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Future climate projections and sustainable development: The impact of Urban Heat Islands and land use land cover in Telangana's GHMC area

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ABSTRACT

This study investigates the urban heat island (UHI) effect in Hyderabad, Telangana, focusing on the Greater Hyderabad Municipal Corporation (GHMC) area, which spans 650 square kilometers. The analysis integrates land use and land cover (LULC) changes and future climate projections, estimating annual average temperature and precipitation trends up to 2100. Utilizing data from USGS Landsat-8, SRTM-DEM, and IMD, various thematic maps, including elevation (ranging from 456 to 637 meters) and natural infrared. LULC data from 1985, 1995, 2005, and 2023 were analyzed to identify significant changes over time. Moreover, other directories like NDBI, NDVI, and NDWI originated from Landsat-8 information collected from different terms in 2021, 2022, and 2023.The results indicated significant trends in climatic impact caused due to urbanization, which outlined the increase in surface temperatures and intensified UHI effects. UHI in the GHMC area is categorized into two groups, with high values of 329.75 and low values of 72.04. Rainfall is categorized into high (251-1500 mm), medium (26-250 mm), and low (0-25 mm). Additionally, the analysis considered different Shared Socioeconomic Pathways (SSPs) – SSP1 2.6, SSP2 4.5, SSP3 7.0, and SSP5 8.5 to project temperature, precipitation and humidity trends until 2100. The findings contribute to understanding climate impacts, guiding sustainable urban development, and enhancing climate resilience in the GHMC region.

Keywords: Urban Heat Island (UHI), Greater Hyderabad Municipal Corporation (GHMC), Land Use and Land Cover (LULC), Landsat-8, Temperature, Precipitation, and Land Surface Temperature (LST).

1. INTRODUCTION

World is rapidly evolving with urbanization, which is transforming cities across the globe. However, that harms environment and leading to diverse climatic changes, among which Urban Heat Island (UHI) effect is considered to be the most critical challenges. The UHI effect, the effect where most of the urban regions experience increased temperature conditions compared to that rural region, it is caused due to manmade activities, human interference disturbing environment and climate, and modifications of land surfaces. This phenomenon can exacerbate the impacts of heatwaves, increase energy demand for cooling, and deteriorate air quality, leading to significant public health (Ahmed, 2018).

Hyderabad, the capital of Telangana, India, exemplifies rapid urbanization with a current population exceeding one million and significant investments from global companies such as Google, Amazon, and Microsoft, Hyderabad has become a critical focal point for urban studies and sustainable development initiatives. The city has turned into an economic hub with enhanced living standards due to rapid developments and advanced technologies, on the other hand, it is facing environmental issues. The Urban Heat Island (UHI) effect in Hyderabad is a growing concern because it can impact public health, increase energy use, and affect the city's overall resilience.

There have been significant transformations in the land use and land cover (LULC) over the period of several years, which covers a span of 650 sq.km in the Greater Hyderabad Municipal Corporation (GHMC) area. Leading to the UHI effect as an aftermath of considerable reduction in vegetative lands accompanied with drastic alterations in thermal characteristics and development of impervious surfaces. Understanding the spatial and temporal dynamics of UHI in GHMC is crucial for urban planning and policymaking aimed at mitigating the adverse impacts of urbanization on climate, health, and energy consumption. This study aims to evaluate the UHI effect in the GHMC area, considering the impact of LULC changes and future climate projections.

Utilizing data from USGS Landsat-8, SRTM-DEM, and the Indian Meteorological Department (IMD), this research develops detailed thematic maps, including elevation (ranging from 456 to 637 meters) and natural infrared (Jumari et al., 2023). LULC data from 1985, 1995, 2005, and 2023 are analyzed to identify significant changes over time. Indices such as the Normalized Difference Built-up Index (NDBI), Normalized Difference Vegetation Index (NDVI), and Normalized Difference Water Index (NDWI) are derived from Landsat-8 data for November 2021, May and November 2022, and 2023, facilitating a comprehensive assessment of average annual Land Surface Temperatures (LST) and the UHI effect. Estimating NDBI, NDVI, and NDWI is critical in this study as these indices provide insights into vegetation health, urban expansion, and the presence of water bodies, respectively.

NDBI helps in identifying built-up areas and understanding the extent of urban expansion, which directly contributes to increased LST. NDVI is a measure of vegetation health and density, which is crucial for understanding how green spaces mitigate the UHI effect by providing cooling through evapotranspiration. NDWI is essential for detecting water bodies, which have a cooling effect on surrounding areas. These parameters are essential for understanding the thermal dynamics of the urban landscape and the extent of the UHI effect. Forthcoming predictions indicate changes in temperature and rainfall patterns, strengthening the UHI effect. To conserve the malleability of Hyderabad's urban areas, these estimates highlight the importance of advanced urban planning and better climatic adaptability measures.

This study represents the importance of responsive urban planning and climate adaptation techniques by identifying the potential increase in temperatures as well as rainfall. The study's findings have a considerable impact on Hyderabad's public health, energy use, and general resilience to disruption. This study is to assist regulators and urban planners in formulating plans to lessen the effects of UHI and encourage healthy urban development in Hyderabad by offering practical insights. Gaining insight into the magnitude and causes of UHI in the GHMC zone will be crucial for creating prevention and adaptation plans that work.

For enhancing the standard of living in general, these tactics may be highly beneficial for lowering energy use and increasing urban resilience. Environmentally sustainable initiatives for urban cities must be introduced in Hyderabad that aim towards a balanced and sustainable economic growth by tackling the UHI phenomena, guaranteeing a more resilient and healthy urban future. Figure 1 represents the study area map that has a spatial distribution of elevation.

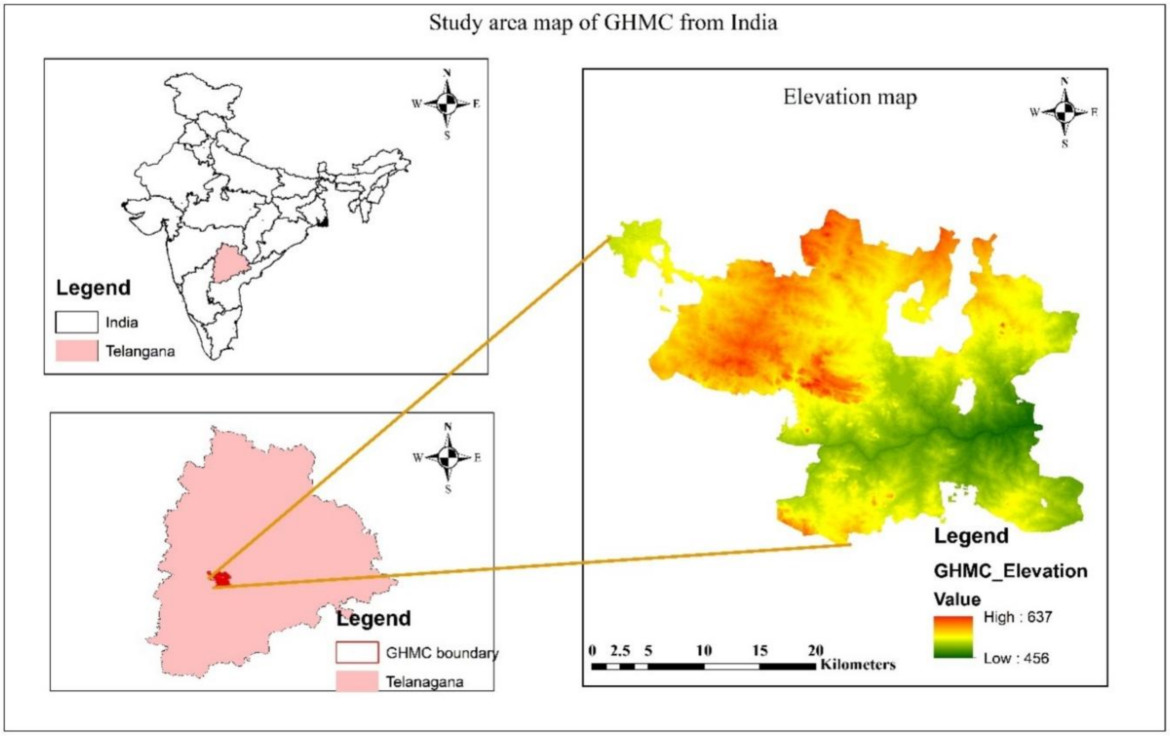


Figure 1 Geographical location map of GHMC region with the spatial distribution of elevation

Considerable environmental and climatic changes brought about by urbanization result in the UHI impact, which exacerbates heat waves, raises the need for energy to regulate buildings, and degrades air quality, all posing serious threats to public health. It is of paramount importance to comprehend the patterns in the temporal and spatial characteristics of LULC changes and its UHI effects. The currently observed climate change phenomena may be attributed to the LULC changes driven by extensive urbanization. With the advent of satellite remote sensing techniques these LULC changes can be tracked over time. The Landsat-8 satellite has given invaluable high resolution spatial and temporal information for a detailed analysis of urban landscapes.

