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Leveraging GIS and Green Building Materials to Mitigate Urban Heat Waves and Advance SDGs

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Abstract:*Urban heatwaves are becoming increasingly challenging due to changes in environmental conditions. These in turn affect public health, energy use, and urban lifestyle. Remote sensing and GIS are robust in monitoring urban heat waves and analyzing their intensity, frequency, and distribution. The present study analyses the effect of urbanization on variations in temperature in Hyderabad and Warangal cities of Telangana, India, during the past 20 years/ two decades. We examined temperature anomalies from 2001 to 2023 compared to the baseline period of 1981 and 2000 using GIS tools and manually gathered data. According to our data, Hyderabad and Warangal witnessed higher daytime temperature anomalies of 0.35°C and 0.30°C, respectively, while nighttime anomalies increased by 0.40°C and 0.35°C. In addition, there were five additional 90th percentile heat days in Warangal and four more in Hyderabad, indicating an increase in severe heat waves. According to land-use and land-cover research, urban areas in Hyderabad and Warangal increased by 13 and 11 times, correspondingly, between 2000 and 2020. These results emphasize the necessity of sustainable urban development to lessen the impact of UHI and future environmental impacts. By reducing the consequences of UHI and creating sustainable environments in cities, encouraging green construction may prove crucial to reaching the Sustainable Development Goals (SDGs).*

Keywords: *Telangana, urbanization, Remote sensing and GIS, Temperature anomalies, and urban heat islands*

I. INTRODUCTION

Urbanization, one of the main causes of climate change, dramatically changes local weather patterns, including urban heat islands (UHIs). As cities expand and built environments take the place of natural surroundings, the thermal properties of towns and cities shift. This often leads to higher surface temperatures, particularly at night. According to research, the temperature rise effect is brought about by modifications to urban elements and land cover, and both of them retain heat. There is plenty of evidence of this phenomenon. The environmental conditions of India's coastline and urban centers have been greatly affected by the country's rapid urbanization rate. Significant temperature increases in major metropolitan areas like Delhi and Mumbai have been attributed by research to urbanization. Similarly, an analysis of Chennai's climate showed that heat waves had been rendered severe by developing temperature irregularities. The Indian Meteorological Department adds credibility to these findings, pointing to the fact that extreme temperature events have risen substantially across the country's cities as a result of climate change and urbanization. Telangana's diversified environment and fast development make it an ideal place to study the HIE and also demonstrate the techniques for its mitigation. Cities like Warangal and Hyderabad have undergone extraordinary urban expansion, which has altered local climates. Increased consumption of energy, a decline in vegetation, and a spike in impermeable surfaces are the main causes of increasing temperatures in these metropolitan environments. According to data from the Central Pollution Control Board (CPCB, 2021), Hyderabad's annual mean temperature has risen dramatically during the previous 20 years, and this increase is directly linked to the urbanization of the city. According to most recent research, Hyderabad's urban sprawl increased by about 12 times between 2000 and 2020, affecting both daytime and evening temperatures. Additionally, Sharma et al., (2023) highlight how heatwaves disproportionately affect urbanized areas, leading to more frequent and prolonged extreme temperature events. This study examines the relationship between urbanization and heatwaves in Telangana's largest urban areas, with a focus on Hyderabad and Warangal. Using meteorological data and GIS maps, this study attempts to quantify how urbanization affects temperature deviations, particularly during pre-monsoon seasons. By reducing the consequences of UHI and promoting adaptable urban ecosystems, the construction of green buildings is essential to reaching the Sustainable Development Goals (SDGs). Energy-efficient designs and the incorporation of green spaces are the two kinds of sustainable architectural practices that can lower heat stress, enhance air quality, and guarantee long-term urban sustainability.

The impact of urbanization, particularly the urban heat island (UHI) effect, on regional climates has been the subject of multiple studies due to the worldwide increase in urbanization. Constructing artificial settings out of natural landscapes is being shown to alter their thermal characteristics, increasing temperatures, especially at night [1,2]. These findings lay the groundwork for understanding how urbanization and temperature rise are related. In India, research has focused on rapidly expanding metropolitan areas. Significant temperature increases in Delhi and Mumbai have been noted and urbanization was linked to these findings. [3]. Similarly, Chennai experiences more heatwaves as a result of increasing temperature variations, based on another study on the urbanization of the city [4]. According to the Indian Meteorological Department [5], urbanization and climate change have both been contributing to an upward trend in severe temperature events in India. Numerous studies have looked at how Telangana's urbanization affects the state's temperature. During 2000 and 2020, Hyderabad's urban growth grew by a dozen [6], resulting in a notable increase in daytime and nighttime temperatures. Additionally, studies examined Hyderabad's energy use and the role of impermeable surfaces in the urban heat island effects of the metropolis [7]. The disproportionate impact of heatwaves upon metropolitan areas has been highlighted by additional studies in 2023, which noted that these events happen more frequently and for a longer duration of time [8]. Global study on changes in the use of land and land cover (LULC) has also looked at how urbanization impacts regional temperatures and further thorough analysis of urban heat islands around the world lead to understanding of severity of UHI in different cities [9]. Similarly, satellite data suggested that urban heat islands (UHIs) are more extreme in urban areas which have been formed, with urbanization having the most effect on nighttime temperatures [10].

