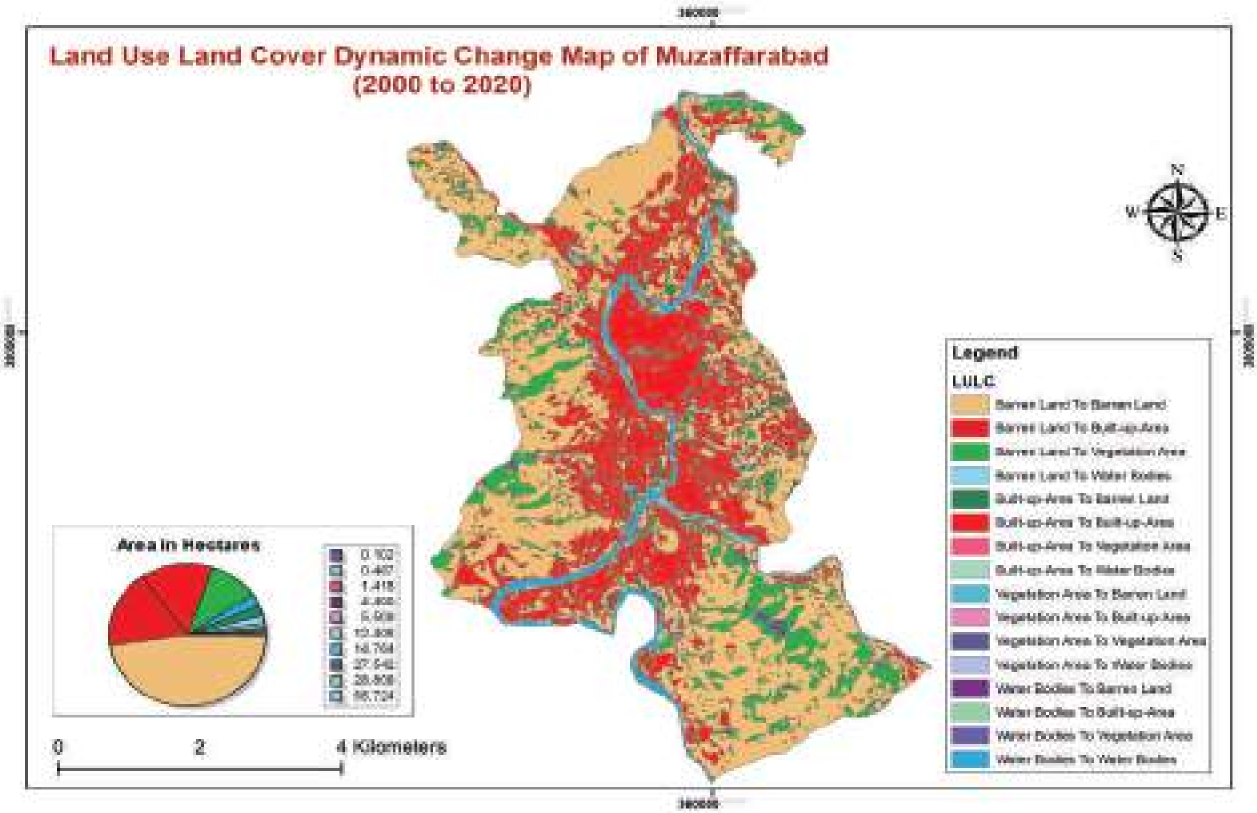


Figure 10: Muzaffarabad Map Show Conversion of LULC Class into Other Class

Table 7: Conversion of LULC Classes

LULC Changes	Islamabad	%	Lahore	%	Multan	%	Muzaffar-abad	%
Barren Land To Built-Up Area	16994	45.6	20601	25.8	12299	11.1	628	51.3
Barren Land To Vegetation Area	8982	24.1	7168	9.0	16292	14.7	372	30.4
Barren Land To Water Bodies	23	0.1	622	0.8	2090	1.9	67	5.5
Built-Up Area To Barren Land	385	1.0	4838	6.1	3137	2.8	89	7.2
Built-Up Area To Vegetation Area	76	0.2	2819	3.5	27989	25.2	1	0.1
Built-Up Area To Water Bodies	2	0.0	166	0.2	844	0.8	12	1.0
Vegetation Area To Barren Land	7894	21.2	18802	23.5	3623	3.3	15	1.2
Vegetation Area To Built-Up Area	2724	7.3	22634	28.3	41787	37.7	6	0.5
Vegetation Area To Water Bodies	17	0.0	385	0.5	1091	1.0	0	0.0
Water Bodies To Barren Land	130	0.3	840	1.1	427	0.4	4	0.4
Water Bodies To Built-Up Area	26	0.1	556	0.7	438	0.4	29	2.4
Water Bodies To Vegetation Area	15	0.0	476	0.6	951	0.9	0	0.0
Total area change in Hectares	**37268**		**79907**		**110968**		**1223.6**	

4.3 LULC Accuracy Assessment

Accuracy assessment of LULC classes is critical to achieve reliable results. The accuracy assessment was conducted using a confusion matrix. A confusion matrix comprises details about the real and forecasted classifications performed by a classification system. User accuracy and producer accuracy are computed individually for every LULC class. The overall classification accuracy ranges between 85% to 95%. The Kappa coefficients value for Islamabad, Lahore, Multan, and Muzaffarabad were 0.94, 0.91, 0.95 and 0.96 respectively. Table 8 shows the detailed accuracy assessment of all four cities.

Table 8: Accuracy Assessment

Year	2000	2010	2020
Islamabad Overall accuracy (%)	95.2	91.3	97.1
Islamabad Kappa coefficient (%)	0.94	0.95	0.96
Lahore Overall accuracy (%)	89.3	92	92.4
Lahore Kappa coefficient (%)	0.91	0.94	0.95
Multan Overall accuracy (%)	91.3	89.3	92.5
Multan Kappa coefficient (%)	0.92	0.91	0.92
Muzaffarabad Overall accuracy (%)	85.3	91.3	91.2
Muzaffarabad Kappa coefficient (%)	0.9	0.94	0.97

4.4 Land Surface Temperature Variations from 2000 to 2020

The calculation of Land Surface Temperature (LST) was performed monthly from Landsat 4-5 and Landsat 8 of the thermal band between 2000 and 2020. Figures 11 to 14 shows the monthly maximum and minimum LST for all four cities. The results show that the maximum temperature continually increased from 2000 to 2020 in all cities. The results show that the LST value of Islamabad city increased from 33.0°C to 34.1°C between 2000 and 2020, which is almost a 2-degree increase. Similarly, in Lahore, Multan, and Muzaffarabad, the LST increased from 32.4 to 35.5°C, 34.4 to 35.7°C and 30.3° to 31.8°C respectively during the study period, which is an alarming situation in the recent climate change. An increasing trend of 1.1, 2.1, 1.9, and 1.5°C was noted in the average maximum land surface temperature of Islamabad, Lahore, Multan and Muzaffarabad during the study period.

