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Urban Spatio-Temporal Changes and its Impact on Urban Heat Island- Kota City

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Abstract—*Kota city of Rajasthan has experienced massive population growth in last two decades due to the educational hub of India. This excessive increase in population leads to the modification in the land use of the city with urban sprawl. The rapid urban expansion is affecting the local climate of the city with the spatial changes in land use/land cover. Therefore, this paper assessed the impact of land use/land cover change on land surface temperature in Kota urban area. Geospatial techniques and split window algorithm were used for determining the land use/land cover and land surface temperature (LST) from Landsat Enhanced Thematic Mapper (ETM^+) and Operational Land Imager (OLI) data respectively for the period of 18 years starting from 1999 to 2016. Three buffer zones with a distance of 5 km were created from the center of the Kota city to assess the impact of land use/land cover change on land surface temperature.The results indicated that there is huge increase in built-up area of the city (167 %) between 1999 and 2016. Results imply that in 0-5 km buffer zone the built-up expanded by 1912.03 ha, however in 5-10 km buffer area, the urban area increased by 3298.79 ha. Built-up area in >10 km zone i.e. in outskirts of the Kota city increased by 635.18 ha. The results reveal that uncontrolled rapid urbanization is leading to urban heat island as suggested by increase in LST from 37.26°C to 41.79°C in 5-10km zone during study period. There is a need to implement of policies preserving vegetative surfaces and mitigating measures to reduce the effects of urban heat island transformation in the study area.*

Keywords*: Land surface temperature, urban growth, Remote Sensing, GIS.*

1. INTRODUCTION

The relationship between urbanization and the ecological environment has become a crucial issue for urban development studies [1]. The global urban spatial extent has been increasing at a rate higher than urban population growth rate. The global urban extent that increased by 5,800 km^2 from 1970 to 2000 is expected to most likely increase by 1.5 million km^2 in 2030 [3]. The rapid urban land use change and its expansion affects the climatic condition [4], [5], biodiversity [6], carbon emissions and use of energy [7], [8]. Land use/land cover change is an important aspect in understanding the interactions of human activities with its surrounding environment. In order to manage and monitor the spatial expansion and land transformation, it is necessary to map different themes periodically [9] using remote sensing and Geographic Information System (GIS).

Rapid urbanization accompanied with population growth and industrialization leads to urban heat island. Urban Heat Island (UHI) effect is well known, which shows higher temperature in urban areas compare to surrounding areas. Many researchers reported UHI effects in different cities of developing and developed countries [10], [11]. Human induced land use/land cover changes gradually expanding the impervious surface in the forms of buildings and road network during the urbanization. This change in the surface materials and land use of the city areas influence local temperatures and make urban areas warmer than the surrounding non-urbanized areas [12], [13].Therefore, change in LST plays an important role in local and regional environment condition of the city. Introduction of thermal remote sensing technology has offered prospects for acquiring data at different spatial resolution and coverage of earth surface. Land Surface temperature is derived using thermal band of satellite data and provides essential and useful information of LST patterns and it's interrelationship with surface characteristics [14]. Various methods to measure and analyze the surface temperature have been proposed by different authors using different approaches [15], [16], [17], [18]. Several algorithms such as split-window, dual angle and single-channel are available to estimate the LST and to understand the influence of the characteristics of urban surfaces on UHI.

In developing country like India, where cities are in growing phase and development taking place in both planned and unplanned way. Urban heat island studies are very limited to metro cities and very few studies monitored the LST changes in rapidly growing cities. Kota city is one of them, which is expanding very fast being the education hub of India and little studies were made on it. Thus this research aims to investigate the temporal and spatial change of urban land use and land transformation in Kota city, further it also try to ascertain the impact of land use/land cover changes and growth of impervious surface on land surface temperature.

2. MATERIAL AND METHODS

A. Study area

Kota city is located between 24°32' & 25°50 N Latitude and 75°37' & 76°34' E Longitude in the southeast of the state of Rajasthan (Figure1). Kota is the third largest city of Rajasthan after Jaipur and Jodhpur. The average elevation of the city is 271 meters. This city has grown up on the banks of Chambal which is the only perennial river of Rajasthan. Kota is 46th most populous city of India and 53rd most populous urban agglomeration of India. The population of the Kota district as per 2011census was 19,51,014 persons including rural and urban population of 7,74,410 and 11,76,604 respectively. Kota city is the prominent industrial and educational town of Rajasthan and named as "Education hub of India" because of its excellence in coaching for entrance examination of national and state level technological institutes for engineering and medical courses. Climate of Kota is semi arid type where temperature normally varies from 10.6 °C - 24 °C in winter and 29.7 °C - 46.2^{0}C in summer. The average annual precipitation in the area is approx 652.17 mm. physiographically, the city is characterized by rocky, barren and elevated land in southern part of city descends towards a plain agricultural land in the north.