It has been highlighted by Roy et al., (2014) that the data of Landsat-8 enables us to develop several indices which help characterize different aspects of LULC, including vegetation health, urban expansion, and the presence of water bodies. NDBI is designed to map built-up areas. It is instrumental in assessing urban expansion and its contribution to the UHI effect. NDBI used to automatically map urban areas from satellite imagery, highlighting its utility in urban climate research (Zha et al., 2003). The NDVI is a widely used index for assessing vegetation health and density (Sadat et al., 2024). NDVI is crucial for understanding the role of green spaces in mitigating the UHI effect, as vegetation provides cooling through evapotranspiration and shading.

High NDVI values typically indicate healthy, dense vegetation, which is essential for maintaining lower surface temperatures in urban areas. The NDWI detects water bodies and assesses their role in the urban environment. Water bodies significantly cool surrounding areas, helping to alleviate the UHI effect. NDWI is particularly useful in identifying changes in water bodies over time, which can result from urban development or climate variations. From McFeeters, (1996) the effectiveness of NDWI in delineating open water features, is crucial for urban climate studies. LST is a critical parameter in studying the UHI effect. Remote sensing data from Landsat-8 allows for the accurate estimation of LST, providing insights into the thermal properties of different land cover types Emphasized.

The importance of thermal infrared remote sensing in urban climate studies is emphasized by Weng, (2009) and its application in identifying UHI hotspots and assessing strategies for mitigation. The combined effects of less vegetation, more built-up areas, and changed surface conditions in urban areas cause the UHI effect (Zha et al., 2003). It is typified by warmer temperatures in cities relative to their rural surroundings, which can result in several problems for the environment and human health. Optimizing urban thermal comfort and creating focused mitigation solutions require knowledge of the spatial distribution of the UHI effect. Future climate projections are essential for understanding their effects on long-term changes in urban localities.

It could be possible to predict the changes and effects of temperature, humidity, and precipitation on urban areas using the trends of these components. Early predictions facilitate taking the necessary action during critical times. Climate models provide valuable insights into how urban areas will respond to future climatic conditions, helping to inform urban planning and policymaking. These projections are vital for cities like Hyderabad, where rapid urbanization and significant climatic changes are expected to intensify the UHI effect. It has been demonstrated by Wang et al., (2019) that remote sensing data combined with meteorological data could effectively project future climate scenarios and their impact on urban areas.

Similarly, Moursi et al., (2020) utilized satellite data to analyze the impact of urbanization on UHI and projected future scenarios under different climate models. The integration of remote sensing indices such as NDBI, NDVI and NDWI with LST analysis provides a comprehensive understanding of theUHI effect and the factors that drive it. The usefulness of these metrics in mapping and examining the geographic distribution of UHI worldwide was shown by (Clinton and Gong, 2013). Furthermore, as Wong et al., (2011) noted, incorporating future climate forecasts into these assessments enables an anticipatory approach to urban development and preventive solutions.

2. METHODOLOGY

In this the GHMC region has been chosen as study area due to its rapid urbanization in Telangana state of India. Data collection included Landsat-8 imagery with zero cloud percentage and using dark object subtraction technique atmospheric scattering and absorption effects have been removed, SRTM-DEM, and IMD data for analyzing indices, LULC changes, and climate trends. The ArcGIS software has been used to define geographical positioning and several spatial distribution themes were developed which include elevation and near infrared (NIR) analysis for LULC classification etc., The LULC analysis from 1985 to 2023 categorized land into vegetation, built-up areas, and water bodies.

Indices like NDBI, NDVI, and NDWI were calculated to assess green spaces, water bodies, and urbanization levels. LST analysis using Landsat-8 data identified UHI hotspots. Climate trends were analyzed for UHI projections and rainfall categorization. Data analysis revealed the impact of LULC changes and climate on the UHI effect. Recommendations focused on urban planning strategies to mitigate UHI, such as increasing green spaces and improving water management (Bagyaraj et al., 2023). The robustness of the observed trends of humidity, temperature, and precipitation the have been analyzed using the statistical methods of Mann-Kendall test.

3. RESULTS AND DISCUSSION

Land Use Land Cover mapping of the study region

LULC mapping plays a crucial role in understanding the urban geographical distributions and changes. It has proven to be highly beneficial in determining land uses such as vegetative or built-up land, water bodies etc that affect regional climate and patterns of urban heat. LULC mapping aids in pinpointing regions susceptible to environmental changes and offers insightful information about how urbanization affects natural resources. We can assess the success of urban planning techniques and create more environmentally friendly urban growth models18 by examining LULC variations over time. In this study, Landsat-8 data for the years 1985, 1995, 2005, 2021, 2022, and 2023 were downloaded from the USGS website with zero cloud coverage.

Using these datasets, an infrared analysis was performed to represent the spatial distribution of land and water over the GHMC region and presented in (Figure 3). The band composites of 5, 6, and 4 were selected to develop an NIR map (Figure 2), which clearly shows the spatial distribution of various land covers and water bodies. Because of its lower height, the southeast part of the GHMC has greater number of water bodies, according to the NIR map. Since the existence of water bodies reduces UHI by producing cooling effects, this information is essential for assessing LST as well as the UHI effect. Regional temperature regulation is greatly influenced by water bodies, which generally have lower temperatures than urban built-up areas (Roy et al., 2014).