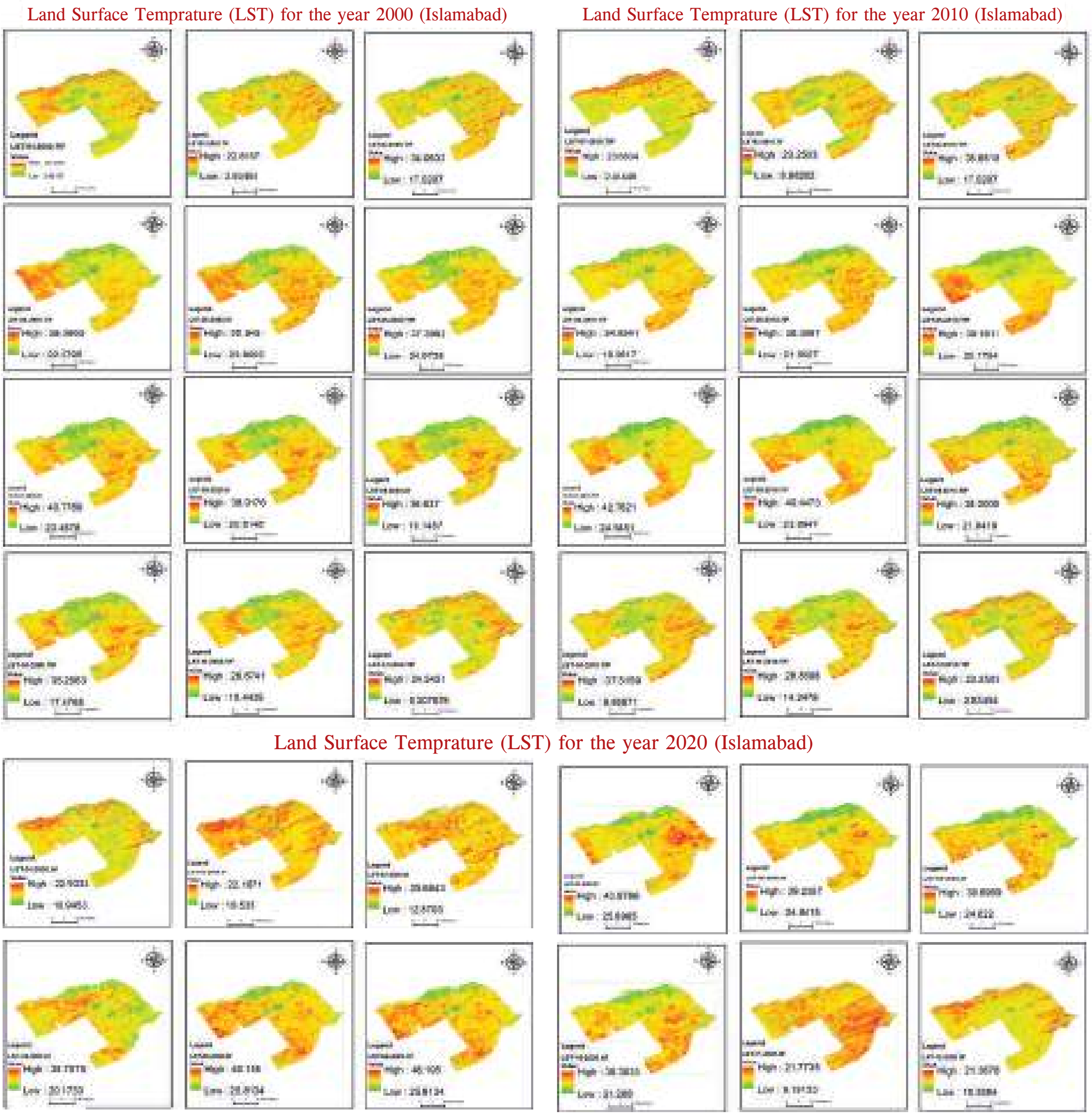
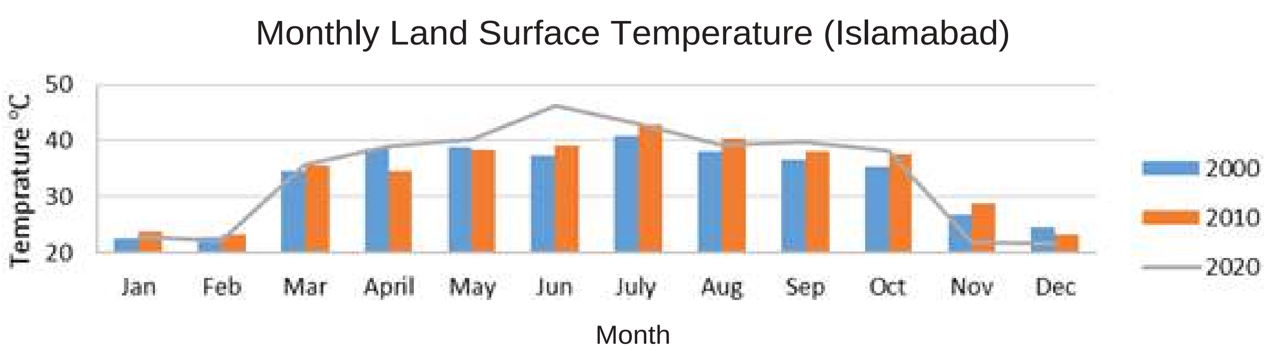


Figure 11: Monthly Land Surface Temperature for the years 2000, 2010, and 2020 (Islamabad)



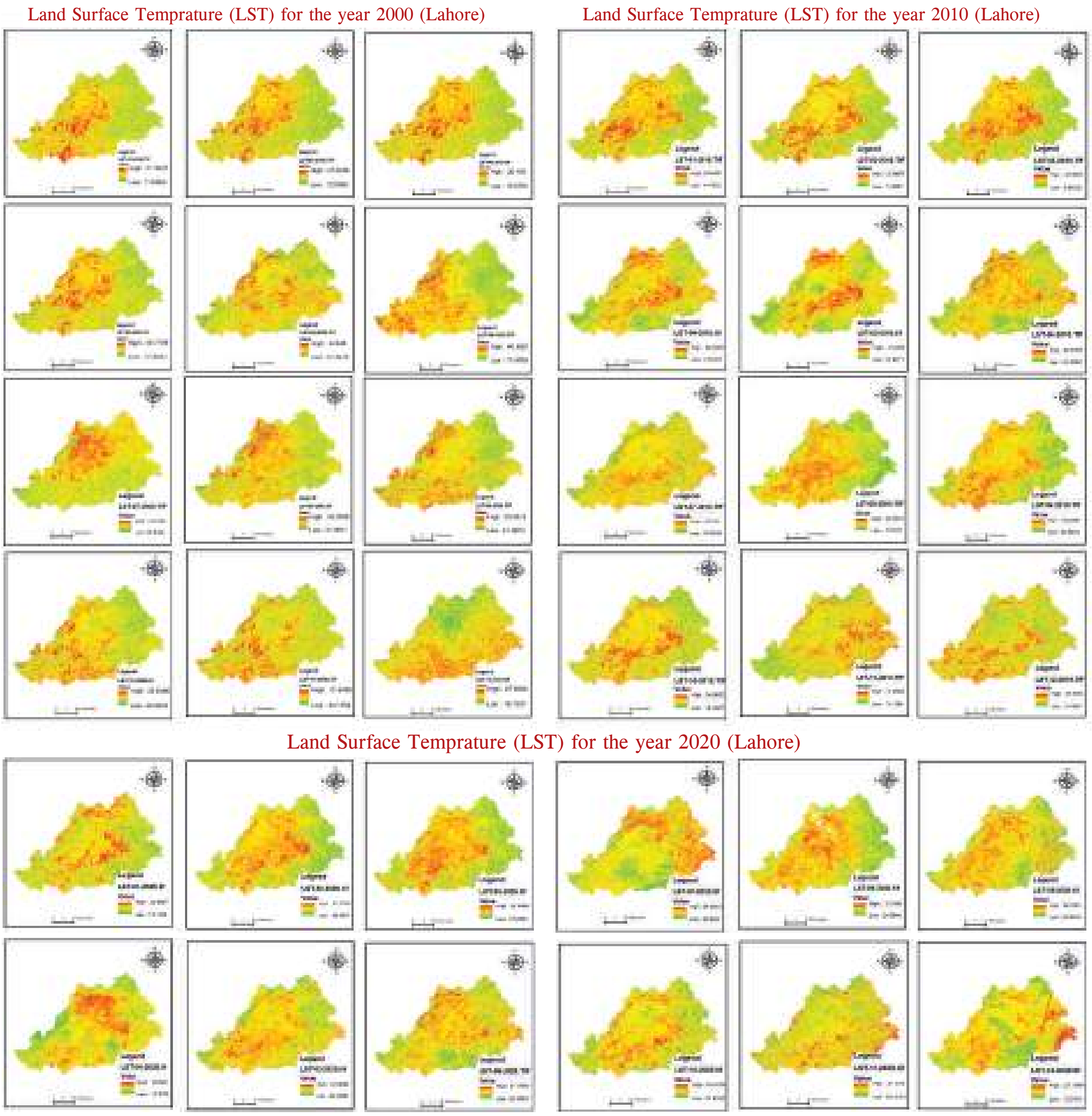
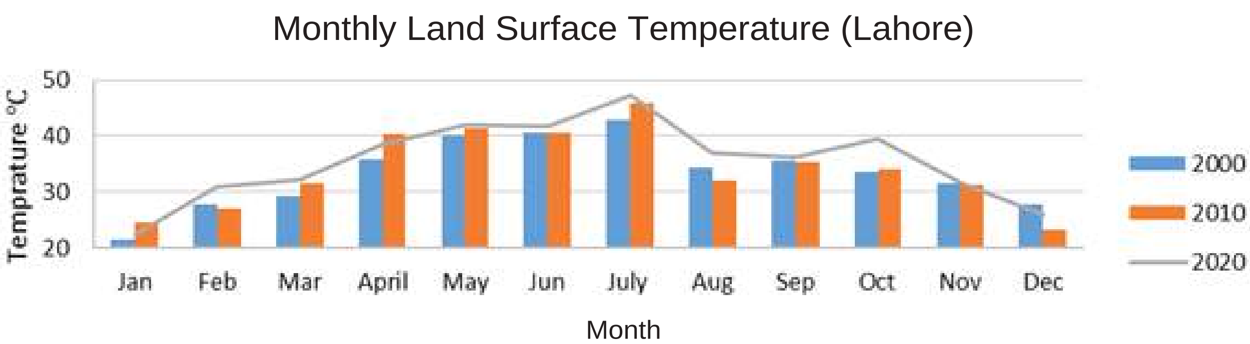


