Land Use/Land Cover Change Analysis of Bangalore Urban District and Its Impact on Land Surface Temperature

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NATIONAL SYMPOSIUM ON

REMOTE SENSING AND GIS FOR ENVIRONMENT WITH SPECIAL EMPHASIS ON MARINE AND COASTAL DYNAMICS

and

ANNUAL CONVENTIONS OF

INDIAN SOCIETY OF GEOMATICS & INDIAN SOCIETY OF REMOTE SENSING

December 4-6, 2013, Visakhapatnam

Full Papers

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Land Use/Land Cover Change Analysis of Bangalore Urban District and Its Impact on Land Surface Temperature

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Abstract: This study mainly aims to analyse the impact of the changes in Land Use/Land Cover (LU/LC) of Bangalore Urban District over its Land Surface Temperature (LST). LU/LC change analysis was performed using temporal LANDSAT TM (Thematic Mapper) Images (1999/2009). The LU/LC change analysis was done by Post Supervised Classification Change Detection technique. The LST was retrieved using the LANDSAT TM's thermal band. Mono window algorithm was used in estimating the atmospherically corrected LST. The LST variation over the different land use over a period of one decade (1999/2009) was investigated. In addition, the correlation between LST and the Normalized Difference Vegetation Index (NDVI); Normalized Difference Built-Up Index (NDBI) has been studied. Rapid Urbanization in Bangalore Urban District has resulted in the changing land use and increasing land surface temperature. The study shows that the Built-up class has increased by 78.96% from 1999 to 2009, indicating rapid urbanization and industrialization of Bangalore Urban District and steep increase in the urban population. The LST was found to be higher in the outskirts compared to heart of the District. It was found that the LST value has increased on an average by 1.7°C and 2.2°C (without and with atmospheric corrections). The NDBI and LST showed a positive correlation whereas the NDVI and LST showed a negative correlation, signifying the increasing built-up and loss of vegetation to higher LST. The impact of land use/ land cover on land surface temperature is discussed.

Keywords: LU/LC, LST, NDVI, NDBI

1. Introduction

The Physical and biological cover of the earth's surface including artificial surfaces, forests, minerals, mountains, natural areas, wetlands, water bodies constitute Land Cover (LC). Land Use (LU) is the human use of land. Land Use involves the management and modification of natural environment or wilderness into built environment such as fields, pastures and settlement features. LU/LC changes date to pre-history and are the direct and indirect consequences of human actions, transforming land to secure essential resources. It may first have occurred with the burning of areas to enhance the availability of wild game and accelerated intensely with the birth of agriculture, resulting in the extensive clearing (deforestation) and management of earth's terrestrial surface that continues today. More recently, industrialization has encouraged the concentration of human populations within urban areas (urbanization) and the depopulation of rural areas, accompanied by the escalation of agriculture in the most productive lands and the abandonment of marginal lands. All these causes and their consequences are observable simultaneously around the world today.Perhaps the most important issue for most of earth's human population is the long-term threat to future production of food and other essentials by the transformation of productive land to non-productive uses, such as the conversion of agricultural land to residential use and the degradation of rangeland by overgrazing. Although these changes can be monitored using several techniques of remote sensing application, adopting a suitable technique to represent the changes accurately is a challenging task.Change Detection is a process that measures how the attributes of a particular area has changed between two or more time periods using Geographical Information System (GIS). Successful use of remote sensing for LU/LC change detection largely depends on an adequate understanding of the study area, the satellite imaging system and the various information extractionmethods for change detection.There are various change detection techniques employed using visual interpretation methods as well as various digital image processing change detection algorithms such as Image differencing, Principal component analysis, Post-classification comparison, Change vector analysis, Thematic change analysis etc.

Urbanization is a form of metropolitan growth that is a response to often bewildering sets of economic, social, and political forces and to the physical geography of an area. It is the increase in the population of cities in proportion to the region's rural population. Urbanization and urban sprawl have posed serious challenges to the decision makers in the city planning and management process involving plethora of issues like infrastructure development, traffic congestion, and basic amenities (electricity, water, and sanitation), etc. Apart from this, major implications of urbanization are Urban Heat Island and Loss of aquatic ecosystems.

Many studies have estimated the relative warmth of cities by measuring the air temperature, using land based observation stations. Some studies used measurements of temperature using temperature sensors mounted on car, along various routes (Yamashita, 1996). This method can be both expensive and time consuming and lead to problems in spatial interpolation. Remote sensing might be a better alternative to the aforesaid methods. The advantages of using remotely sensed data are the availability of high resolution, consistent and repetitive coverage and capability of measurements of earth surface conditions. In remote sensing, Thermal infrared (TIR) sensors can obtain quantitative information of surface temperature across the LU/LC categories

The drastic change in land use/land cover associated with human activities is regarded as a powerful driving force in local climate and environment changes. Urban Heat Island (UHI) intensity is closely related to LU/LC patterns over time. Therefore, accurate detection ofLU/LC changes associated with urbanization and LST distribution is critical to environmental monitoring, management and planning. Therefore for this research, much emphasis is placed on determining the urban LU/LC changes and their impact on LST patterns. The present study aims at detecting the impact of Land Use/Land Cover Changes of Bangalore Urban District on its Land Surface Temperature over a period of one decade. For this purpose Multi-temporal LANDSAT TM Images of 1999 and 2009 are used for Post classification (supervised classification) change detection. This emphasizes the change in Built-up, Water bodies other land use classes. The LST retrieved from multi-temporalLANDSAT TM Images of 1999 and 2009 is analysed for its increase due to the LU/LC Changes.

