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Assessment and Mapping of Urban Heat Island using Field Data in the New Capital Region of Andhra Pradesh, India

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Abstract

Objectives: To assess and map Urban Heat Island (UHI) and its intensity using field-based measurement of Land Surface Temperature (LST) in the newly formed capital region of Andhra Pradesh. Methods/Statistical **Analysis:** UHI development is one of the several consequences of urban sprawl and land use changes causing several environmental impacts on the urban dwellers. Assessment through field-based measurement of LST provides an instant and accurate insight into the extent and intensity of UHI. New capital region of Andhra Pradesh is having a lot of potential for urban sprawl because of the developmental activities proposed and hence taken as the case study. Using Infrared thermometer, LST was measured at 212 locations in the capital region, and corresponding locations were identified using latitudes and longitudes obtained from a hand-held GPS. LST measurements were made between 11 a.m. to 02 p.m. during the month of May, 2016. The latitude, longitude and LST data were used to develop map showing the UHI phenomenon using Arc GIS. Inverse Distance Weighted method, an interpolation algorithm available with spatial analyst module of Arc GIS, is used to develop a map showing the spatial variation of LST. **Findings:** From the output, it is clearly understood that UHI occurs mainly in the Vijayawada and Guntur cities. The max and min temperatures of LST measured in the study area are 50.49°C and 25.43°C respectively. UHI spreads to about 16708 hectares in Vijayawada and 25057 hectares in Guntur. **Applications/Improvements:** Field measured data-based analysis gives an accurate picture of the UHI in the study area. It was also found that low temperatures were recorded in areas with dense vegetation. Urban greening is the only method to reduce the UHI phenomenon and to mitigate the impacts.

Keywords: Capital Region, Field Measurement, GIS, GPS, IR Thermometer, Land Surface Temperature, Urban Heat Island

1. Introduction

1.1 Urban Sprawl

With ever increasing population and rapid growth in industrialization, cities are experiencing swift spatial growth, and the phenomenon is known as urban sprawl. The urban sprawl is regarded as one of the potential threats to sustainable development in which urban planning with effective resource utilization and allocation of infrastructure initiatives are key concerns. This lateral urban expansion has got several environmental and ecological implications and hence becomes a key element in sustainable urban environmental management. Several studies are made to estimate urban sprawl and its impacts, and it is well documented. Researchers quantified the urban growth and determined its spatial trends and also predicted the impacts. In recent years, there has been an escalating amount of literature on application of Remote Sensing (RS) techniques and Geographical Information Systems (GIS) to the urban sprawl studies. The three-decade urban growth in the city of Shiraz, Iran was studied by[1] using RS and GIS. Urban Sprawl Analysis of Tripoli

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Metropolitan City (Libya) Using RS data was estimated by[2] using the Multivariate Logistic Regression Model and explored the relationship between urban sprawl and various driving forces. Shannon's entropy Index method is used to quantify the degree of dispersion or concentration of built-up areas in Rajkot city[3]. GIS was widely used in the analysis of urban expansion, urban sprawl, its metrics, dynamics and modelling[4-5].

1.2 Land-Use and Land-Cover

The rapid expansion of cities occurred in recent days leads to the drastic changes in the Land Use and Land Cover (LULC). LULC is the bio-physical characteristic of area that exists by nature, and its alteration by anthropogenic activities may result in ecological imbalance. A considerable amount of literature has been published on this aspect. In[6] the spatial and temporal LULC changes in Western Black Sea region of Turkey were monitored and found that rapid LULC changes have taken place in many cities of Turkey. Use of multi-temporal satellite images, and their study provided a better understanding of the LULC change pattern[7]. The concept of maximum likelihood for LULC mapping and change detection has been used by several researchers[8-10].

1.3 Land Surface Temperature

It says about how hot the "surface" of the earth would feel to the touch in a particular place on it. Thus, Land Surface Temperature (LST) is not the same as the air temperature that is mentioned in the daily weather report. It is the radiative skin temperature of ground surface. It depends on the albedo, the vegetation cover, impervious surfaces and the soil moisture. In most cases, LST is generally a mixture of surface temperatures of both vegetation and bare soil. The LST influences the part of energy between ground and vegetation, and accounts for the surface air temperature. However, LST is one of the important key parameters in the physics of land surface processes from local scales through global scales. The use of satellite-based data for LST monitoring has been widely reported. Satellite-derived LST make it evident that LST is one of the significant parameters in the study of land surface processes from local through global scales[11-15]. LST–vegetation abundance relationship is used for urban heat island studies[16]. The down scaling of the UHI intensity was investigated using time-dependent energy balance[17].

