Urban Heat Island and Land Use Land Cover Dynamics in Hyderabad, Telangana: A Geospatial Analysis

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ABSTRACT

Global warming has obtained more and more attention because the global mean surface temperature has increased since the late 19th century. As more than 60 of the human population lives in cities and metropolises, urbanization has become an important contributor to global warming. Hyderabad is one of the regions experiencing rapid urbanization that has redounded remarkably. The Urban Heat Island (UHI) effect will undoubtedly have an impact on the local climate, environment, and socio-economic development. Land-use/land-cover changes are the most vulnerable factor in any developing urban environment. The pattern of land use in a particular area or region keeps changing continuously because of its connection with multitudinous factors, for example, natural and human-made processes. Land-use/land-cover change may affect the environment and also impact bare land use. Increased structure and population density tend to alter the land features, which will have an impact on the thermal terrain and increase the impermeable layer. This investigation has taken the initiative to conduct research in the Hyderabad Metropolitan Area (HDMA). Hyderabad is the fifth largest metro city in India and one of the rapidly urbanizing areas of South Asia and the capital of Telangana. Results show that the UHI effect has become more prominent in areas of rapid urbanization in the city. The spatial distribution of heat islands has changed from a mixed pattern, where bare land, semi-bare land, and land under development were warmer than other surface types, to increase UHI. The analysis showed that the advanced temperatures in the UHI were located in a scattered pattern, which was related to certain land-cover types. This study uses a quantitative approach to look at the relationship between temperature and a number of indicators, such as the Normal Difference Vegetation Index (NDVI), in order to figure out how UHI affects changes in land cover.

Keywords: Land use Land cover, Land Surface Temperature, Urban Heat Island and NDVI.

Objectives of the study:

1. To study the dynamics of land use land cover over Hyderabad and its surrounding areas.

2. To study the seasonal variation in Urban heat island intensity (UHII) over Hyderabad.

3. To study the relationship between LST (Land Surface Temperature) and LULC over Hyderabad and its surrounding areas.

Research Gap:

The present study work is focused on three aspects. The first aspect is how effectively the geospatial data can be utilized for land use / land cover mapping for urban sprawl analysis and its dynamics. The second focus of the present study is on seasonal variation in Urban heat island intensity (UHI) over Hyderabad. how effectively the geospatial data can be utilised for extracting the LST and UHI., the third focus was on study the relationship between LST (Land Surface Temperature) and LULC over Hyderabad and its surrounding areas. The study outline in the Introduction section, followed by the importance of land use / land cover map and its preparation. The land use, land cover, LST, UHI were then introduced and their impacts were discussed., In these studies on seasonal variation in urban heat island analysis, LST, and NDVI were thoroughly reviewed. Materials and methods, details about the study area, data collection and methodology were presented in detail. Most of the reported studies have just compared the areal extent of different land use / land cover across the years to infer about the urban growth. In-depth urban sprawl analysis like transition analysis (contribution of each land use / land cover to the development of other land use / land covers), zone-wise density analysis,conclusion of the present study work was given followed by the references and list of publications.

INTRODUCTION

The main causes of a rise in air temperature or an urban heat island include the urban structure of a city, which incorporates land use planning, building morphology, surface characteristics, and anthropogenic heat from automobiles and equipment like air conditioners. They have the effect of increasing both air pollution and the energy required by buildings to employ refrigeration to maintain a comfortable inside temperature. This ultimately has a severe impact on people of emerging cities' health and causes an increase in greenhouse gas emissions.

Urban regions are quite diverse in their makeup as microclimatic zones. Urban environments are a modified version of the natural world. Many environmental activities have changed the metropolitan environment. The climate in big urban regions, such as metropolises and megacities, differs dramatically from that in rural settings, which are distinguished by soil and vegetation cover. One of India's urban areas with the fastest growth is Greater Hyderabad. Greater Hyderabad is rapidly urbanizing, which is causing urban sprawl and core city densification to expand. The surrounding surroundings have experienced radical change as a result of changes in land use and land cover. Built-up regions with impermeable surfaces have an impact on Hyderabad's urban landscapes.

Urban heat islands (UHI) are created and occur as a result of rapid urbanization and related concretization. Urban locations expose people to unanticipated health concerns because of the intensifying heat and high pollution levels. In this perspective, the study seeks to provide a comparison between the UHI in rural and urban Hyderabad. Using the Landsat 5 TM image from May 2020, the existence of surface UHI is examined. The heat island is verified using the Normalized Difference Vegetation Index (NDVI) patterns. The study shows that whereas vegetation-covered areas and bodies of water have cooler temperatures, built-up and fallow lands record higher temperatures. Hyderabad, a city in the interior, boasts a mix of land uses, large tree cover, and long highways; the forests and rivers that run through Hyderabad have a significant impact on regulating the city surface temperatures. In the East, the temperature peaks at 34℃, while in the West, it dips to 24°C. With the exception of the border areas, the highest temperature in west Hyderabad is 31℃. Hyderabad's Northeast and Central regions have cold temperatures (28℃ to 31℃), but the suburbs experience hot temperatures (36℃ to 37°C). Where heat is trapped, or in built-up areas, the UHI is much stronger, whereas Jubilee Hills, Narayanaguda, and Nagole have high temperatures between 40 and 41 degrees Celsius. Nearly 39 ℃ to 40 ℃ are the temperatures in the southern part of the Hyderabad city. Due to the Sanjeevaiah park & variable greenery density, the temperature fluctuates between 30 and 31 degrees Celsius. The lowest temperatures are recorded by Osman Sagar Lake, Hussain Sagar Lake, and other bodies of water (26 °C to 28 °C). Due to the low percentage of green and vegetated regions in Hyderabad, there is a substantial negative association between NDVI and UHI.