2. Study Area: Bangalore Urban is a district of the Indian State of Karnataka. It is surrounded by the Bangalore Rural district on the West, East and North and the Krishnagiri district of Tamil Nadu on the south. Bangalore Urban district came into being in 1986, with the partition of the erstwhile Bangalore district into Bangalore Urban and Bangalore Rural districts. Currently, Bangalore Urban has four taluks: Bangalore North, Bangalore East, Bangalore South and Anekal. It covers an area of 2208 sq. km. The city of Bangalore is situated in the Bangalore Urban district. Bangalore is a hub for Information Technology, Biotechnology, Aerospace and Key Knowledge based industries. Bangalore is also known as the Garden City and Silicon Valley of India.Bangalore Urban District is located on Deccan Plateau in the South Eastern part of Karnataka. Its geographical extent ranges from 12°39'32":13°14'13" Latitude and 77°19'44":77°50'13" Longitude.

3. Data Used: Several types of data have been used in this project work. This data can be categorised as spatial and non-spatial data. The Raster datasets used in this study are shown in Table 1

Table 1: Description of Raster Datasets used in the current study

Sensor	Date of Acquisition	Resolution(m)	Source
LANDSAT TM 5	02-02-1999	30	USGS
LANDSAT TM 5	12-01-2009	30	USGS

Other data used are: IMD Data of Bangalore City and HAL Observatories - Near surface temperature (°C),Relative humidity (%) data for both the acquisition dates. Legacy data on wasteland and land use generated for 2008-09, State Natural Resource Information System (SNRIS) datasets of 2000-01, ground truth data etc.:ERDAS Imagine, ARC GIS and ENVI Softwares have been used in this study.

The LU/LC Classification Scheme adopted in this study is as follows:
a) **Built-up Class**(includes settlements, industries, mining, roads, runway etc.)

b) **Water bodies Class**(includes lakes, reservoirs, etc.)

c) **Vegetation Class** (includes crop land, agriculturalplantation, forest, grass land etc.)

d) **Others Class**(includes wasteland, fallow land, open land etc.)

4. Methodology: The methodology used in carrying out the LU/LC change analysis, LST retrieval and analysing the impact of LU/LC on it LST is shown in Fig. 1.

4.1 LU/LC Change Detection using LANDSAT TM
The LU/LC Change Detection using LANDSAT TM was carried out in the ERDAS Imagine Environment. Post00 classification change detection technique was adopted to find the changes of Bangalore Urban over a decade. Following are the steps involved in carrying out the LU/LC change detection using LANDSAT TM.

4.1.1Pre-Processing
The Landsat TM Images were downloaded for the full scene from global land cover facility site. These imagesare Standard Terrain Correction (Level 1T) Products i.e. they provide systematic radiometric and geometric accuracy by incorporating ground control points while employing a Digital Elevation Model (DEM) for topographic accuracy. Thus these images are Pre- processed images. The LANDSAT TM Images are in the UTM Projection and have datum as WGS84. The LANDSAT TM - 4, 3 and 2bands were layer stacked to form a False Colour Composite (FCC) and the study area was clipped for further processing

4.1.2 LU/LC Classification using Supervised Classifier-Maximum Likelihood Classifier
The LU/LC classification was carried out for the temporal images of LANDSAT TM using the Maximum Likelihood Classifier individually. The Accuracy Assessment for both the datasets of LANDSAT TM was done.

4.1.3 LU/LC Post Classification Change Matrix
Post classification change detection technique is used to study the Land Use/Land Cover changes of Bangalore Urban District over the decade (1999-2009).

The Change matrix and area statistics were also derived from this step.

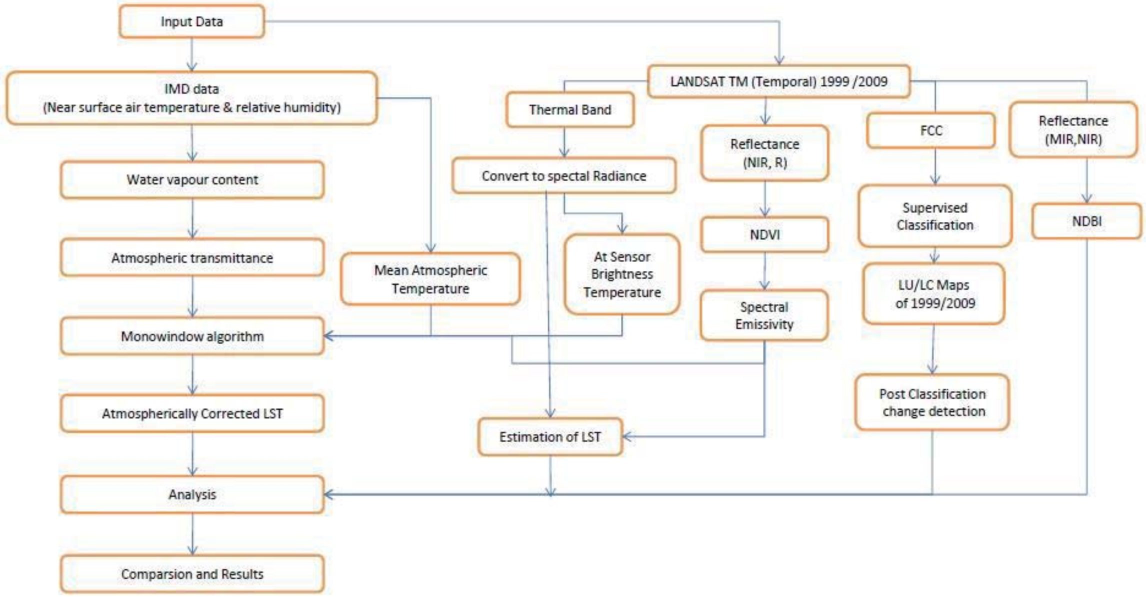

Fig 1. : Methodology used for the LU/LC change analysis of Bangalore Urban District and its impact on LST

4.2 Estimation of Land Surface Temperature from LANDSAT TM

The estimation of Land Surface Temperature from LANDSAT TM Images was carried out in the ERDAS Imagine and ENVI environment.

