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Relationship Between Surface Temperature and Land Cover Types Using Thermal Infrared Band and NDVI for Vellore District, Tamilnadu, India

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ABSTRACT

Increasing urbanization in Vellore, Tamilnadu creates a serious anthropogenic pressure resulting rapid change in land cover in recent time. Changing land use condition affects surface temperature. The relationship between surface temperature and land cover types has been studied for Vellore district interpreting satellite image of landsat-7 ETM+thermal infrared bands and values of NDVI for 2016. Analysis reveals that urban and most populous areas have higher surface temperature (35-43°C) than temperature in the dense forest cover areas (13-27°C) with high NDVI value (0.98) in scrub land and low value (-0.95) in water bodies. Several eco-geological influencing factors those interplay to bring about change in land cover were found correlated with thermal infrared band spectra and NDVI values. The study envisages the utility of thermal spectra and land use/land cover change in urban planning.

INTRODUCTION

The climate change, changing pattern of land use and land use change effect on climate is an important issue worldwide (Pielke et al. 1991). Among them temperature variation caused by land use change has brought serious condition due to its direct effect on environment and has changed the way of living of human beings (Wijitkosum 2011). Vellore district lies in the northern part of Tamilnadu, a southern state of India which is under sub-tropical climate with average high temperature and low rainfall with increasing population. There are only three meteorological stations (Vellore city, Gollapally, Tirupatur) in Vellore district which have been recording temperature daily twice revealing atmospheric temperature condition of the surrounding areas. However, these recording facilities are not enough for covering temperature condition of the whole district. Moreover, different types of land surfaces are responsible for temperature difference in local level also (Philke et al. 1991). To overcome the situation and to understand the near-to-real time condition, thermal remote sensing is the best option (Thi Van & Xuan Bao 2010). The relationship between land surface temperatures and land cover types can easily be made by satellite infrared band (Chen et al. 2008). Chen et al. (2006) studied the Pearl River Delta region of southern China and revealed that rapid changing pattern of urbanization from the year of 1990 made Pearl River delta region as an "urban heat island". Again, study showed that urban surface could be responsible for producing the influence of the dynamics of air movement where varied surface temperature was observed from urbanized surface to forest cover, agricultural land and water logged area (Oke & Cleugh 1987). Owen et al. (1998) observed that soil moisture condition, different vegetation cover as well as evapotranspiration, and latent heat fluxes are responsible for variation of different surface temperatures. It is observed that more vegetated as, for example, forest cover area has higher level of latent heat exchange than the sparsely vegetated area, like urban area (Oke & Cleugh 1987). Processing thermal data from satellite image and producing temperature distribution image of an area is a simple process but the interpretation and understanding the cause of temperature variation is not an easy task due to many other factors, which are responsible for it. Surface temperature in urban or built up areas depends upon urban morphology such as building materials, geometry of the buildings, and density of buildings (Weng et al. 2004). Besides, certain internal properties of surface materials are also involved to govern the temperature, such as heat capacity, thermal conductivity and inertia (Campbell & Wynne 2011). Martha et al. (2008) described the relationship between surface temperatures with vegetation types (Raynolds et al. 2008). They calculated normalized difference vegetation index (NDVI) from satellite data for clear identification of the greenness

of vegetation cover in Arctic region to relate with surface temperature. Summer temperature increases in faster rate in Arctic region. Researcher studied the relationship between forest cover and temperature and effectively monitored the significant changes of temperature (Raynolds et al. 2008). Land surface temperature effectively could be related to vegetation and was shown experimentally elsewhere (Carlson et al. 1994). Advanced Very High Resolution Radiometer (AVHRR) data were used for surface temperature monitoring, however recently Thematic mapper, Enhanced thematic mapper+TIR data with 60 meter spatial resolution are used for extracting surface temperature (Weng 2001).