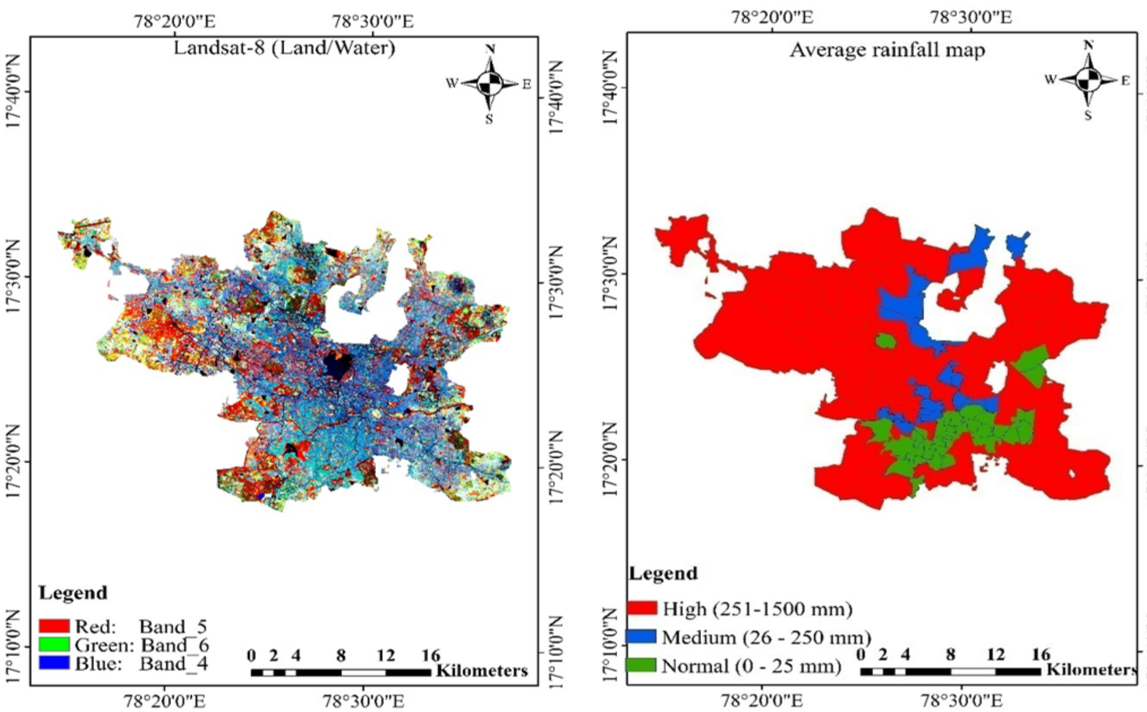
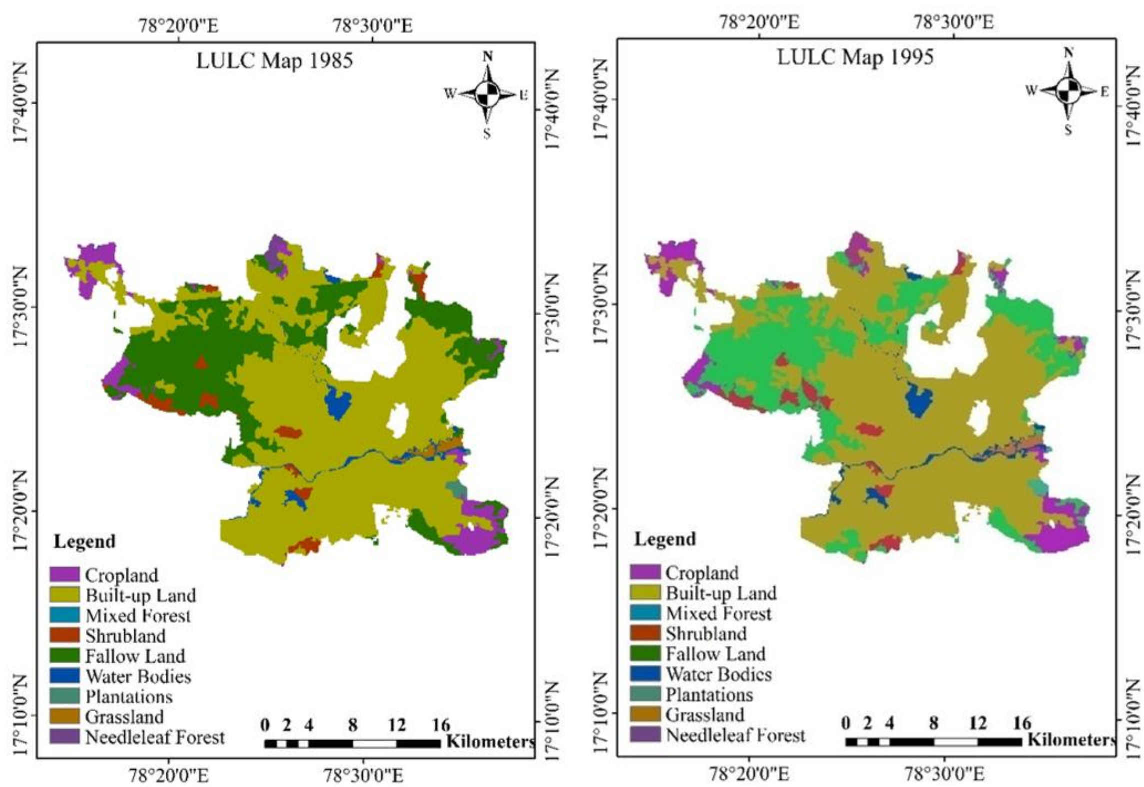


Figure 2 Landsat-8 (NIR) and annual rainfall map representing the natural land \ water and intensity of the rainfall over the GHMC region



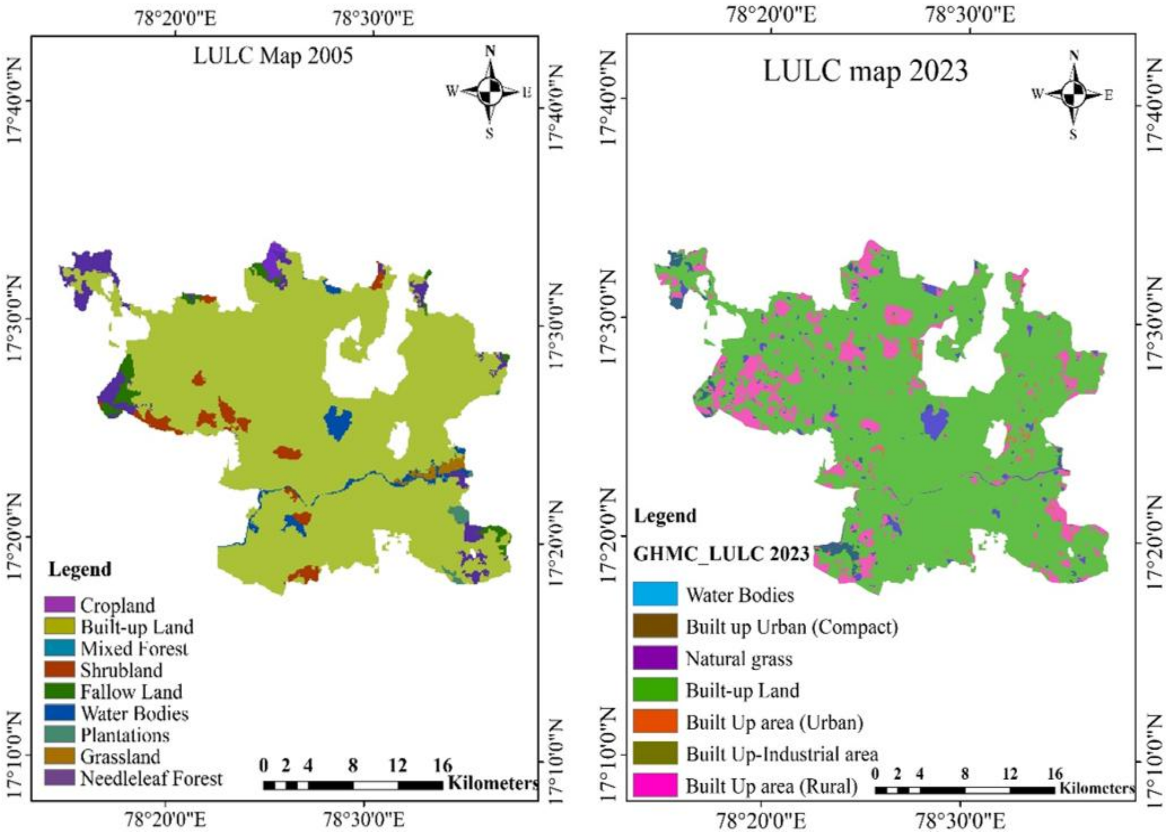


Figure 3 LULC variation of GHMC region for different time periods

Additionally, an annual rainfall map of the GHMC was developed and categorized into three main groups such as low, medium, and high and as shown in (Figure 2). The distribution of rainfall and its impact on LST and UHI may be interpreted effectively with the help of categorization. Areas with more vegetative land and water bodies is most likely to experience heavy rainfall pattern, contributing to lower LST and reduced UHI intensity (Sadat et al., 2024). Conversely, areas with low rainfall may experience higher temperatures and more pronounced UHI effects due to the lack of natural cooling elements.

Normalized Difference Built-up Index Mapping of the study region

The NDBI is essential for evaluating LST and the UHI effect, as it measures the density of built-up areas in a geographic region. Calculated using the ratio of short-wave infrared (SWIR) to NIR bands, NDBI values range from -1 to 1. In this study, NDBI was derived from Landsat-8 data, specifically using bands 5 and 6 from equation 1, for the periods of May 2021, May 2022, November 2022, and March 2023. The NDBI values for May 2021 ranged from -0.36 to 0.42, reflecting a combination of natural and built-up areas. In May 2022, the range narrowed to -0.32 to 0.24, indicating changes in urban density. November 2022 values ranged from -0.35 to 0.25, while March 2023 values ranged from -0.38 to 0.25. These values were categorized into five groups (Reddy et al., 2024a), and shown in (Figure 4).

$$\mathrm{NDBI} = \frac{\mathrm{Band\ 6} - \mathrm{Band\ 5}}{\mathrm{Band\ 6} + \mathrm{Band\ 5}} \qquad (1)$$

Where, the band 5 and 6 are the feature of the footprint of landsat-8 data.