Spatial insights into temperature anomalies and the impacts of UHI were obtained via complimentary studies utilizing Geographic Information System (GIS) maps. For instance, a GIS-based examination of Delhi's temperature fluctuations showed that urbanization significantly exacerbated nighttime becoming warmer, which falls in line with the UHI phenomena [11]. Comparably, Geographic Information Systems (GIS) mapping in Bengaluru showed that, mostly as a result of urban sprawl and reduced plant cover, urban regions have much greater surface temperatures than nearby rural areas [12]. Additionally, research indicates that urbanization affects soil temperatures, with urban areas showing higher daytime soil temperatures than those in rural areas [13]. The geographic location of plants and impermeable terrain were additionally examined using GIS maps, providing information on how urban expansion influences the production of UHI. Furthermore, studies by Verma et al. [14] emphasized the feedback loop between urbanization and energy demand by demonstrating a significant connection between developing metropolitan temperatures and higher energy use by cooling systems. It has been acknowledged that promoting green building is an essential tactic for mitigating UHI. Urban microclimates are enhanced and heat absorption is reduced by green buildings with energy-efficient designs, reflecting surfaces, and roof-top greenery. To combat heat island effects, studies that incorporate GIS methods with planning frameworks emphasize the significance of expanding urban green spaces such as parks and green roofs. By improving urban resilience, reducing energy consumption, and creating sustainable habitats, the use of green building techniques advances the objectives of the Sustainable Development Goals (SDGs). These strategies are crucial for reducing the negative effects of UHI and guaranteeing the long-term viability of cities that are rapidly expanding. This study focuses on the largest cities in Telangana, particularly Hyderabad and Warangal, to quantify the feedback loop between urbanization and heat waves. This method will shed new light on the pressing need for efficient mitigation plans and climate-sensitive urban planning to combat the growing effects of UHIs.

This study on urban heat islands (UHIs) and temperature anomalies in Hyderabad and Warangal aligns with multiple Sustainable Development Goals (SDGs) by addressing the effects of heatwaves on human health, energy consumption, urban resilience, and climate adaptation. SDG 3 (Good Health and Well-being) is linked to minimizing heat-related illnesses like heat stress and respiratory issues, emphasizing the need for urban cooling strategies such as increased vegetation and reflective surfaces. SDG 7 (Affordable and Clean Energy) connects to the study's findings on rising temperatures driving higher energy consumption for cooling, highlighting the importance of energy-efficient buildings and green infrastructure. SDG 11 (Sustainable Cities and Communities) is supported through GIS-based LULC and heatwave mapping, offering insights into urban expansion and helping design climate-resilient cities with improved green spaces and adaptive urban planning. Lastly, SDG 13 (Climate Action) is addressed by recommending sustainable construction practices like green roofs, permeable pavements, and heat-resistant urban designs to mitigate UHI effects and enhance long-term climate resilience. By integrating urban climate studies with sustainable development, this research advocates for holistic urban planning strategies that promote healthier, energy-efficient, and climate-adaptive cities

II. DESCRIPTION OF THE STUDY AREA

The selected study areas for this research are Hyderabad and Warangal, two major urban centers in Telangana, India, experiencing rapid urbanization and rising temperature anomalies. Hyderabad, the capital of Telangana, is one of India's fastest-growing metropolitan cities, covering an area of 650 km² with a population exceeding 10 million (Census 2011). It is situated between 17.3850° N latitude and 78.4867° E longitude, bounded by Medchal-Malkajgiri district in the north, Rangareddy district in the west and south, and Yadadri Bhuvanagiri district in the east. The city has witnessed extensive urban expansion, contributing to increased land surface temperatures and intensifying the Urban Heat Island (UHI) effect. Warangal, a historical and rapidly urbanizing city, is located in northeastern Telangana and serves as a key educational and industrial hub. It is positioned at 17.9784° N latitude and 79.5910° E longitude, covering an area of 406 km², with a population of over 800,000 (Census 2011). It shares its boundaries with Hanamkonda to the north, Jangaon to the west, and Bhupalpally to the east. The city's transformation, marked by infrastructure growth and land-use changes, has resulted in higher heat stress and climate variability.For this study, GIS-based LULC maps were developed for Hyderabad and Warangal using high-resolution satellite imagery from Landsat and Sentinel missions, capturing urban expansion and vegetation loss between 2000 and 2020. Additionally, heatwave maps were prepared by analyzing pre-monsoon season temperature data (March to May) for the years 2000 and 2020, highlighting the intensification of extreme heat events in both cities. Figure 1 illustrates the location map of the study area, demonstrating its geographical extent and urban landscape transformation.