In the present study, land surface temperature for Vellore district has been estimated and related from the thermal band of ETM+ imagery and values of NDVI for the year 2016. The study depicts the surface temperature variation with land cover types. The aim of this study is to understand the surface temperature differences between different land uses and main drivers behind these types of temperature differences for the year 2016. The analysis would be useful in urban planning.

STUDY AREA

The study area is Vellore district, which lies in the northern part of the state Tamilnadu of India. It is bounded by 78°20' East longitude to 79°59'East longitude and 12°15' North latitude to 13°15' North latitude (Fig. 1). Geographically, Vellore district is surrounded by the state of Andhra Pradesh and Tiruvallur district by its north, Andhra Pradesh state by its north-western part, Dharmapuri and Tiruvannamalai districts by its southern part, and Kancheepuram district by its eastern part. The main river is "Palar", which was once the heart of the district, has now been totally dried up. Other tributaries of "Palar" also became dry. The area is under sub-tropical climate and high temperature (~40°C) has been prevailing all the year round. Vellore gets rainfall two times in a year; first time monsoonal rainfall occurs in the months of July-August and the area gets rain second time from retreating monsoon occurring in the months of November-December. As the area lies under rain shadow part of Western Ghat range of hills, it gets very less rainfall from monsoonal season (July-August). Jawadhu hills surround the district in its southern part and other hills cover its western and northern part (Fig. 2). The hilly regions are filled with forest covers, which are under reserve forest area. Dense scrub, open scrub and bush lands are found throughout the area (Fig. 2). Most of the ponds and tanks are dry, and are full of scrubs. Furthermore, about 16,000 ha is occupied by *Prosopis julifera* (Staff Reporter 2017) and about 35,000 ha agricultural land in the western part of the district is unfit

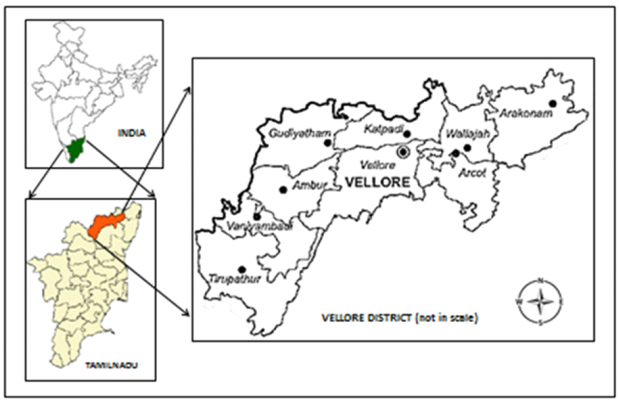

Fig. 1: Location map of the study area (not to scale).

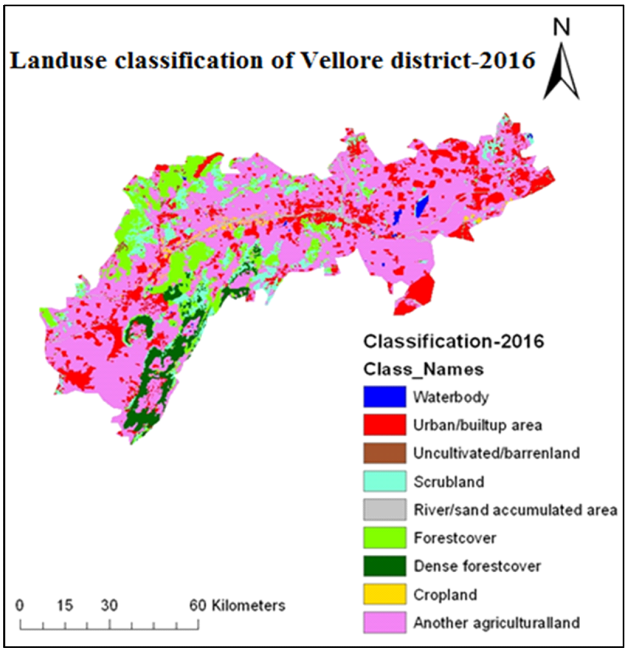

Fig. 2: Land use classification map of Vellore district, 2016.

for cultivation because of contamination with tannery effluent water (Venkattakumar 2004). All these eco-geological conditions express the dryness of the area.

