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Emerging Urban Heat Islands in the New Capital Region of Andhra Pradesh, India - A Satellite based Evaluation

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Abstract Satellite-based estimation and evaluation of urban heat islands (UHI) are latest in the field of urban micro climate and environmental management. UHI is one of the serious upcoming climatological issues regarding the development of cities. Conversion of the vegetative area into the impervious surface is the root cause of this problem of development of urban heat. Large-area coverage, quick process, more economical, less energy and other requirements are the attractive features of the satellite-based studies. The present study deals with the formation of UHI in the new capital region of Andhra Pradesh, a recently formed state in India in the year 2015. Satellite images of Landsat-8 are procured and processed to develop LULC and land surface temperature (LST) images. Field data of about 100 points, collected in the study area is also used in this work and the classification accuracy obtained is about 93%. From LULC and LST images it was concluded that the capital region is experiencing severe UHI phenomenon. The two big cities Vijayawada and Guntur are emerged as hot spots. High and low LST obtained are 58^{0}C and 23^{0}C respectively. The corresponding areas of hot and cold regions were estimated and presented. The outcome of this research can be used as a scientific basis for urban planners in urban planning and management as well as to increase the community awareness in urban heating effect. Urban greening is an essential measure to be adopted by the urban planners to protect the citizens from the ill effects of UHI.
Keywords *Urban Heat Island; Land Surface Temperature; Landsat-8; Land Use; Land Cover*

1. Introduction

Urban heat island is an upcoming serious issue which causes discomfort to the city dwellers and increases the power consumption because of the increased requirements of cooling, etc. Increased heat waves also result in the rise of the death toll, particularly old age people. Urban heat island is also connected to other micro climatological factors like humidity, rainfall, etc. Large scale conversion of forests and agricultural lands into impervious surfaces comprising roads, buildings and other infrastructure amenities is the main cause to this issue. The conversion of vegetative land into impervious land is changing the energy budget and responsible for excess heat development. Normally green areas with vegetation receive sunlight and utilize in the process of photosynthesis, and the energy will be converted into mass in the form of carbohydrates. Whereas the rocky area or concrete or asphaltic surfaces do not utilize the solar energy instead, the accumulated energy will be converted into heat. So the short wave light energy from the sun is received by the impervious surfaces and converts in to heat energy in the form of infrared long wave. The cooling effect of vegetation is mainly due to the evapotranspiration. Through evapotranspiration water escapes from the plant leaves which contributed to the loss of energy and causes cooling effect. This makes the surrounding environment cooler. Bare soil or impervious surfaces will not perform this phenomenon and thereby appear hotter always compared to vegetative or green surfaces.

Detection of urban heat island (UHI) is useful for protection of the urban area from the potential evil effects of UHI effect. Proper environmental management with suitable strategies to control deforestation and de-vegetation together with development of green spaces can reduce the intensity of the problem. Conventional measurement of temperatures with thermometers could be very cumbersome and their interpretation in the form of maps is very tedious. Application of Satellite images can be a right option for this. Several researchers used satellite technology for study of UHI effect. Satellite images with thermal band information can be processed to obtain land surface temperature. *Landsat* is one of the largest satellite supplying satellite images since 1970's with multi-spectral as well as thermal bands.

Analyzing the spatio-temporal characteristics of land use land cover change is essential for understanding the pattern of urbanization [1]. Multi-temporal satellite images can be used to detect and assess the changes in land use land cover [2]. Divine Odame Appiah et al. applied the techniques of geo information for change analysis of land use and land cover [3]. Lewoye Tsegaye analysed land use land cover change and its drivers using remote sensing data and GIS analysis [4]. Sahoo Satiprasad et al. monitored the urban land use land cover change by using multi temporal remote sensing satellite information [5]. Several researchers used multi-temporal and multi spectral satellite imagery for detecting, assessing and monitoring the land use land cover changes [6-11]. Satellite images are widely used to study the urban heat island phenomenon [12]. There are several methods of extracting land surface temperature from satellite data. One of the prominent techniques, which provide simple, easy and highly effective result called Mono-Window algorithm, was used in this study [13]. Evaluating urban heat is very important for gauging urban ecological environment, surface atmospheric interaction and energy fluxes between land surface and earth's atmosphere [14,15]. It also directly influences the health and comfort of urban dwellers. It is also connected to the mortality related to the heat waves [16,17].

1.1. Objective of the Present Study

Our objective is to identify the impact of land use land cover on the thermal environment of the capital region of Andhra Pradesh, using satellite images. Through the study of thermal environment, formation urban heat islands will be identified and their extent will be estimated which is useful for proper urban thermal environmental management. Hence development of land use and cover image and corresponding land surface temperature images from the satellite images are the key elements in this research work.

2. Study Area and Data

2.1. Capital Region of Andhra Pradesh

Andhra Pradesh is located in the south-eastern part of the country, bordered by Odisha & Chhattisgarh on the North, Telangana & Karnataka on the west, Tamil Nadu towards the south and Bay of Bengal on the east. With the bifurcation of Andhra Pradesh in to two states, Telangana and Andhra Pradesh, the new state of Andhra Pradesh has got tremendous potential for development in infrastructure, industrial and commercial sectors.