4.2.1 Pre-processing

LANDSAT TM Images were downloaded for the full scene from global land cover facility site. These images are Standard Terrain Correction (Level 1T) Products i.e. they provide systematic radiometric and geometric accuracy by incorporating ground control points while employing a Digital Elevation Model (DEM) for topographic accuracy. Thus these images are Pre-processed images. The Images are in the UTM Projection and have datum as WGS 84. The thermal band i.e. Band 6 of LANDSAT TM was used in retrieving the LST.

4.2.2 Converting DN to radiance

The Landsat Thematic Mapper (TM) sensors acquire temperature data and store this information as a digital number (DN) with a range between 0 and 255. DN to radiance conversion step is done using the bias and gain values specific to the individual scene we are working. The DN units are converted to radiance using the following equation.

L_λ= gain * QCAL + offset (1)

Also expressed as:

$$L_\lambda = \frac{(LMAX_\lambda - LMIN_\lambda)}{(QCALMAX - QCALMIN)} * (QCAL - QCALMIN) + LMIN_\lambda \quad (2)$$

Where,

L_λ= Spectral Radiance at the sensor aperture in watts/ (meter squared * ster * µm)

gain = Rescaled gain (the data product "gain" contained in the Level 1 product header or ancillary data record) watts/ (meter squared * ster * µm)

offset = Rescaled bias (the data product "offset" contained in the Level 1 product header or ancillary data record) in watts/ (meter squared * ster * µm)

QCAL = the quantized calibrated pixel value in D

$LMIN_\lambda$ = the spectral radiance that is scaled to QCALMIN in watts/ (meter squared *ster * µm)

$LMAX_\lambda$ = the spectral radiance that is scaled to QCALMAX in watts/ (meter squared *ster * µm)

QCALMIN = the minimum quantized calibrated pixel value (corresponding to LMINλ) in DN = 1 (LPGS Products) = 0 (NLAPS Products)

QCALMAX = the maximum quantized calibrated pixel value (corresponding to LMAXλ) in DN = 255

The LMINs and LMAXs are the spectral radiances for each band at digital numbers 0 or 1 and 255 (i.e. QCALMIN, QCALMAX), respectively. Since the dataset used here is a LPGS (Level 1 Product generation system) product therefore the value of 1 is used for QCALMIN. The values of all the parameters required for calculating the radiance are found in the metadata file of the acquired LANDSAT TM image.

4.2.3 Converting Radiance to at Sensor Brightness Temperature

For converting the radiance to at Sensor Brightness Temperature, the inverse of the Planck's function is used. This is given by

$$T_{at\ sensor} = \frac{K2}{Ln(K1/L_\lambda + 1)} \quad (3)$$

Where,

$T_{at\ sensor}$ is the At Sensor Brightness Temperature

L_λ is the radiance which is calculated from equation (2)

K1 and K2 are the calibration constants whose values are

K1= 607.76 watts/ (meter squared * ster * µm) and K2=1260.56 watts/ (meter squared * ster * µm) for LANDSAT TM

$T_{at\ sensor}$ can be converted to degree Celsius by subtracting the value of $T_{at\ sensor}$ in degree kelvin from 273.15.

4.2.4 Calculation of Land Surface Emissivity

For the effective estimation of temperature, the emissivity values are to be derived at pixel level. In fact the emissivity can be calculated using Normalized Difference Vegetation Index (NDVI).

i. Calculation of NDVI

The NDVI is one of the most widely applied vegetation indices. Doing ration calculation between the reflectance of near infrared (NIR) band and the red (R) band can strengthen the vegetation information. The calculation of NDVI is done using the following equation,

$$NDVI = \frac{NIR - R}{NIR + R} \quad (4)$$

Band 4(NIR) and Band 3(Red) bands of LANDSAT TM are used for calculating the NDVI

ii. Estimation of Land Surface Emissivity

Van de Griend and Owe's 1993 study showed the relationship between emissivity and NDVI. Emissivity can be expressed by the following equation when the NDVI values range from 0.157 to 0.727.

$$\varepsilon = 1.009\,4 + 0.047*\ln(NDVI) \quad (5)$$

For the area with NDVI values out of the above range were divided into three ranges and their corresponding emissivity values are inputted according to the values of emissivity given in Table 2. These values are based according to past studies and statistical characteristics of different images. The land use is mostly like the water or urban or others land use class when NDVI is less than 0.157, and it is absolutely the vegetation land when NDVI is larger than 0.727. (Zhang et al, 2006)

Table 2: Estimation of Land Surface Emissivity using NDVI

NDVI	Land Surface Emissivity (ε)
NDVI < −0.185	0.995
−0.185 ≤ NDVI < 0.157	0.970
0.157 ≤ NDVI ≤ 0.727	1.009 4 + 0.047*ln(NDVI)
NDVI > 0.727	0.990

4.2.5 Calculation of LST - For data without atmospheric correction

The inverse of the Planck's function is used to derive emissivity corrected Land Surface Temperature which is given as

$$LST = \frac{K_2}{\ln(K1*\varepsilon / L_\lambda + 1)} \quad (6)$$

Where,
LST is Land Surface Temperature in degree kelvin.
ε is the emissivity which is estimated from Table 2

4.2.6 Estimation of Atmospherically corrected Land Surface Temperature

The estimation of atmospherically corrected Land Surface Temperature is done by applying the Mono window algorithm. There are three critical parameters in the algorithm namely emissivity, transmittance and mean atmospheric temperature, which need to be calculated to retrieve the atmospherically corrected Land Surface Temperature from LANDSAT TM band (Qin *et al,* 2001)

i. Calculation of water vapour content

The water vapour content is one of the important atmospheric parameter for the retrieval of atmospheric correction of LST. It can be calculated as

$$w_6 = 0.0981*\{10*0.6108*\exp[17.27*T_o / 237.3 + T_o] * RH\} + 0.167 \quad (7)$$

Where,

w_6 is the water vapour content (g/cm^2)

T_o is the near surface air temperature in degree kelvin
RH is the relative humidity.