METHODOLOGY

In order to analyze the spatio-temporal UHI effect over Hyderabad city, the LANDSAT-7 TM data was processed with layer stacking, and the LST and other relevant parameters including NDVI and LULC were extracted. The DN values of the imageries were transformed into Radiance values in order to calculate the LST values. We used ENVI software to convert the Geo-TIFF format data we already had into radiance data. The data was further corrected for the effects of the atmosphere using local values for meteorological variables. For LANDSAT data, the USGS has a webpage with figures for transmittance, upwelling radiation, and down welling radiation. Equations for Landsat-7. NDVI is calculated as follows: (TM4 - TM3)/(TM4 + TM3) • (NDVIOutput + 1)/(1 + 1) 2Emissivity equals 0.004 times passive vegetation plus 0.986. Radiance is

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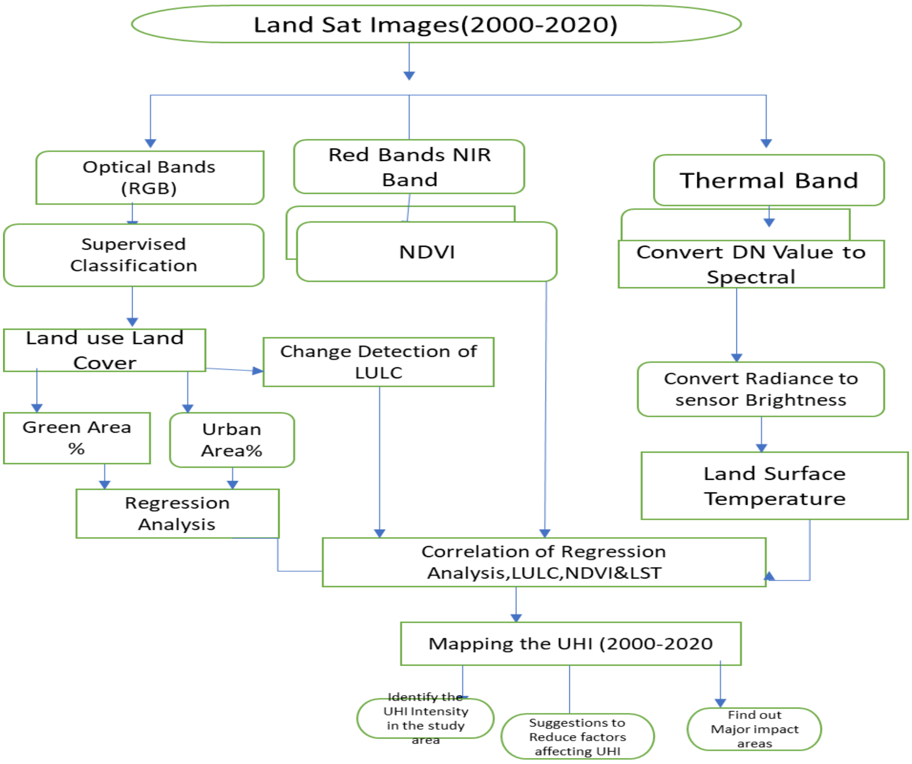
calculated as follows: (Lmax - Lmin)*Qcal - Qcalmin) + Lmin Qcalmax - Qcalmin.

• The formula for calculating land surface temperature (LST) is T= K2/(ln[(K1)/L) + 1)-273, where K1 = 607.76 and K2 = 1260.56. As depicted in Flowchart 1, the analysis was conducted systematically throughout the study area. Landsat imagery spanning from 2000 to 2020 was employed to generate maps of LULC, LST, and NDVI. The relationship between the percentage of urban area and LST, as well as the relationship between green area and LST, were examined through regression analysis. Subsequently, UHI intensity values were calculated based on LST. Finally, the study identified UHI occurrences in the study area and explained the major impacts associated with these areas.