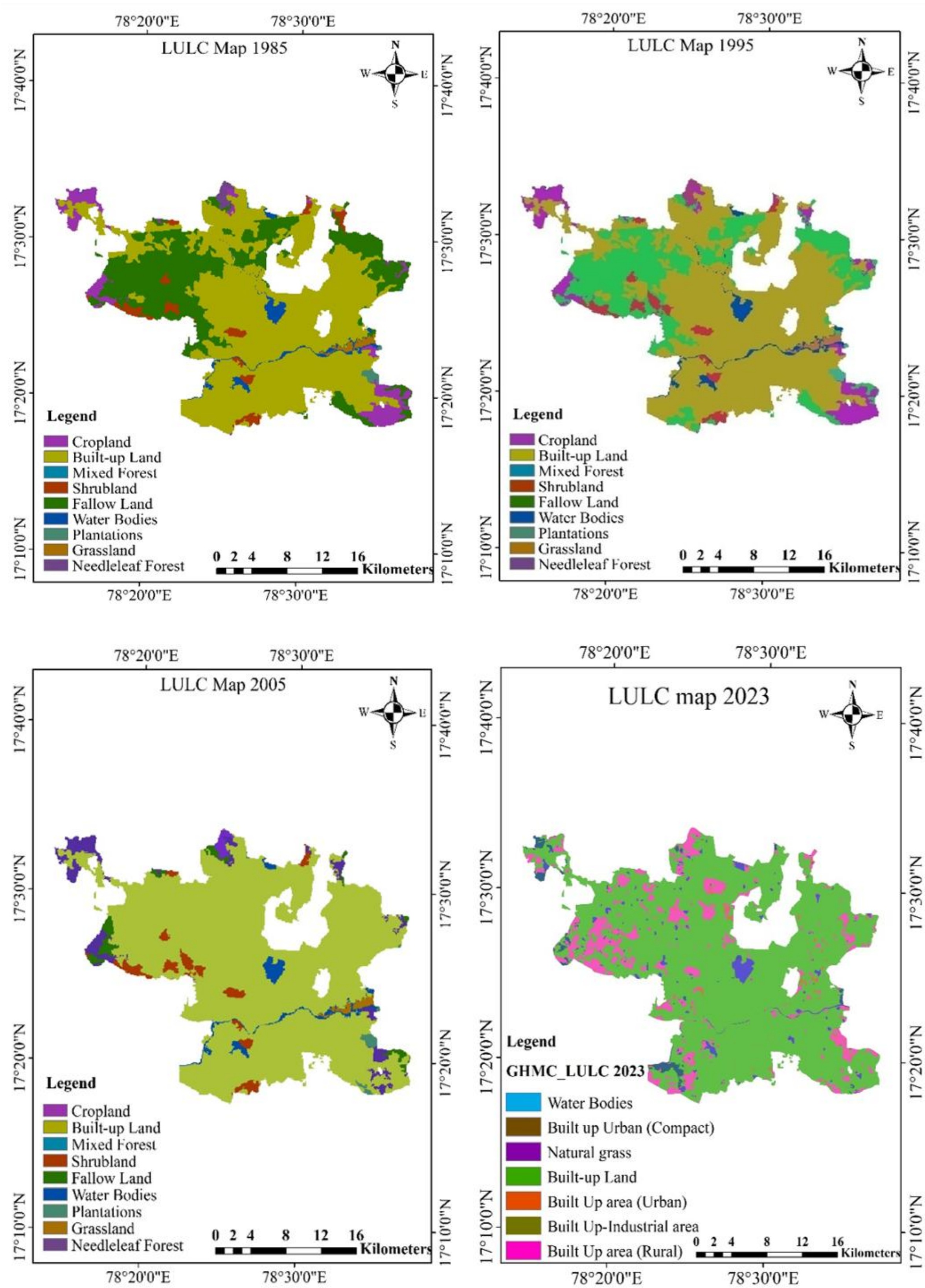


Figure 4 NDBI indices of the GHMC region representing built-up scenario for different time periods

The surface temperatures are relatively higher in urban areas due to heat retention, thus LST and UHI can be evaluated with the help of NDBI mapping. The major heat hotspot areas must be delineated by urban planners for finding solutions to mitigate the increasing UHI. Some of the solutions may include expansion of green plantation spaces, improve urban landscape with proper knowledge of geographic distributions and proportions of built-up zones. Invaluable insights can be obtained with the help of NDBI analysis regarding the temporal changes and its effects on LST and UHI in the GHMC region, supporting sustainable urban development initiatives.

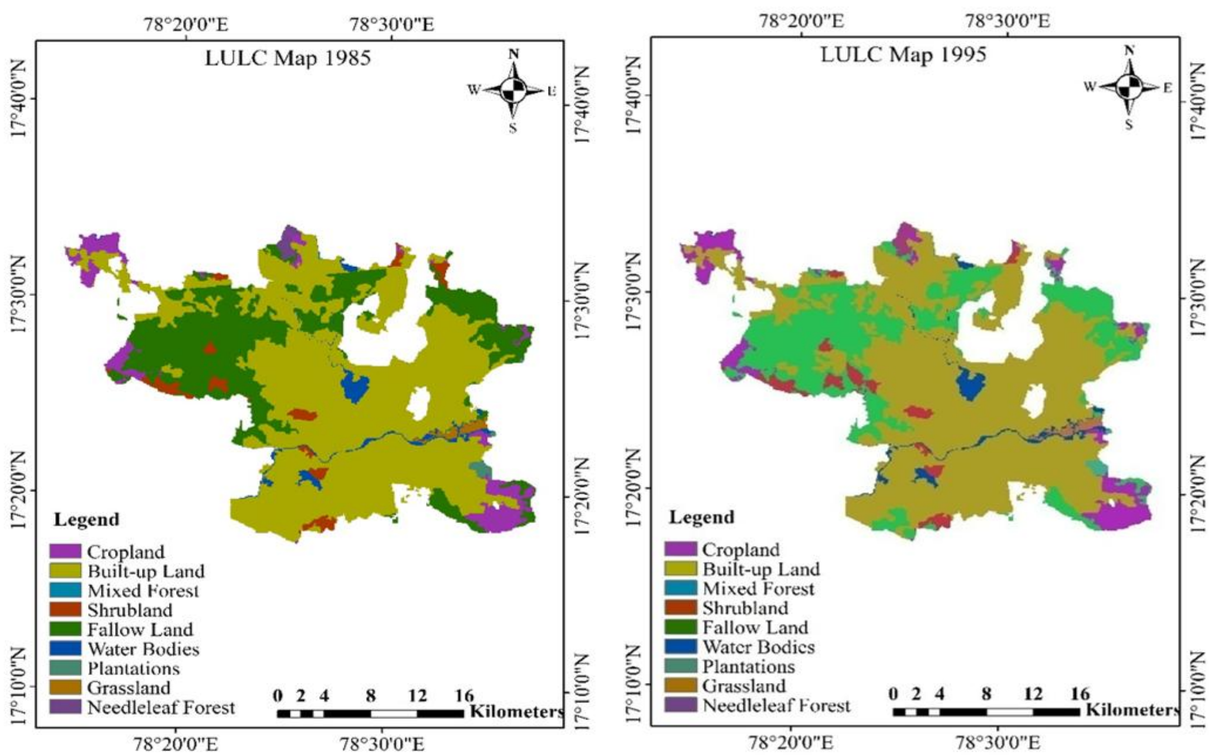
Normalized Difference Water Index Mapping of the study region

The NDWI is instrumental in analyzing water bodies and their influence on LST and the UHI effect (Favretto, 2018). NDWI leverages the Green and NIR bands of remote sensing images, with higher values indicating adequate moisture and lower values signaling water stress (Reddy et al., 2024b). In this study, NDWI was computed using Landsat-8 bands 3 and 5 (Equation 2). The mathematical expression for NDWI is given in Equation 3. For the periods of May 2021, May 2022, November 2022, and March 2023, the NDWI values were calculated. The values for May 2021 ranged from -0.48 to 0.11, while May 2022 displayed a range from -0.46 to 0.055. For November 2022, the values varied from -0.7 to 0.12, and for March 2023, they ranged from -0.65 to 0.13. These values were divided into five categories, as depicted in (Figure 5).

$$\mathrm{NDWI} = \frac{\mathrm{Green} - \mathrm{NIR}}{\mathrm{Green} + \mathrm{NIR}} \quad (2)$$

$$NDWI = \frac{Band\ 3 - Band\ 5}{Band\ 3 + Band\ 5} \quad (3)$$

Where, the band 3 and 5 are the feature of the footprint of landsat-8 data and the NIR is used for data insights, and which enable user to be informed with decision and further the NIR is used to identify the key issues in the data. The green colure further used in NDWI mapping for identifying the moderate water content with vegetation.