The near-surface air temperature and relative humidity used in calculating the water vapour content are obtained from the IMD Data of Bangalore City and HAL Observatories. They are the average values of both the stations observations of near surface air temperature and relative humidity taken on 2nd Feb 1999 and 12th Jan 2009 at 0830hrs (IST) as the LANDSAT TM images were acquired on the same days around 1020hrs (IST).

ii. Estimation of atmospheric transmittance

Atmospheric transmittance is one of the essential parameter to be keyed into the mono–window algorithm. The water vapour content obtained from the above step is used to select the equation from Table 3 to calculate the atmospheric transmittance of Landsat TM band 6. The estimation of Atmospheric transmittance is given as

$$\tau_6 = 1.053710 - 0.14142 * w_6 \quad (8)$$

Where,
τ_6 is the atmospheric transmittance of Landsat TM 6 and

w_6 represents the water vapour content which can be calculated using Equation (7)

Table 3: Estimation of atmospheric transmittance

Profiles	Water vapour (w_6) (g/cm2)	Transmittance estimation equation (τ_6)
High air temperature	0.4–1.6	$0.974290 - 0.08007 * w_6$
	1.6–3.0	$1.031412 - 0.115\,36 * w_6$
Low air temperature	0.4–1.6	$0.982007 - 0.09611 * w_6$
	1.6–3.0	$1.053710 - 0.14142 * w_6$

iii. Calculation of mean atmospheric temperature

The mono-window algorithm also requires the mean atmospheric temperature. As our study area has sub-tropical climatic conditions, the equation for the tropical area from Table 4 is used for the calculation of the mean atmospheric temperature which is given as follows

$T_a = 17.976\,9 + 0.917\,15 * T_o$ (9)

Where T_o is the near-surface air temperature (K).

Table 4: Estimation of mean atmospheric temperature

Area	Atmospheric temperature equation (T_a) (K)
For USA 1976	$25.9396 + 0.88045 * T_o$
For tropical	$17.9769 + 0.91715 * T_o$
For mid-latitude summer	$16.0110 + 0.92621 * T_o$
For mid-latitude winter	$19.2704\ .91118 * T_o$

iv. Mono- Window Algorithm for LST Retrieval

Three variables (*i.e.*, emissivity, transmittance and effective mean atmospheric temperature) obtained from the above steps are used for the calculating the atmospherically corrected LST (using the mono-window algorithm)which is given as:

$T_s = \{a\ (1\text{-}C\text{-}D)+[b(1\text{-}C\text{-}D)\ +C+D]\ T_{at\ sensor} - D^*\ T_a\}/\ C$ (10)

$a = -67.355351$, $b = 0.458606$, $C = \varepsilon_i * \tau_i$

$D = (1 - \tau_i)\ [1 + (1 - \varepsilon_i) \times \tau_i]$

Where, T_s is the LST (K);

$T_{at\ sensor}$ is the brightness temperature (K), which can be calculated using Equation (4); ε_i is the emissivity, which can be classified and computed by NDVI (Table 2);

τ_i is the transmittance, which can be calculated from Equations (7-8), and

$T_a$represents the effective mean atmospheric temperature, which can be calculated using Equation (9).

The atmospherically corrected LST in degree Celsius can be obtained by subtracting 273.15 from T_s (K)

4.3 Estimation of NDBI from LANDSAT TM

The Normalized Difference Built-Up Index is an indicator of the built-up land use class. The development of the index is based on the unique spectral response of built-up lands that have higher reflectance in MIR wavelength range than in NIR wavelength range. NDBI is calculated using the reflectance values of the MIR and NIR bands of the satellite imagery. NDBI is given as

NDBI = (MIR-NIR) / (MIR+NIR) (11) Where,

MIR is the reflectance values of the Middle infra-red band and

NIR is the reflectance values in the near infra-red band. For the LANDSAT TM Imagery the TM5 (MIR) and TM4 (NIR) bands are used for estimating the NDBI.

4.4 Impact of Land Use/ Land Cover Change on its Land Surface Temperature

The LU/LC map, NDVI, NDBI layers of 1999/ 2009 were overlaid on LST (with and without atmospheric corrections)in the ARC GIS environment and analysed for the impact of Land use/ land cover changes on the land surface temperature

5. Results and Discussion

The LU/LC Classification for LANDSAT TM Datasets for 1999 and 2009 was carried out by taking spectral signatureof four classes namely Built-Up, Vegetation, Water bodies and Othersas training sets and then classifying the datasets usingthe Supervised Classification-Maximum Likelihood Classifier. An overall accuracy of 89.84% (Kappa Coefficient: 0.8580) for Feb 1999 datasets and 88.28% (Kappa Coefficient: 0.8375) for Jan 2009 datasets was obtained during the accuracy assessment of the LU/LC classification.

The classified map of LU/LC of Bangalore Urban District for Feb 1999 is shown in Fig. 2(a) and for Jan 2009 is shown in Fig. 2(b). The LU/LC Maps show different LU/LC classes such as Built-up, Vegetation, Water bodies and others. The maps also delineate the greater Bangalore region from the outskirts.