Figure 12: Monthly Land Surface Temperature for the year's 2000, 2010, and 2020 (Lahore)



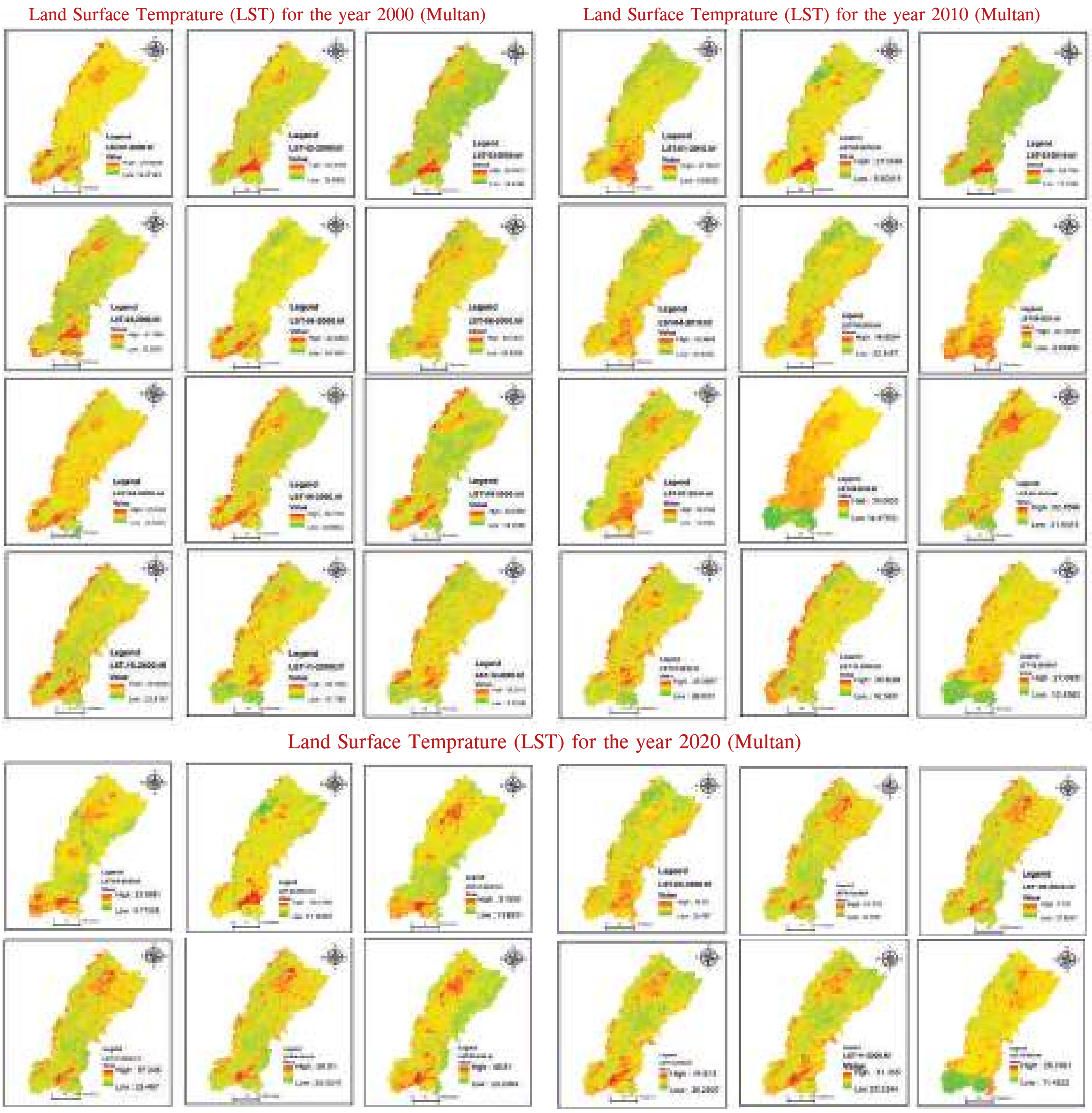
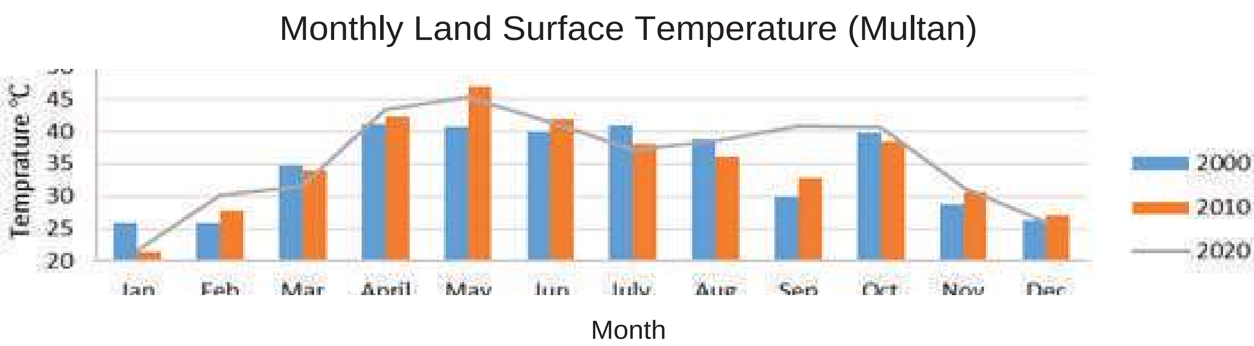


Figure 13: Monthly Land Surface Temperature for the years 2000, 2010, and 2020 (Multan)