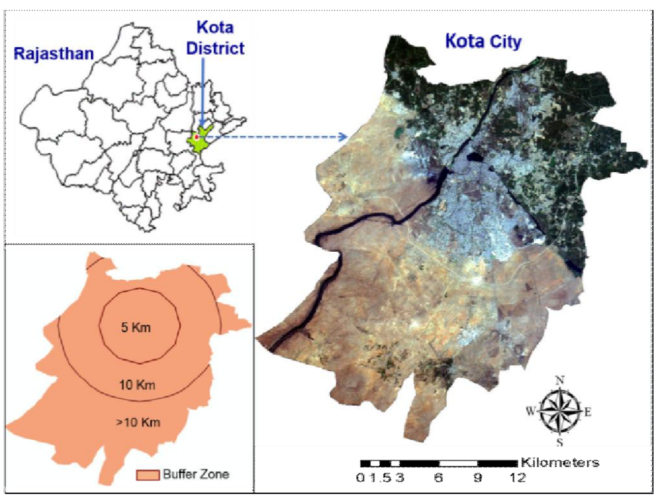

Fig. 1: Location map of Study area

B. Data used

This study employed the use of cloud free remotely sensed Landsat satellite images i.e. Landsat 7 (October 1999) and Landsat 8 OLI/TIRS (October 2016) of Kota acquired from the USGS website (https://earthexplorer.usgs.gov).These imageries were used for assessing the land use/land cover changes and their impact on LST. Remote sensing data were supplemented with the Survey of India (SOI) toposheets of 1:50000 scale, and administrative boundary from Kota Municipal Corporation, which were used to generate base layers of the study area. In addition to these datasets Google Earth Maps and Ground control points (GCPs) collected in the field using handheld calibrated GPS were used for the study.

C. Data analysis

ArcGIS software have been used to generate various thematic layers, like district boundary map and Municipal boundary map of Kota (Figure1). Image processing was performed using ERDAS Imagine software to find out the spatio-temporal changes in the land use/land cover of the study area during 1999 and 2016. The study area image was classified into four different classes; built–up, vegetation, water body and barrenland. Supervised classification was carried out by using maximum likelihood algorithm on the study area image. Homogenous pixels representing the different land use/cover were identified, selected and merged in the signature editor tool of the Erdas Imagine software The output images were reclassified using ground truth data and Google Earth imagery to reduce the classification error and improve the accuracy of the classification.

D. Land Surface Temperature Estimation

Spectral radiance model (Landsat-7, 1999) and Split window Algorithm (OLI/TIRS, Landsat-8) was used to derive surface temperature. Spectral radiance was calculated using following equation [19]:

$$L_{(\lambda)} = L_{\min(\lambda)} + \left(L_{\max(\lambda)} - L_{\min(\lambda)}\right) Q_{dn} / Q_{max} \quad (1)$$

where $L_{(\lambda)}$is the spectral radiance received by the sensor (Wm^{-2} sr $^{-1}$ µm^{-1}), $Q_{\max}$ is the maximum DN value with $Q_{\max}$=255, and $Q_{dn}$is the grey level for the analysed pixel of ETM$^+$ image, $L_{\min(\lambda)}$ and $L_{\max(\lambda)}$are the minimum and maximum detected spectral radiance for Q_{dn}=0 and Q_{dn}=255, respectively.

Spectral Radiance (L $_\lambda$) to BrightnessTemperature (BT) in Celsius may becalculated by using inverse Planck function as expressed in equation (2)

$$BT = \frac{K2}{ln\left[\frac{K1}{L_\lambda}+1\right]} - 272.3 \quad (2)$$

Where; BT=at-satellite brightness temperature [Celsius degree], K1=calibration constant 1(Wm^{-2} sr $^{-1}$ µm^{-1}), K2=calibration constant 2 (degree Kelvin) refer Table 1, ln =natural logarithm, L $_\lambda$=spectral radiance from equation (1)

Land Surface Temperature can be calculated from At-Satellite Brightness Temperature (BT) as [20]:

$$LST = BT / [1 + (w * BT / C_2) \ln(e)] \quad (3)$$

Where, BT=at-sensor brightness temperature, w =wavelength of emitted radiance,

$C_2 = h \times \frac{c}{s}$ i.e. 1.4388×10^{-2}mK, h=Plank's constant i.e. 6.626×10^{-34} Js, s=Boltzmann constant(1.38 × 10^{-23}J/K), c

=velocity of light(2.998×10^8 m/s), e =Land Surface Emissivity (LSE).

LSEwas estimated using Normalized Differential Vegetative Index(NDVI) and calculated using following equations

$$NDVI = \left(\frac{NIR-RED}{NIR+RED}\right) \quad (4)$$

$$P_V = (NDVI - NDVI_{min} / NDVI_{max} - NDVI_{min})^2 (5)$$

$$e = 0.004 P_V + 0.986 \quad (6)$$

Where, NIR=Near InfraRed band, Red=Red band, P_v=Proportion of vegetation,$NDVI_{min}$=minimum value of NDVI, $NDVI_{max}$=maximum value of NDVI, e= Land Surface Emissivity

Surface temperature from Landsat 8 OLI/TIRS was derived using the split-window algorithm proposed by Mc Millin in 1975.

$$LST = BT_{10} + C_1(BT_{10} - BT_{11}) + C_2(BT_{10} - BT_{11})^2 + C_0 + (C_3 + C_4W)(1 - m) + (C_5 + C_6W)\Delta m \quad (7)$$

Where, LST = Land surface temperature, C0–C6 = Split-window coefficient values (Table 2), BT10 and BT11 =Brightness temperature of band 10 and band 11, m = mean LSE of band 10 and band 11 i.e. $\frac{LSE_{10}+LSE_{11}}{2}$, Δm = Difference of LSE i.e. (LSE_{10}-LSE_{11}), W = atmospheric water vapor content.