The new state of Andhra Pradesh is spread across an area of approximately 160,200 square kilometers and divided into 13 districts with a total population on base of approximately 49 million as per 2011 census. Andhra Pradesh is endowed with a variety of geographic features such as Eastern Ghats, Nallamala Forest and the state is fed by Krishna and Godavari rivers. The state boasts of vast arable fertile land and rich endowments of natural resources such as asbestos, coal, limestone, granite, bauxite, gypsum, manganese, etc. Some of the major urban centres in the Andhra Pradesh state include Visakhapatnam, Vijayawada, Tirupati, Guntur and Nellore.

The new Andhra Pradesh state is envisioning to build a new Capital City, close to Vijayawada and Guntur. Andhra Pradesh Government aspires to build a world class Capital City; the glowing pride for all the people of Andhra Pradesh. The development of the New Capital City will be on a green field site of 217.23 sq.km located centrally within the Capital Region. The Capital Region comprises of 8,603.32 sq.km including forest and hills, straddling on both sides of the Krishna River in both Krishna and Guntur Districts. The Capital Region is well connected to the surrounding economic hubs by air, rail, road, and ports. The Andhra Pradesh Capital Region Development Authority (AP-CRDA) was notified on December 30th, 2014 by the Government of Andhra Pradesh, which replaced the existing Vijayawada-Guntur-Tenali-Mangalagiri Urban Development Authority (VGTMUDA). The extent of the region is spread in 58 mandals, of which 29 are in Krishna district and 29 in Guntur district. The capital region covers 18 mandals fully and 11 mandals partially in Guntur district. In Krishna district, it covers 15 mandals fully and 14 mandals partially under the jurisdiction of AP-CRDA.

Within this new capital region, several infrastructural projects were already proposed. One outer ring road project and one inner ring road project, capital city development project, airport development project are some examples. All these projects will definitely consume lot of land and there will be a significant change in the land use and land cover. These changes can affect the environmental conditions of this area. For estimating the future scenario, we need to know the present status. Hence the effect of land use land cover on the environment is estimated in the present day context. Particularly impact of land use land cover on the local climate was focussed in this study. For this land surface temperature is estimated from satellite images. The location of the study area selected is shown in the Figure 1.

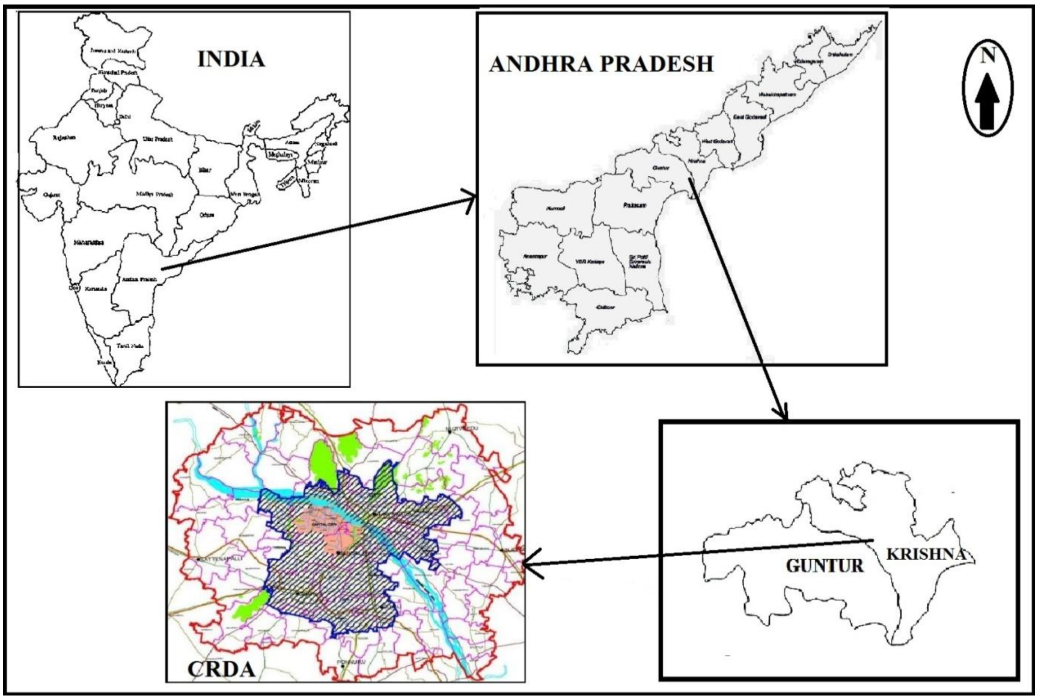

Figure 1: *Location of the Study area: AP-CRDA*

2.2. Data Collected

To carry out the present work first CRDA master plan proposed was collected from the authorities. Total 20 topo-maps were collected from Survey of India with the following numbers: 65 D/1 to 65 D/16, 65 H/1 to 65 H/4. The mosaic of these topo-maps after clipping the study area is obtained as a base map of the study area. Landsat-8, OLI-TIRS satellite image for the study area for the year 2015 was selected and downloaded from official website of USGS: http://earthexplorer.usgs.gov/. The details of satellite imagery collected were presented in the Table 1. For supplementing the image classification process with ground truth data, field visits were conducted in the entire study area and about 100 locations were identified and latitude and longitude were noted using hand held GPS. Some of the field data points collected were shown in the Table 2 as a sample.