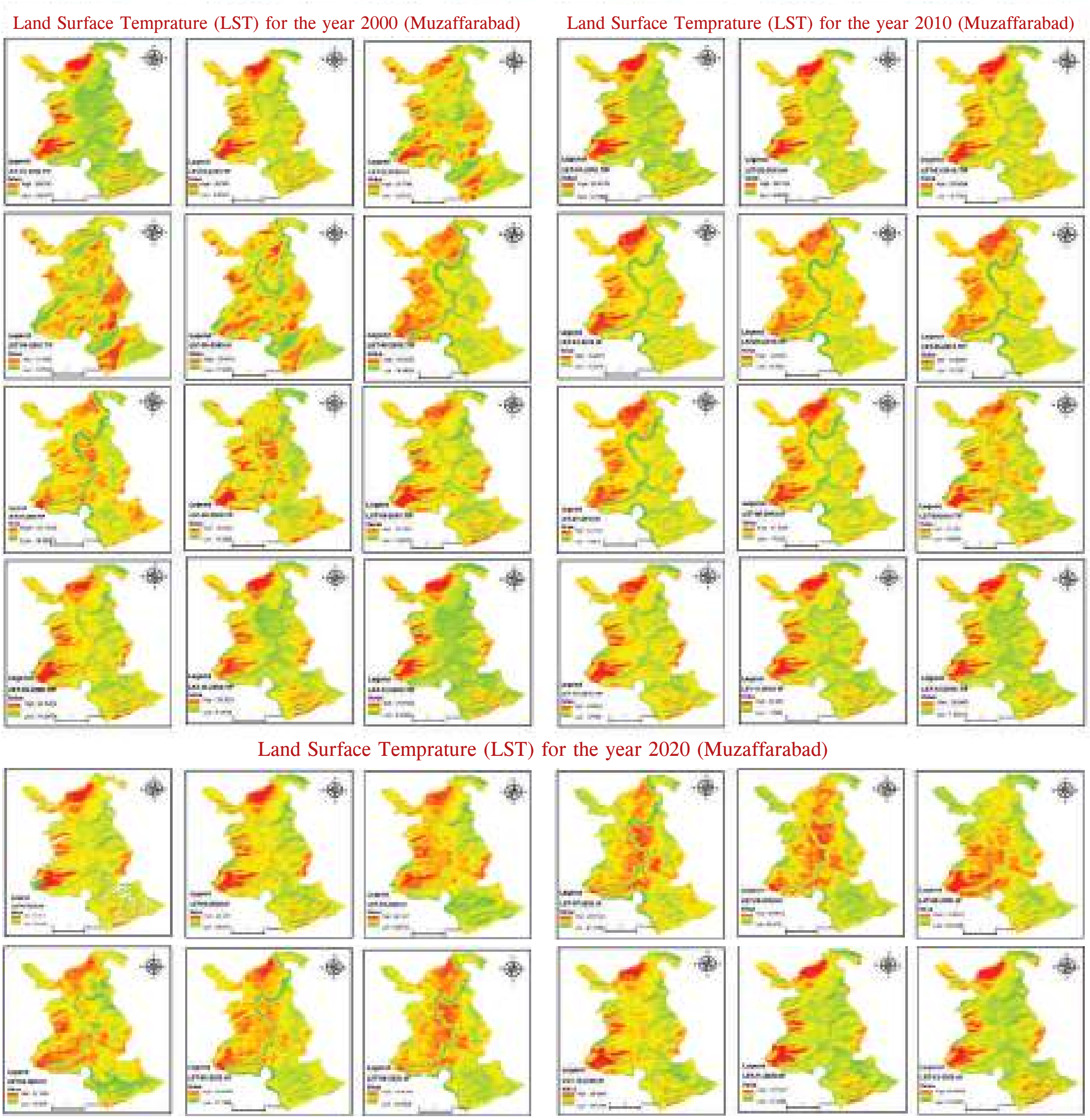
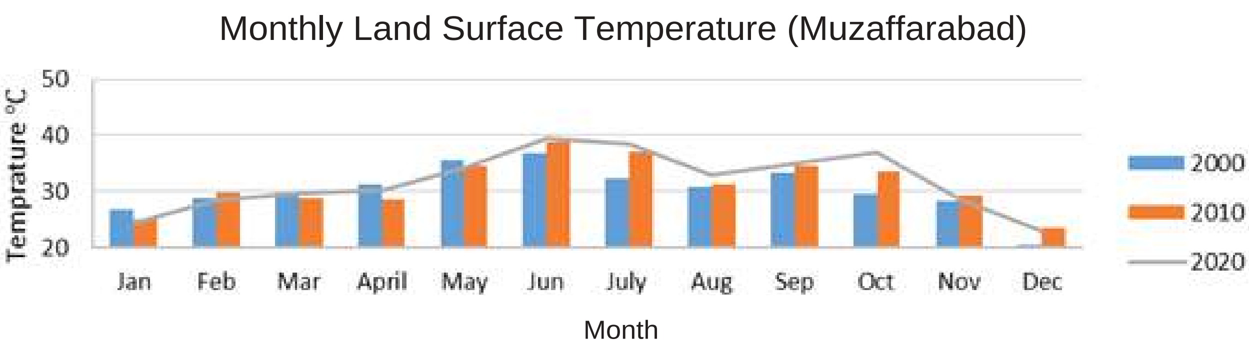


Figure 14: Monthly Land Surface Temperature for the years 2000, 2010, and 2020 (Muzaffarabad)



4.5 LULC Influence on LST

The results indicate a parallel increase in both LST and the built-up area from 2000 to 2020 (Table 9). LST increased with time due to urbanization. Between 2000 and 2020 the built-up area of Islamabad increased from 5.2% to 26.5% of the total area. Thus an ultimate rise in the ranges of minimum (15.5 to 18. 5°C) and maximum (33.0 to 34. 1°C) LST. (Sadiq Khan et al. 2020) analyzed LULC changes from 1993 to 2018 in Islamabad, using remote-sensing data. Their findings revealed an increase in impervious surfaces which contributed to a warming effect of 1.52 °C on LST. In Lahore, the built-up area was 21.7% in 2000, and the average minimum and maximum LST were 18.1 and 33.4°C respectively. When urban area increased by 36.5% in 2020, the average minimum and maximum LST also increased to 20.0 and 35.5°C respectively. (Mumtaz et al. 2020) observed that the transformation of vegetation cover and water surface into built-up areas or barren land leads to an increase in Land Surface Temperature (LST). The built-up area in Multan and Muzaffarabad was 16.3 and 18.3 % of the total land in 2000, which increased to 22.4 and 33.3% in 2020. The average minimum LST of Multan and Muzaffarabad increased from 19.3 and 12.3 °C to 20.8 and 14.2°C, whereas the maximum LST increased from 34.1 and 30.3°C to 35.7 and 31.8 °C respectively. These results confirm the direct relationship between the built-up area and LST. A similar observation was recorded in other cities in which the urban areas had the highest LST (Akomolafe and Rosazlina 2022). The increase in temperature could have been driven by the reduction in the greenness or vegetation cover.

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

Urban heat island (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 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 Urban Heat Island (UHI) effect, is considered to be urbanization. The trend of UHI is discussed below;

4.6.1 Islamabad

The result of UHI maps for Islamabad (Figure 15) shows that the maximum land surface temperature was found where built-up areas and barren land exits while lower temperature values were found in vegetation areas and water bodies. In 2000, the temperature in built-up areas and barren land were associated with the highest temperatures, averaging 38.7˚C and 33˚C, with the water body and vegetation area being the lowest at 23.9˚C for that year.