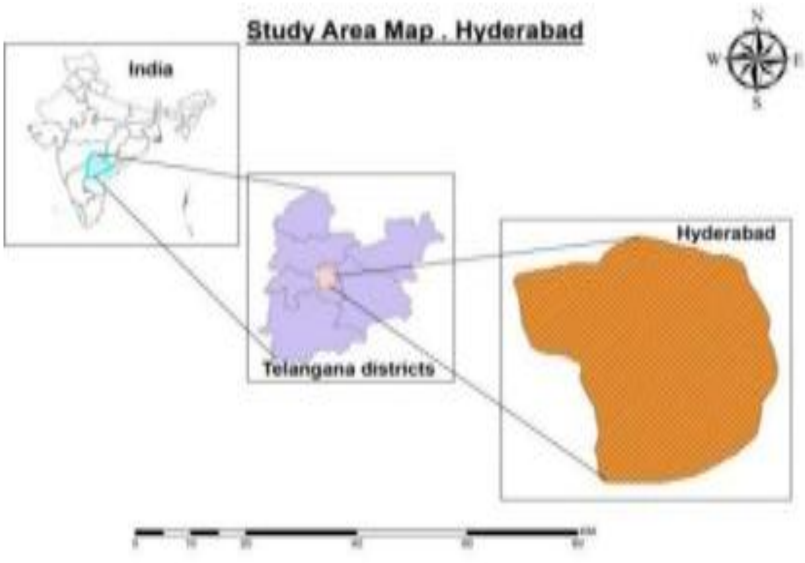

Figure 1: **Location map of the study area**

II. MATERIALS AND METHODS

Preparation of LULC Map for Hyderabad and Warangal

The **Land Use/Land Cover (LULC) maps** for Hyderabad and Warangal were developed to analyze urban expansion, environmental changes, and land transformation between **2000 and 2020**. These maps help in understanding the increasing built-up areas, loss of agricultural and forest land, and the encroachment of water bodies, which contribute to the **Urban Heat Island (UHI) effect**.

High-resolution **Sentinel satellite imagery (10m resolution)** was used to generate these maps through**unsupervised classification** in **ArcGIS 10.5 software**. The classification process helped in distinguishing different land types and quantifying their changes over time.

Urban expansion in **Hyderabad** was primarily observed in **western and south eastern regions**, replacingagricultural land and green spaces with residential, commercial, and industrial developments. Similarly,**Warangal** showed significant built-up growth, particularly around its core city area and transport corridors.

These LULC maps provide critical insights into land-use changes and support sustainable urban planning by identifying areas requiring conservation efforts, green infrastructure, and climate-resilient strategies.

This study uses a combination of data collection, land-use land-cover (LULC) analysis, and GIS-based heatwave mapping to assess how urbanization affects variations in temperatures and heatwave occurrences in Telangana. The India Meteorological Department (IMD) and local weather stations provided historical temperature data for Hyderabad and Warangal from 1981 to 2023, with an emphasis on the pre-monsoon season (March to May), when heatwaves are most common. The IMD criteria were used to identify heatwaves, which are characterized as occurrences with maximum temperatures that surpass the average for the past decade while taking regional climate situations into account. Both cities' LULC maps, which show trends in urban growth, vegetation loss, and the increase of impermeable terrain between 2000 and 2020, were generated using high-resolution satellite images from Landsat 5 and sentinel satellite 2 data. Heatwave maps for the years 2000 and 2020 were produced using GIS tools, which evaluated average maximum temperatures and identified extreme temperature days that were higher than the 90th percentile of historical data. By comparing the pre-monsoon averages for the years 1981 and 2000 and 2001 and 2023, temperature anomalies were determined. To reduce urban heat islands (UHIs), lower energy needs, and promote environmentally friendly urban growth, the study suggests using green buildings, surfaces that reflect sunlight, and climate-resilient urban architecture. The methodology is presented in figure 2.