Table 1: *Details of satellite image collected*

Date	Time of Pass (GMT)	Satellite	Sensor	Reference System	Path/ Row (Scene centre)	Bands	Resolution in Meters
2015-05-23	4:56:46	Landsat-8	OLI-TIRS	WRS-II WGS-84 Zone--44	142/49	11	30 (Both Reflective and Thermal)

Table 2: *Ground truth data collected by field visit in the study area (12 points were shown here as a sample)*

Point ID	Class ID	Latitude	Longitude	Place	Photo
1	AL	16 12 56.21 N	80 46 17.38 E	Vellabadu	
2	AL	16 33 35.77 N	80 41 46.32 E	Nunna	
3	OD	16 37 02.94 N	80 25 14.69E	Kothapeta	
4	BR	16 39 42.42 N	80 45 53.18E	Agiripalli	
5	BR	16 33 36.76 N	80 49 34.91 E	Atkuru	
6	FD	16 13 13.53 N	80 00 56.17 E	Kaza	

7	WB	16 20 56.73 N	80 43 48.74 E	Krishna river	
8	AL	16 03 52.33N	80 32 19.49 E	Kasukarru	
9	BR	16 28 00.58 N	80 35 33.39 E	Yerrabale-m	
10	OD	16 23 52.37 N	80 32 55.99 E	Chinnakka-ni	
11	AL	16 24 43.55 N	80 36 38.55 E	Pedavadla-pudi	
12	AL	16 05 04.37 N	80 46 40.59 E	Vemavaram	

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

3. Methodology

In this section, the methodology adopted in this work has been described briefly. As the main objective of the present research work is to determine the development of urban heat islands in the new capital region of Andhra Pradesh, the task completion involves the development of LULC image and LST image from the satellite images. The procured Landsat-8 satellite image which is in the form of 11 bands was first stacked and pre-processed for image enhancement using ERDAS Imagine. The blue, green red and near infrared bands were stacked to develop LULC. Supervised classification method was adopted using the maximum likelihood algorithm by selecting training sites within the study area. The entire study area has been classified into seven classes according to the site. The classification accuracy was also verified by performing the accuracy assessment using the collected field data. Field data from 100 points within the study area were collected using GPS and digital camera. Thus the LULC image of the study area was obtained. The process of LST image was explained below.

Cloud free Landsat-8 scene of the study area was downloaded from "earthexplorer" of USGS [18]. From the 11 bands of the image, band 11 was considered for generation of LST map. The band 10 image carries 16 bit information with digital numbers ranging from 0 to 65535. These digital numbers are brightness values in the thermal infrared region sensed by Landsat-8. Next step involves conversion of DN (Digital Number) to the physical measure of Top of Atmospheric Reflectance (TOA) and the Thermal band to At-Satellite Brightness Temperature. TIRS band data can be converted from spectral radiance to brightness temperature using the thermal constants provided in the Landsat8 data users handbook [19].

3.1. Calculation of Spectral Radiance

Lλ = MLQcal + AL

where: Lλ = TOA spectral radiance (at the sensor's aperture) (Watts/(m^2* sr * μm))

ML = Band-specific multiplicative rescaling factor

AL = Band-specific additive rescaling factor

Qcal = Quantized and calibrated standard product pixel values (DN)

3.2. Calculation of Brightness Temperature

TB = K_2 / ln((K_1/ Lλ)+ 1)

where: TB = At-satellite brightness temperature (K)

K_1 = Band-specific thermal conversion constant (watts/m^2 * sr * μm)

K_2 = Band-specific thermal conversion constant (in kelvin)

In this work Band-11 was considered for estimation of LST. From the metadata file the following constants were extracted for use in the above algorithm.

K_1 =1201.14 and K_2 = 480.89 for Band 11

ML = 0.0003342 and AL = 0.1 for Band 11

3.3. Estimation of Land Surface Temperature

Estimation of Land Surface Temperature Contact measurements of emissivity values of the surfaces using thermal radiometers and spectral assessment of samples supplemented LST estimation procedures in this study. Since the temperature values obtained as at-satellite temperature TB, referenced to black bodies, the land cover classes were assigned emissivity values derived through field measurements. Thus the emissivity corrected land surface temperatures can be calculated as

LST = T_B ⁄[1+ [λ* TB⁄ρ] lnε]

λ = Wavelength of emitted radiance,

ρ =h * c / σ = (1.438 * 10-2 m K)

h = Planck’s constant (6.626 * 10^{-34} Js)

σ = Stefan Boltzmann constant (5.67 * 10^{-8} Wm^{-2} K^{-4})

c = velocity of light (2.998 * 10^8 m/s)

From the metadata, λ =0.0000113m.

In the above LST algorithm ε is the emissivity of the surface.

Emissivity depends on the characteristic of the surface and it is inherent property of the material. The energy received from sun will be emitted back to space in different quantities by different materials. The emissivity values depend on the LULC. Emissivity image is obtained by developing a model in ERDAS which uses LULC and corresponding emissivity values. The emissivity values used in the model are given in the Table 3 below.

