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Estimation of Spatial Variability of Land Surface Temperature using Landsat 8 Imagery

[1]Prasad Rajendran , [2]Dr.K.Mani
[1]*Assistant Professor, Department of Geography, UniversityCollege, Thiruvananthapuram, Kerala*
[2]*Associate Professor, Department of Geography, University College, Thiruvananthapuram*

ABSTRACT
Land Surface temperature(LST),the skin temperature of the ground,is identified as a significant variable of microclimate and radiation transfer within the atmosphere.Remote sensing(RS) has been widely recommended for its potential to detect surface temperature variability and,GIS (Geographic Information System) supplemented with ground truthing allows spatio-temporal analysis of surface temperature in the urban regions.In this study,land cover classification is used to define LSE(Land Surface Emissivity),which is required for the calculation of LST over Thiruvananthapuram, Capital city of the state of Kerala,India.Landsat8 TIRS (Thermal Infrared Sensor) and OLI (Operational Land Imager) bands were primarily utilized to classify land cover types and to estimate the surface thermal characteristics.The results showed that surface temperature is a function of diverse surface soil-water content and vegetation cover.

Keywords: *Land Surface Temperature, Remote Sensing, GIS, Thermal Infrared Band*

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I.INTRODUCTION

The process of urbanization, in general, is concerned with conversion of arable lands into paved surfaces and decline in the natural vegetation cover. The increasing Impervious Surface (IS) has a warming effect on the surface temperature of the urban environment. Urban development coupled with unsustainable land management practices has a great impact on the local climate of a city. The abrupt land cover changes modify amount of absorption of solar radiation, evaporation rates, thermal storage of surfaces and wind turbulence. Surface temperatures are increased by anthropogenic heat discharges due to energy consumption, increased land surface coverage by artificial materials having high heat capacities and conductivities and the associated decrease in vegetation cover [1].LST can provide important information about the surface physical properties and climate which plays a role in many environmental processes [2].LST is the brightness temperature of the ground,and thus determines the surface air temperature. The changes of Land Surface Temperature were related to many factors, including changes in land use,l and surface parameters, economic development etc.[3].Surface emissivity is a crucial parameter for estimating LST. It is a dimensionless number between 0 (for a perfect reflector) and 1 (for a perfect emitter).The emissivity of a surface depends not only on the material but also on the nature of the surface.Emissivity is defined as the ratio of the energy radiated from a material's surface to that radiated from a blackbody (a perfect emitter) at the same temperature and wavelength and under the same viewing conditions.Spatio-temporal values of LST derived from remotely sensed satellite data can be used as an index to support sustainable urban development and landscape planning. Satellite based Thermal Infrared (TIR) data is directly linked to LST through radiative transfer equation [4].