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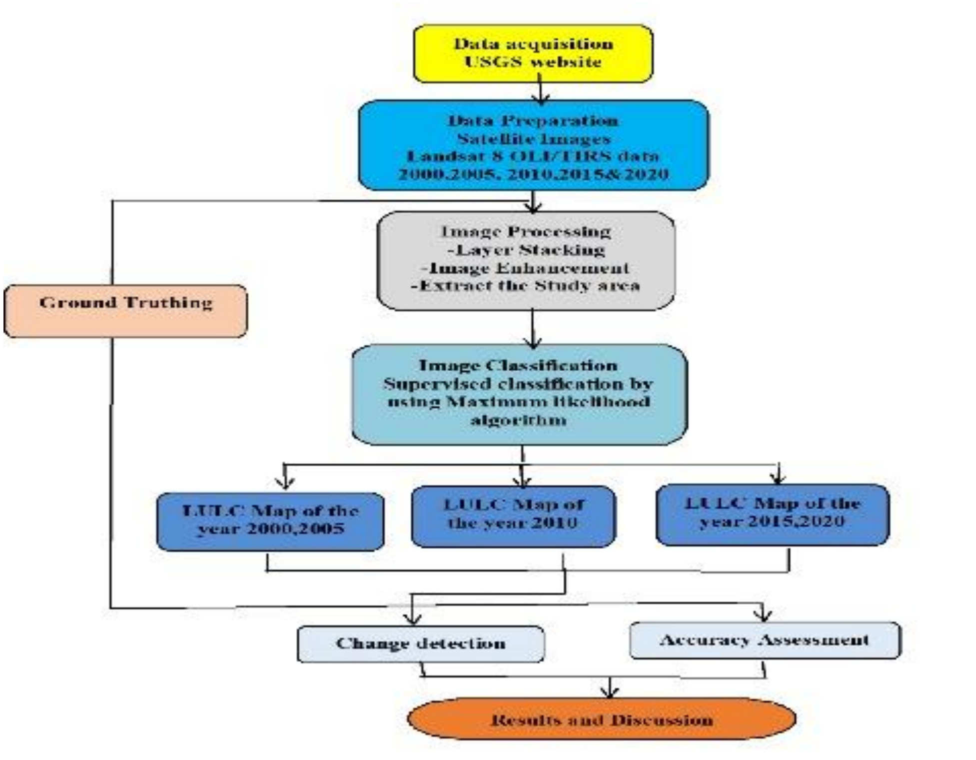

Figure 2:-Methodology Flowchart of present work

III. RESULTS AND DISCUSSION

A. LULC Maps

The LULC maps show the different land cover types' spatial distribution. The maps demonstrate how land cover categories have changed significantly over time, showing how urbanized zones have grown and how green places have decreased. These changes are a sign of increasing urbanization, which has affected the ecological balance of the area directly.

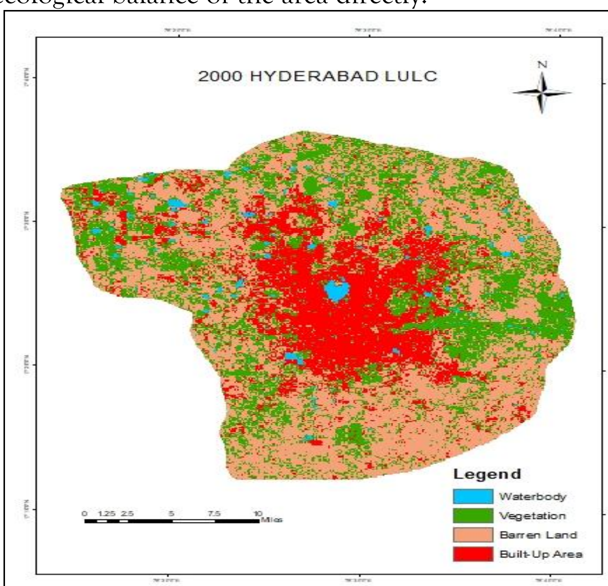

Fig 3: LuLc map of Hyderabad- 2000

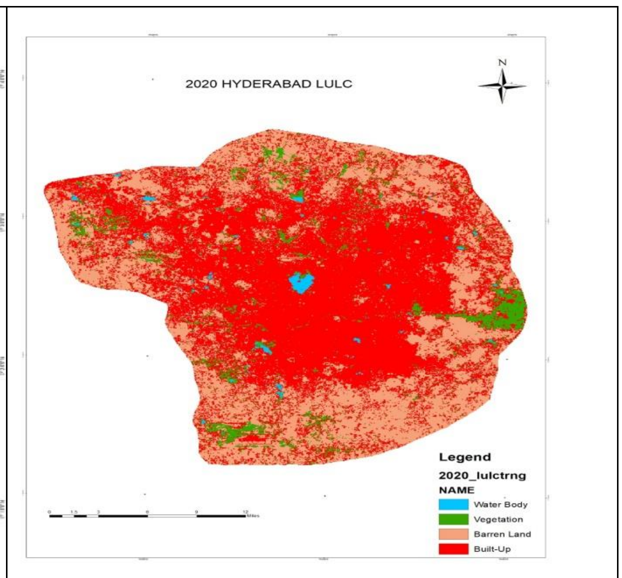

Fig 4: LuLc map of Hyderabad- 2020

Fig 3, The categorized image for the year 2000 was created using data collected by the Landsat 5 and sentinel satellite data. Vegetation made up 30% of the total area, with 435.21km2, while built-up area accounted for 22%, 318.93km2, barren land made up 46%, and water body made up 2%, with 25.55km2. While fig 4, the categorized image for 2020 was created using data collected from Landsat 8. There are now 84.72km2 of vegetation, which is 6% of the total area, has further more increased to 55% of the total area with 804.64km2 dominated the land area in 2020, barren land is gradually decreased to 38% with 550.92km2 and water body is slightly decreased to 1% with 12.02km2.