Flow chart of methodology

Study area:

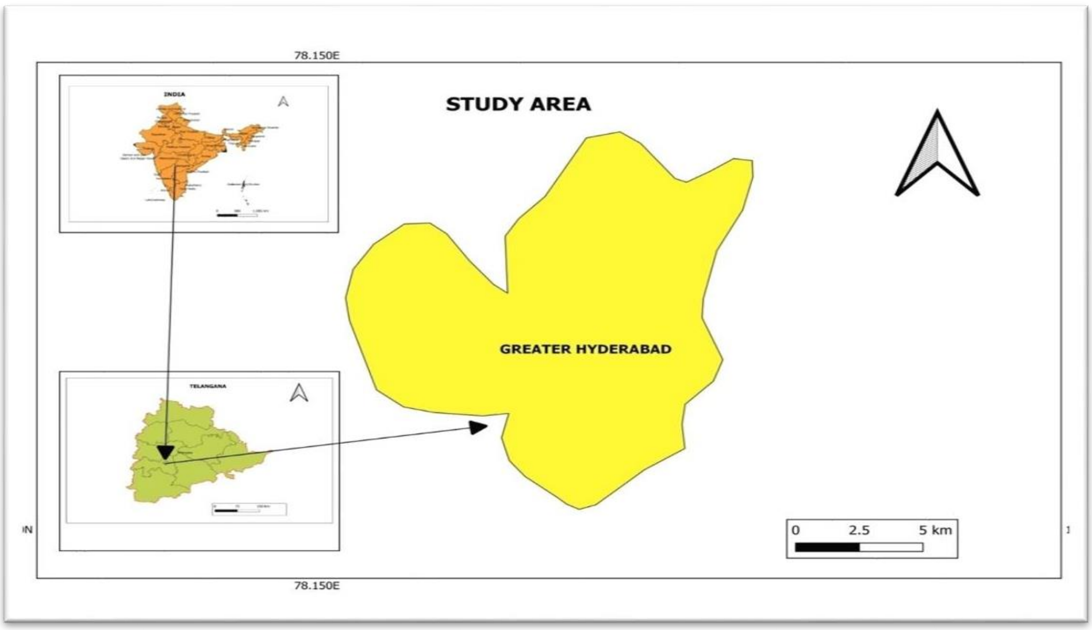


Figure:1. Study Area

The study focuses on the Hyderabad, situated in the South-central India, as shown in Fig. 1. The city is located at approximately 17°.36& N and 78°.47 W. Hyderabad features varying elevations. It occupies 650 km (250 sq. mi) on the Deccan Plateau along the banks of the Musi River, in the northern part of Southern India. Specific elevations vary by location within the city. As per 2024 data, the estimated population of Hyderabad city was around 11,068,900. It is important to note that the population figures are subject to change over time, so referring to the most up-to date data is available. The city experiences a tropical climate characterized by warm temperatures year-round, though temperature values may vary depending on the season and specific locations within the city.

Data collection:

To examine the UHI influence spatially and temporally in Hyderabad City, LANDSAT-7 TM data was processed using layer stacking, extracting LST and other significant metrics, including NDVI and LULC. The DN values of the images were converted into Radiance values to compute the LST values. We utilized ENVI software to transform the existing GeoTIFF format data into radiance data. The data was subsequently adjusted for atmospheric influences utilizing local meteorological variable values. The USGS maintains a webpage for LANDSAT data that includes numbers for transmittance, upwelling radiation, and downwelling radiation.

Land surface temperature:

We analysed the patterns of Land Surface Temperature (LST) in Hyderabad and compared them to the patterns of Normalized Difference Vegetation Index (NDVI) and Land Use/Land Cover (LULC), which indicate plant health. Recent advancements in the area have rendered the utilization of remote sensing data more prevalent for examining the impacts of variations in Land Surface Temperature (LST) and Normalized Difference Vegetation Index (NDVI) on public health and the urban environment. LST, near-infrared, and red (R) wavelengths have been extracted from the sixth thermal band of a Landsat Thematic Mapper 5 (TM) satellite image to assess plant health and gather associated data. Landsat satellite pictures were acquired from the United States Geological Survey (USGS) website. The photos of Hyderabad were captured on 18 April 2021 and 6 May 2021, respectively (Table 1). In our previous research, we utilized the Landsat image of Hyderabad, which distinctly linked land use change, land surface temperature, and NDVI. This study examines the two major cities in India, focusing on the patterns of Urban Heat Island (UHI), Normalized Difference Vegetation Index (NDVI), and Land Surface Temperature (LST) in relation to varying physiographic and meteorological conditions. They are situated in distinct geographic regions within a perpetually developing metropolis; hence, the UHI study produces intriguing outcomes.

Table:1

Satellite	Sensor	Acquisition Date	Spatial Resolution	Cloud cover
Land sat 5	TM	18 April 2021	120m	1%
Land sat 5	TM	21 MAY 2021	120m	0%

Source: Satellite Data

Urban Heat Islands:

Remote sensing and GIS are acknowledged as extremely efficient and adaptive instruments in urban climate research and decision-making assistance. They are essential for evaluating, especially in the research of the UHI phenomena in urban environments. Urban Heat Island (UHI) can be measured with Land Surface Temperature (LST) maps by analyzing temperature disparities between urban and non-urban areas. Metropolitan Heat Island (UHI) is a phenomenon where metropolitan regions exhibit elevated temperatures compared to adjacent rural or non-urban areas

Regression Analysis:

The regression analysis of LST and LULC maps indicates a troubling trend marked by decreasing green spaces and increasing urbanization. The concurrent rise in LST values indicates the existence of Urban Heat Island effects in particular regions. In 2000, the UHI effect in Hyderabad was somewhat restricted, with only the city core exhibiting noticeable patterns. In 2020, the UHI effect has markedly intensified. The UHI effect significantly influenced a broader region within the city centre and the expansion of Hyderabad. The proliferation of UHI in 2020 signified a substantial growth of urban regions and their corresponding heat island effects throughout Hyderabad. Figure 9 illustrates the most extensive Urban Heat Island (UHI) phenomenon recorded during the past twenty years.