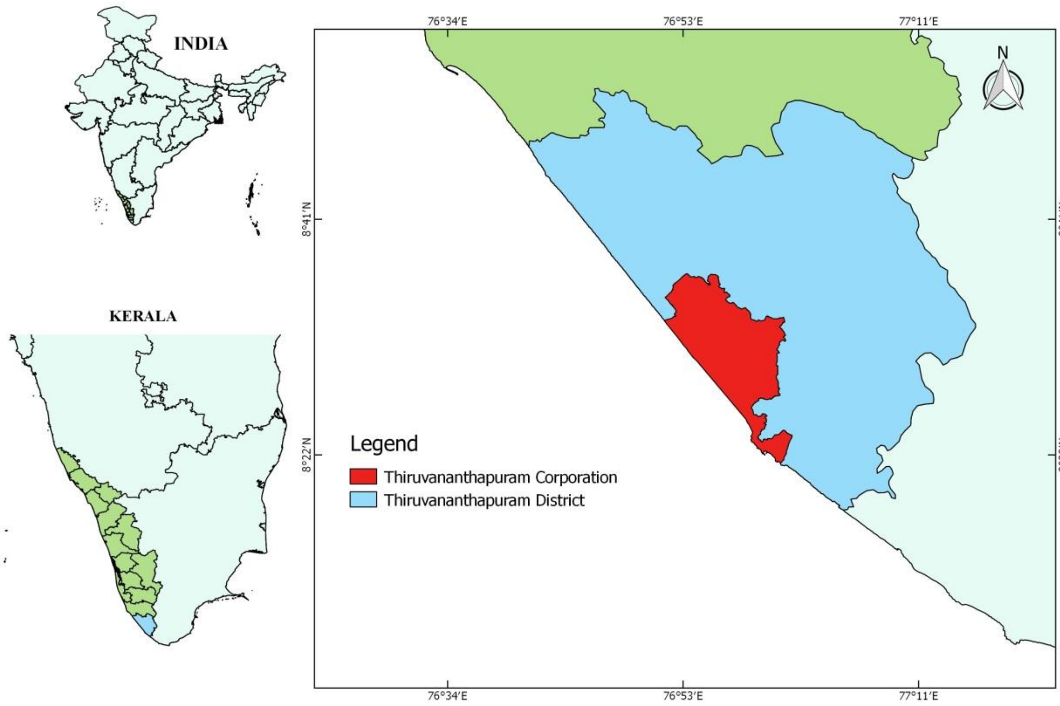
The Landsat program is the longest continuous exercise in the acquisition of multispectral digital record of the earth's surface from space.Landsat 8 has two thermal bands 10 & 11(TIRS) to capture data with a minimum of 100 meter resolution, but are registered to and delivered with the 30-meter OLI data product,useful in providing more accurate surface temperatures.TIRS uses Quantum Well Infrared Photo detectors (QWIPs) to detect long wavelengths of light emitted by the Earth whose intensity depends on surface temperature.The QWIPs TIRS uses are sensitive to two thermal infrared wavelength bands, helping it separate the temperature of the Earth's surface from that of the atmosphere [5].Since surface temperatures directly related with surface physical properties, land cover classification is ideal for estimating LST in the urban environments.

The major objective of the study is to estimate the spatial variability of land surface temperature based on the land cover patterns in the rapidly growing urban agglomeration of Thiruvananthapuram, the capital city of Indian state of Kerala.

II.STUDY AREA

Thiruvananthapuram is an Urban Agglomeration (TUA) coming under the category of Million plus UA/City (Census of India, 2011) located on the west coast of India. Thiruvananthapuram metropolitan area/Urban Agglomeration consists of Thiruvanthapuram Corporation, municipalities of Attingal, Nedumangad ,Kazhakkoottam, Varkala, Neyyattinkara. The area selected for the study is Thiruvananthapuram Corporation covering an area of 214.86 km².It lies between 8°12'23"N to 8°36'27"N latitudes and 76°51'17"E to 77°0'58"E longitudes.The region is characterized by undulating terrain of low coastal hills with mean elevation ranging from 0 to 80 m above MSL.The region enjoys a warm-humid climate with high annual variability of rainfall.Thiruvananthapuram is drained by Karamana and Killi rivers which joins the Arabian Sea at Thiruvallom.The Corporation has a population of 9,57,730 (2011) with a population density of 4,454/km².

Study Area :Thiruvananthapuram Corporation



III.MATERIALS AND METHODS

Landsat 8 OLI and TIRS images of March,2015(Path/Row-144/054) pertaining to the study area were used to classify land cover types and the estimation of land surface temperatures.Topographic maps of Survey of India (SOI) of 1:25,000 were used as the base map for the present study. Hand held GPS (Global Positioning System) was used to collect necessary ground truth data and the classified outputs were validated using Google Earth.All tasks were carried out in Free and Open source (FOSS) Quantum GISenvironment,usingSemi-Automatic Classification Plugin 4.3.3 for image classification and estimation of land surface temperatures.

Methodology

Techniques of Thermal Infrared (TIR)remote sensing has been used to study urban climate and environment,and especially for assessing LST patterns and their relationship with surface characteristics[6].The study utilized potentials of Semi-Automatic Classification plugin integrated with Open Source GIS package Quantum GIS for image acquisition,pre-processing,image classification and derivation of LST from land surface emissivity values.Detailed description of the methodology is outlined here.