B. LULC Changes in Warangal City

Fig. 5: The classified image for 2000, produced with data from the Landsat 5 satellite, reveals that vegetation covered over 470 km², or 32% of the total area. 18% (265 km2) of the total area was built up, 48% (705 km2) was made up of bare land, and 2% (30 km2) was made up of water bodies. Figure 6: Using Landsat 8 data, the classified image for 2020 shows a notable 8% (120 km2) decrease in vegetation. Growing urbanization is seen in the built-up area, which climbed to 50% (735 km²). Water bodies somewhat decreased to 2% (25 km²), while barren land dropped to 40% (585 km²). This comparison demonstrates Warangal city's 20-year trend of rapid urban expansion and declining open space.

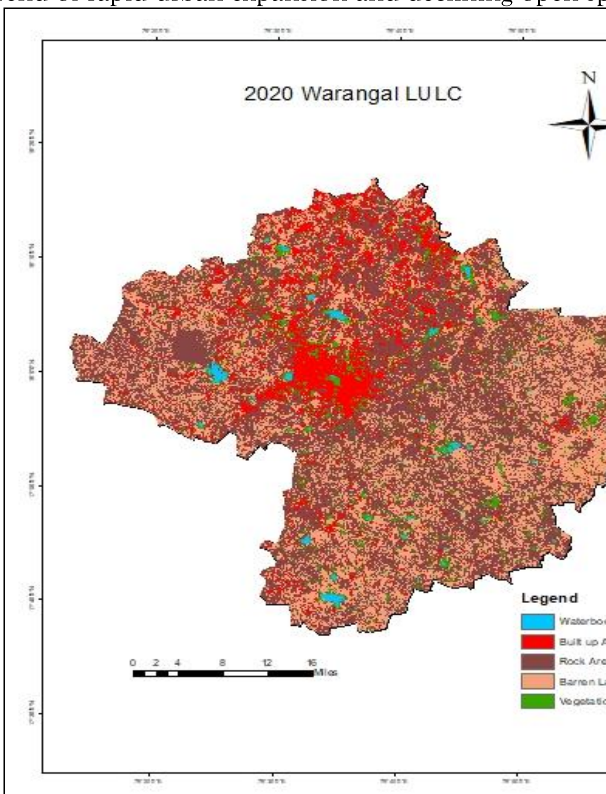

Fig 5: LuLc map of Warangal- 2000

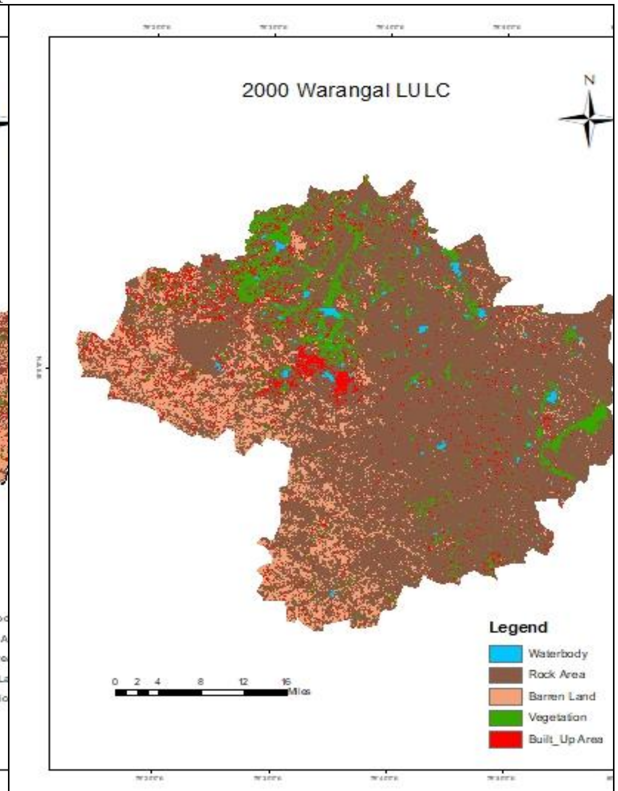

Fig 6: LuLc map of Warangal- 2020

C. Heat wave intensity Maps of Hyderabad City

The severity and geographic distribution of heatwaves throughout the study period are shown on the heatwave maps. Figure 7&8 depicts the heat wave intensity maps of Hyderabad based on average temperatures calculated for Hyderabad city. The information shows that heatwaves are occurring more frequently and with greater intensity, especially in urban areas. These maps provide as a visual depiction of patterns in rising temperatures associated with both human activity and climate change.