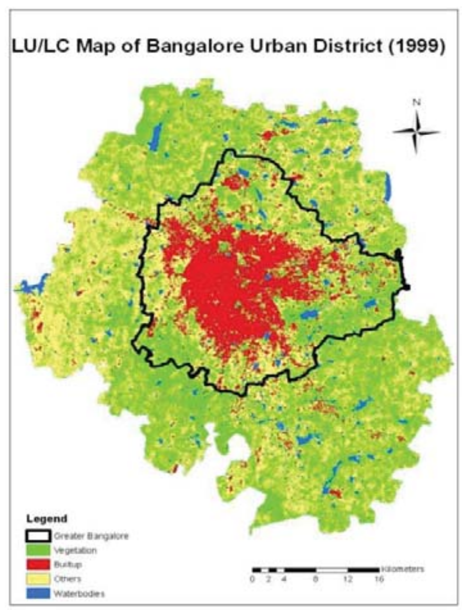

Fig. 2 (a): LU/LC Map of Bangalore Urban District for Feb 1999

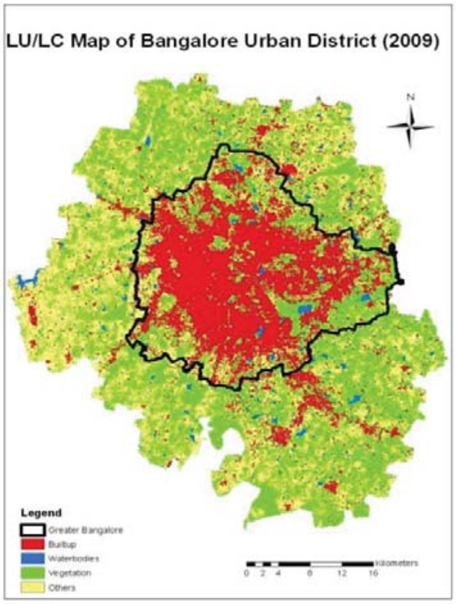

Fig. 2 (b): LU/LC Map of Bangalore Urban District for Jan 2009

We can visualize an increase in the built-up class and others class and a decrease in the Vegetation and Water bodies classes in both the LU/LC maps of 1999 and 2009. The built-up expansion can be seen more towards the South East region because of the emerging electronics city in the Anekal taluk. The built-up progression in North Bangalore can be attributed to the establishment of the New International Airport at Devanahalli in Bangalore Rural District, which is very near to the Bangalore North Taluk. The built-up enlargement towards Bangalore East is ascribed due to the formation of the ITPL in Whitefield in the Bangalore East Taluk. The built-up expansion towards Bangalore West is because of the settlements coming near the Peenya Industrial Area and also the increase in the number of industries in that region. The increase in the urban expansion is a resultant of the increasing population and population density as the census of 2001 and 2011 states that the Bangalore Urban district's population to have increased by 46.68% and population density to have increased from 2985 per sq. km in 2001 to 4378 per sq. km in 2011.

The increase in the Built-up land use class and a decrease in the Vegetation and Water bodies classes can be clearly appreciated in the Fig. 3(a) and 3(b). These Figures show the percentage wise distribution of the area of different LU/LC classes of Feb1999 and Jan 2009 respectively.

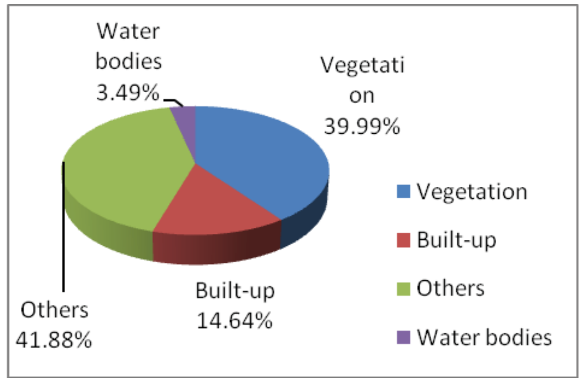

Fig. 3(a): LU/LC Area Statistics (in percentage of the total area) for Feb 1999

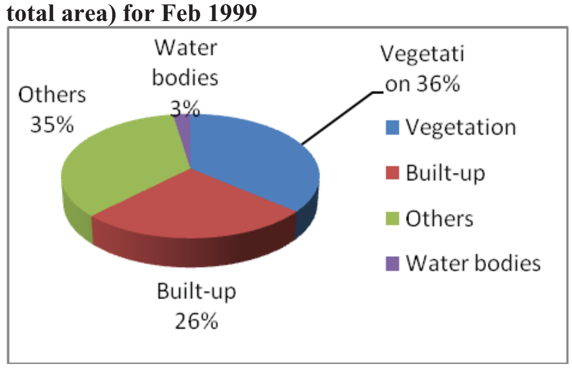

Fig. 3 (b): LU/LC Area Statistics (in percentage of the total area) for Jan 2009

The increasing urbanization and industrialization may be attributed as the reasons for the loss of vegetation and water bodies.

The LST values without atmospheric corrections were retrieved from the emissivity and radiance values for both the LANDSAT TM datasets of Feb 1999 and Jan 2009. The LST Maps of Feb 1999 and Jan 2009 are shown in Fig. 4(a) and Fig. 4(b) respectively.

The LST values with atmospheric correction were retrieved from the emissivity values, atmospheric parameters and at sensor brightness temperature for both the LANDSAT TM datasets of Feb 1999 and Jan 2009. The atmospherically corrected LST Maps of Feb 1999 and Jan 2009 are shown in Fig. 5(a) and Fig. 5(b) respectively. The LST maps with and without atmospheric corrections both indicate an increase in the Land surface temperature of Bangalore Urban District from 1999 and 2009. The LST maps indicate an astonishing higher Land Surface Temperature in the outskirts compared to the Greater Bangalore Region for both the temporal data. This may be attributed to the fact that there are more urban greenery and water bodies and wetlands in the heart of the city which keeps the city cooler compared to the outskirts. The outskirts have increasing vacant lands, mining activities, and urban agglomerations resulting in the loss of vegetation. Abinakudige,2011carried out a study on remote sensing of land cover's effect on surface temperatures: a case study of the urban heat island in Bangalore, India witnessed similar observations of lower LST values in the heart of the city compared to the outskirts.