Image acquisition and Pre-processing

Cloud free Landsat scenes of the study area (Path/Row-144/054) was downloaded via direct access using SCP in QGIS environment.The images were further rectified to Universal Transverse Mercator Projection based on 1:50000 topographical maps of SOI (Survey of India).Next step involved 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 metadata:

$T_B = K_2 / \ln((K_1/ L\lambda)+ 1)$ *where:*

T_B *= At-satellite brightness temperature (K)*
K_1 *= Band-specific thermal conversion constant (watts/m² * ster * µm)*
K_2 *= Band-specific thermal conversion constant (in kelvin)*

*Lλ is the Spectral Radiance at the sensor's aperture (watts/(m² * ster * µm)*
$L_\lambda = M_L Q_{cal} + A_L$

where:
Lλ = TOA spectral radiance (Watts/(m² srad * µm))*
ML = Band-specific multiplicative rescaling factor
AL = Band-specific additive rescaling factor
Qcal = Quantized and calibrated standard product pixel values (DN)

Image Classification and derivation of emissivity (e) values

In order to detect changes in the surface reflectances, it was necessary to categorize the land cover of the study area. The land cover classification was used to define the land surface emissivity.The major land cover classes identified in the study area include: Built up (Buildings,asphalt roads and artificial areas),Bare Soil (Soil without vegetation),Agricultural land,Mixed Vegetation (include scrubland and grasses),and Water body (surface water). For performing classification procedure,a training shapefile was created to store the several ROIs that define the land cover classes.This study employed a supervised signature extraction with Spectral Angle Mapping algorithm to classify the Landsat bands.The classification accuracy was assessed with ROIs already created and ancillary data collected through field survey [7].

In the post-classification phase,land cover classes were reclassified using the land surface emissivity values.Surface emissivity of different land cover classes were obtained through field broadband measurements under cloud free sky and laboratory spectral measurement for samples selected from the study area.

Estimation of Land Surface Temperature

Contact measurements of emissivity values of the surfaces using thermal radiometers and spectral assessment of samples supplementedLST estimation procedures in this study.Since the temperature values obtained as at-satellite temperature T_B,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 [8]:

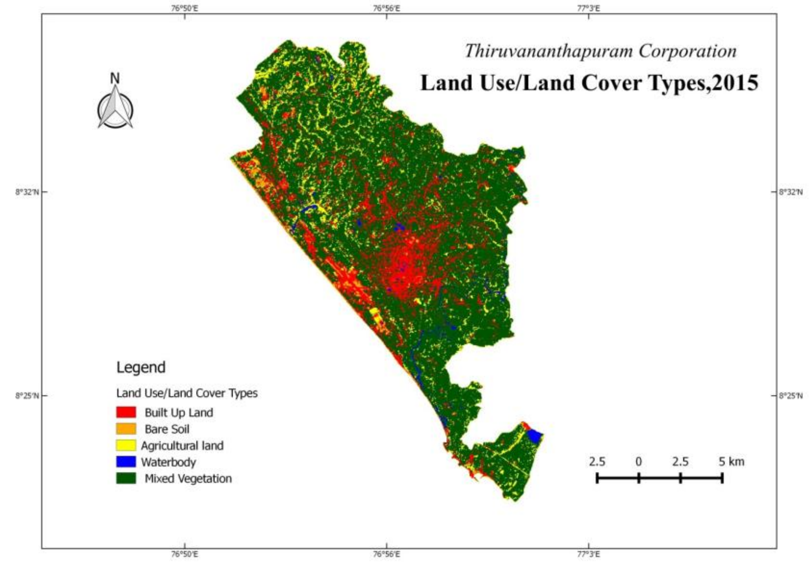
$$St = T_B / 1 + [\lambda * T_B / \rho] \ln\varepsilon$$

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 = Boltzmann constant (1.38 * 10^-23 J/K, c = velocity of light (2.998 * 10^8 m/s)