Besides, increasing population in Vellore district has made it the third populous district of the state (http://www.tn.gov.in). The century old renowned Christian Medical College and Hospital (CMC) attracts floating population from throughout the country as well as from neighbouring countries for medical help. Besides, Vellore Institute of Technology (VIT) (educational) and Golden temple (pilgrimage) are other attracting points of the district. This area is within 140 km from the state capital, Chennai. According to census 2001, the population was 34,77,317 and

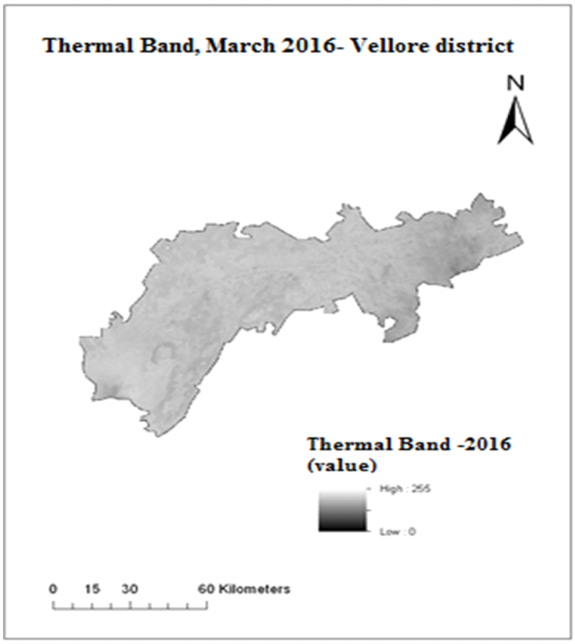

Fig. 3: Thermal band map of March, 2016 of Vellore district.

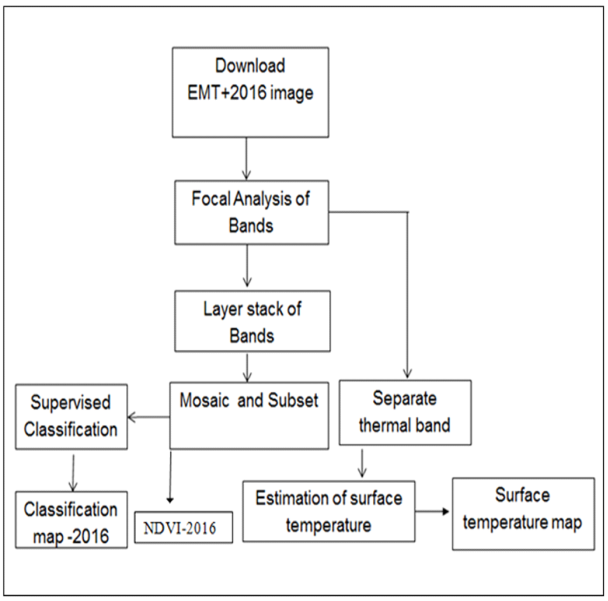

Fig. 4: A descriptive flow chart of methodology followed.

39,28,106 in 2011 in the district with 12.96% increase and there is high rise in urban population from 37.62% to 43.13% in decadal time (http://censusindia.gov.in/2011).

MATERIALS AND METHODS

To evaluate surface temperature and its relationship between land cover types, two sets of satellite imagery have been downloaded from USGS Earth Explorer. As the study area is large (6405km^2), so two scenes were collected, mosaicked, and extracted the area of interest gradually for further processing following standard procedure. Landsat-7 ETM+2016 data were downloaded. March is a summer month in Vellore district. The Infrared band, which is Band number-6 from Landsat 7 ETM+, data were acquired on 14th March, 2016 for one scene and 21st March, 2016, for another scene. For extracting surface temperature, only thermal band is necessary. For ETM+sensor Band number 6 was the thermal band used (Fig. 3). Other bands (total 9 bands) also were downloaded and layer stacked by ERDAS software, for supervised image classification (Fig. 2). Then NDVI for the year 2016 (Fig. 8) was employed for monitoring the vegetation cover and other features of the area for assessing the relationship with surface temperature with necessary statistical analysis.