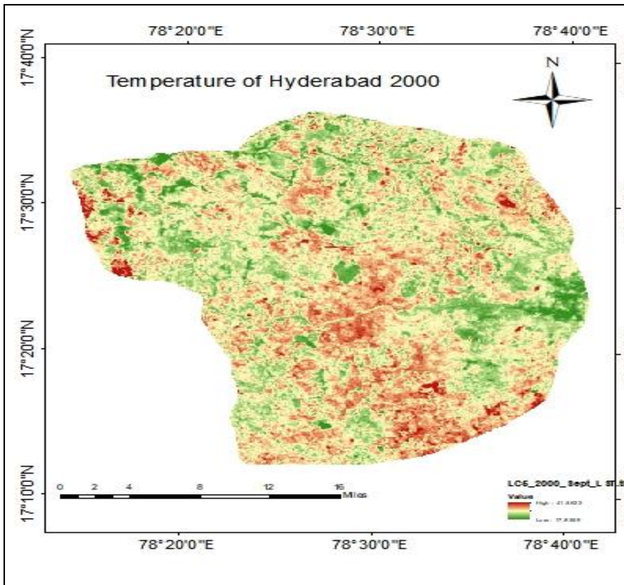

Fig 7: Heatwave Intensity Map During Summer Hyderabad- 2000

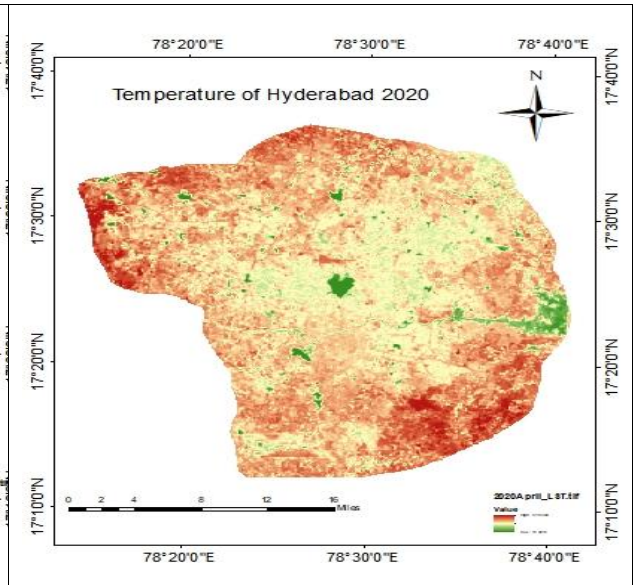

Fig 8: Heatwave Intensity Map During Summer Hyderabad- 2020

D. Heat Wave Intensity Maps of Warangal City:

Figure 9&10 depicts the heat wave intensity maps of Warangal based on average temperatures calculated for Warangal city. Increase in Heatwave Intensity in Hyderabad and Warangal (2000-2020) Over the last 20 years, both Hyderabad and Warangal have experienced a significant rise in heatwave intensity, particularly during the summer months. In 2000, heatwaves were relatively less frequent and localized. However, by 2020, there has been a notable expansion of high-temperature zones, with urban heat islands forming in both cities due to rapid urbanization, reduced vegetation cover, and climate change. The maps clearly depict an increase in severity of heatwaves, indicating a growing vulnerability to extreme heat conditions.

