Research & Reviews: Journal of Space Science & Technology
Volume 1, Issue 1, April 2012, Pages 1-10

Land Surface Temperature Analysis in an Urbanising Landscape through Multi-Resolution Data

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ABSTRACT

Rapid changes in the land use and land cover of a region have become a major environmental concern in recent times. This has lead to unsustainable development with the reduction of green spaces and also changes in local climate and formation of urban heat islands (UHIs). Monitoring and management of land use dynamics would help in land use planning and mitigation of environmental impacts.The main goal of this paper is to quantify the changes in the land cover and consequent changes in land surface temperature. Land use and land cover dynamics were assessed using temporal remote sensing (Landsat Thematic Mapper and Enhanced Thematic Mapper) data of Himachal Pradesh, India. The thermal infrared bands of the Landsat data were used to retrieve land surface temperature. The results revealed that there was a huge increase in urban area (including barren land), which is the causal factor for the changes in land surface temperature. Overall, remote sensing and geographic information system technologies were effective approaches for monitoring and analyzing urban growth patterns and evaluating their impacts on land surface temperature.

Keywords: *Land surface temperature, landsat,land use, land cover, NDVI*

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1. INTRODUCTION

Land cover and land use (LCLU) changes induced by human and natural processes play a major role in global as well as at regional scale patterns of the climate and biogeochemistry of the Earth system. Studies have revealed changes in water cycling process between land and atmosphere due to the large scale land cover changes, affecting the local to regional climate. Geo spatial technologies such as remote sensing (RS) and geographic information systems (GIS) are very effective in measuring, monitoring and predicating the land use/cover changes. Timely information with higher accuracy of landuse (LU) and land cover (LC) changes is crucial for long-term planning, economic development, and sustainable management [1] of natural resources. The analysis of temporal remote sensing data helps in understanding the land cover changes and their impact on the environment. The thermal infrared bands of remote sesning data of space borne sensors help to retrieve land surface temperature (LST). LST is the measure of heat emision from land surface due to various activities associated with the land surface. Increase in paved land cover is an indication of concentrated human activities, which often leads to increased LSTs [2]. Increased LST in certain urban pockets in comparison to its surroundings consequent to the increase in paved surfaces is known as urban heat island (UHI) phenomenon [3, 4].

Detection of the thermal charecteristics of land surface using remote sensing data of space borne sensors and the analysis of land surface temperature (LST) has been reported earlier [5]. Spatio-temporal data were used to develop models of land surface atmosphere exchange, and to analyze the relationship between temperature and land use and land cover (LULC) in urban areas [6] highlighting the relationship between LST and surface characteristics such as vegetation indices [7, 8, 9]. Also, the studies reveal the effect of biophysical factors on LST by using vegetation fraction instead of qualitative LULC classes [9, 10, 11]. The vegetation index-LST relationship has also been used to retrieve surface biophysical parameters [7] to extract sub-pixel thermal variations [12], and to analyze land cover dynamics [13]. Many investigators have observed a negative relationship between vegetation index and LST, leading to further research into two major pathways, namely, statistical analysis of the relationship and the temperature/vegetation index (TVX) approach. TVX is a multi-spectral method of combining LST and a vegetation index (VI) to monitor their associations.