RESULTS AND FINDINGS

Change Detection of Land Use and Land Cover:

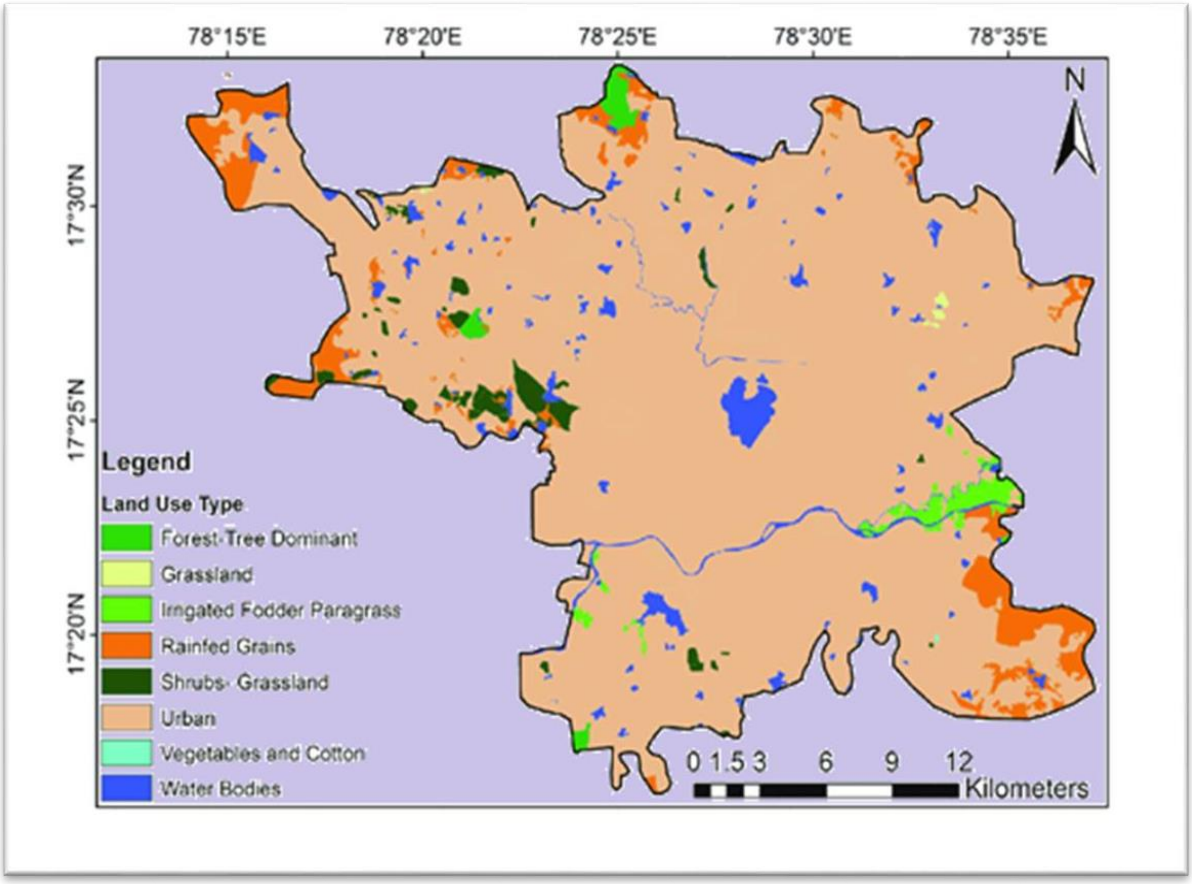


Figure:2 Base map of Land use:

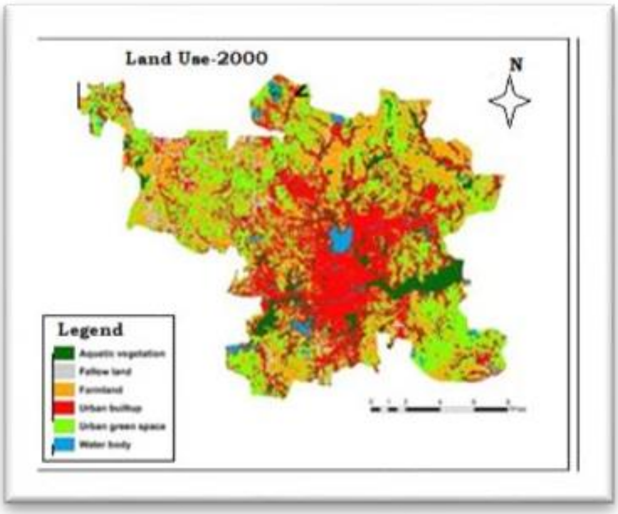


Figure:3 Land use 2000

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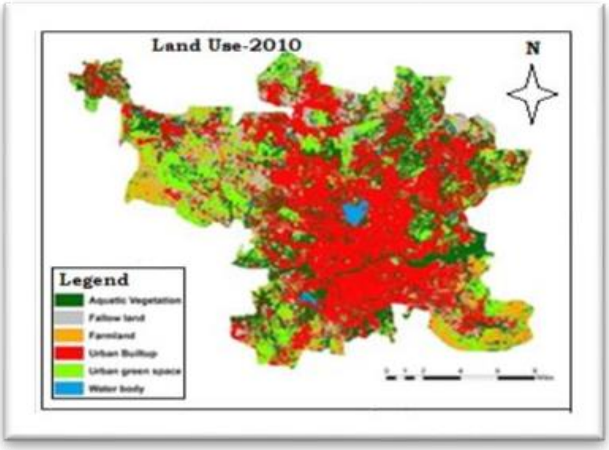