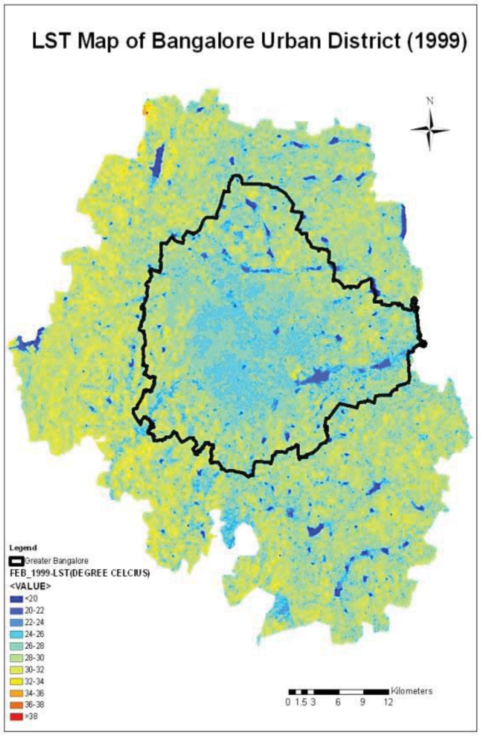

Fig. 4 (a): LST Map of Bangalore Urban District for Feb 1999

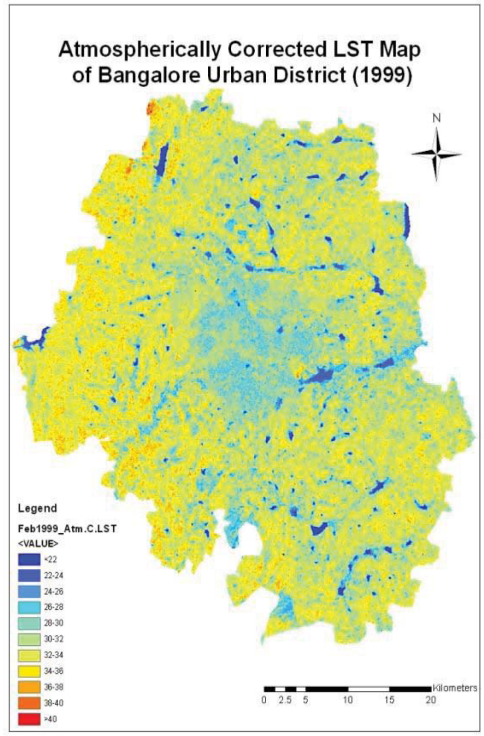

Fig. 5 (a): Atmospherically corrected LST Map of Bangalore Urban District for Feb 1999

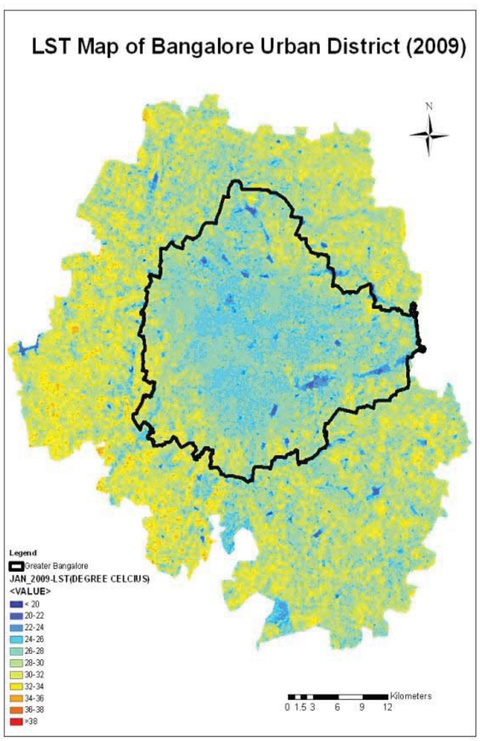

Fig. 4(b): LST Map of Bangalore Urban District for Jan 2009

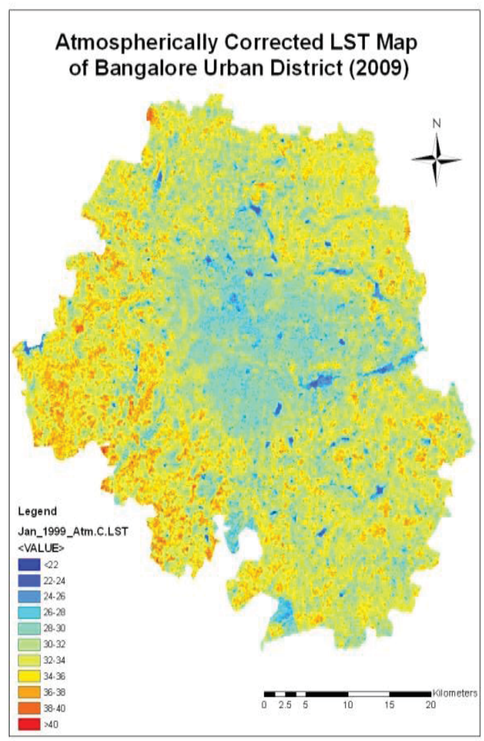

Fig 5 (b): Atmospherically corrected LST Map of Bangalore Urban District for Jan 2009

The impact of the LU/LC changes of Bangalore Urban District on its LST was analysed by overlaying the NDVI Index, Built-Up Index, and LU/LC Maps over the LST (with and without atmospheric corrections maps).

The Relationship between NDVI and LST are illustrated in Fig. 6(a), (b) and Fig. 7(a), (b) wherein the Fig. 6(a) and (b) show the relation between NDVI and atmospherically corrected LST for Feb 1999 and Jan 2009 respectively. Fig. 7(a) and (b) show the relation between NDVI and LST for Feb 1999 and Jan 2009 respectively. A negative correlation between NDVI values and LST values are clearly observed from the above graphs. The Pearson's correlation coefficient was found to be -0.78 and -0.75 for the Feb 1999 datasets of NDVI and LST with and without atmospheric correction respectively. The negative correlation between NDVI and LST values indicates that as the NDVI values increase the LST decreases and as the NDVI decreases the LST values increase. The NDVI values have decreased from Feb 1999 to Jan2009 which has led to an increase in the observed LST values.