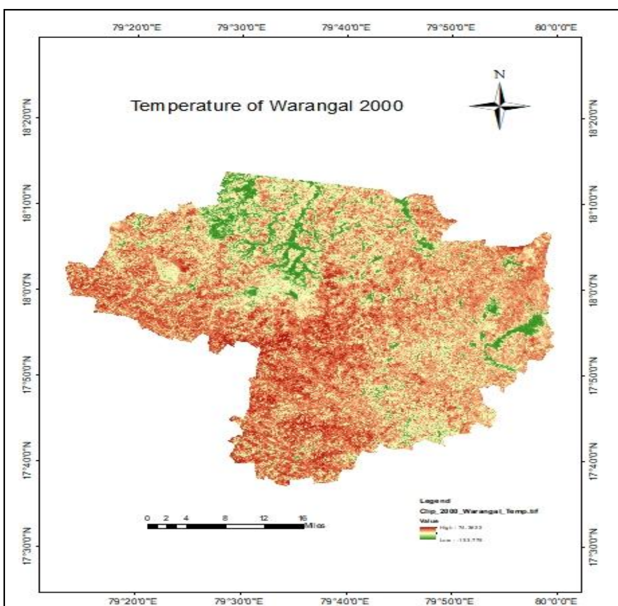

Fig 9: Heatwave Intensity Map During Summer Warangal- 2000

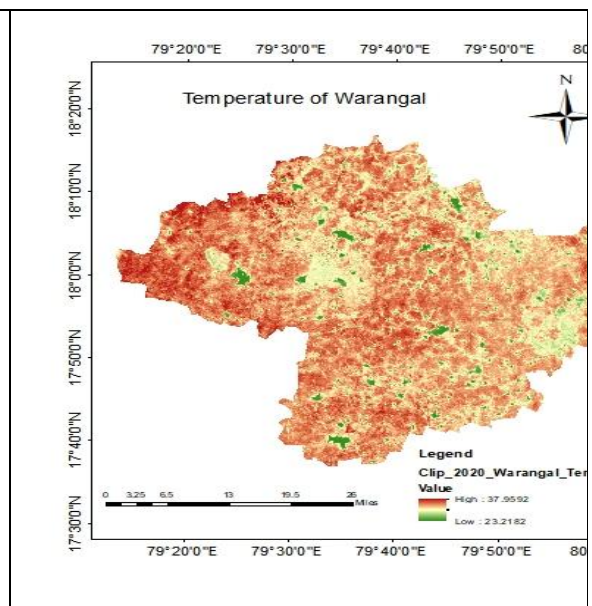

Fig 10: Heatwave Intensity Map During Summer Warangal- 2020

D. Temperature Anomaly Analysis

Significant patterns emerged from the examination of temperature anomalies in Hyderabad and Warangal between 1981 and 2023. During the pre-monsoon season (March to May), the mean maximum temperature increased significantly between 1981–2000 and 2001–2023 periods under analysis. Table 1 represents the mean maximum temperatures and anomalies for both periods, highlighting the changes observed in both cities.

Table 1 The mean maximum temperatures and anomalies for both periods, highlighting the changes observed in both cities.

Period	City	Mean Maximum Temperature (°C)	Temperature Anomaly (°C)
1981 and 2000	Hyderabad	34.5	-
1981 and 2000	Warangal	35.2	-
2001 and 2023	Hyderabad	34.85	+0.35(day)
1981 and 2000	Warangal	35.50	+0.30(day)

E. Heat wave Frequency

The number of days that both cities' historical temperature records above the 90th percentile was used to calculate the frequency of heatwave episodes. Table 2 Summarizes the frequency of heatwave days in each city for the periods studied. The air and surface temperatures increased from 2000 to 2020 are presented in table 3.

Table 2 : Summarizes the frequency of heatwave days in each city.

City	Heatwave Days (1981 and 2000)	Heatwave Days (2001 and 2023)
Hyderabad	12	25
Warangal	10	22

Table 3 : The simulated air temperatures and heat fluxes for both cities.

Scenario	City	Air Temperature (°C)	Surface Temperature (°C)	Sensible Heat Flux (W/m²)
2000	Hyderabad	34.0	36.5	200
	Warangal	34.2	36.7	205
2020	Hyderabad	36.0	38.5	300
	Warangal	36.5	39.0	310

H. Interpretation and Suggestions for Policy

The results indicate a clear trend of increasing temperatures and a rise of urbanized heatwaves in Telangana. The results highlight the necessity of climate-sensitive urban planning, and techniques for mitigating urban heat island effects ought to be incorporated, as well as green space development and reflective surfaces. Strong regulatory frameworks and government backing are required for such measures, especially to encourage eco-friendly and environmentally conscious endeavors that can transform urban infrastructure in a sustainable manner. To advance green growth, urban greening programs, and eco-friendly infrastructure, government incentives and regulatory support are crucial. The government can incentivize developers to invest in environmentally friendly building materials, green roofs, and sustainable construction techniques by offering financial support, tax incentives, and expedited approvals for green projects. While urban woods, green roofs, and parks enhance air quality, lower ambient temperatures, and promote local biodiversity, reflective and high-albedo materials, for instance, can dramatically lower surface temperatures. Furthermore, these actions immediately aid in the accomplishment of the Sustainable Development Goals (SDGs) of the UN, especially SDG 13 (Climate Action) and SDG 11 (Sustainable Cities and Communities). In addition to lessening the effects of UHI, green buildings increase building energy efficiency, reducing the need for artificial cooling and, as a result, carbon emissions. These cuts support SDG 15 (Life on Land) by fostering biodiversity in urban areas and SDG 7 (Affordable and Clean Energy) by reducing energy needs. In conclusion, the development of climate-resilient, sustainable communities that successfully tackles the dual issues of urbanization and climate change while promoting advancement toward global sustainability goals requires cooperative policy action from the government, developers, and urban planners.