1.4 Urban Heat Island

The relative high-temperature area development in the core urban area compared to the adjacent villages and sub urban area is popularly known as the Urban Heat Island (UHI). It causes several health problems to the city inhabitants. It increases the consumption of electricity for cooling purpose. It may alter the micro-climate of the urban area, and it was established that UHI can cause imbalance in urban ecology[18-19]. Impacts of landscape structure on surface urban heat islands were explored using a case study of Shanghai, China[20-21]. In their study they have investigated how the land composition and configuration would affect the UHI in the Shanghai metropolitan region of China. The influence of LULC on LST was well studied and documented[22-24]. Researchers studied the impact of a heat wave on morbidity and mortality in the elderly population[25-26]. Socio-spatial dynamics of extreme urban heat events were studied[27]. Monitoring of LST and UHI are essential elements of urban thermal environmental management, and several researchers contributed regarding methods and techniques for the same[28-29]. A comparative assessment of surface urban heat island is made in 18 mega cities in various climatic regions[30].

1.5 Field Measurements

Field-based measurement of LST and evaluation of the occurrence of UHI phenomenon can give a realistic picture of the situation in the area. Studies based on field measurements are more accurate than the indirect methods of deducing LST and UHI[31]. Researchers studied on the satellite derived thermal emission with on-site measurements over an urban surface[32].

The present work considers the new capital region of Andhra Pradesh as study area. This area has got a lot of potential for development in urban and infrastructural sectors. The urban microclimate would suffer several impacts due to this transition. To predict the future implications of urban sprawl, the evaluation of the present condition is essential. In this connection, the present work deals with the assessment and evaluation of UHI in this area.

1.6 Objectives of the Present Work

Objectives of the present work are: 1. Measurement of LST in the field, 2. Identification of features of land, 3. Mapping of LST using GIS, and 4. Study of the extent and intensity of UHI.

2. Study Area

2.1 New Capital Region of Andhra Pradesh

After the bifurcation of Andhra Pradesh, Telangana and Andhra Pradesh have emerged as two separate states recently. The new state of Andhra Pradesh has got lot of potential for development in various sectors. The Andhra Pradesh state Capital Region Development Authority (AP-CRDA) was formed on December 30th, 2014. The extent of the capital region is spread across 8,352.69 km². The river Krishna passes across the capital region separating Guntur and Vijayawada. Along with construction of the capital city at Amravati with the collaboration of Singapore based construction companies, several infrastructural projects were already proposed. All these projects will definitely have impact on the land resources and there will be a significant change or alteration in the land use. The rapid growth in urban area causes the so called 'urban sprawl', and it will definitely impact the urban environment adversely in many ways. Increase in land surface temperature is one of the significant impacts, which makes the city warmer than the surrounding village which is called as "Urban Heat Island" phenomenon. This UHI development causes severe discomfort to the urban dwellers and hence detection of its extent will be useful for adopting mitigation measures. The study area is shown in the Figure 1.

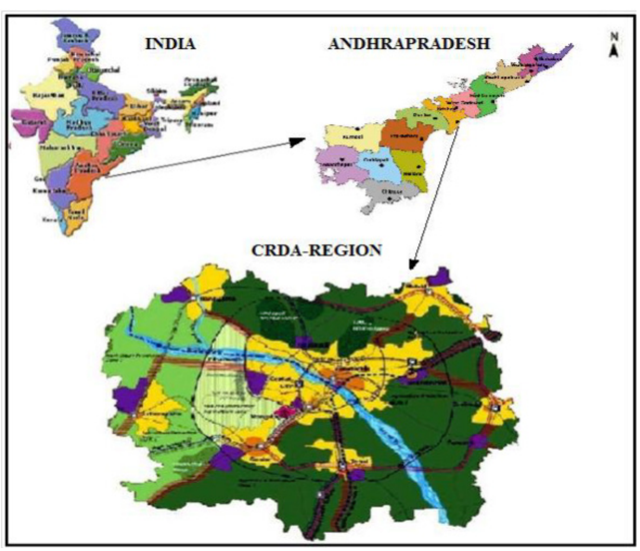

Figure 1. Location of the study area.