Land surface and atmospheric temperatures rise by various anthropogenic activities like increased land surface coverage by artificial materials and energy consumption, which have a high heat capacity and conductivity, and are also associated with the decreases in vegetation and water surfaces, which are the major factors that reduce surface temperature through evapo-transpiration [14]. Temperatures can be monitored through space borne remote sensing(rs) sensors, which account for the top of the atmosphere (TOA) radiances in the thermal infrared (TIR) region.TOA radiance is the net radiance of the emitted radiance from the earth's surface upwelling radiance from the atmosphere, and downwelling radiance from the sky. The brightness temperatures (also known as blackbody temperatures) can also be derived from the TOA radiance [15]. These brightness temperatures account for various properties of the land surface, the amount and nature of vegetation cover, the thermal properties and moisture content of the soil [16]. However, lack of knowledge of spectral emissivity can introduce an error which ranges from 0.2 to 1.2 k for mid-latitude summers and 0.8 to 1.4 k for the winter conditions for an emissivity of 0.98 and at the ground height of 10 km [15]. Two approaches have been developed to recover LST from multispectral TIR imagery [17] as on date. The first approach utilises the radiative transfer equation to correct the at-sensor radiance to surface radiance, followed by an emissivity model to separate the surface radiance into temperature and emissivity [16]. The second approach applies the split-window technique for sea surfaces to land surfaces. Assuming that the emmisivity in the channels used for the split-window is similar [15], TIR region corresponding to 8–14 µm in the electromagnetic spectrum is being used for quantifying the thermal urban environment. Data from space-borne remote sensors (Landsat series satellites) are one of the most widely used for environmental studies. Landsat thematic mapper is composed by seven bands, six of them in the visible and near infrared, and only one band located in the thermal infrared region (with an effective wavelength of 11.457 µm) is used for LST retrieval. Availability of one thermal band might be stated as a disadvantage/limitation in order to obtain LST as it does not allow the application of the split-window method [18] nor a temperature/emissivity-separation method [19, 20] to obtain information about the emissivity spectrum of natural surfaces.

The objective here is to investigate the land surface temperature with land use dynamics to understand the urban heat island phenomenon in Himachal Pradesh considering multi-senor, multi-resolution and temporal RS data acquired through space borne sensors. This involved:

1) Temporal LU change analysis (during 1989 and 2005)
2) Computation of LST and NDVI (Normalized Difference Vegetation Index) from Landsat TM (1989) and Landsat ETM (2000) and Landsat ETM + (2005) data
3) Investigation of the role of NDVI in LST

2. STUDY AREA

This analysis has been carried out for Himachal Pradesh, which lies between the Latitudes: 30° 22' 40" N to 30° 12' 40" N, Longitude: 75° 47' 55" E to 79° 04' 20" E (Fig. 1). LST was computed for a region lying between the latitudes: 30 ° 18 ' 30 " N to 30 ° 10 ' 30 " N and Longitude: 76 ° 19 ' 35 " E to 78 ° 59 ' 10 " E and covers Shimla. Himachal Pradesh comprises 12 districts in total, covering an area of 55,673 sq. km. Its total population is 6,077,248 as per 2001 census. Shimla is the state capital of Himachal Pradesh, with its population around 7,21,745 as per 2001 census with geographical area of 5131 sq. km. Density of population in Himachal Pradesh is 109/sq. km. Himachal Pradesh is one of the major Indian states undergoing rapid urbanization. Labor force has about 49.3% of total population employed in industrial sectors. The number of industrial units located in Himachal Pradesh as on 31. 03. 2010 are 36845 (micro, small, medium and large enterprises) of which 444 in medium and large scale industries.