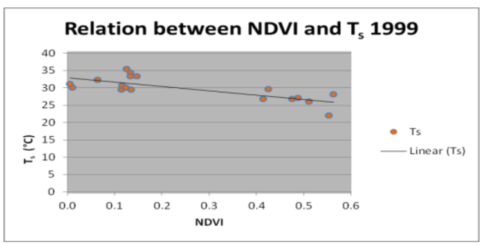

Fig. 6(a): Relation between NDVI and atmospherically corrected LST for Feb 1999

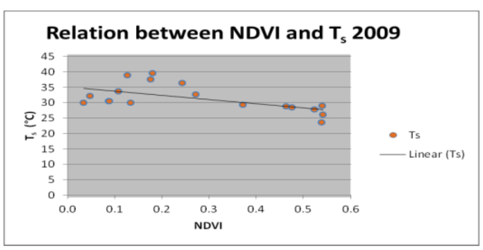

Fig. 6(b): Relation between NDVI and atmospherically corrected LST for Jan 2009

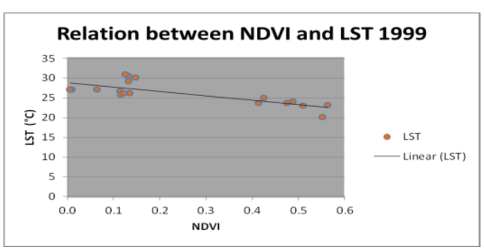

Fig. 7(a): Relation between NDVI and LST for Feb 1999

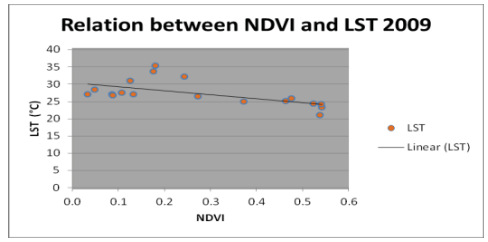

Fig. 7(b): Relation between NDVI and LST for Jan 2009

There exists a strong correlation between NDBI and LST values which is explored using the correlation coefficient between the two variables. The Relationship between NDBI and LST are illustrated in Fig. 8(a), (b) and Fig. 9(a), (b) wherein the Fig. 8(a) and (b) show the relation between NDBI and atmospherically corrected LST for Feb 1999 and Jan 2009 respectively and Fig. 9(a) and (b) show the Relation between NDBI and LST for Feb1999 and Jan 2009.

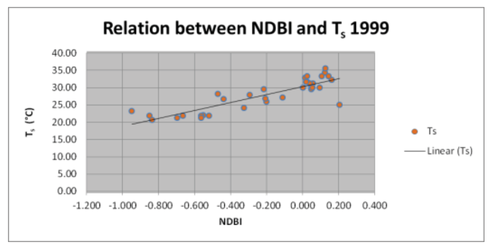

Fig.8 (a): Relation between NDBI and atmospherically corrected LST for Feb 1999

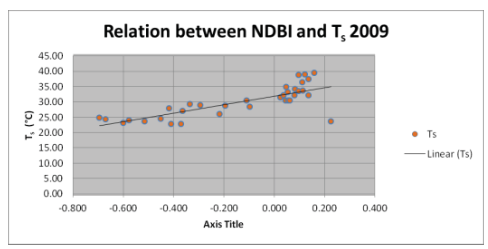

Fig. 8 (b): Relation between NDVI and atmospherically corrected LST for Jan 2009

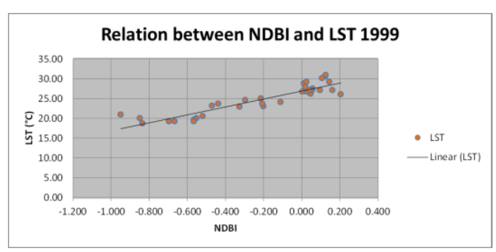

Fig. 9 (a): Relation between NDBI and LST for Feb 1999

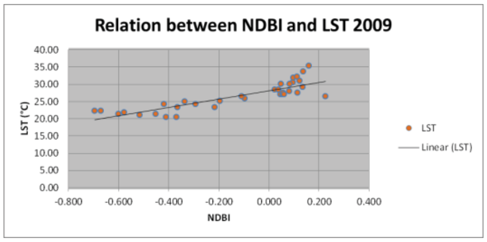

Fig. 9 (b): Relation between NDBI and LST for Jan 2009

The study clearly indicates that here exists a positive correlation between the NDBI and LST as the Pearson's correlation coefficient for NDBI values and LST (with and without atmospheric correction) of both the datasets for 1999 and 2009 ranged between 0.78-0.91. This positive correlation indicates an increase in LST values with increasing Built-up Index. Thus the increasing urbanization is a clear indicator of high LST values

The relationship between the LU/LC and LST (with and without atmospheric corrections respectively) is shown in Fig. 10and Fig. 11respectively. The LST values (with and without atmospheric correction) show an increasing trend for all the LU/LC classes from 1999 and 2009 as seen in the below figures. The Others Class dominate the highest land surface temperature than the Built-up land use class. This may be attributed due to the mixed sub class pixels such as the wastelands, barren rocky, fallow land, bare soil, open lands etc. Also since the time of acquisition of the LANDSAT TM is around 1020hrs (IST), the others land use class warms up much quickly in the morning hours than the built-up class which on an average will result in more warming of their respective land cover and result in higher LST values. Ramachandra et.al, 2010 reported that Greater Bangalore an emerging Urban Heat Island showed highest LST values for Urban-Built up followed by open lands , vegetation and water bodies in that order. The present study has shown highvalues of LST for the Others land use compared to the built up class. The change in this observation of the Built-up class of Ramachandra et al indicated that the Built-up class has higher LST than Others land use class may be because of the use of MODIS data for 2000 and 2007 which has a coarser resolution and also due to the reason that data may have been acquired during the night time. In the night time images, the urban built-up shows high LST values as the impervious built-up area takes a longer time to cool down compared to the other land use classes.