3. Data Collection Procedure

1. For the field investigation, we have visited the entire capital region area within the AP-CRDA which is taken as the study area for our work. The study area is selected considering the sudden changes which got occurred in the state of Andhra Pradesh. The capital region has the jurisdictional area of 8,352.69 km^2, which is spread in Guntur and Krishna districts. It also includes 214 km^2 of the newly proposed capital city of Andhra Pradesh called Amaravati. The Capital region would have an arterial road over a stretch of 135 kilometres, connecting Vijayawada and Guntur with the other towns in the State, which will show signs of rapid growth of urban area in the future. We have visited 212 places in CRDA region in May, 2016, and data collection was performed by using the equipment like GPS, Infra Red-Thermometer, and digital camera in the daytime from 11 a.m. to 02 p.m. local time.
2. We have noted the latitude and longitude of each and every place which we visited using GPS, corresponding to that we measured the land surface temperature and air temperature at every place using infrared thermometer and a photograph of the land use at that places was taken using a digital camera. The equipments used in this work are shown in the Figure 2. The method of field data collection is shown in the Figure 3. Field data collection points loaded on Google Earth map is shown in the Figure 4.

The Infra-red Thermometer, which used to measure the land surface temperature, has the following specifications: It has a laser-target pointer selection, with screen light and LCD display. The temperature range that can be measured is *-50° to + 550°C*. It has an adjustable

Figure 2. Equipment used in the field measurement of LST.

Figure 3. Measuring L with IR thermometer and GPS.

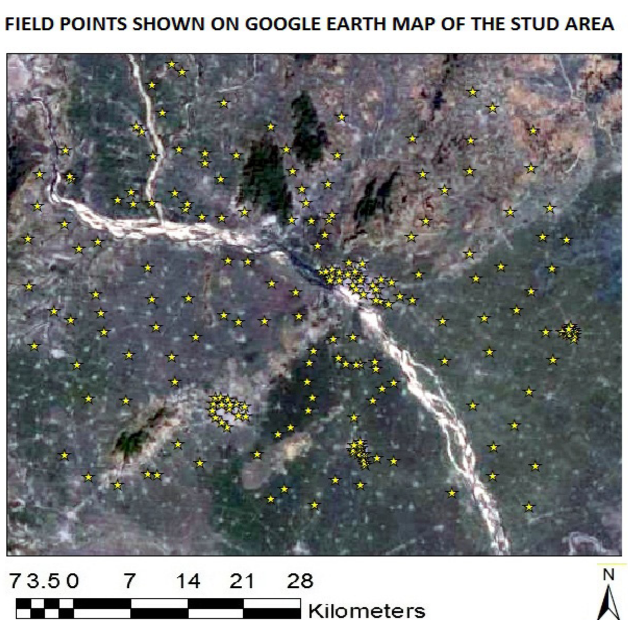

Figure 4. Field investigation points shown on Google Earth image.

emissivity ranging between 0.1 and 1.0. Accuracy of measurement is +2 ^{0} to +4^{0}C. It works on the principle of sensing temperature from a portion of the thermal radiation sometimes called blackbody radiation of the object being measured. The field investigation reveals that the land surface in the study area can be classified into six types. These are: (1) WB- Water Bodies/Wet Lands, (2) AL- Agricultural Land/Light Vegetation, (3) FD- Forests/Dense Tree Clad Area, (4) OD- Open Area/Dry Fields, (5) BR- Barren Land/Rocky Area, and (6) BU-Built up Rural & Urban. According to the type of land surface, the emissivity characteristics of the area will change and different surface features emit different radiations. The land surface temperature depends upon this emission. The IR thermometer has adjustable emissivity ranges from 0.1 to 1.0, for selection before taking the reading of LST. Different emissivity values used corresponding to different land surfaces, in this data collection process are given in the following Table 1. The sample field data collected from the study area is presented in the following Table 2.

4. Methodology

In this section, the methodology adopted to carry out the present research work is outlined briefly. Firstly, the details and basic data regarding study area were collected from the relevant sources like APCRDA Government office and Survey of India. The CRDA outline is extracted from the master-plan, and a shape file is created in GIS and geo-referenced. Using topo-sheets a base map of the study area was developed. The field survey data consisting of latitude, longitude, LST value, land use types were tabulated in XL spreadsheet. This data is then converted into ".csv file" to enable it to be fed to GIS. By importing the ".csv file" to Arc GIS, the 212 points are shown on the map. Then the Shape file of AP-CRDA boundary which is

Table 1. Emissivity values selected for the study area.