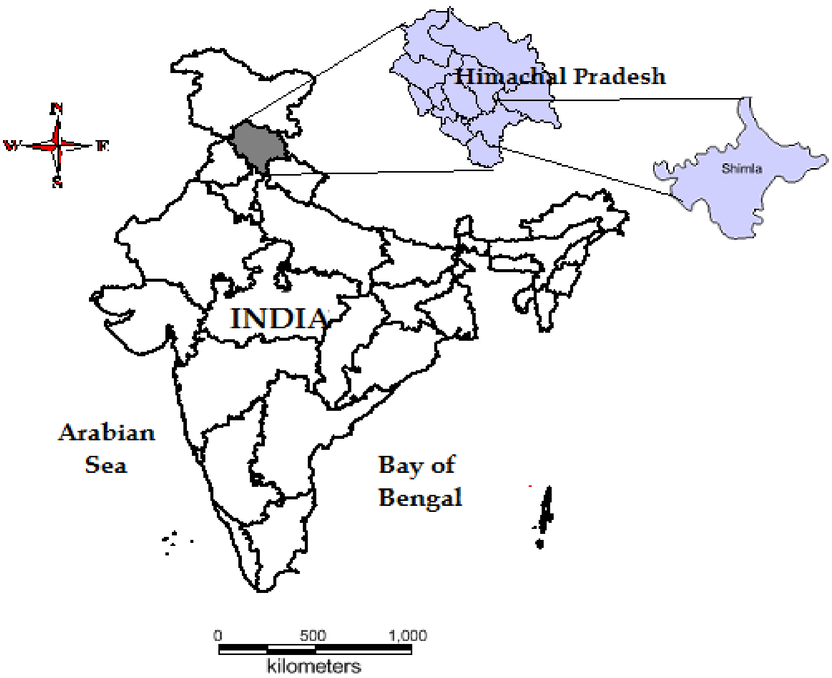


Fig. 1 *Study Area – Shimla, Himachal Pradesh, India.*

3. DATA

The data used were from Landsat series thematic mapper (28.5 m) and enhanced thematic mapper (28.5 m) data acquired over years 1989 to 2010. Collateral data includes Google Earth (http://earth.google.com) and the Survey of India topographic maps (1:50000 scale).

4. METHODOLOGY

The RS data used to study the temporal changes in landscape pattern were Landsat Thematic Mapper (TM), Landsat Enhance TM Plus (ETM+) of 1989 to 2006 [21]. The data were geo-referenced, rectified and cropped pertaining to the study area. Landsat ETM+ bands of 2010 were corrected for the SLC-off by using image enhancement techniques, followed by nearest-neighbor interpolation.

A. Land use and land cover analysis: This was carried out using data of Landsat satellite using supervised pattern classification using Gaussian maximum likelihood classifier (GMLC). This method has already been proved as a superior method as it uses various classification decisions using probability density functions [22]. Mean and covariance matrix are computed using estimate of maximum likelihood estimator. Application of this method resulted in accuracy of about 75% in all the datasets. For the purpose of accuracy assessment, a confusion matrix was calculated. Land use was computed using the temporal data through open source program GRASS (Geographic Resource Analysis Support System) (http://ces.iisc.ernet.in/grass, http://grass.fbk.eu/).

B. Calculation of land surface temperature from Landsat data: LST was computed [23] from TIR bands (Landsat TM and ETM). Emissivity correction for specified LC is carried out using surface emissivity [20, 24] and land surface temperature is calculated as per [16, 25 and 26].

$$T_s = \frac{T_B}{1+(\lambda \times T_B/\rho)\ln\varepsilon}$$

……. ………. 1

where, λ is the wavelength of emitted radiance for which the peak response and average of the limiting wavelength (λ = 11.5 µm) [5] were used, $\rho = 1.439 \times 10^{\circ 2}$ mk and ε = spectral emissivity.

LC was determined through the computation of normalized difference vegetation index (NDVI) using Landsat visible red (0.63–0.69 µm) and near-infrared band (0.76–0.9 µm) bands of Landsat TM/ETM. NDVI was computed in order to calculate emissivity for computing LST.

NDVI is given by

$$NDVI = \frac{(Band\,4 - Band\,3)}{(Band\,4 + Band\,3)}$$

…………….(2)

5. RESULTS AND DISCUSSION

The classified images from 1989 to 2006 showed an overall accuracy of 76%. Land use changes were more prominent in the area during the last 2 decades consequent upon increase in barren land as indicated in Table I and represented in Figure 2. The LU analysis shows that there has been a 55% increase in urban and open areas during 1989 to 2000 and 39% increase during 2000 to 2005, and 18.92% increase during 2005-06 (Fig. 3). This land cover changes have also influenced the local climate. The minimum (min) and maximum (max) temperature was found to be − 2 °C and 31 °C from Landsat Data as tabulated in the Table II. The analysis showed that there has been an increase in temperature from 1989 to 2006, evident from Figure 4.