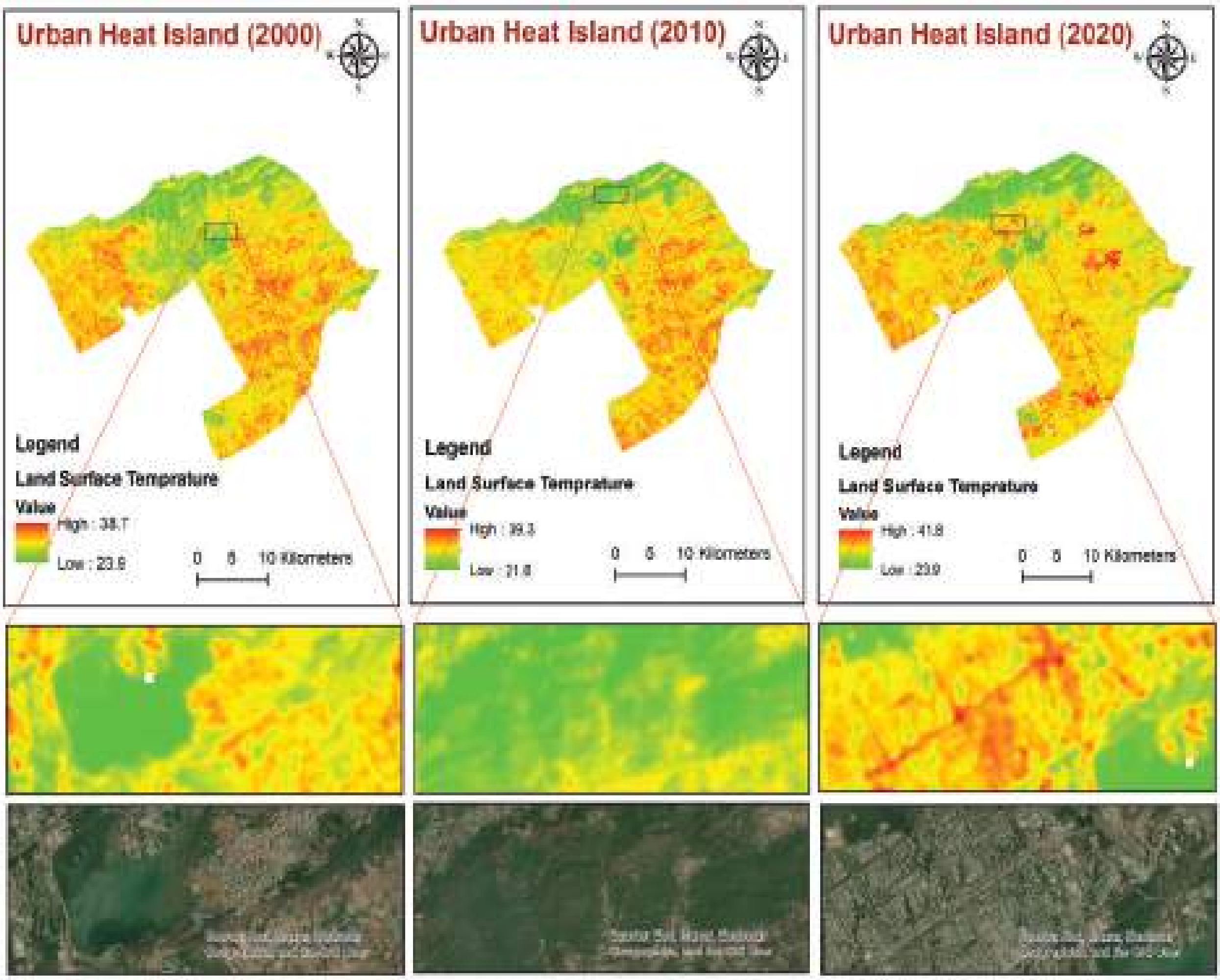


Figure 15: Urban Heat Island Map (Islamabad)

In 2010, a significant rise in land surface temperature was detected in each of the classes. The temperature in built-up areas increased to 39.3˚C (almost 0.6˚C increase from 2000), while on barren land increased to 36.2˚C. The temperature on water bodies and vegetation area temperature decreased to 21.6˚C, a consequence of many factors.

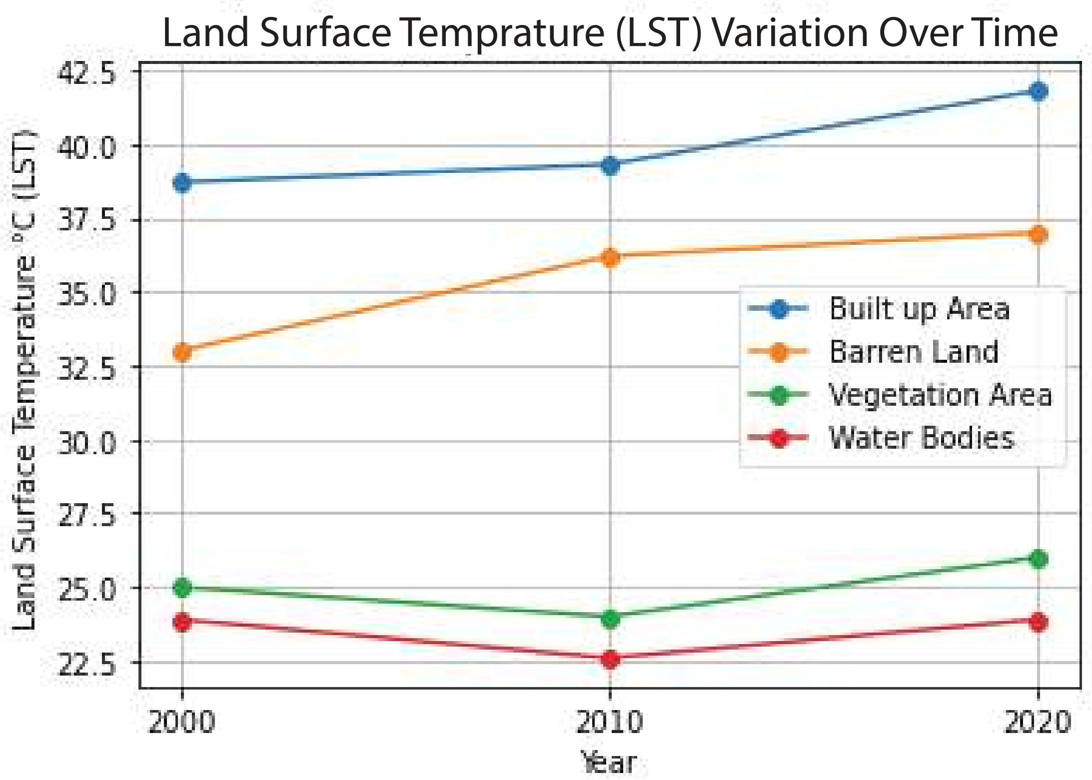


Figure 16: Correlation scatter plot (Islamabad) for 2000, 2010 and 2020 LULC and

These values continued to increase to 2020 with built-up areas reaching an average temperature of 41.8˚C and an increase of 2.5˚C from 2010. The water body and vegetation area temperature increased to 23.9˚C (Figure15 and 16).

4.6.2 Lahore

The results of UHI maps of Lahore (Figures 17 and 18) indicate the maximum land surface temperature in the built-up area rose from 37.2˚C, 39.1˚C and 40.8 ˚C in 2000, 2010, and 2020. While minimum land surface temperature also rose from 20.3˚C in 2000 to 21.3˚C in 2010 and 24.1˚C in 2000 where water bodies and vegetation areas exist.