Sl. No.	Land surface	Emissivity selected
1	Forests/Dense Tree Clad Area	0.99
2	Water Bodies/Wet Lands	0.98
3	Agricultural Land/Light Vegetation	0.97
4	Open Area/Dry Fields	0.92
5	Barren Land/Rocky Area	0.90
6	Built up Rural& Urban	0.89

Table 2. Sample Field data collected from the study area.

S.No	Latitude	Longitude	LST	LULC	Place
1	16 39 36.2038 N	80 9 28.8270 E	39.64	OD	POKKUNURU
2	16 42 25.7539 N	80 8 49.3047 E	39.55	OD	USTHE PALLI
3	16 39 50.8670 N	80 9 19.9793 E	28.23	FD	KASARABADA
4	16 37 31.9609 N	80 14 5.4161 E	28.12	AL	PUNNAVALLI
5	16 37 4.1391 N	80 15 35.5609 E	27.32	AL	POPURU
6	16 37 12.3539 N	80 17 29.5018 E	38.89	WB	VIBHAREETAPADU
7	16 38 17.2555 N	80 15 25.1944 E	39.43	BR	VELADI
8	16 41 52.7306 N	80 17 34.3355 E	27.98	AL	KANCHELA
9	16 44 22.5192 N	80 16 28.7830 E	47.23	BU	MUNAGALA PALLE
10	16 44 52.3980 N	80 15 53.6682 E	47.34	BU	MUNAGALA PALLE

(WB- Water Bodies/Wet Lands, AL- Agricultural Land/Light Vegetation, FD- Forests/Dense
Tree Clad Area, OD- Open Area/Dry Fields, BR- Barren Land/Rocky Area, BU-Built up Rural & Urban)

already drawn is opened in Arc GIS and used to clip the 212 points. Now the AP-CRDA map appears, containing 212 points on it. These points are also loaded and shown on Google Earth image for better identification of sampling locations.

In order to get the spatial variation of LST throughout the study area, spatial interpolation techniques available in the spatial analysis tools of Arc GIS can be used. Hence the points are categorized and interpolated using Inverse Distance Weighted (IDW) tool in Arc GIS. The surface developed using IDW depends on the selection of a power value (p) and the neighbourhood searches strategy. IDW is a very good interpolator. IDW assumes that the surface is being driven by the local variation, which can be captured through the neighbourhood. The output of the interpolation is nothing but the image of LST.

The LST image so developed was classified into three categories, as high, medium and low temperatures. Forests and other densely vegetated areas have recorded low temperatures, whereas open and barren lands have recorded medium temperatures. However high temperatures were observed in mostly built up areas which are urbanized. The high temperatures are found to exist in the cities of Guntur and Vijayawada. The surrounding areas maintain low temperatures because of greenery. A clear UHI is observed in Guntur and Vijayawada cities.

5. Results and Discussion

For the present work first, the proposed AP-CRDA master plan was procured from the government authorities. Total 20 topomaps consisting numbers: 65 D/1 to 65 D/16, 65 H/1 to 65 H/4 were collected from the Survey of India. These are processed in ArcGIS. All these topomaps are georeferenced and rectified and projected to Universal Transcverse Mercator projection system. Then these are joined together by "mosaic" tool. The mosaic of the topomaps after clipping the selected area is shown in the Figure 5. Using this to mosaic of topomaps, a base map of the study area has been developed. The basemap of the study area produced from AP-CRDA master plan and topomaps of Survey of India is shown in the following Figure 6.

The temperature data collected from the field along with coordinates were fed to Arc GIS and after interpolation using IDW the spatial map of LST obtained. This map showing the spatial variation of LST throughout the study area gives an idea about the hot and cool areas existing in the area. The LST map output was shown in the following Figure 7.

From the LST map showing the spatio-temporal variation of temperature, the capital region was extracted and shown in the following Figure 8. From this map, it is clearly understood that the two cities Vijayawada and Guntur are holding high temperatures. The high-temperature rises up to 50.49 °C, and the low-temperature value recorded is 25.43 °C.