Image pre-processing: For the purpose of image clearance and to remove noises from the image, focal analysis for each band was done with ERDAS IMAGINE software. Periodic noises like strips affected to retrieve land surface temperature from thermal band (Chen et al. 2006). Images were registered with UTM/WGS84 projection zone.

Classification: Supervised landuse classification with the help of ERDAS IMAGINE was prepared for better understanding of the surface feature condition of the study area (Fig. 2). Nine classes of land uses, namely waterbody, cropland (paddy), another agricultural land (ground nut, sugarcane, vegetables, fruit gardens), dense forest cover, forest cover (open or sparse vegetation), scrub land (dense/open thorny bush), river/sand accumulated area, urban/built up land and uncultivated or barren land which were identified for land use classification thematic map (Fig. 2). For identification of the signature required for each class in the supervised classification, Google Earth, Ground truth, satellite image of ETM+ 2016, false colour composite with band combination of 4, 3 and 2 were used. To remove salt and pepper effect on the classified image, statistical filtering was carried out. A detailed description of the methodology is depicted in a flow chart (Fig. 4).

Estimation of the land surface temperature: Three steps were followed to estimate the land surface temperature from thermal infrared band (NASA 2009). These were as follows:

1. *Calculation of conversion of DN values of the study area to spectral radiance (λ):* The Digital number (DN) of Band 6 is converted to spectral radiance (λ) by the following formula:

$$\lambda = \{LMIN\lambda+(LMAX\lambda-LMIN\lambda)\div(QCAL\ MAX)*QCAL\}$$

Where, LMAXλ and LMINλ are the spectral radiance

values for the thermal band 6, QCALMAX and QCALMIN are the maximum and minimum digital number for the study area which are 255 and 1 respectively. QCALis the total digital number of the study area (Chen et al. 2006).

2. *Conversion of spectral radiance to temperature (K):* The spectral radiance then was converted to at-satellite brightness temperature in Kelvin (T) by the following formula:

$$T = \frac{K2}{In\left(\frac{K1}{L_\lambda} + 1\right)}$$

Where, T is the effective satellite temperature in Kelvin,
K_1 = Calibration constant 1 (watts/meter squared* ster* µm)
K_2 = Calibration constant 2 (watts/meter squared* ster* µm)
Lλ = Spectral radiance (derived from the first formula).

3. *Conversion of temperature from Kelvin to degree Celsius:* T is the effective satellite temperature in Kelvin is converted to Celsius (°C):

(Celsius = T-273.15)

In this study, the maximum radiance value of **-17.040** and the minimum radiance value of 0.000 were used for 2016 image where quantize cal max was 255 and quantize cal min was 1. Calibration Constant, K_1 = 666.09 and K_2 = 1282.71 were used for the necessary calculations.

With the help of Arc GIS 9.3, the boundary of the district was extracted (extracted by mask option in Arc Toolbox) from mosaicked thermal bands. This extracted area of interest was used in Raster calculator module for further calculation followed by deriving a surface temperature thematic map (Fig. 5).

NDVI was calculated from Visible (0.63-0.69µm) and Near Infrared (0.77-0.90µm) Band of 3 and 4 respectively from ETM+image of the year 2016 and an NDVI map was prepared (Fig. 8). Subsequently, land use classification image of 2016 (Fig. 2), surface temperature image (Fig. 5) and NDVI image (Fig. 8) were overlaid to derive the proper condition of land surface area under different temperatures.

Statistical analysis: The necessary statistical calculations like mean, standard deviation and correlation were performed to define the results in this study.