Table 3: *Emissivity values of different LULC classes*

S. No.	Material/LULC	Emissivity
1	Water Bodies - Wet Lands	0.98
2	Sand - River Course	0.90
3	Built Up - Rural & Urban	0.75
4	Forest - Dense Tree Clad Area	0.99
5	Agriculture Land - Light Vegetation	0.97
6	Open Area - Dry Fields	0.92
7	Barren Land - Rocky Area	0.85

4. Results and Discussion

In this section the results obtained from the present work has been presented and discussed. The output LULC image obtained from the supervised classification in ERDAS was given in Figure 2. The seven LULC classes and corresponding areas are given in the Table 4. The classified images are assessed for accuracy using the field data. The overall classification accuracy obtained is 93% and the corresponding Kappa Statistic was found to be 0.9102. From the emissivity, and the thermal band data of Landsat-8, land surface temperature image was developed in ERDAS and was presented in Figure 3.

Table 4: *Areas of different LULC classes in the study area*

S. No.	Land Use Type	Area in Hectares
1	Water Bodies - Wet Lands	8281.08
2	Sand - River Course	14008
3	Built Up - Rural & Urban	35750.3
4	Forest - Dense Tree Clad Area	73216.9
5	Agriculture Land - Light Vegetation	187164
6	Open Area - Dry Fields	338747
7	Barren Land - Rocky Area	58516.61
	Total	715683.89