These are the temperature values of land surface measured by IR thermometer in the time between 11 a.m. to 02 p.m. local time. From this map, it is evident that the UHI

Figure 5. Study area extracted from mosaiced topomaps.

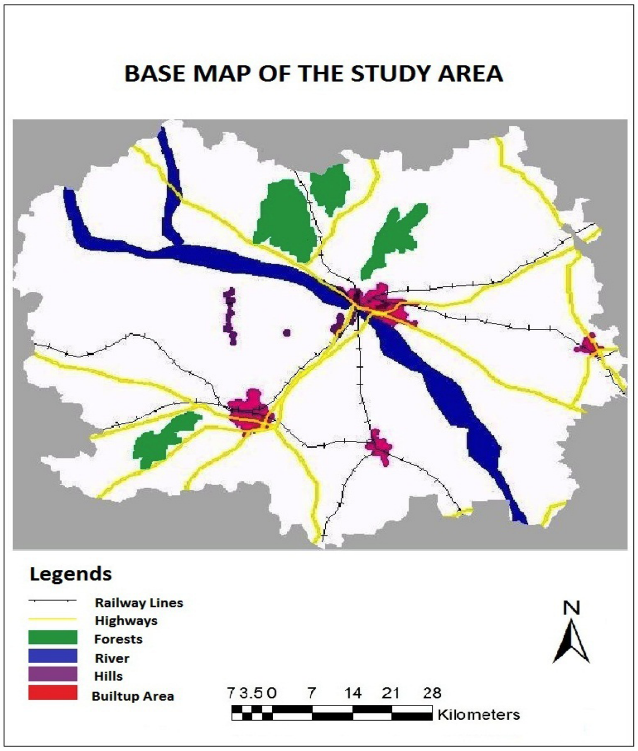

Figure 6. Base map of the study area prepared from Topo-maps.

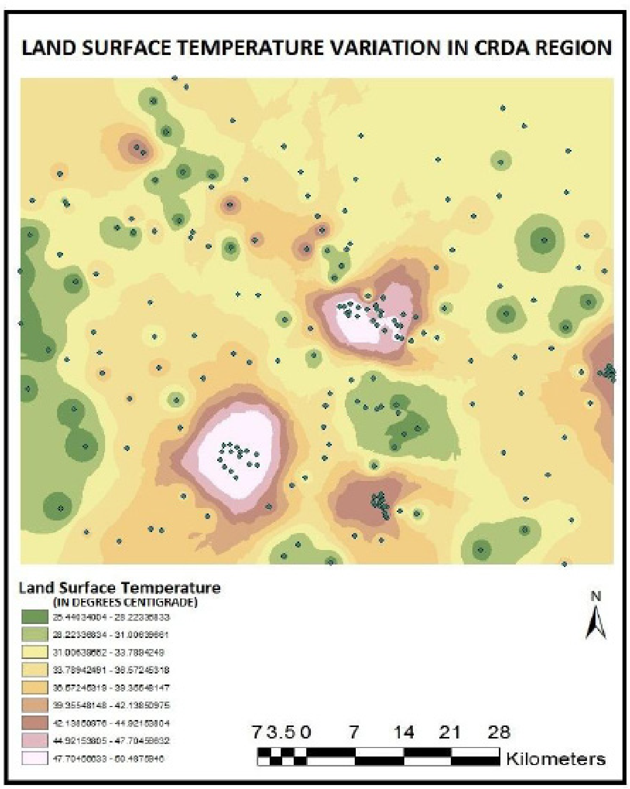

Figure 7. Spatio-temporal variation of LST in the study area.