Figure:4 Land use 2010

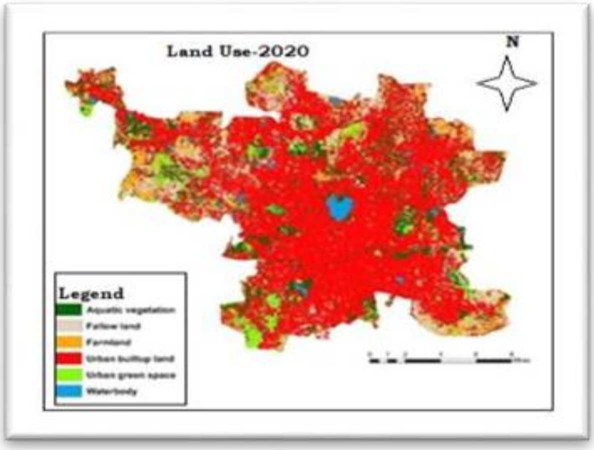

Figure:5 Land use 2020

The several LU/LC classes that were identified for the study area, along with their ground characteristics and image expressions in the FCC images of the various seasons, are shown. Major and minor cities, rivers, tanks, canals, main roads, minor roads, a railroad line and other features are shown on the base map. The information is gathered from survey of India toposheets, and it is updated using satellite information. (Fig-2. Figures 3 and 4 depict the area land use and land cover in 2000 and 2010, while figures 3, 4 and 5 depicts the area land use pattern in 2000,2010 and 2020, comparing land use in 2000,2010 and 2020 is shown in Figure. The process involves combining and correlating outdoor observations with calculated LU/LC classes from satellites.

Table:2

Residential	13.65	21.22	7.57
Industrial	3.3	4.69	1.39
Agriculture Land	191.25	85.5	-105.75
Plantation	0.61	5.62	5.01
Fallow Land	0.3	48.08	47.78
Land with without scrub	76.43	71.89	4.54
Barren Rocky	52.57	75.85	23.28
Forest	31.93	31.93	0
Research Institute	11.04	11.04	0
Water Bodies	24.18	20.34	3.84
Stone Quarry	2.72	5.35	2.63
Airport	0	11.14	11.14
Open plots for Residential areas	0	15.33	15.33
Total Area	407.98	407.98	

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The study involved the utilization of Landsat 7 and 5 satellite images to perform LULC classification. To study the classifier, representative training samples were collected, encompassing various land cover classes present in the study area. These samples were meticulously selected to accurately represent each class of interest. Ground truth data and existing land cover maps were utilized to guide the sample collection process. The LULC maps were created to determine the change in Land Cover in each decade from 2000-2020 and the relevant maps are shown in Fig. 5. The land cover classes identified included urban areas, vegetation lands and water bodies. The year 2000 depicts a significant expanse of green areas, indicating the presence of abundant vegetation cover. The landscape consists of primarily vegetation, grasslands, and agricultural fields. Urban areas are relatively limited, with minimal human settlement and infrastructure encroachment. As seen in the LULC map in 2020, there is a visible decrease in green areas compared to 2000, suggesting the conversion of natural vegetation to other land uses. The expansion of agricultural land, urbanization, and the establishment of human settlements becomes more apparent. The increasing presence of built-up areas signifies the encroachment of human activities into previously vegetated regions. The 2020 LULC map reveals a clear trend of increasing urban areas and decreasing green areas. The expansion of urbanization, primarily influenced by main roads, railway lines, and highways, is the main factor behind this change. In the 2020 LULC map, notable changes are observed compared to previous years, with a significant increase in urban areas and a corresponding decrease in green areas. The extent of each land cover class was quantified for each time period studied, as presented in Table 2, showcasing the LULC area in square kilometres for each year. This study has developed a comprehensive LULC database for three time periods. Changes Occurred in Hyderabad during 2000–2020. As per the observation and analysis from the data collected from the year 2000 to 2020, we observe that there is a change much seen in the built-up area in Hyderabad of 13.65 sq. km. of area, specifically an open space to built-up change seen mostly in 7.57 sq. km.