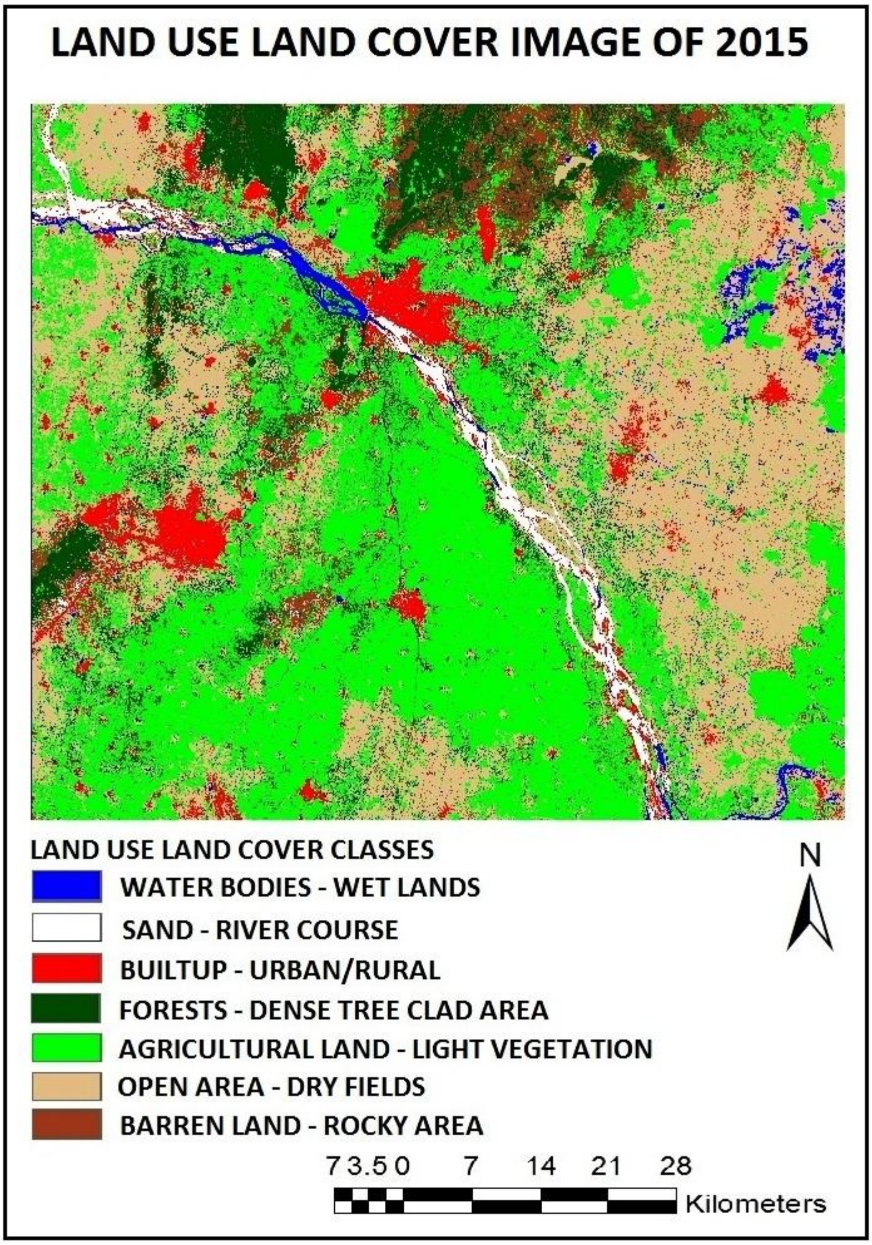

Figure 2: *Land use Land cover image of the study area in the year 2015*

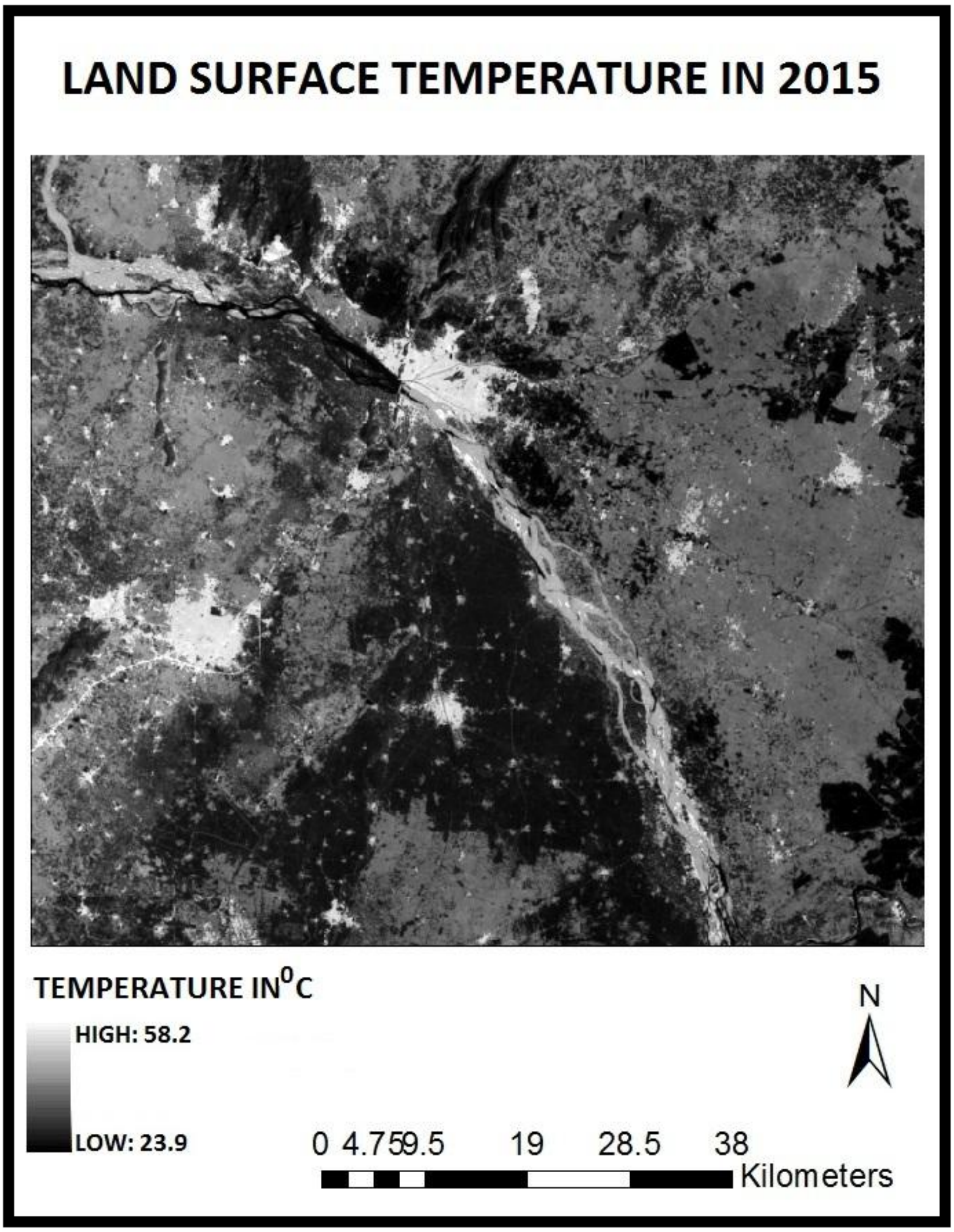

Figure 3: *Land Surface Temperature image of the study area in the year 2015*

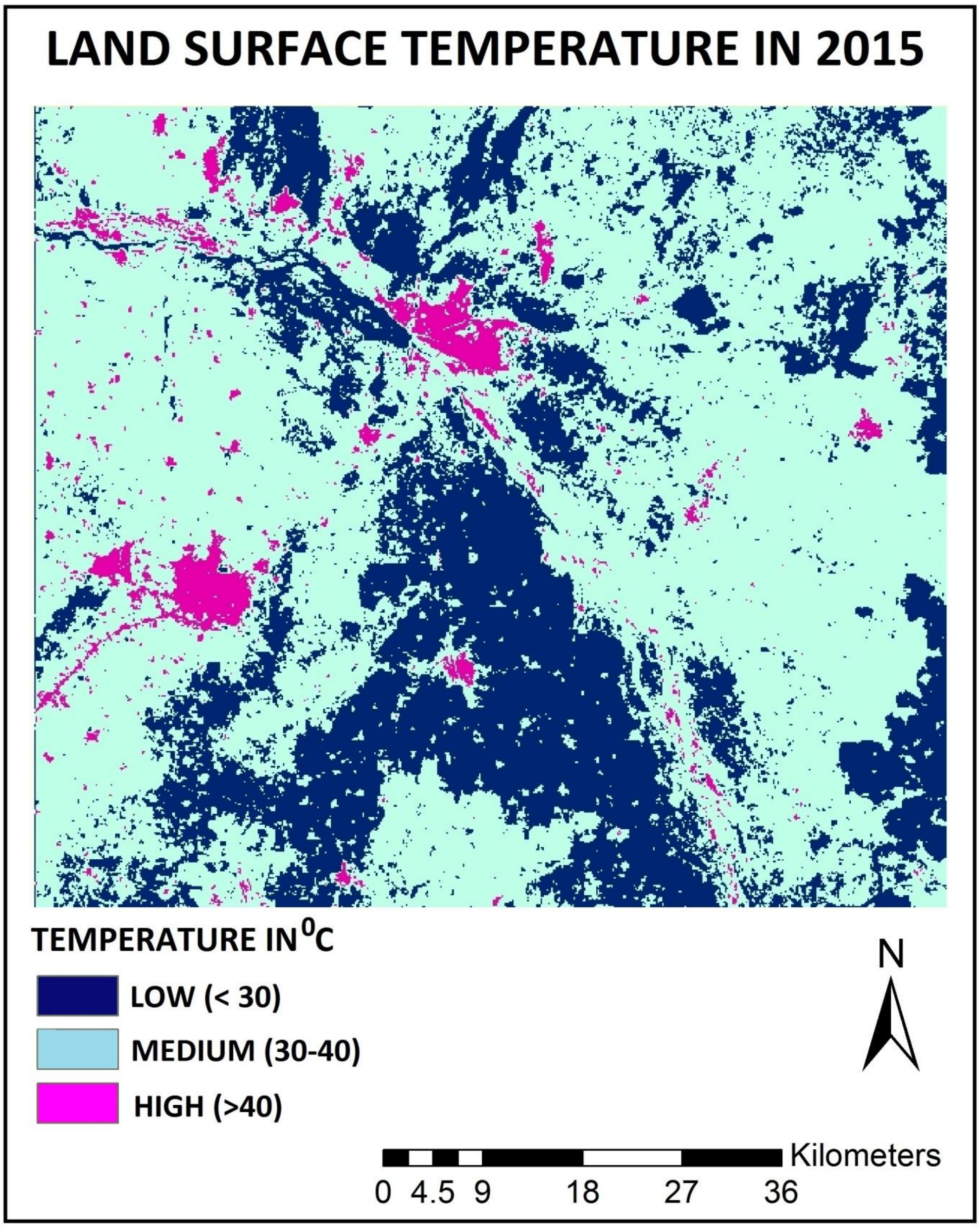

Figure 4: *Classified Land Surface Temperature image of the study area in the year 2015*

The LST image obtained from the ERDAS model has been classified into three classes: Low, Medium and High according to temperature ranges. Temperature less than 30^{o}C was considered low, temperature in between 30 and 40 was considered medium and temperature greater than 40 were considered high. The satellite pass time on the study area is 4:56:46 GMT, which comes around 10.30 a.m. according to Indian Standard Time (IST). So at this time the maximum and minimum temperatures obtained in the study area are 58.2^{0}C and 23.9 ^{0}C respectively. Low temperature was observed in water bodies-wet lands, forests-dense tree clad area and agricultural land-light vegetation. Medium temperature, which is around 40 ^{0}C was observed