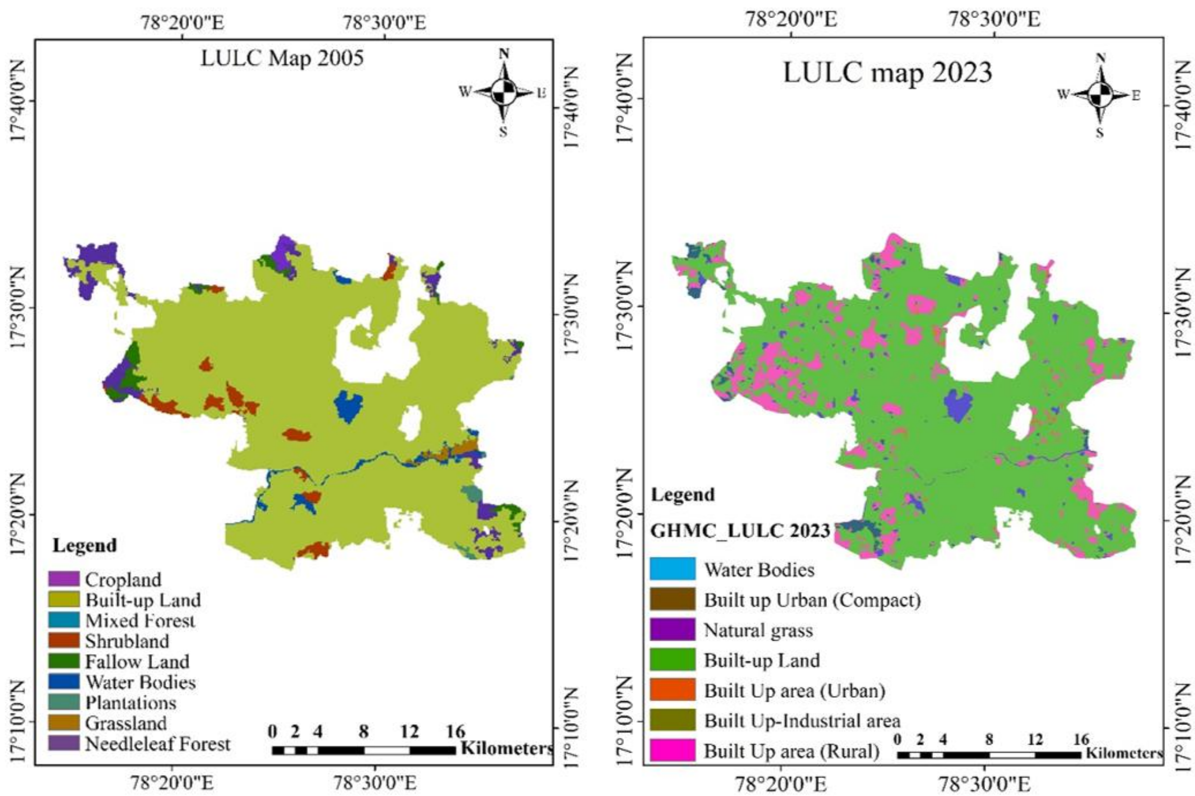


Figure 5 NDWI indices of the GHMC region representing moisture content for different time periods

Since water bodies greatly control temperatures and offer cooling benefits in urban settings, mapping NDWI is essential for assessing LST and UHI. Developers can pinpoint areas experiencing water stress and create plans to improve the management of water and lessen the effects of UHI by knowing the geographical location and moisture content of water bodies. A thorough NDWI investigation makes understanding the temporal variations in the distribution of water bodies and how they affect LST and UHI in the GHMC area possible. This information supports sustainable urban development initiatives and improves climate resilience by informing policies and interventions to reduce the adverse effects of urban heat islands.

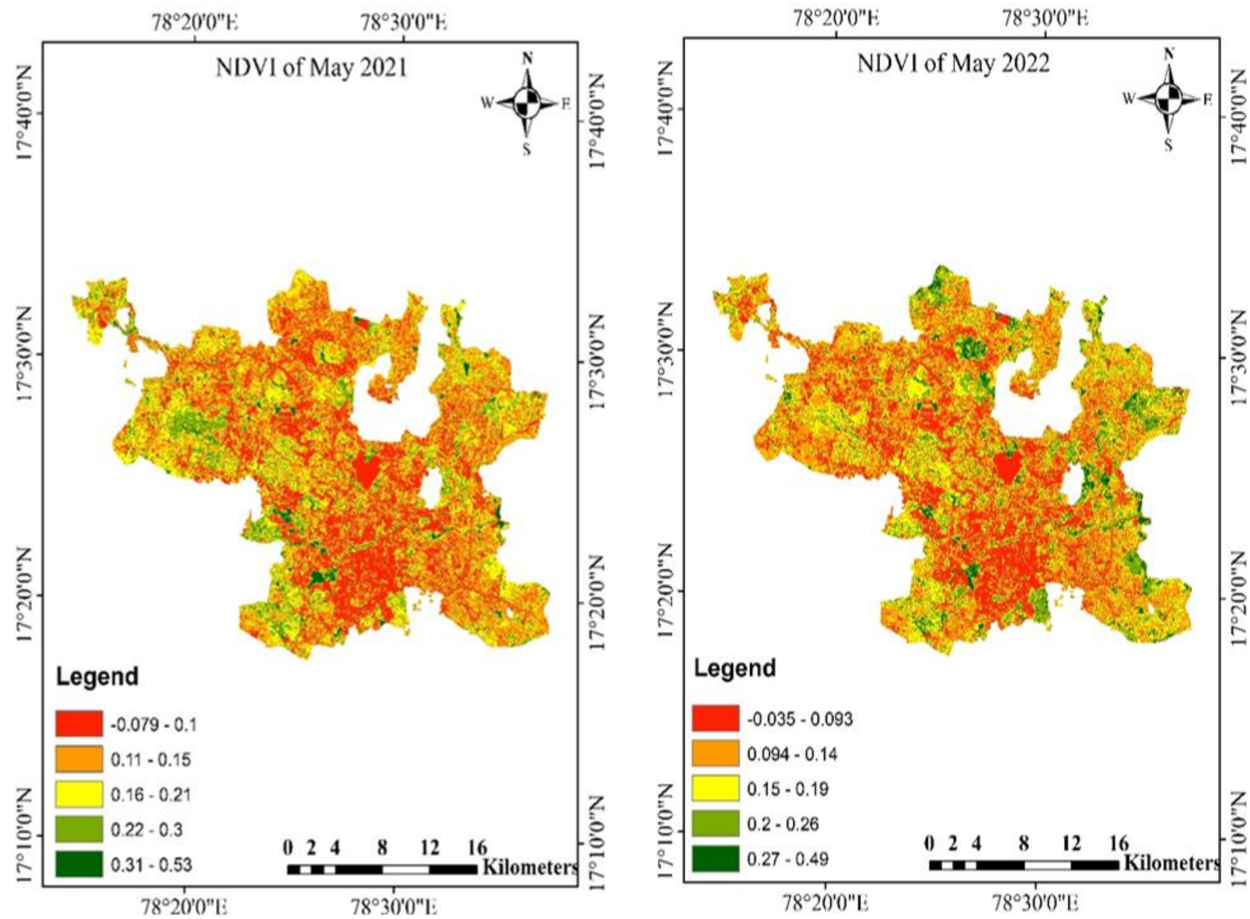
NDVI features of the GHMC's region

The NDVI analysis for the GHMC region from May 2021, May 2022, November 2022, and 2023 offers a thorough understanding of vegetation health and land use changes. The NDVI readings in May 2021 showed a varied environment with different levels of vegetation cover and land types, ranging from -0.079 to 0.53 (Chandra et al., 2024). Whereas regions with scant vegetation or non-vegetated surfaces, including lake bodies or built-up areas, are indicated by lower values, higher values suggest healthy vegetation cover (Equation 4). The GHMC region's diverse land cover, which includes a blend of urban, suburban, and natural landscapes, is highlighted by this variety of NDVI values (Figure 6). The range of the NDVI readings in May 2022 was between -0.035 and 0.49.

Changes in land use trends and abundance of vegetation occurred throughout this time, possibly because of urban growth, land management techniques, and seasonal variations. When evaluating environmental changes and the effects of urbanization, it is crucial to consider the dynamic character of the development of vegetation and land use transformations over time, which are highlighted by variations in NDVI values. The NDVI measurements in November 2022 showed a wider range from -0.14 to 0.65. This broader range suggests notable changes in the types of land cover, which may have been brought about by climatic fluctuations, vegetation dynamics, and land management techniques. Water bodies, land, bushes, limited vegetation, and dense vegetation were among the different groups into which the 2023 categorization further divided land cover.

$$NDVI = \frac{Band\ 5 - Band\ 4}{Band\ 5 - Band\ 4} \qquad (4)$$

The present study offers information about the geographical distribution of types of land cover use and vegetation in the area, to help in better understanding the dynamics of the ecosystem and environmental flexibility. The detailed analysis provided by NDVI stands as a fundamental tool for estimating LST, UHI effects, and climate changes in the GHMC region. It offers valuable information for land managers, urban planners, and policymakers to make informed decisions regarding sustainable land use practices, green infrastructure development, and climate adaptation strategies.