Changes of LST Pattern:

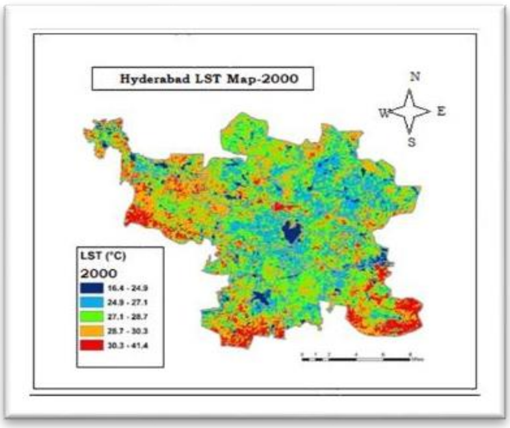

Figure:6 LST 2000

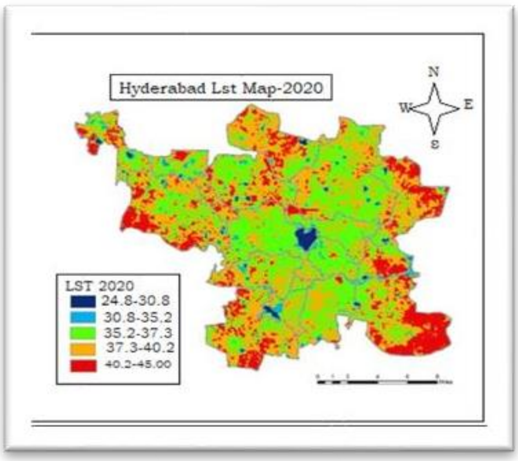

Figure:7 LST 2010

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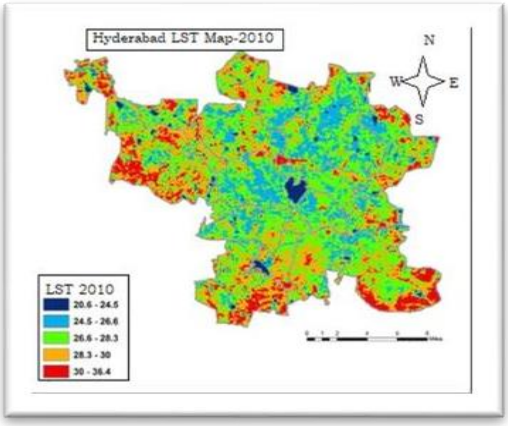

Figure:8 LST 2020

Land Surface Temperature on hot days decreasing over time:

In Hyderabad, the LST on April 6, 2020, was 32.5°C on average. From April 5, 2016, the average LST has decreased by 3°C. In addition, April 6, 2020's daily average air temperature was 3.9°C colder than April 5, 2016's. At Begumpet, the main meteorological station for the city, the daily average air temperature was lower than the LST. It was previously a little lower in 2000, 2010, and 2020. Figure 8: The maximum number of hotspots with LST over 40°C was detected on April 27, 2020, followed by April 5, 2010, according to hotspots found over Hyderabad on hot days in 2000, 2010, and 2020. The fewest hotspots have been observed this year. Turkayamjal, Nadergul,and the Rajiv Gandhi International Airport are further locations in the city with consistently high LST. The hotspot places have been observed to be in Turkayamjal, Nadergul, and Rajiv Gandhi International Airport in the southwest, which are both heavily populated and degraded areas. A few hotspots are located in the northeastern part of the city, including JawaharNagar and the Bollaram Industrial District. Locations with the lowest LST, or "cold spots have been identified beside water bodies like Hussan Sagar Lake.

Urban Heat Islands:

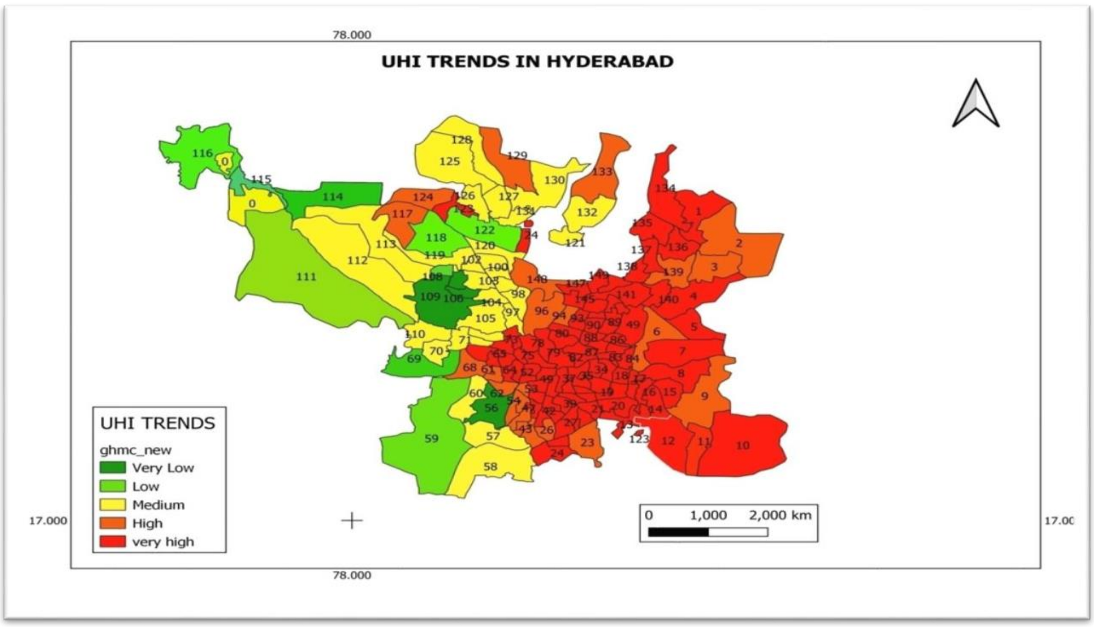

Figure:9 UHI Trends in Hyderabad:

The average temperatures recorded at several places were compared in order to investigate the possibility of UHI, as shown in Figure 9. Low-density areas with dense vegetation experience less temperature compared to high-density areas with less or nil vegetation.