RESULTS AND DISCUSSION

March month is a hot month in the year for Vellore district in the state of Tamilnadu. The Infrared band number-6 from Landsat 7 ETM+data was acquired; one scene on 14th March, 2016 and another scene on 21st March, 2016. Different kinds of land use were found responsible for different temperature conditions (Fig. 2). The study from surface temperature

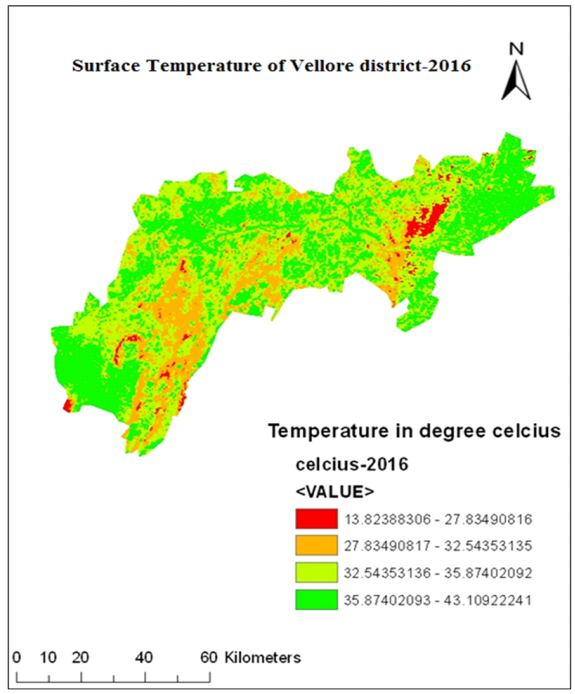

Fig. 5: Surface temperature map of Vellore district, 2016.

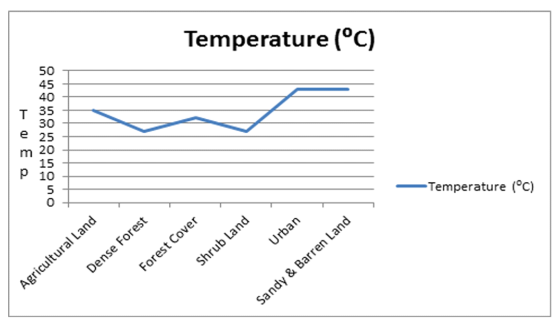

Fig. 6: Relationship between landuse classes and surface temperature.

reveals that the surface temperature is ranging from 13°C to 43°C throughout the area (Fig. 5). The water body, shrub land and dense forest area had temperature ranging from 13°C to 27°C (20°C ± 9.9) (Table 1). This is explained with the differential thermal energy responses (Earth's albedo) with the landforms of the study area. Earth's albedo is a diffuse reflectivity or reflecting power of the surface (Lillesand et al. 2004). Forest cover generally has a low albedo due to maximum absorbance of most of the light of ultraviolet and visible spectra by the trees (Lillesand et al. 2004). So, it is suggested that afforestation is beneficial due to its cooling effect and carbon adjustment in the environment (Betts 2000). Further, trees are responsible for evapotranspiration (loss of water as vapour through stomata)

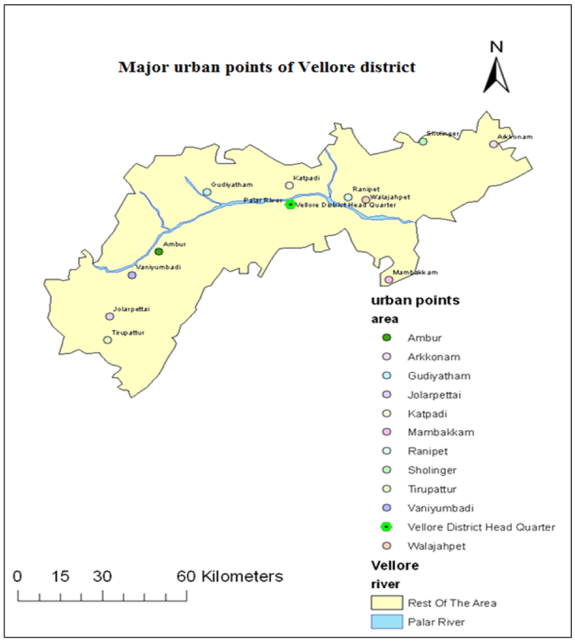

Fig. 7: Map of major urban locations of Vellore district.