IV.RESULTS AND DISCUSSION

Analysis of Land use/Land Cover

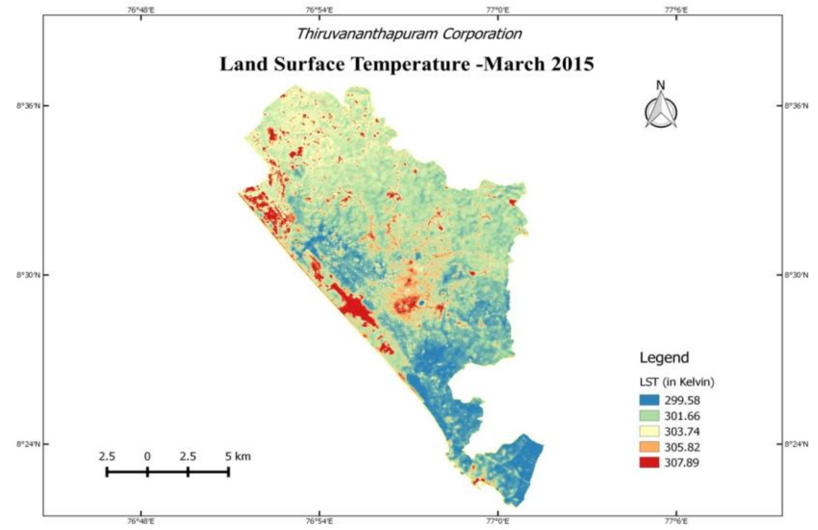
Landsat scenes of March,2015 (Path/Row-144/054) were used to characterize land use/land (LULC) cover patterns and their dynamism in TUA.The images were classified using the Spectral Angle Mapping algorithm with an overall accuracy of 98 %.Pattern of urban growth has profoundly influenced the LULC patterns of the study area during the last two decades. Prior to 2000,spatial evolution of urban expansion represented a linear pattern, typically along the major roads,radiating from the city centre.Contrarily,period after 2000 witnessed intense urban growth in the peripheral rural landscapes.This tremendous shift in the spatial patterns of urban growth trend was contributed to the developments related to industrial and IT-based services in the fringe areas.Unplanned infrastructural developments and un regulated urban sprawl effects have modified the physical character of the urban core and the peripheral rural areas.There has been large scale conversion of agricultural lands and low-lying wetlands into urban residential land usewhich has become a common phenomenon in the study area.These undesirable spatial changes resultedin the increase of impervious cover,loss of greenness;factors that govern the local climate of the area.Hence,characterizing land use/land cover patterns of the study area wasnecessary for understanding surface temperature characteristics.Built up land covers an area of 84.01 km²,contributing 39% of the total surface area.Largest area is occupied by mixed vegetation (132.86 km²).Spatial interpretation of the land use/land cover reveals dominance of built up environment along the coast and the urban core.A diagrammatic description of the land use/land cover distribution is given in the following figure.



Estimation of Land Surface Temperature (LST) using Emissivity (*e*)

In order to derive the emissivity raster,the classification raster representing LULC classes were reclassified by assigning the surface emissivity (*e*) values obtained through field broadband measurements under cloud free sky and laboratory spectral measurement for samples selected from the study area.The following surface emissivity values were obtained the for the land cover classes: Built-Up-0.94,Bare Soil-0.93,Agricultural land-0.95,Water Body-0.98,Mixed Vegetation-0.98.

The reclassified map (emissivity raster) indicated variability of surface emissivity of various surfaces in the study area.Using the brightness temperature raster (T_B) and Emissivity raster (*e*) Land Surface Temperature (in Kelvin) was determined for the study area.The resultant LST image is given below.



LST output derived using the brightness temperature and surface emissivity ranges between 299.58ºK (26.43ºC) and 307.89ºK (34.74ºC).It is observed that highest LST values (above 305ºK) are recorded over north western,north eastern and central part of the area where built environment,waste lands and bare earth dominate the land surface.Lowest LST values below 300ºK (26.85ºC) are observed in areas where vegetation is abundant.Moderate values ranging between 301.66ºK (28.51ºC)and 303.74ºK(30.59ºC) are recorded over agricultural lands mostly in the northern part of the study area. LST recorded over Built up environment is maximum and the values are minimum over vegetated areas.

V.CONCLUSION

This study investigated the spatial variability of land surface temperature over Thiruvananthapuram located on the south western part of India.This rapidly growing urban agglomeration represents a heterogeneous landscape structure.Landsat 8 OLI and TIRS bands where used to determine the thermal characteristics of surface environment.The LST values derived through the analysis are dependent on land cover distribution and are negatively correlated with vegetation abundance.The variations of land surface temperature are also indicators of the spatial patterns of urban heat island effects.The results derived through this study indicate that that geospatial methodology of the surface temperature estimation would assist the studies on urban microclimate and effective land use planning.

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