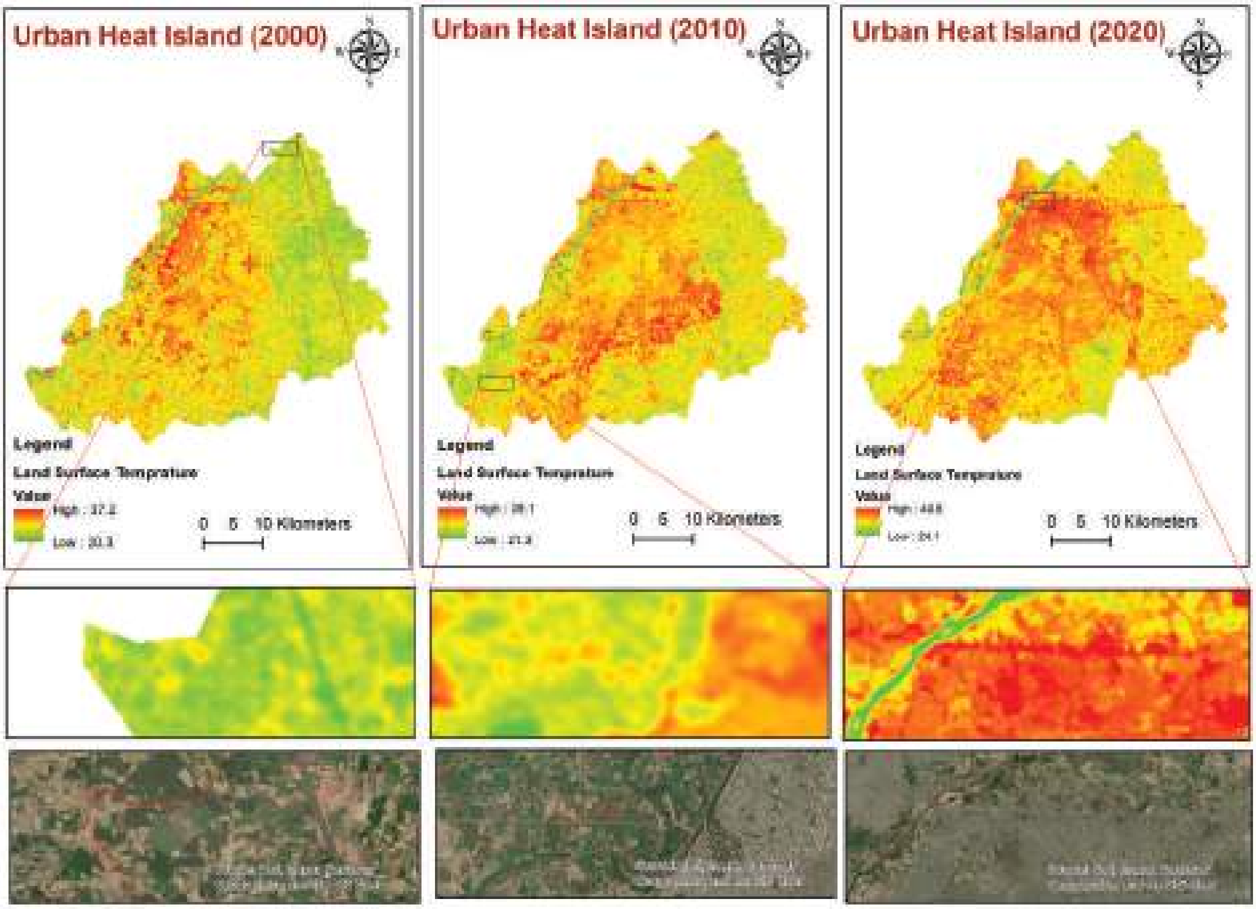


Figure 17: Urban Heat Island Map (Lahore)

The land surface values continued to increase in 2020 with built-up areas and barren reaching an average temperature of 40.8˚C and 38.0 ˚C increase of 1.7˚C from 2010. The water bodies and vegetation area temperature was increased to 24.1˚C.

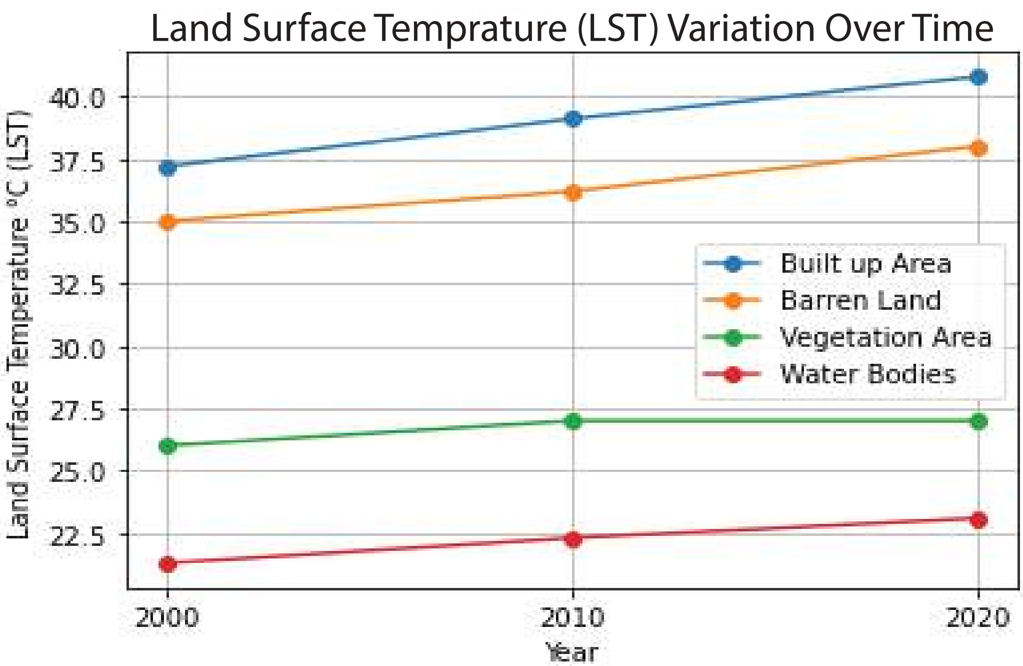


Figure 18: Correlation scatter plot (Lahore) for 2000, 2010 and 2020 LULC and

4.6.3 Multan

The Results show that in 2000 the maximum land surface temperature of Multan was 38.4˚C and the minimum land surface temperature was 23.9˚C. Figure (19,20)

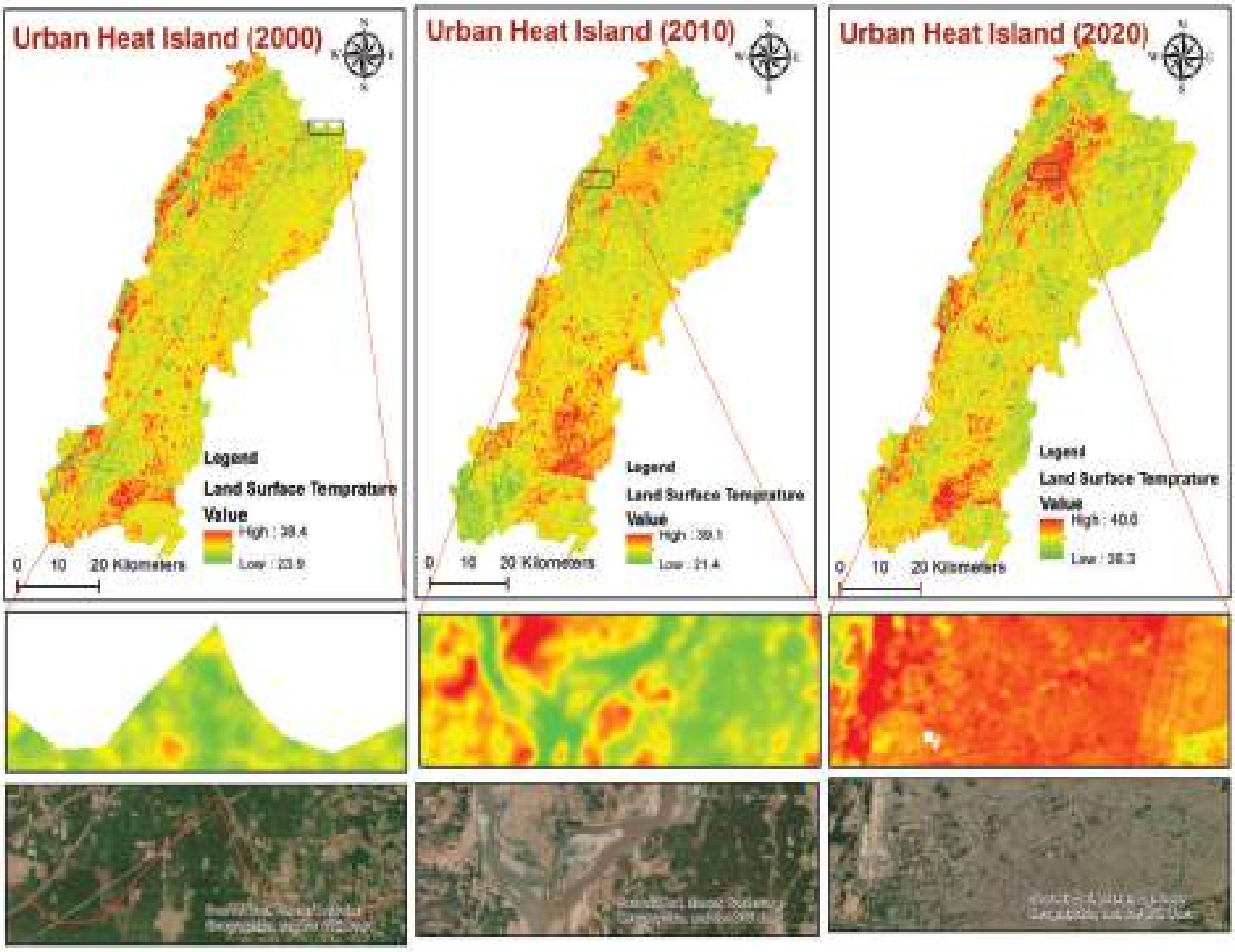


Figure 19: Urban Heat Island Map (Multan)

In 2010 increase in surface temperature was recorded. Land surface temperature in Built-up areas increased to 39.1˚C while on barren land it increased to 35.2˚C. Land surface temperature in water bodies and vegetation areas decreased to 21.4˚.

LST continued to increase to 2020 with built-up areas reaching an average temperature of 40.6˚C and an increase of 2.2˚C from 2000. The water body and vegetation area temperature increased to 24.3˚C.