in sand-river course, open area-dry fields and barren land- rocky area. Similarly high temperature was observed in built-up-urban/rural area. The temperature levels and corresponding LULC classes were shown in a bar chart in Figure 5. The details of LST, corresponding LULC and respective areas in hectares are presented in Table 5.

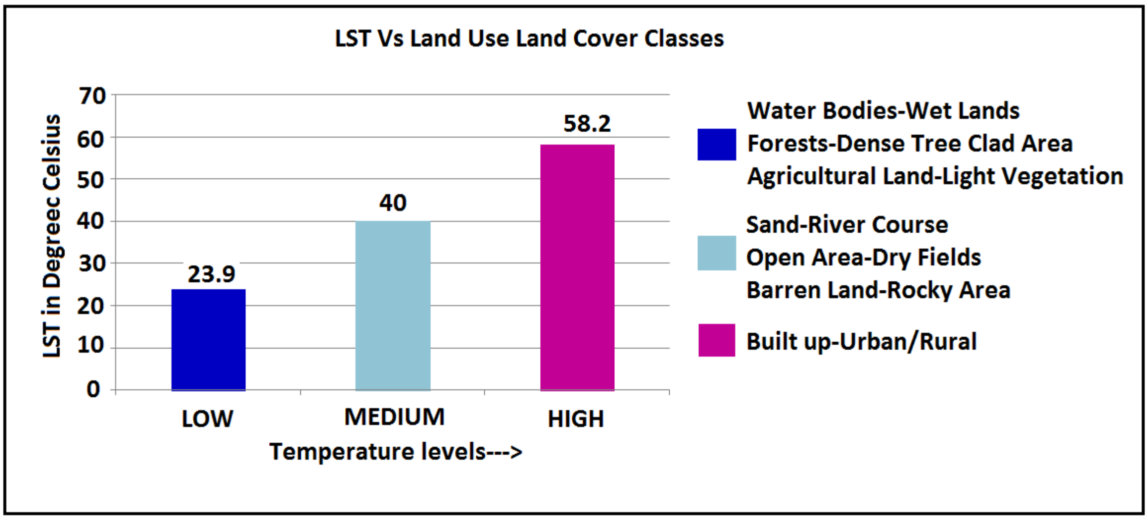

Figure 5: *Land Surface Temperature Verses Land use Land Cover classes*

Table 5: *Land Surface Temperature and corresponding type of LULC classes and areas*

LST Level	LST IN ^{O}C	Area in Hectares	Type Of LULC
LOW	23.9-30	186156.72	Water Bodies-Wet Lands, Forests-Dense Tree Clad Area, Agricultural Land-Light Vegetation
MEDIUM	30-40	385939.99	Sand-River Course, Open Area-Dry Fields, Barren Land- Rocky Area
HIGH	40-58.2	31892.68	Built-up-Urban/Rural

Urban Heat Island

From the LST image developed for the study area, it was clearly understood that there is a buildup of Urban Heat Island (UHI) in the core urban areas. In APCRDA region Vijayawada and Guntur cities are two major hot spots for the development of (UHI).