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Low UHI Risk Potentials Zone: 30 percent of the total area of Hyderabad falls under the low-risk zone. Most of the peripheral Hyderabad falls under this category (Golconda, Shivarampally, Chandrayangutta, Rajendranagar). This symbolizes the prevalence of fewer traffic intersections in these regions, accompanied by more open spaces in comparison with the other zones. The presence of more water bodies in these regions ultimately helps in the re-radiation of the trapped heat. The zone also comes under the low-income housing group, where people use fewer appliances for heating the houses and possibly low-quality housing materials for the construction of their houses.

Moderate UHI Risk Potential Zone: This zone covers 35 percent of the city's areal extent. Places surrounding the heart of the city fall under this category (Kukatpally, Yusufguda, Medhipatnam, Chandanagar, Shamshabad, Medchal, Alwal, and Malkajgiri). Here lies the highest number of traffic intersections. The zone is devoid of open spaces, and the housing patterns are very congested, which aggravates the formation of such heat islands.

High UHI Risk Potential Zone: This zone covers 35 percent of the city, mainly located in the heart of the city. Main industrial outlets, main traffic jam zones, and the lowest vegetative cover make the zone face the maximum possible negative consequences of the heat island formation. Further, the urban lifestyle, style of buildings, and livelihood pattern result in high-risk zone formation. South Eastern side and North Eastern side and some city center places of the city, such as (Moosapet, Kairathbad, Goshamahal, Gajularamaram kapra, Keesara, L.B.Nagar, Panjagutta, Banjarahills, Sanathnagar, Patancheruvu, Ameerpet, Mondamarket, Malakpet, Amberpet, Begumpet).

Changes of vegetation cover:

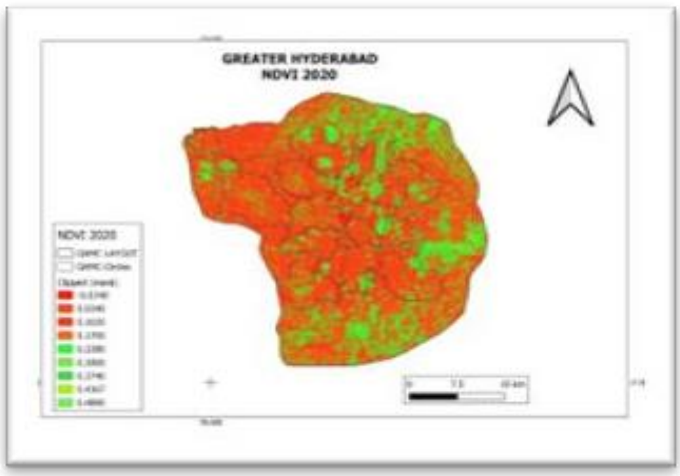

Figure:9 NDVI 2010

Figure:10 NDVI 2015

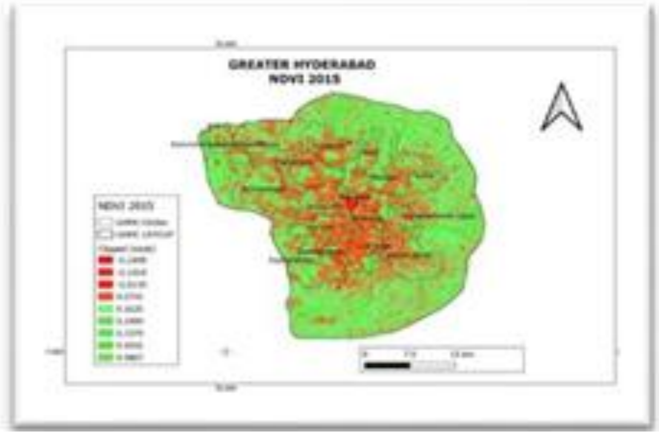

Figure:9 NDVI 2020

A spatial-temporal examination of the NDVI estimated for the city of Hyderabad: To understand the spatiotemporal changes in LST and the UHI effect, it is required to do NDVI research on the NDVI parameter. You can ascertain how much vegetation is there on a specific piece of land by looking at the different colors (wavelengths) of visible and near-infrared sunlight reflected by the plants. Less and less land was covered by plants between 2010 and 2020, as may be shown in the case of land use.