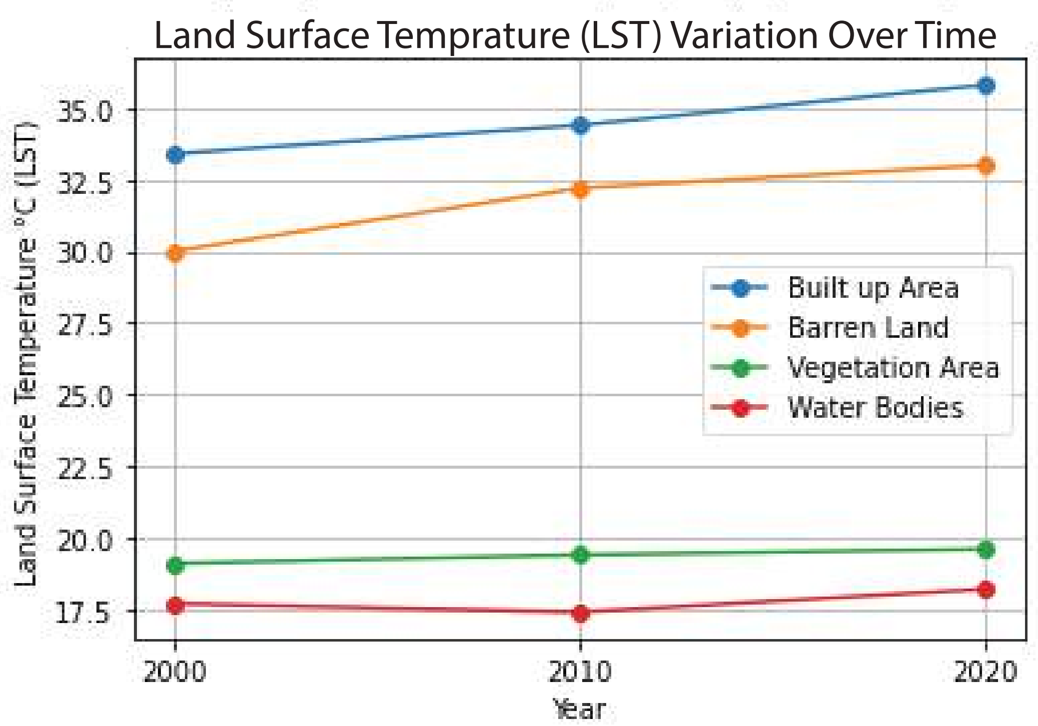


Figure 20: Correlation scatter plot (Multan) for 2000, 2010 and 2020 LULC and LST

4.6.4 Muzaffarabad

Figures 21 and 22 show that the maximum land surface temperature of Muzaffarabad was 33.4˚C found in the built-up area while the minimum surface temperature of 17.7˚C was recorded where water bodies. Each class experienced a rise in land surface temperature. The built-up areas exhibited a noticeable increase in maximum land surface temperature to 34.4˚C, while barren land increased to 33.2˚C. Temperatures in vegetation and bodies of water dropped to 17.4˚C. the built-up regions will experience an increase of 1.7°C from 2010 to 35.8°C in 2020. The temperature of the vegetation and water body rises to 19.8˚C.

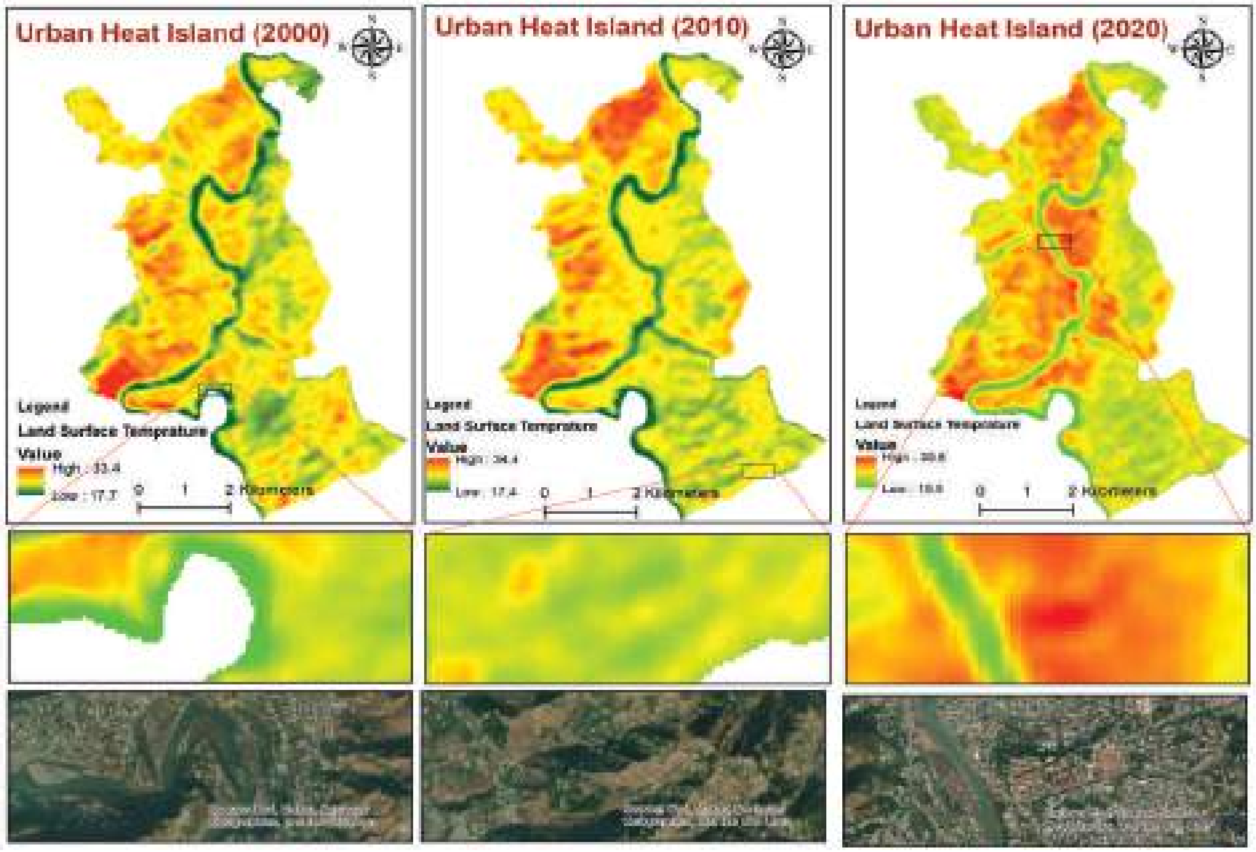


Figure 21: Urban Heat Island Map (Muzaffarabad)

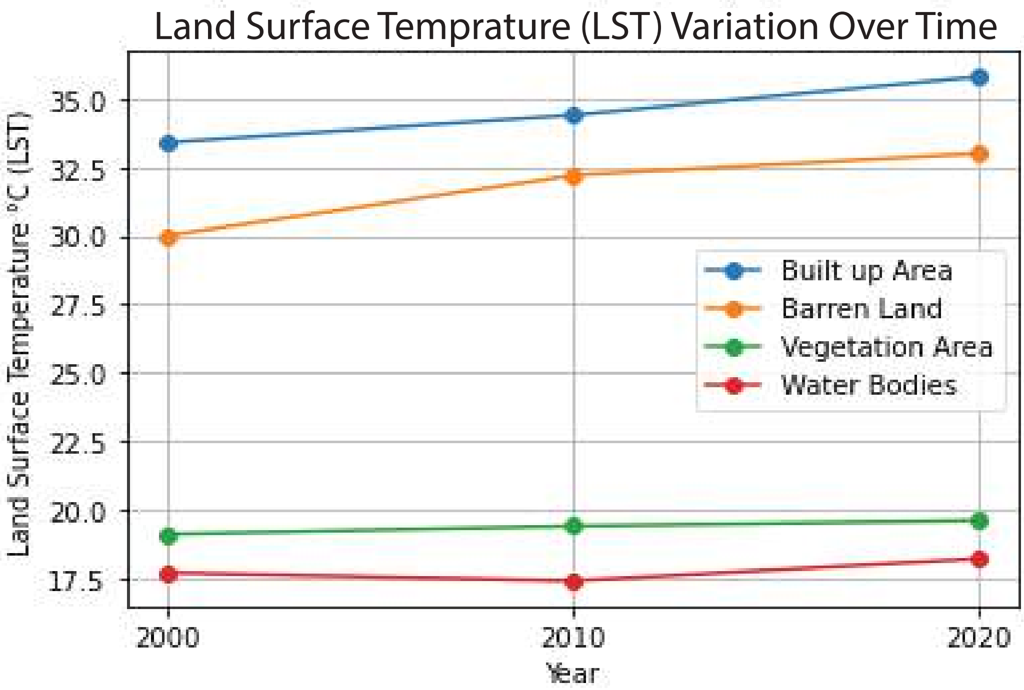


Figure 22: Correlation scatter plot (Muzaffarabad) for 2000, 2010 and 2020 LULC and

The changeability of UHI intensity is associated with a change in LULC (He et al. 2007). The urban built-up areas expanded, and a positive Urban heat island intensity became apparent, confirming the presence of a UHI (Karakuş 2019).