From the LST images it was clearly understood that the land surface temperature is inversely proportional to the vegetation cover. Higher values of LST were observed only at built up surfaces. Forests, agricultural areas and other light vegetative areas showed low temperature. The LST is increasing from rural areas to the urban areas. The non-evaporating and non-transpiring surfaces such as stone, metal and concrete brings up the surface radiant temperature. This is the root cause of the urban heat island phenomenon. To reduce this effect the trees must be grown and vegetation cover must be increased. In the APCRDA region, Vijayawada and Guntur are the two big cities which has lot of potential for development if UHI. In these cities a temperature rise of nearly 12 ^{0}C is observed.

The temperature profile across the two cities from north to south and east to west were prepared by taking transects and shown in Figures 6 to 9. From these figures also the UHI phenomenon is clearly evident. The field survey also confirms the absence or low density of green cover in the urban areas.

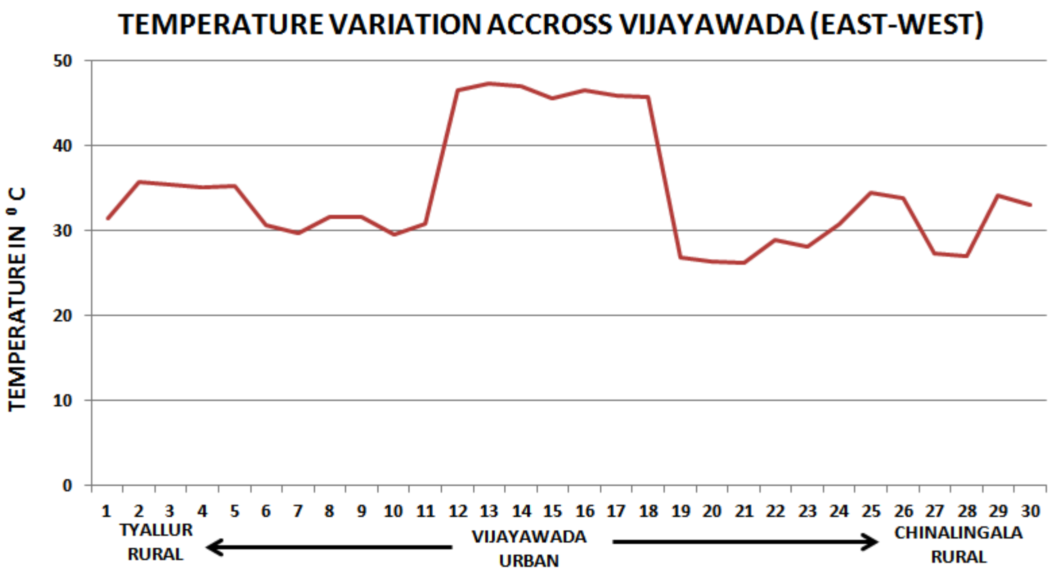

Figure 6: *Land Surface Temperature variation across Vijayawada from East to West*

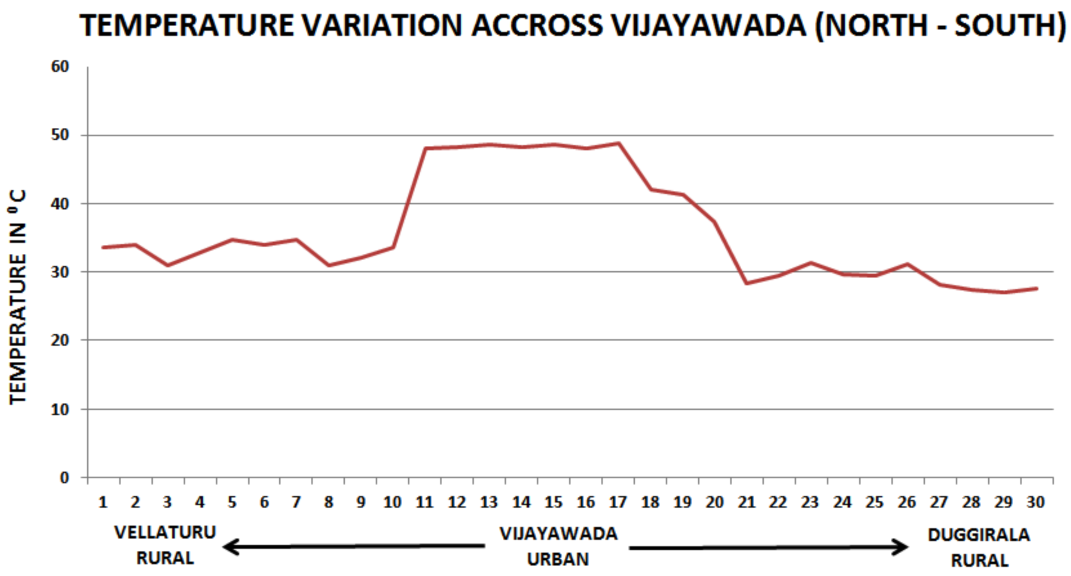

Figure 7: *Land Surface Temperature variation across Vijayawada from North to South*