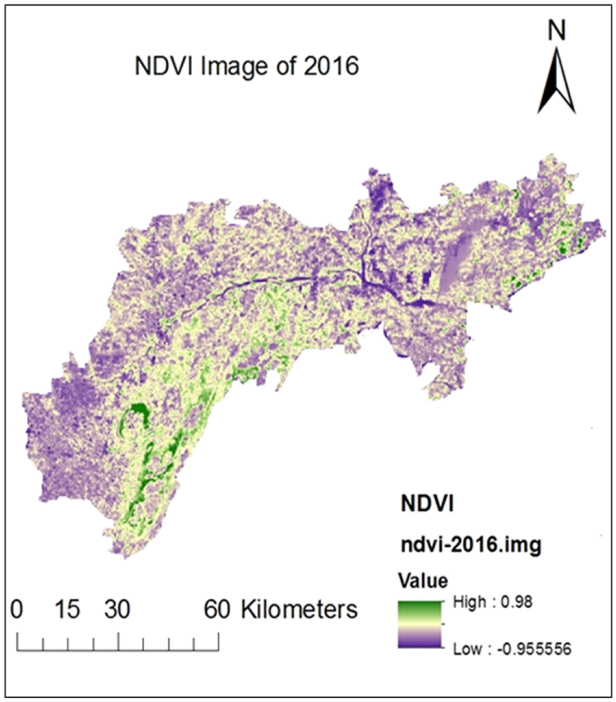

Fig. 8: Map of NDVI-2016 of Vellore district.

cause little cooling effect nearby (Environmental Encyclopaedia 2003). It is also perceived that different types of land cover/use are possible to differentiate on the basis of thermal band based surface temperature analysis. Scrub lands sometimes dense or open are mainly thorny bush, babul, acacia varieties are found (Fig. 3) throughout the area with the temperature of °C. It is unlike from forest cover due to its height, width, canopy distribution. Local name of the thorny plant of scrubland in the district is Seemai Karuvelam which is familiar by *Prosopis juliflora* scientifically. Recently State Government has started the project to clear the thorny bush land, Seemai Karuvelam and 15% trees have been removed already (Staff Reporter 2017).

Beside dense forest cover, open forest or sparse vegetation is also present in the district (Fig. 2) where temperature lies between 27°C and 32°C (mean 29.5°C± 2.2) (Table 1), depending on several conditions like types of forest cover, thickness of the forest and leaf canopy (Raynolds et al. 2008). In the sparse vegetation area, soil temperature and soil moisture also affect the radiant temperature condition (Weng et al. 2004), so correct temperature is difficult to derive. Due to existing forest cover, the temperature and vegetation dynamics interplay and lead to the variation in spectral radiance and texture in land surface temperature (Weng et al. 2004).

Land cover like crop land and another agricultural land, urban or built up areas, sandy and uncultivated land displayed temperature between 35°C and 43°C (Fig. 6) with mean temperature of 39°C (±5.65) describing a wide variation in the temperature in this group. Crop land and another agricultural land were shown as agricultural land due to same temperature condition (35-43°C). As observed, open uncultivated fields, sandy areas, urban land use have high spectral radiance throughout the study area with temperature range of 35- 43°C. With the high spectral radiance and lowest rainfall, no significant food crops are cultivated in March (Rasheed & Venugopal 2009).