05 DISCUSSION

The study highlights the variations and trends of UHI effects, along with urban thermal changes influenced by LULC. Significant changes in LULC patterns, due to urbanization, greatly affect the urban thermal environment, exacerbating UHI effects. The expansion of urban areas is observed in all cities with a decline in vegetation cover. Furthermore, transitions in LULC contribute to variations in UHI and LST trends, proving their fundamental relationship. Urban expansion causes the conversion of rural areas into urban areas and the occurrence of new paved infrastructures. Additionally, temperature differences are notably higher within urban areas compared to surrounding regions. Since 2000, the LULC maps have shown noticeable urban expansion across all cities, particularly in both urban and rural areas. This expansion reveals the growth in urban area size due to urbanization, accompanied by the development of urban infrastructures. These constant changes are directly attributed to urbanization. The expansion of urban areas compares with a decline in vegetated areas, including parks and green spaces, which are converted into urban and barren land. This conversion primarily occurs through the formation of new housing societies, the expansion of road networks, and the development of industrial complexes. The urban area extends into all the study areas, indicating the loss of vegetated areas and the acquisition of urban and barren land from 2000 to 2020. The constant rise in population and migration from surrounding areas to urban has caused significant changes in green areas, barren lands, and water bodies within urban environments (Hassan et al. 2021).

Uncontrolled urbanization resulting from population growth, rural-to-urban migration, and infrastructure development contributes to the depletion of natural resources, such as agricultural land (Fu and Weng 2018). The constant population growth and an influx of individuals from neighboring areas to urban centers have led to transformations in green spaces, barren lands, and water bodies within urban areas. (Hassan et al. 2016) noted increasing built-up areas alongside decreasing vegetation and barren land from 1992 to 2012, driven by factors including economic growth, climate change, and population expansion, exacerbating habitat degradation through rapid urbanization and deforestation. The details of LULC conversion for the selected cities are mentioned in Table 7 and Figures 7-10.

As shown in Figures 15 and 16, a significant rise in LST was detected in each class in 2010. The temperature in built-up areas increased to 39.3˚C (almost 0.6˚C increase from 2000), while on barren land increased to 36.2˚C. The temperature on water bodies and vegetation area temperature decreased to 21.6˚C, a consequence of many factors. Each city presents different ecological conditions in its urban and rural areas, marked by red or worsened conditions in urban areas and green or favorable ecological conditions in rural or vegetated areas. Especially, the minimum values indicate excellent conditions around vegetation areas and water bodies. Furthermore, this index emphasizes the UHI effect, which is most pronounced in urban areas with high values. This phenomenon is attributed to rapid and continuous urbanization, coupled with the expansion of infrastructure. The changeability of UHI intensity is associated with a change in LULC (He et al. 2007).

The urban built-up areas expanded, and a positive UHI intensity became apparent, confirming the presence of a UHI (Karakuş 2019). A steady increase has been detected in surface UHI intensity compared to the surrounding rural areas. The urbanized areas might have acquired the lost vegetation and barren land. As mentioned by Wonorahardjo et al. (2020), the urban heat island effect in major cities is caused by the extensive use of concrete and brick, leading to challenges in thermal comfort and increased energy consumption. This increase in heat is attributed to the energy expended by the urban population., transports, buildings and other absorbing materials in cities such as Islamabad, Lahore, Multan and Muzaffarabad. Despite the distinct locations and physiography of the four cities, their surface temperatures show minimal differences. In Lahore and Multan, the highest temperatures are typically observed in these regions while Islamabad and Muzaffarabad have lower temperatures compared to the two cities. This suggests that the UHI effect is less pronounced in Muzaffrabad than in Islamabad compared to other cities. Various factors contribute to the formation and intensity of LST and UHI phenomena. These factors comprise green cover, water body distribution, usage of impervious materials like concrete, asphalt, and metal, LULC patterns, and surface roughness. The major factors that contributed to the formation of UHI are buildings and industrial structures which are often closely spaced in urban areas (Voogt and Oke 2003). Urban environments are characterized by high population density, where a large number of people inhabit a relatively confined area. Promoting urban development with green building integration and reduced concrete structures is recommended to lower LSTs (Kibert 2016). Various strategies to mitigate UHI effects, categorized into the roof (high-reflectance, vegetated), non-roof (shading structures, high-reflectance paving, plantation, water bodies), and covered parking strategies, can positively impact both local and global climates (Khare et al. 2021). Physical building modifications such as using high-albedo materials, incorporating green walls and roofs, greening parking lots, and addition of vegetation around buildings and along roads also reduce the UHI effects (Sasmito et al. 2019). Several other features including planting trees, green roofs, water bodies installations, green corridors, open spaces, street orientation, and environmental management can help in managing UHI and provide a very eco-friendly environment to live in (Rehan 2016). The cities of Pakistan should implement policies to mitigate UHI effects by increasing green spaces and water bodies through urban tree plantations and creating water and green parks. This study highlights the significance of analyzing LULC and emphasizing the role of LULC in temperature rise. Governments should encourage further research to address these issues comprehensively, considering factors like population, city landscapes, and socioeconomic factors.

06 LIMITATIONS OF THE STUDY

In this study, Landsat products were employed for analyzing LULC, LST, and UHI analysis for 2000, 2010 and 2020. To enhance future studies, it is recommended to employ datasets with better temporal and spatial resolutions to mitigate uncertainties arising from cloud cover or low spatial resolution. Additionally, future research should explore new methodologies to deal with innovative techniques for upcoming studies. While this study focused on urban areas and LULC changes for UHI studies, future investigations should also consider other factors such as regional climate change and its impact on UHI, as well as the influence of urbanization on climate change. In this study, we thoroughly examined the UHI phenomenon, particularly its correlation with changes in LULC pattern. This study encourages more research studies to focus on other cities in Pakistan and to provide deeper insights into UHI and related problems on regional and small levels to understand and mitigate this problem.

07 CONCLUSIONS

This research study utilized geospatial techniques to analyze 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 results have shown a significant increase in urban areas in all four 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. The changes detected in LULC from 2000 to 2020, due to the replacement of vegetation areas with impermeable surfaces have brought about a noticeable shift in the climate of all four cities. This transformation has resulted in the loss of approximately 2% of its original land area in Islamabad, 18.5% in Lahore, and 3.3% in Multan. Variations in LST were observed for the years 2000, 2010, and 2020. The results show that from 2010 to 2020, the LST rose from 33.0°C to 34.1°C in Islamabad, 33.4°C to 35.5°C in Lahore, 34.4°C to 35.7°C in Multan while for 30.3 °C to 31.8 °C in Muzaffarabad. 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, with Lahore and Multan showing the highest value. This research aims to 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. The Punjab Central Business District Development Authority has introduced the Blue Road concept in Lahore. Blue Roads reduce the Urban Heat Island Effect and promote a healthier environment

4. Smart Urban Planning: Integrate heat island mitigation strategies into urban planning and design processes. Prioritize mixed land use, compact development, and pedestrian-friendly infrastructure to minimize heat-generating activities and enhance natural cooling mechanisms.

5. 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.

6. 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.

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.

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