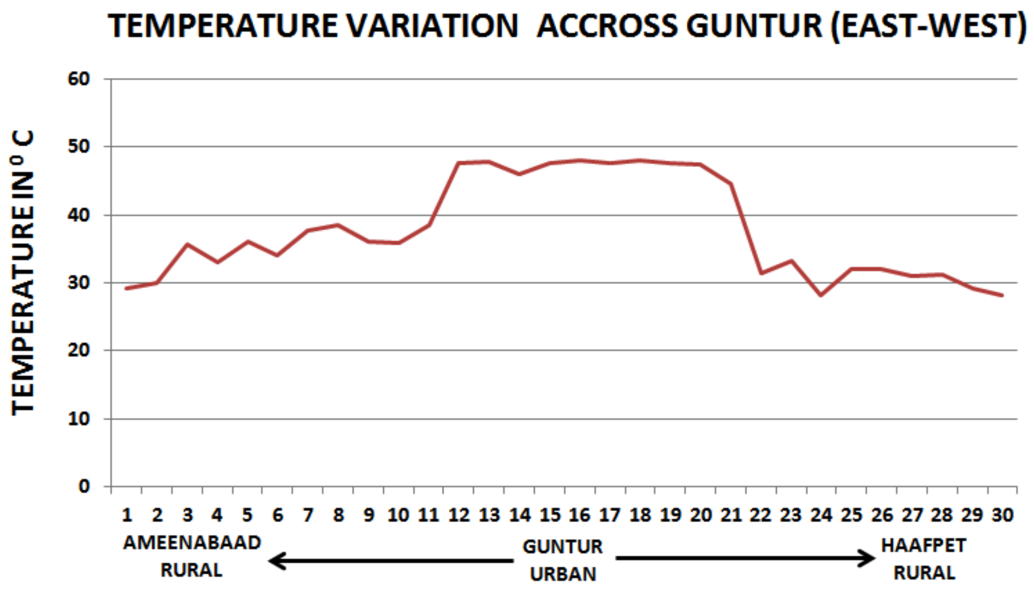

Figure 8: *Land Surface Temperature variation across Guntur from East to West*

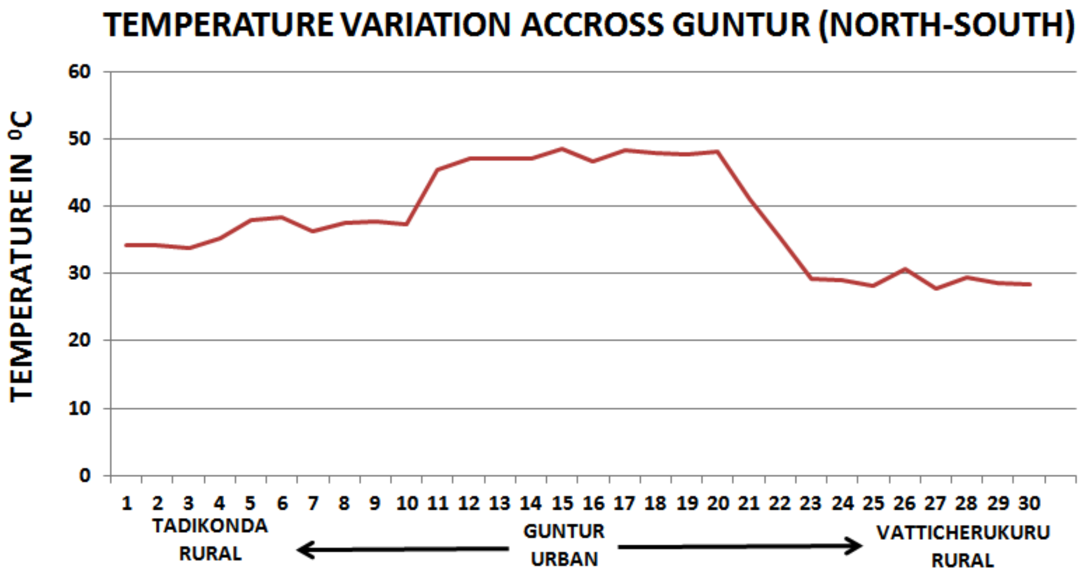

Figure 9: *Land Surface Temperature variation across Guntur from North to South*

5. Conclusion

The new capital of Andhra Pradesh state situated in APCRDA region is considered as a case study to examine the land use land cover (LULC) and land surface temperatures (LST). In this work Landsat-8 image for the date 23-05-2015 was collected and processed to develop LULC images. The area has been divided in to seven classes according to the type of land observed in the field. More than 100 points were selected in the study area and conducted field survey work with GPS. The field data was supplemented for LULC classification as well as for development of emissivity. The classification accuracy was obtained as 93%. From the thermal band and emissivity, LST image has been developed using ERDAS modelling. By studying the LULC image and LST image it is observed that high temperatures are developed in those areas where urban or built-up areas exist with less vegetation. The low temperature and high temperature values observed are 23.9°C and 58.2°C respectively. Through this satellite based study it is concluded that the region experiences severe UHI phenomenon. The two big cities namely Vijayawada and Guntur are identified as hot spots. This research can be used as a reference or scientific basis for urban planners in urban planning and management as well as to increase the community awareness in urban heating effect.

Acknowledgement

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