IV. DISCUSSIONS

A comparison of Hyderabad and Warangal's Land Use Land Cover (LULC) trends between 2000 and 2020 shows substantial urban growth, a marked decline in vegetation, and an increase in built-up areas. Hyderabad's built-up areas increased from 22% to 55%, while the amount of vegetation fell from 30% to 6%. Warangal exhibits a comparable pattern, with built-up areas rising from 18% to 50% and vegetation declining by 8%. These changes indicate that infrastructure and urban sprawl are expanding quickly, frequently at the expense of ecological balance. Telangana is not alone in this trend. Similar urban changes have occurred in Delhi, the National Capital Region, where there has been a sharp rise in impervious surfaces, which has led to worsening air quality and the urban heat island (UHI) effect [15]. Once renowned for its lushness, Bangalore has seen a loss of more than 88% of its vegetation between 1973 and 2016, which has resulted in more irregular temperatures and fragmented green areas [16]. High population density, the loss of open areas, and inadequate adaptation measures has all contributed to the rising frequency of heatwaves in Kolkata [17].
Hyderabad and Warangal's heatwave intensity maps show a concerning trend: both cities now see increasingly frequent and intense heatwaves, particularly in the summer. Urban heat islands have become more noticeable, high-heat zones have spread geographically, and average summer temperatures have risen between 2000 and 2020. The pre-monsoon mean maximum temperatures in both cities have increased significantly during 1981–2000 and 2001–2023, according to temperature anomaly study. Cities like Delhi and Kolkata, whose summer temperature anomalies surpass 2–3°C, have seen similar warming tendencies, increasing their susceptibility to heat-related illnesses and energy stress [18]. Green building techniques can significantly improve urban resilience and climate adaption in the face of warming temperatures. The study's conclusions emphasize how urgently climate-sensitive urban planning needs to be put into practice.

Green roofs and vertical gardens are two important sustainable building techniques that can be used in Hyderabad, Warangal, and other quickly urbanizing Indian towns. They lower roof temperatures by 10 to 25°C and serve as insulators, which lowers energy consumption [19]. Cool Roofing Technologies: Reflective roof coatings may mitigate the effects of urban heat islands and cut indoor temperatures by 2 to 5°C. Thermal mass, sun shading, natural ventilation, and building orientation all reduce energy use and enhance occupant comfort. Rainwater harvesting and permeable surfaces help to mitigate localized flooding by reducing surface runoff and promoting groundwater recharge. Increased Vegetation and Urban Forestry: To improve carbon sequestration and lower ambient temperatures, native species should be planted and green belts should be preserved.

Materials with high albedo and heat resistance (such fly ash bricks and hollow concrete blocks) can be preferred to increase energy-efficiency of buildings. Linking Intelligent Internet of Things Systems: Real-time monitoring of indoor temperature, humidity, and energy consumption enables the optimization of water and energy use.

This study's integration of GIS mapping and IoT-based AQI monitoring offers a scalable, scientifically proven method of regulating urban environmental stress. This approach promotes green infrastructure design in future building policies by linking heatwave zones with LULC change. Municipalities and development authorities can use these findings to directly inform zoning laws that need green spaces in urban planning. In susceptible areas, offer incentives to green buildings that have earned IGBC/GRIHA certification. Assist in locating urban heat islands for specific green roof and tree planting projects.

V. CONCLUSIONS

This study thoroughly investigates how urbanization affects Telangana's temperature anomalies and heatwave occurrences, especially in Hyderabad and Warangal. The examination of past temperature data shows a significant increase in urban day and night temperatures, which has a strong connection with the city's fast urbanization. The results show that heat islands in urban areas (UHIs) have made heatwave episodes more frequent and intense, which is a result of urbanization. Furthermore, the transformation of green spaces into impermeable surfaces is highlighted by land-use land-cover (LULC) analysis, which has caused modifications in the local climate. With suggestions for putting in place green buildings, using reflective building materials, and creating climate-resilient areas in cities, it is clear from these findings that climate-sensitive design of cities is crucial to minimizing the negative consequences of city heat designs. By using sustainable design elements like more vegetation, rooftop gardens, and reflective materials, green buildings can help control urban temperatures. For example, reflective building materials limit heat buildup, and green roofs and facades promote natural cooling and decrease heat absorption, all of which reduce the energy required for cooling [20]. Additionally, water-efficient landscaping and permeable surfaces can improve water retention, lower surface temperatures, and help cool microclimates in crowded cities [21]. Green construction principles have been incorporated into climate-resilient urban planning, which supports sustainability objectives and may reduce the consequences of urban heating. Green buildings can also lower carbon emissions, which is a crucial first step in combating climate change, by enhancing building insulation and promoting the use of renewable energy. By using such designs, artificial heat accumulation may be reduced, which would ultimately improve the general well-being of the urban ecology [22]. Climate-sensitive designs support resilient, healthy, and adaptable cities by improving air quality and natural shading [23]. To sum up, implementing green building principles has several advantages, such as lower energy consumption, improved climate change adaption, and sustainable urban growth. As temperatures rise and the frequency of extreme heat events increases, this strategy offers stakeholders, urban planners, and policymakers a workable and efficient framework for building ecologically friendly and climate-resilient cities in Telangana.

This study lays the groundwork for future investigations into the long-term effects of urbanization and warming temperatures in addition to highlighting the crucial connection between both of these events. In the end, the knowledge acquired will assist stakeholders, urban planners, and legislators create environmentally friendly and adaptive cities in Telangana as temperatures rise and the frequency of heatwaves increases.

VI. ACKNOWLEDGMENTS

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