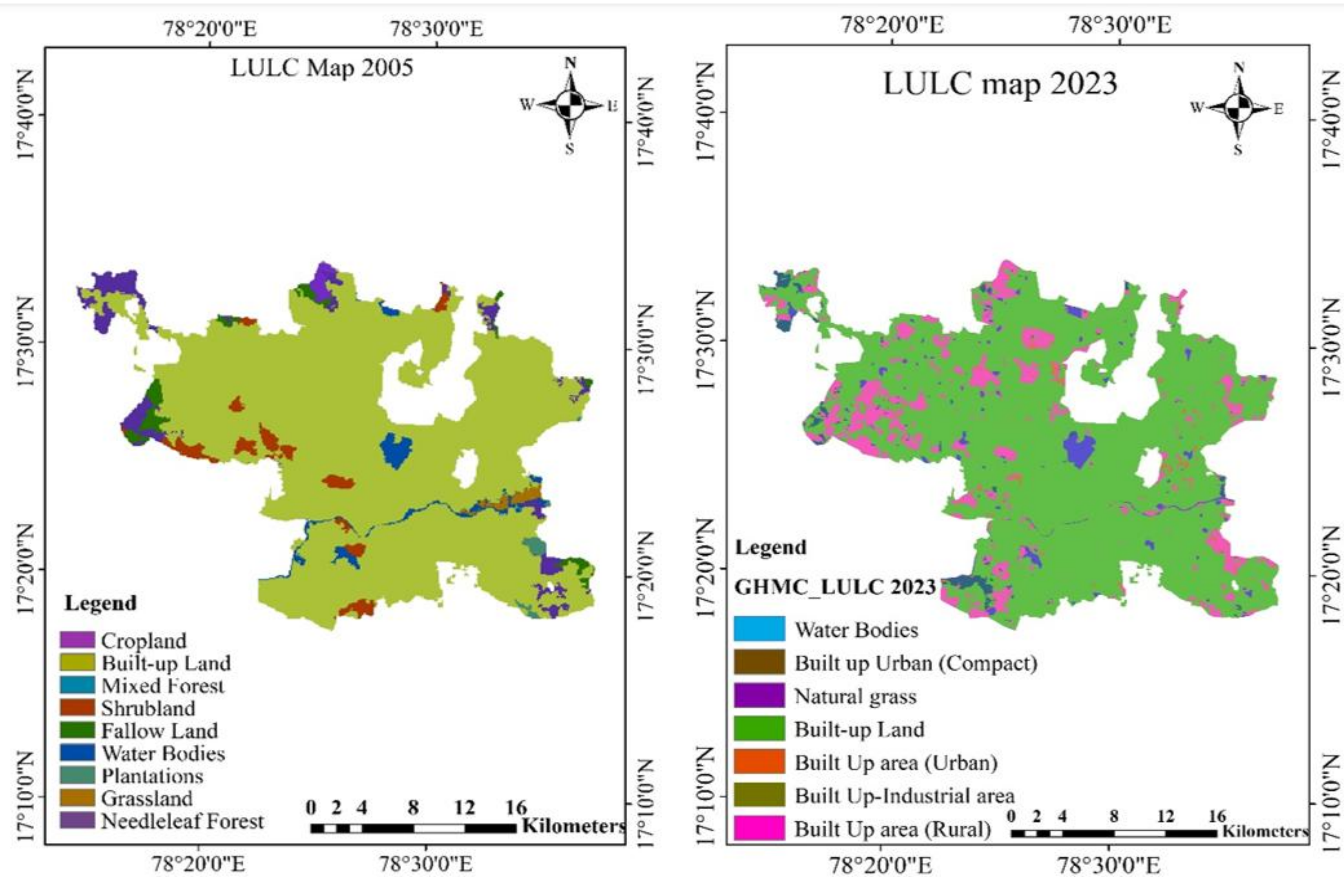


Figure 6 NDVI indices of the GHMC region representing Vegetation scenario for different time periods

Land surface temperature and Urban Heat Island mapping

Mapping LST and UHI effects in the GHMC region involves a detailed analysis of temperature variations and urban heat patterns (Cetin et al., 2024). In the study, LST is measured in Celsius and categorized into five classes: 83.3-111°C,112-134°C, 135-145°C, 146-158°C, and 159-341°C. Concurrently, UHI, which represents the temperature difference between urban areas and their rural surroundings, is examined across the GHMC area, ranging from 72°C to 329.7°C. The spatial distribution if LST and UHI of the GHMC is illustrated in (Figure 7).

An illustration of the way UHI intensity varies with distance throughout the GHMC region may be found in the UHI stack profile. Hyderabad's urban development, environmental oversight, and climate resilience measures may be significantly impacted by this stack profile, which is essential for comprehending the geographic distribution of UHI effects. The UHI stack profile-derived map (Figure 8) provides useful information on local hotspots and regions with elevated UHI impacts (Rana et al., 2024). Researchers can determine areas of greatest vulnerability, evaluate how urbanization affects temperature patterns, and suggest focused interventions to reduce heat-related risks and improve urban sustainability by examining this map in conjunction with other environmental data, especially modifications to LULC, population growth, and climate shifts (Hussain et al., 2023).

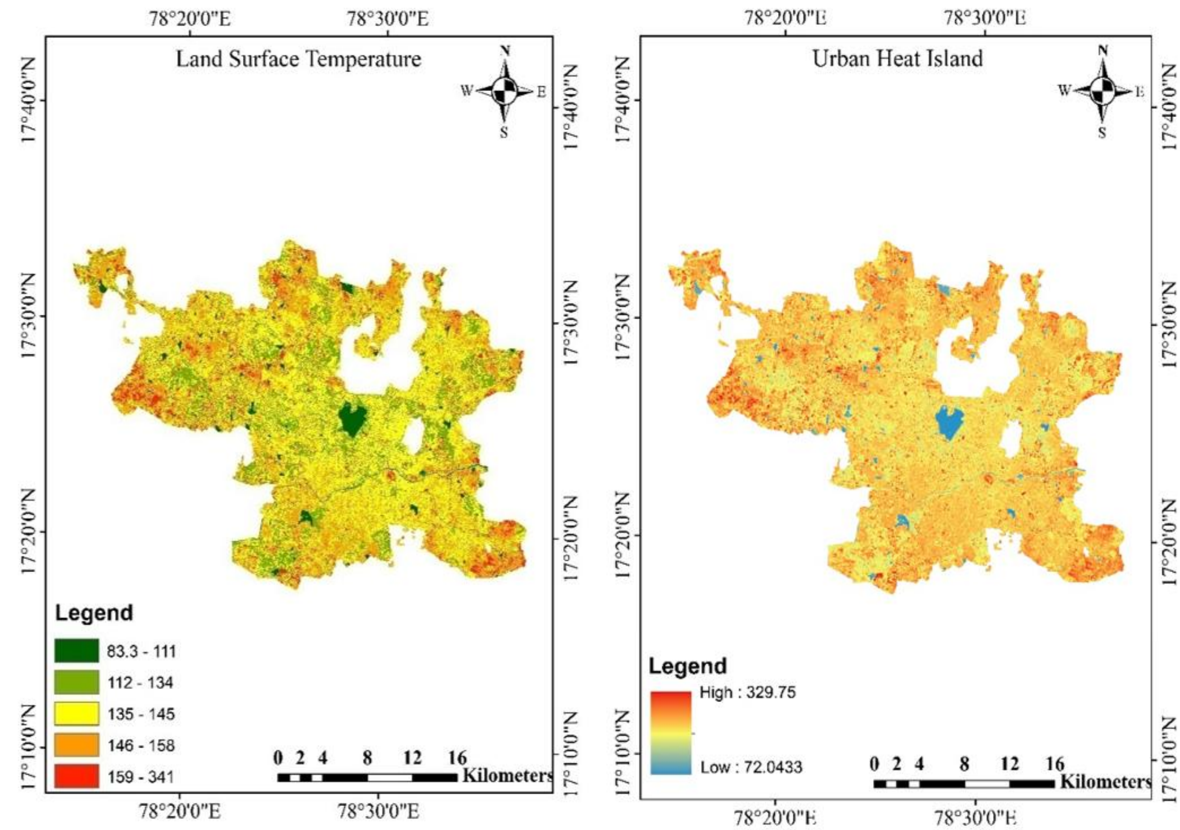


Figure 7 LST and UHI maps of the GHMC region representing the temperature and heat over the region

Future climate change mapping

Understanding the future climatic situation and its possible effects on different sectors requires an evaluation of humidity trends in the GHMC region (Mohamed et al., 2021). By considering a variety of potential socioeconomic and environmental futures, the analysis of various Shared Socioeconomic Pathways (SSPs)—SSP1 2.6, SSP2 4.5, SSP3 7.0, and SSP5 8.5 adds depth to the research. For example, the humidity trend under SSP1 2.6 increases gradually over time, reaching 1.33 by 2100. The trend in SSP2 4.5 is marginally higher, peaking at 1.49 in the same year.