The LANDSAT TM images used in the present study have been acquired in the winter mornings of 1999 and 2009 around 1020hrs,where in the others land use class warms up much sooner compared to the built-up class yielding in high LST values compared to the built-up. Yogesh Kant et al, 2009 reported similar findings for Others land use sub classes such as wasteland, bare soil and fallow land to have shown higher LST values compared to the built-up industrial and residential land use class for Delhi, when day time MODIS data was used in the winter season.

The Point 3 corresponding to the Runway pixel of Built-up class and Point 20 corresponding to the Water bodies class show an abnormal increase in Fig. 10. The increase in the runway LST values for Jan 2009 may be attributed due to Air traffic activity. The increase in the LST value of the water bodies land use class is because of the increase in shallowness of the water body in Jan 2009.

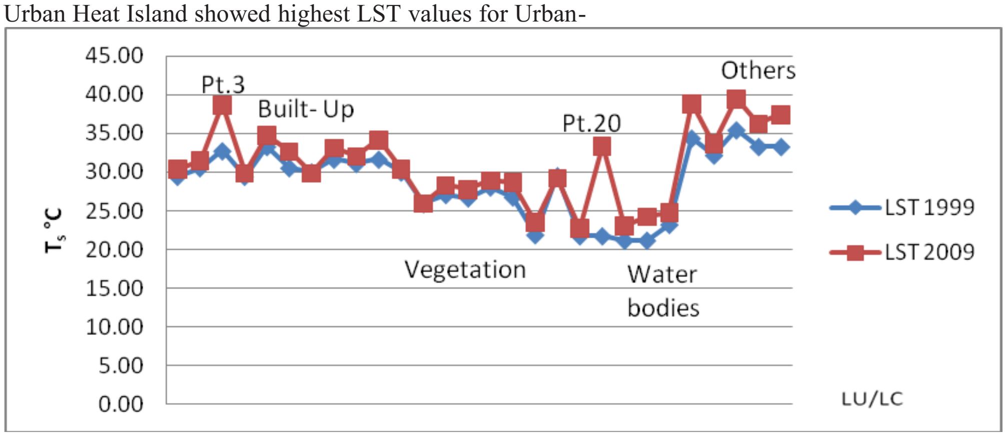

Fig. 10: Relationship between LU/LC and atmospherically corrected LST of Bangalore Urban District(1999-2009)

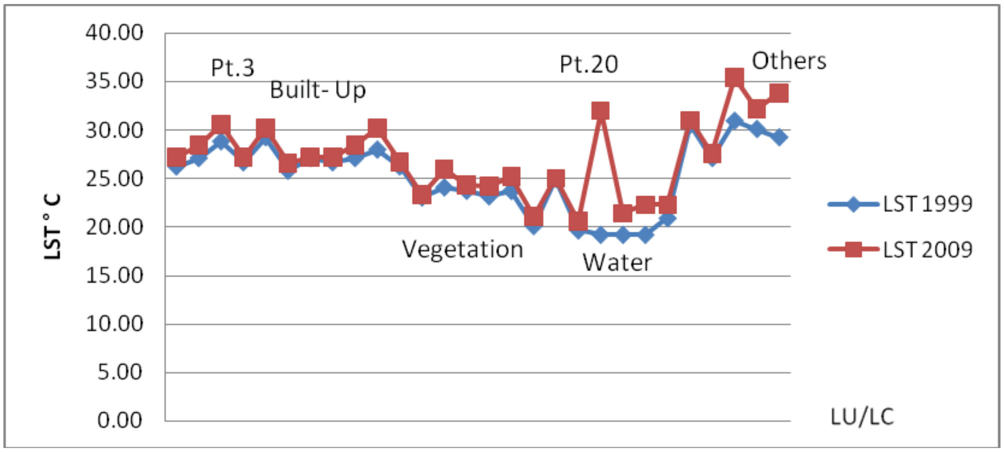

Fig. 11: Relationship between LU/LC and LST of Bangalore Urban District (1999-2009)

6. Conclusion

It was found that the Built – Up class had increased by 78.96% from 1999 to 2009, whereas Vegetation and Water bodies classes have decreased by 9.39% and 29.87% respectively which may be attributed due to rapid urbanization and industrialization. The LST (with and without atmospheric corrections) of Bangalore Urban District is higher for Built-up and others classes and the lowest for water bodies. The LST is higher in the outskirts of the District compared to the Greater Bangalore region. This may due to more urban greenery and water bodies and wetlands in the heart of the city which keeps the core of the district cooler compared to the outskirts. The outskirts have increasing vacant lands, mining activities, and urban agglomerations resulting in the loss of vegetation and thus a greater LST. The atmospherically corrected LST of Built-Up class of Bangalore Urban District has increased from 30.9°C to 32.5°C and the LST (without atmospheric corrections) has increased from 27.2°C to 28.1°C. The atmospherically corrected LST of Water bodies of Bangalore Urban District has surprisingly showed an increasing trend from 21.8°C to 25.7°C. The LST values without atmospheric correction of water bodies of the study area showed an average increase from 19.6°C to 23.7°C. This may be due to the increasing water pollution (sewage and industrial effluent) and the shallowness of the water bodies. The analysis of the relationship between NDVI and LST showed a negative correlation The analysis of the relationship between NDBI and LST showed a positive correlation. Built-up class showed the maximum increase of land use class during the decade. The increasing population of Bangalore Urban District are the contributors for this built-up increase. The change detection analysis shows that the Vegetation class has transformed to built-up by 11.06%, Others class has transformed to built-up by 21.06% and Water bodies class has transformed to built- up by 7.46%. The increase of Built - Up Land Use class and a decrease in the vegetation and water bodies has resulted in the increase in LST between 1999 and 2009.

7. Acknowledgements: The Authors are thankful to IMD(Indian Meteorological Department), Bangalore for providing data for this study.

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