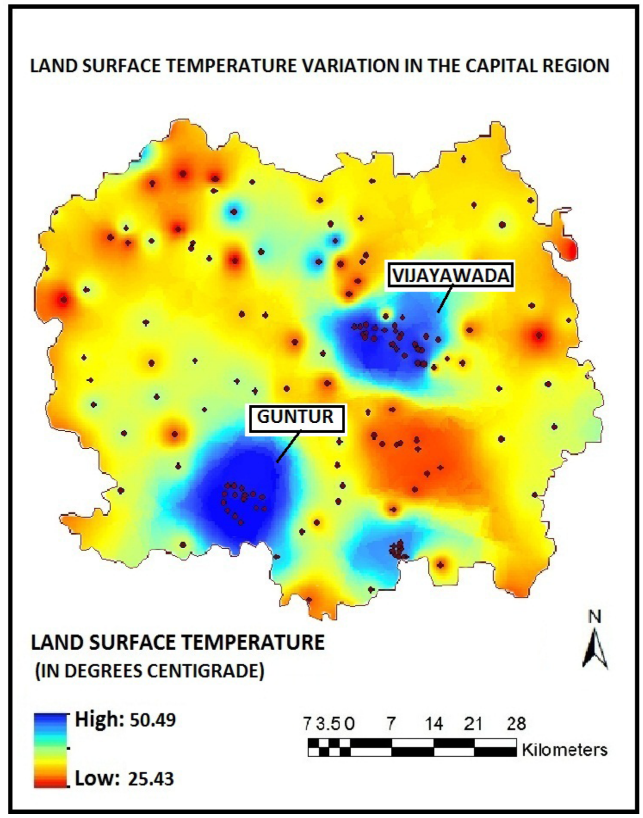

Figure 8. LST variation in the new capital region.

Table 3. Temperature data and type of LULC.

LST Level	LST in ^{o}C	Area in Hectares	Type of LULC
Low	25.43-30	258933	Water Bodies-Wet Lands, Forests-Dense Tree Clad Area, Agricultural Land
Medium	30-40	534573	Open Area-Dry Fields, Barren Land- Rocky Area, and Sand
High	40-50.49	41763	Builtup-Urban/Rural

phenomenon occurs in Vijayawada and Guntur cities. The LST values are categorised into three levels, viz., Low Medium and High. Low temperature ranges from 25.43 ^{o}C to 30 ^{o}C, medium temperature ranges from 30 ^{o}C to 40 ^{o}C and high-temperature ranges from 40 ^{o}C to 50.49 ^{o}C. According to these ranges, land areas are calculated and presented in the following Table 3. Along with the temperature values measurement, the local-area land use type was also noted and already presented in the Table 2. From this, it is understood that low temperature was observed in water bodies, dense forests and agricultural areas, and medium temperature was observed in open area, barren

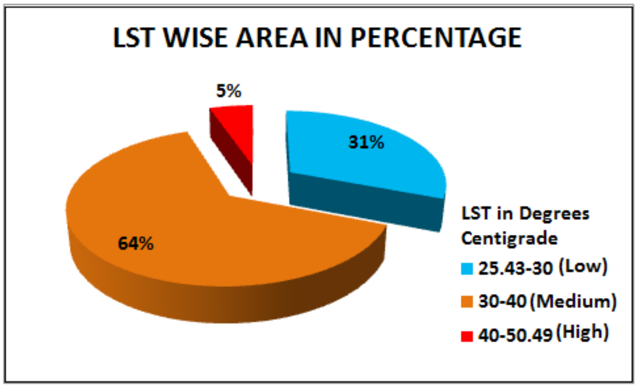

Figure 9. LST-wise area in percentage in the new capital region.

area and sandy areas. High temperature was recorded in built-up areas. The percentage of low, medium and high-temperature areas are shown in the pie chart as seen in Figure 9. High-temperature area, calculated from LST map in GIS is about 16708 hectares in Vijayawada and 25057 hectares in Guntur.

6. Conclusion

This study demonstrated the development of the urban heat island over the two cities of Vijayawada and Guntur of Andhra Pradesh state, India. Clear, distinguishable and prominent high-temperature patterns exist in these two cities making them as heat islands.

This was established by direct field measurement of land surface temperatures at more than 200 points, using IR thermometer during May, 2016 from 11a.m. to 02 p.m. local time. The temperature values measured along with the latitude, and longitudes are used to develop a map by GIS, showing the spatial disparity of the LST in the selected study area. This study reveals that, a high temperature of 40 to 50.49 ^{o} C exists over an area of 41763 hectares, which spreads to about 16708 hectares in Vijayawada and 25057 hectares in Guntur**.** The UHI is observed in built up area only. This non-evaporating, impervious surface affects the radiant surface temperature and modifies the surface energy budget. This is the main reason observed for development of UHI in these areas. Other areas which are showing low temperatures are mostly covered with vegetation and wet soil. From this study, it is concluded that maintaining vegetative cover in the urban built-up areas is the only measure that can reduce the LST which in turn affect the local air temperature. Hence development of green cover should be given top priority by the planners of the new capital region to mitigate the future UHI formation and its effects.

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