Results: The NDVI parameter value gradually reduced from 0.24, 0.26, and 0.25 in 2010, 2015, and 2020. Areas in the southwestern and east-northeastern parts of Hyderabad displayed higher NDVI values of roughly 0.4 to 1 when the city's spatial evaluation was conducted. The eastern and southern regions, which had significant industry, had very low NDVI values in comparison to the central sections, which had dense metropolitan centres. Hyderabad is an inland city with a variety of land uses and a substantial amount of vegetation cover. The city's surface temperatures are significantly influenced by the forests and rivers that pass through it. The East experiences a maximum temperature of 34°C, while the West experiences a minimum of 24°C. With the exception of the border areas, the highest temperature in west Hyderabad is 31°C. Hyderabad's North and Central regions experience cold temperatures (28°C to 31°C), while the surrounding areas get hot temperatures (36°C to 37°C).

In the instance of Hyderabad, the UHI is not very notable. This is seen by the connections between surface temperature and NDVI. The park is surrounded by intensive horizontal and vertical building expansion due to high NDVI in the central and western Hyderabad districts near the rivers Osman Sagar and Hussain Sagar. Where heat is trapped, or in built-up areas, the UHI is much stronger. The previous few decades have seen a significant increase in urban heat islands. Built-up areas are the main cause of urban heat islands. Different land uses and cover have an impact on or a mitigating effect on the urban heat island effect. Changing the physical and chemical properties of the atmosphere and the land surface is the main way that urbanization harms the environment in cities. Urban heat islands are caused by the interaction of many of these factors. Urbanization is the most important and obvious anthropogenic activity that influences both air and land surface temperatures. The air and surface temperatures in urban environments differ significantly from those in non-urban settings. Warmer air temperature compared to surrounding areas' colder air temperature is the primary sign of an urban heat island.

CONCLUSION

Surface temperature was shown to be significantly impacted by Hyderabad's urban growth pattern, and the hotspots' spread correlated with the level of urban build-up during the previous two decades. When compared to soft surfaces like the green cover and dense vegetated regions, hard surfaces like buildings, highways, parking lots, etc., considerably raised surface temperatures.

The heat distribution pattern and land use/Land Cover categories significantly correlated, according to the UHI profile in Hyderabad. The study discovered that surface temperatures varied during the day in descending order from industrial, commercial, transport hubs, residential, and open places. The dense urban built-up is responsible for the industrial zones on Hyderabad's outskirts. Due to the prevalence of vegetation within the household plots of the residential properties, Hyderabad's residential sections were generally more comfortable than the city's commercial ones. Due to the natural ground cover's moisture availability, the open areas had the lowest surface temperatures.

But at night, the air temperatures changed in descending order between commercial, residential, transport hubs, industrial, and open areas. The nocturnal air temperatures in Hyderabad were shown to significantly correlate with the roadway geometry in metropolitan regions. In opposed to shallow canyons of the transportation nodes and industrial sectors, the narrow urban canyons of Hyderabad's commercial and residential sections had greater ambient air temperatures at night. In Hyderabad, it was discovered that the different land use and land cover types had an impact on the heat distribution pattern. This emphasis's the necessity of improving the comfort levels through sensible planning.

The results reveal a dramatic expansion of the built-up class in the Hyderabad city at the expense of cultivated land, leading to significant changes in the study area. The analysis of the UHI indicates a growing influence of urbanization on local temperatures. UHI effects, which were initially confined to urban centres such as Kukatpally, Yusufguda, Medhipatnam, and Chandanagar. UHI effects, which were initially confined to urban centres such as Shamshabad, Medchal, Alwal, and Malkajgiri in 2000, gradually spread to other divisions, including Kukatpally, Yusufguda, and Medhipatnam, by 2020. Moreover, the UHI threshold values have increased over time, indicating a substantial rise in urban temperatures. These findings clearly demonstrate that the Hyderabad city has undergone significant environmental changes, characterized by rising temperatures, reduced vegetation density, and the expansion of urban areas. This underscores the pressing need for sustainable land management practices and effective urban planning strategies. Preserving green areas, promoting afforestation, and implementing measures to mitigate UHI effects are crucial steps toward maintaining a balanced and healthy environment within the city. The study investigated numerous components of Hyderabad, including LULC change, LST, and the urban heat-health nexus, as well as its mitigation. The following are the primary conclusions of the study based on the results and outcome: The study on LULC change over the course of the last 20 years in IMD reveals a significant reduction in vegetated and agricultural regions, along with a considerable increase in built-up areas. This spatio-temporal study highlights the alarming trend of land use transformation in Hyderabad, indicating the shrinking of green cover and the rapid expansion of urbanization.

The primary data collected from the community-based perception study affirms the accuracy of satellite-derived LULC findings. Additionally, the respondents identified infrastructure development and settlement expansion as the main adjacent causes of LULC change, with a lavish mindset of people and population growth as the key underlying factors driving these changes. This suggests that the local community's perceptions align with the empirical evidence derived from the satellite data and highlights the human factors driving land use change in the study area. The spatial and temporal analysis of spectral indices indicated a significant decline in the intensity of NDVI. These findings suggest a widespread reduction in vegetation and a rise in impermeable surfaces, such as buildings and roads. This could be attributed to the rapid urbanization and expansion of the city, which has led to a decline in green cover and an increase in impervious surfaces. The microclimatic conditions in Hyderabad are progressively declining, with urbanized areas witnessing raised temperatures, increased levels of discomfort, and intensified solar radiation. Moreover, the extent of the UHI phenomenon has been expanding over the last twenty years.

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