A more noticeable increase is seen in SSP3 7.0, where humidity levels reach 1.75 by 2100. However, SSP5 8.5 predicts that humidity would rise the most, hitting 2.09 by 2100. Figure 9 shows the overall pattern of the humidity till 2100. These disparate patterns demonstrate how humidity is sensitive to several environmental and socioeconomic conditions (Zargari et al., 2024). To improve resilience against anticipated climatic effects in the GHMC region, it is imperative to comprehend these trends under various SSPs to influence climate adaptation plans, policy creation, and infrastructure planning (Tesfamariam et al., 2023).

To Understand and alleviate the impacts of climate change, it is crucial to evaluate temperature patterns in the GHMC region (Sahoo et al., 2022). The previous information from 1950 to 2014 reflects the steady average temperature ranging between 29 and 30 degrees Celsius. As per various SSP forecasts, the temperature will change drastically in the coming few decades. It is expected to rise gradually under SSP1 2.6, a course marked by healthy climate mitigation plans and slow population expansion. Temperatures are expected to reach about 31.77°C by 2100, showing the mild impacts of environmentally approachable methods and climate legislation.

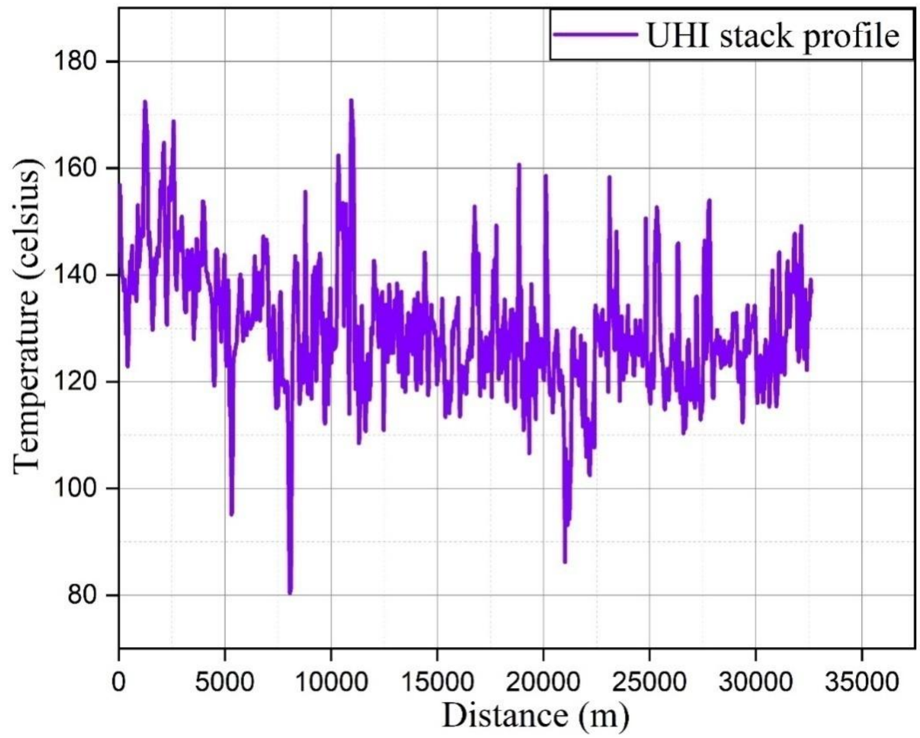


Figure 8 UHI stack profile representing the peaks of temperature vs distance

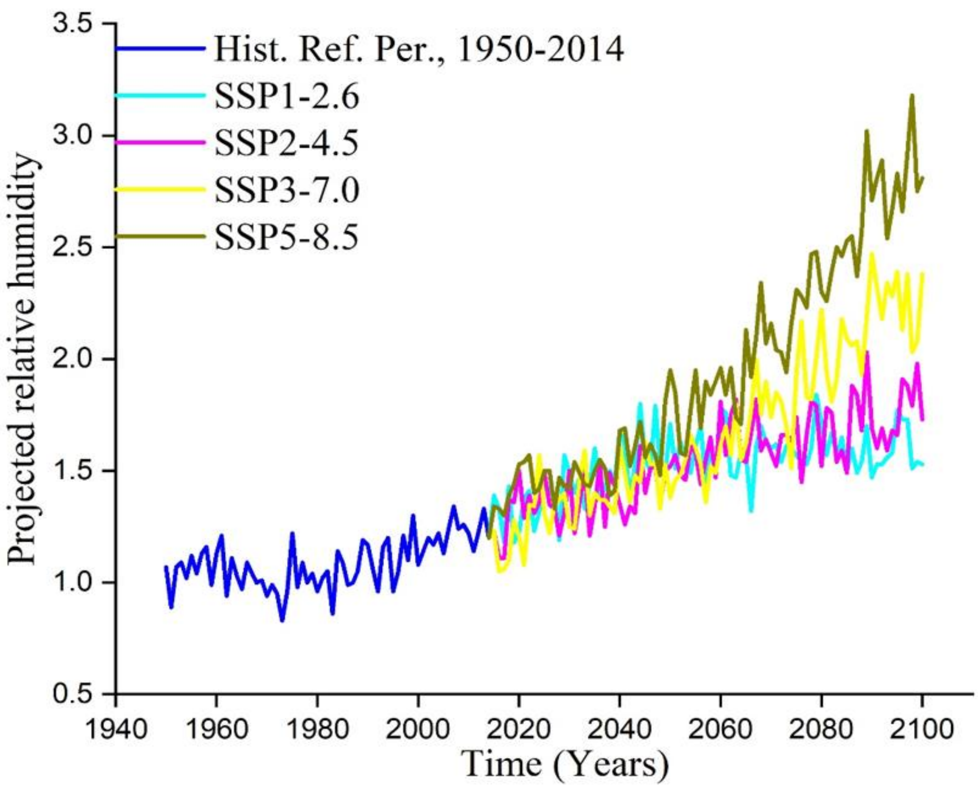


Figure 9 Trend showing the humidity of the GHMC region till the year 2100.

Moreover, SSP2 4.5 shows a significant temperature rise and reflects an outlook with significant emissions and socioeconomic development reduction. Under this course, temperatures can increase to about 33.08oC by the end of the century, highlighting the impact of both ongoing developments and climatic actions. SSP3 7.0 predicts a sharp rise in temperatures in a world with substantial emissions of greenhouse gases and lax environmental regulations. As per this course, temperatures in the GHMC region can reach 34.20oC by 2100, highlighting the need for extensive climate vindication steps. SSP5 8.5 is highly beneficial during extreme scenarios causing high emissions and drastic temperature peak variations. Under such scenarios 't' is predicted that the temperatures would reach to 34.20oC by the year 2100.

Thus, there is a pressing need to focus on decreasing emissions by implementing effective measures to mitigate the harmful effects of climate change. Figure 10 displays the trend of the GHMC's anticipated average maximum surface temperature. The intricate relationship between factors affecting socioeconomic status, governmental choices, and climate outcomes is highlighted by these temperature projections. To lessen the negative consequences of rising temperatures in metropolitan places like the GHMC region, they emphasize the significance of putting strong climate policies, environmentally friendly development practices, and strengthening resilience measures into place.