It is clear that urban areas raise high temperature of 43°C which is a sign of ecological threat for the area (Fig. 7). Vellore city is in the heart of the district. Besides Vellore, other urban areas like Gudiyatham, Vaniyambari, Ambur, Arkkonam, Ranipet, Wallajahpet, Sholinger, Jolarpet and Tirupattur are the populated areas where the thermal band corresponds distinctly to landuse classification (Fig. 7). Van & Bano (2009) studied the surface temperature with thermal band of NOAA/AVHRR Data, and land surface relationship for Hochimin city, Vietnum was described the urban heat island effect on the city area. For increasing population, cultivated land transferred to urban settlement and the cause of concrete buildings in Hochimin city became "urban heat island" than nearby areas. Likely, it is observed that high surface temperature prevails in Vaniyambari, Ranipet and Wallajahpet are the industrial park of the district and are known for leather industry, leather based prod-

Table 1: Relationship between land use classes and surface temperature difference.

Land use classes	Temperature-range (°C)	Mean	S.D. (standard deviation)
Water body, Dense forest, Scrub land	13-27	20.0	9.9
Forest cover	27-32	29.5	3.5
Agricultural land	32-35	33.5	2.12
Urban/built up land,Sand accumulated area, Barren/uncultivated area	35-43	39.0	5.65

Table 2: Relationship among land use classes, NDVI and surface temperature (ST).

Land use classes	NDVI value	ST(mean)	Correlation
Scrub land	0.98	20.0	-0.1212
Dense forest	0.51	20.0	
Forest cover	0.26	29.5	
Agricultural land	0.15	33.5	
Urban/built up land, Sand accumulated area, Barren/uncultivated area	-0.09	39.0	

uct production and heavy electricals (Fig. 7). Population density is also comparatively high in these areas (http://www.tn.gov.in) and has been increasing with the announcement of making Vellore as a smart city in resent time (Staff Reporter 2017). Thus, the increasing anthropogenic activities with the landuse/cover change, climatic conditions, scarcity of surface water, overexploitation of groundwater (Staff Reporter 2017) has pushed the study area to be a part of drought-prone area in near future. Due to corresponding eco-geo-climatological changes, Palar, the main river of the area became dry for more than 30 years and filled with sand emits high temperature. Land surface patterns and temperature relation curve identifies the condition of the area (Fig. 6).

Besides thermal band analysis, NDVI and mean surface temperature correlation (Table 2) has notified that there is negative correlation of -0.1212 between vegetation cover and mean surface temperature, depicting that forest cover (open), dense forest cover, scrub land area have higher NDVI of 0.27, 0.51, 0.98 respectively with lower temperature range of 13°C to 32°C in south-western part of the district than urban/built up, sand accumulated area, barren land with 35°C - 43°C (Table 2). Water body having the lowest NDVI of -0.95 with low temperature of 13°C, was found in the eastern part of the district. It is explained that available waterbodies in the region generally absorb day time heat more slowly than land surface. In vegetated areas higher level of exchange of latent heat was found while minimum latent heat exchange was more favoured in less vegetated areas like urban or built up area, and barren land (Oke & Cleugh 1987) resulting in different cooling effects of different areas and surface temperature displayed. Most of the areas of the district were under high temperature range of 35°C to 43°C because of less vegetation cover and urbanization (Fig. 8).

CONCLUSION

Association between land surface temperature and land cover types directly has been derived from the remote sensing data which enable to monitor the relationship between environment with anthropogenic activities. The study endorses the importance of application of thermal infrared remote sensing to qualify landuse/cover classification with surface temperature of different surface patterns. In the Vellore district, the core city area has been expanding rapidly with rapid conversion of agricultural land to urban land. Throughout the district urban pockets are increasing rapidly by width and length, damaging agricultural land for spreading waste water from tannery industries causing development of open, bare land which are becoming responsible factors for increasing surface temperature. Improvement of soil quality, wastewater treatment from tannery industry, conversion of scrub land to agricultural ground, irrigated agriculture, afforestation, rejuvenation of Palar river from its dry sandy condition to perennial, improvement of groundwater quality and proper urban planning can improve the sustainable environmental condition of the study area. The study between the surface temperature and land cover types may offer help to upgrade environmental conditions and can control reduction of excess temperature condition by adopting correct planning strategies.

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