Table I(a): *Land-Use Changes in Himachal Pradesh.*

Class	Himachal Pradesh (1989)		Himachal Pradesh (2000)		Himachal Pradesh (2005)		Himachal Pradesh (2006)	
	Ha	%	Ha	%	Ha	%	Ha	%
Water	16485.67	0.78	16039.310	0.68	10655.53	0.44	9454.23	0.53
Vegetation	1774602.38	73.16	1537166.84	63.37	1250625.53	51.56	1150875.26	47.32
Snow	142757.71	5.8	107648.80	4.43	99234.98	4.09	98756.32	4.07
Rock and Urban	491566.38	20.26	764532.92	31.52	1064898.29	43.09	1166326.25	48.08
Total (ha)	2425412.17							

Table I(b): *Land-Use Changes in Shimla, Himachal Pradesh.*

Year→	Shimla (1989)		Shimla (2000)		Shimla (2005)		Shimla (2006)	
Class	Ha	%	Ha	%	Ha	%	Ha	%
Vegetation	240397.53	87.45	223778.3	81.3	217684.6	79.13	215684.6	78.4
Water	10.88	0.05	12.98	0.1	7.44	0.05	7.41	0.05
Snow	9373.37	3.4	9092.591	3.3	9499.76	3.45	9199.76	3.35
Rock & Urban	25176.713	9.1	42074.63	15.30	47766.69	17.37	50066.72	18.20
Total (ha)	274958.493							

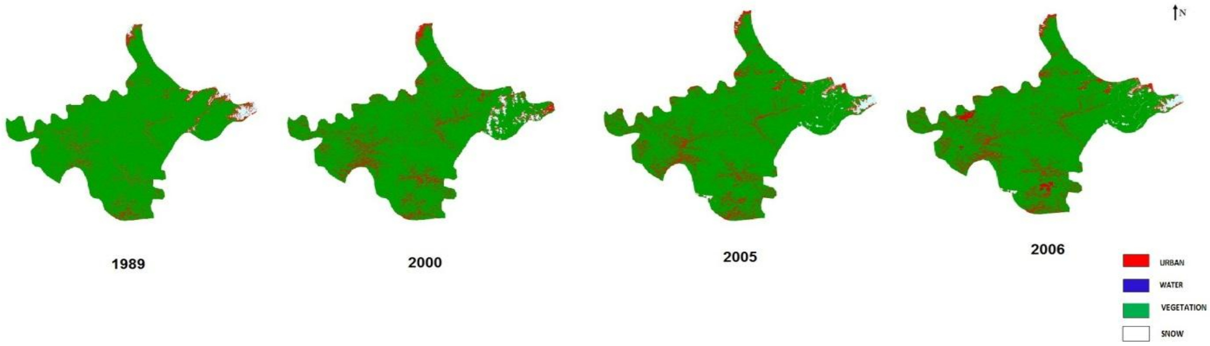


Fig. 2 Land Use in 1989, 2000, 2005 and 2006.