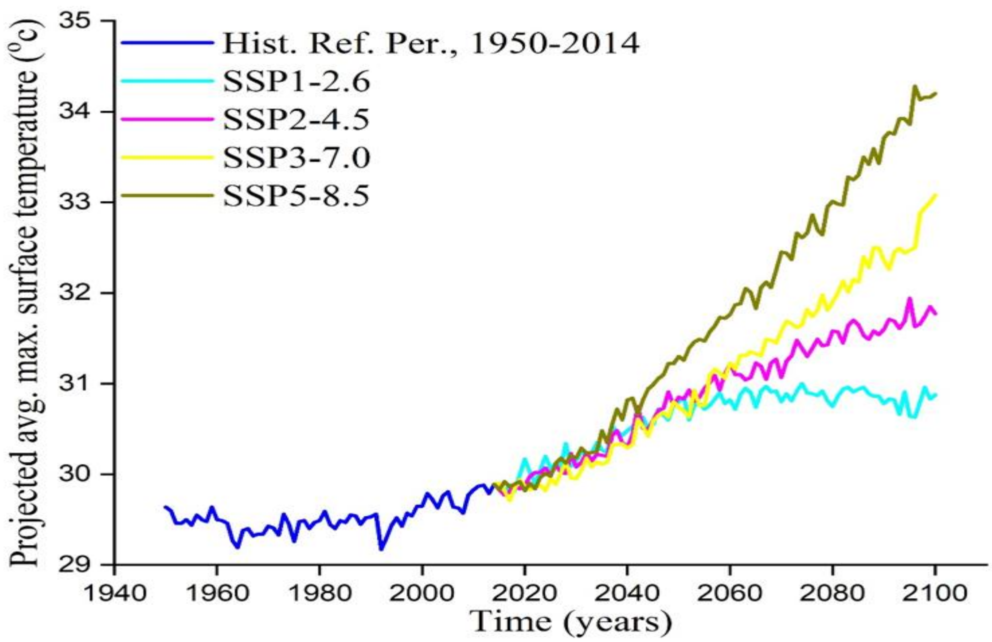


Figure 10 Estimated average maximum surface temperature pattern of the GHMC region

The precipitation data of the GHMC region under this study is highly crucial in obtaining valuable insights on the past and existing climate pattern as well as predict the future climatic variations. There have been variations throughout the region between 1950 and 2014; yearly averages ranged from approximately 1,100 mm to 1,200 mm, reflecting the decades-long fluctuations in rainfall patterns. The projections show possible changes in precipitation patterns under various SSPs. The scenarios with significant climate mitigation efforts, SSP1-1.9 and SSP1-2.6, predict comparatively constant precipitation amounts with just slight variations over the ensuing decades.

On the other hand, SSP2-4.5, SSP3-7.0, and SSP5-8.5 show more pronounced changes in precipitation and represent different levels of emissions and policy options. The levels of rainfall change slightly but most of the time stay within a modest range in SSP2-4.5, which is known for its moderate emissions decrease. Whereas SSP3-7.0 helps identify large changes in precipitation, proposing difficulties that are likely to occur while controlling water resources in a high-emission condition with few environmental regulations. Significant variation in rainfall levels is shown in SSP5-8.5, a high-emission condition with few climatic policies, underlining the urgent need for effective alternative steps.

Figure 11 shows the rainfall trends until 2100. The predictions emphasize the implications of taking preventative measures to deal with possible shifts in rainfall patterns, such as conserving water, building infrastructure, and using environmentally approachable resource management techniques. These results focus on the complicated interactions between human activity, climate changes, and the requirement of adaptive measures to assure water safety and adaptability in metropolitan settings such as the GHMC region.

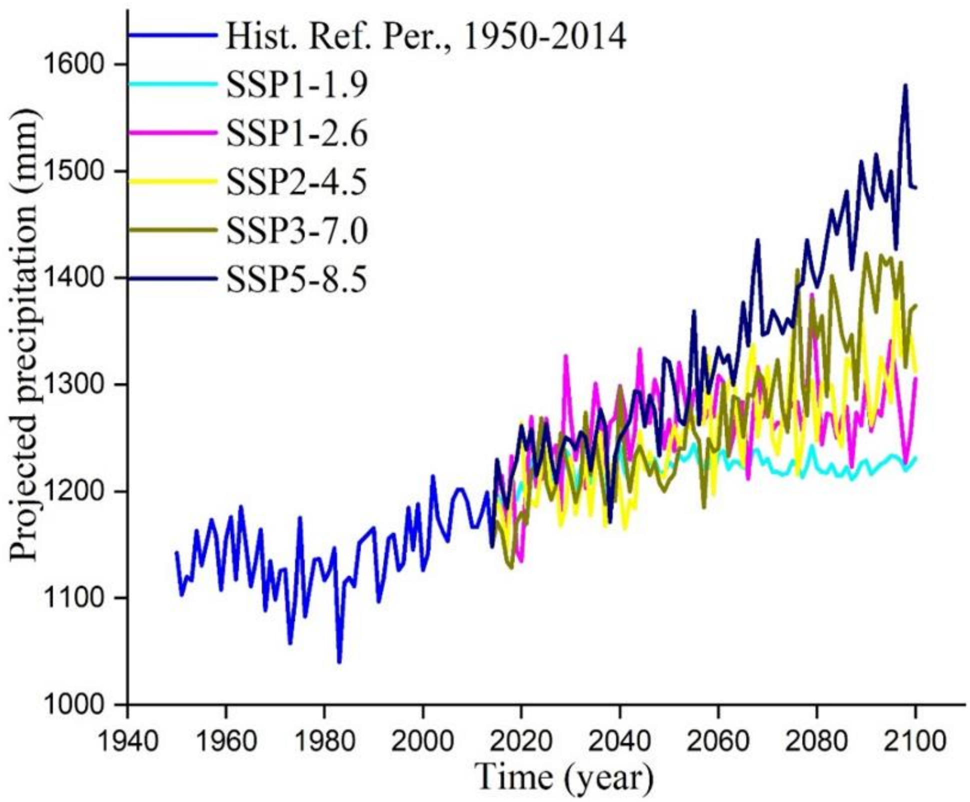


Figure 11 Trend showing the projected precipitation over the GHMC region until 2100.

4. CONCLUSIONS

The impact of UHI in the GHMC region, which is fuelled by fast urbanization and population increase, is thoroughly evaluated in this study. Comprehensive analysis, including the use of georeferencing, environmental modification, and thematic mapping of LULC, were made possible using data sources including Landsat-8 imagery from many years in addition to SRTM-DEM and IMD data. For evaluating the health of the vegetation, water bodies, built-up regions, and urbanization patterns, key indices such as the NDBI, NDVI, and NDWI were essential. For the better understanding of the temperature variations and its harmful effects on UHI it is essential to have information pertaining to locations of UHI hotspots and LST data.

In the NDVI analysis of 2021-2023 dynamic land use and vegetation changes were reported, indicating variations in the health and density of vegetation. This data has been vital for the management of natural spaces, urban infrastructure design and development, climate resilience, etc. It was further highlighted by the analysis of LST regarding the need for sustainable urban development planning using Landsat-8 thermal infrared data, which revealed temperature changes connected to land use and climate conditions. Moving on to patterns in temperature, humidity, and precipitation from 1950 to 2014, the study emphasized variations in precipitation, which ranged from 1,100 mm to 1,200 mm per year. For the management of water resources and finding adaptable solutions the different scenarios such as SSP1 2.6, SSP2 4.5, SSP3 7.0, and SSP5 8.5 with estimates for future have been very beneficial.

The variations of precipitation levels because of these scenarios indicate the intricate relationship between urbanization, climate change, and the necessity of taking preventative action to guarantee water security and resilience. In conclusion, this multidimensional analysis, incorporating NDBI, NDVI, and NDWI alongside climate data, provides critical insights for urban planners and policymakers. It supports the development of strategies to address UHI effects, promote sustainable urban development, and enhance climate resilience in the GHMC region and beyond and it is further recommended to use the latest data and apply the necessary correction for better improvement of the similar studies in another urban localities.

Limitation of the study

In this study several data sources have been used input, and some data corrections have been done before using. Despite the corrections, the following list of limitations are applicable to the present study.

The 30-meter resolution landsat-8's data may limit the detection of the small-scale features.

The 16-day revisit temporal resolution may not effectively recognize the changes effectively.

Despite applying several corrections, the minor residual, shadow and adjacent pixel might be influencing the results slightly.

Authors' Contribution

All authors contributed significantly to the conceptualization, methodology, data analysis, and manuscript preparation for the study on future climate projections and sustainable development, with a focus on urban heat islands and land use land cover in Telangana's GHMC area.

Informed consent

Not applicable.

Ethical approval

Not applicable.

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Conflict of Interest

The author declares that there are no conflicts of interests.

Data and materials availability

All data associated with this study are present in the paper.

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