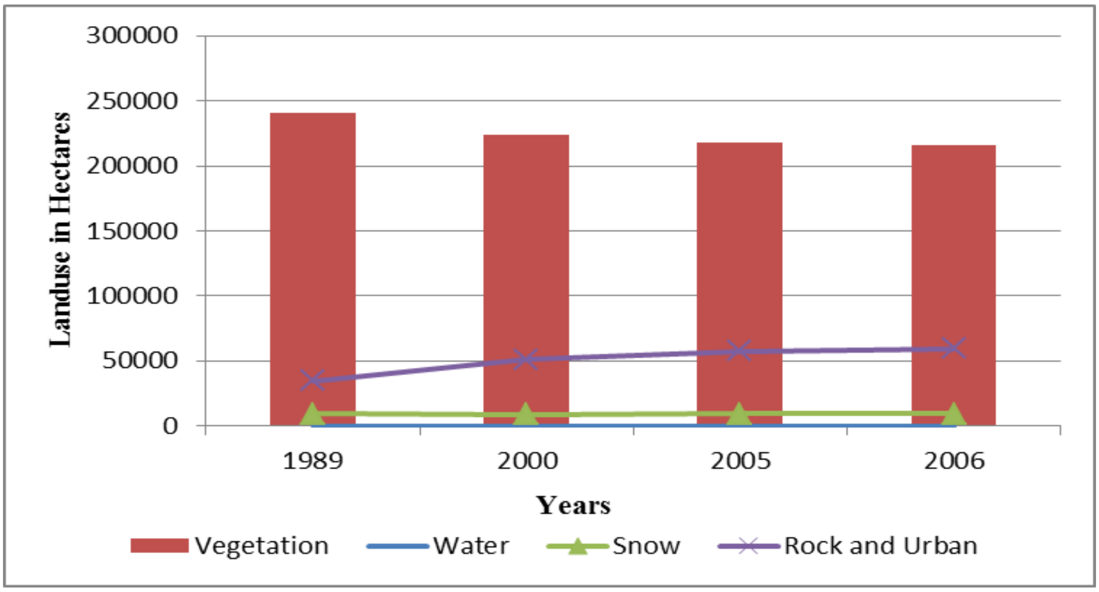


Fig. 3 Land Use Changes in Shimla, Himachal Pradesh.

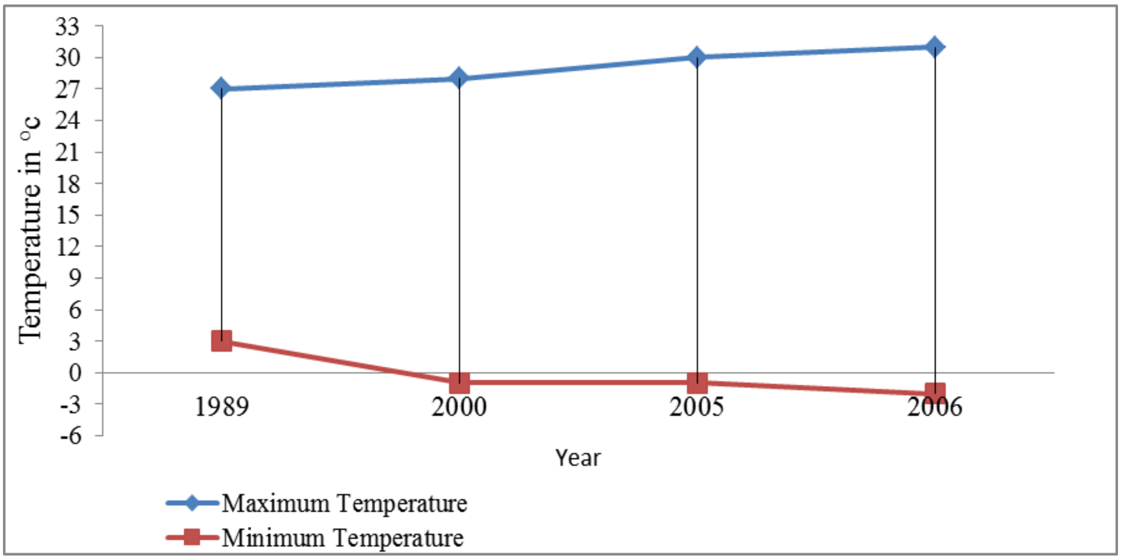


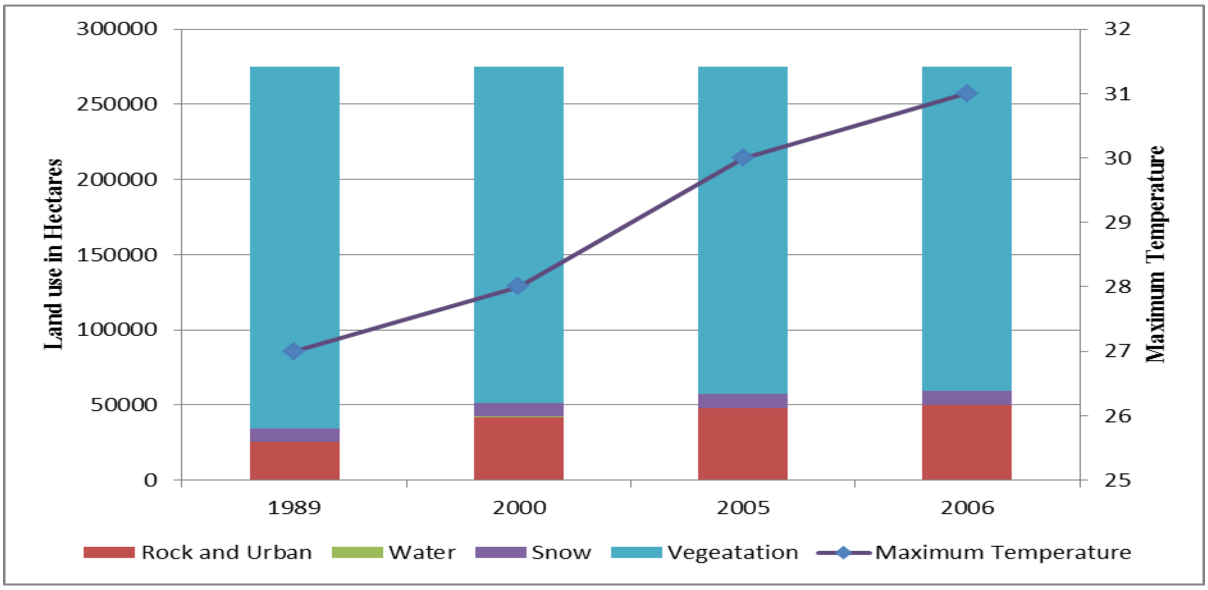
Fig. 4 Changes in the Temperature with respect to Time in Shimla, Himachal Pradesh.

Figure 5 illustrates the linkages between local temperatures with the changes in land use. The temperature in the study area during the year 1989 was minimum 3 °C and maximum 27 ° C, whereas in the year 2006 the minimum − 2 °C and maximum 31 °C (Table II), which highlights that LU characteristics play a significant role in maintaining the ambient temperature and also in the regional heat island phenomenon. Built-up and corresponding temperature (at pixel level, n, number of pixels = 83922 (in 1989), 140228 (in 2000), 159222 (in 2005) and 166889 (in 2006), were analyzed to see the spatio-temporal relationship. The analysis illustrates that built-up increase significantly contributes to the enhanced temperature ($r = 0.994$, $p < 0.05$). The vegetation and water bodies have relatively lower temperature suggesting that they aid as heat sinks and moderate the local climate. The population of this region exceeds its carrying capacity and is exerting pressure on the local natural resources such as land, water, etc. [27–29].

Table II: *Land Surface Temperature Changes in Shimla, Himachal Pradesh.*

Year	**Temperature °C(Maximum)**	**Temperature °C(Minimum)**
1989	27	3
2000	28	− 1
2005	30	− 1
2006	31	− 2

Fig. 5 *Temporal Variations in Land-Use and Temperature in Shimla, Himachal Pradesh.*



6. CONCLUSIONS

The LU analysis shows that there has been a 55% increase in urban and open areas during 1989 to 2000 and 39% increase during 2000 to 2005, and 18.92% increase during 2005-06. This land use changes have also influenced the local climate. The minimum (min) and maximum (max) temperature was found to be $-2\,^{\circ}C$ and $31\,^{\circ}C$. This study clearly shows that the rate of increase in the urbanization leads to change in the land surface temperature. The increase in the temperature is in the range of $3\,^{\circ}C$ to $4\,^{\circ}C$ during 1989 to 2010. Change detection techniques from multi-resolution images integrating spectral, structural and textural features to generate changed patches and change attribute are also desirable and a challenging area of research.

ACKNOWLEDGEMENTS

We are grateful to NRDMS Division, The Ministry of Science and Technology, DST, Government of India, for the financial support. We thank Mr. Uttam Kumar for his suggestions during the analysis.

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