Table 1: Thermal constant value

Band	K1	K2
6	666.09	1282.71
10	774.89	1321.08
11	480.89	1201.14

Table 2: Split-window coefficients value

Constant	Value
C_0	-0.268
C_1	1.378
C_2	0.183
C_3	54.3
C_4	-2.238
C_5	-129.2
C_6	16.4

E. Buffer Zones

Three buffer zones with a distance of 5 Km were created from the center of the Kota city to assess the spatio-temporal changes in land use/land cover and LST at different distances (Fig 1). These buffer zone boundaries (i.e. 5 km buffer, 5-10 km buffer and >10 km buffer were overlaid on the classified output of land use/land cover and LST to extract the area under each zone during 1999 to 2016.

3. RESULTS AND DISCUSSION

Over the past decade, the pressure exerted by urbanization motivated city planners and managers to evaluate the magnitude of urban expansion and the associated urban heat island effect [21], [22]. Present study was influenced by large observed changes in land use/cover in Kota City.

A. Spatio-temporal changes in Land use/land cover

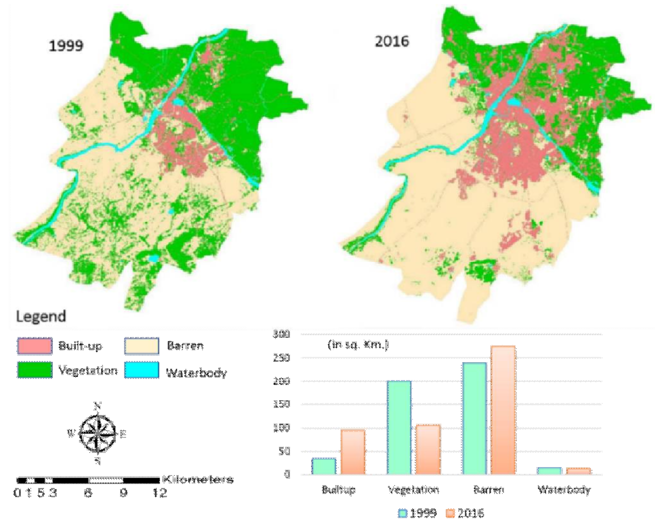

Fig. 2: Land use/land cover classification of Kota city

The land use land cover map of Kota city for 1999 and 2016 is presented in Figure 2. Results indicate that in 1999, the vegetation (40.94 %) and barren land (48.86 %) dominates majority of the land use/cover of the Kota city compared to the other LULC classes. In 2016, a major expansion of the built-up area was observed (19.47%) as compared to built-up in 1999 (7.15%). The increase in built-up area has been clearly seen in the north-west and north-east direction engulfing fertile (mixed red and black soil) and productive land area of the Kota city. The unprecedented population growth coupled with unplanned developmental activities has led to urban sprawl (Dadhich et al. 2017). The increase in population could be attributed to the evolvement of the city as Education hub of India, which is characterized by the establishment of engineering and medical coaching institutes leading to an influx of students from across the country.

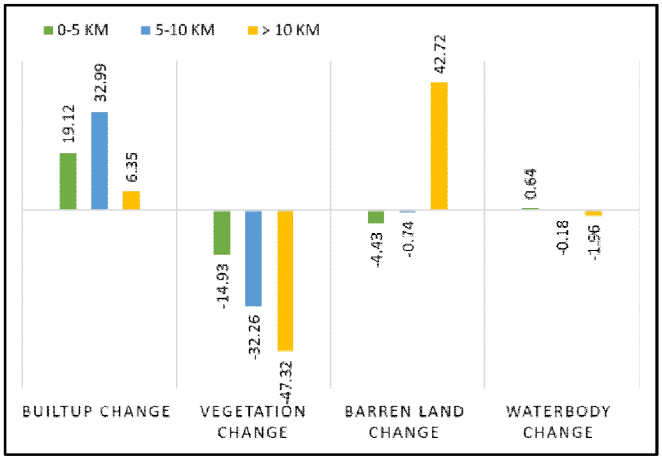

Fig. 3: Land use/land cover changes (in Sq.km) in different buffer zones during 1999-2016

The changes in land use/cover under different buffer zones are shown in Figure 3. Buffer zone analysis results clearly depict the increase in built-up area during 1999 to 2016. In 0-5 km buffer zone, built-up area increased by 99.14% followed by 223.1% in 5-10km zone. However, in >10 km buffer zone, built-up and barren land increased by 645.75% and 32.85% respectively. Results indicate that lesser urban expansion in 0-5 km buffer zone is due to non possibility of further expansion in this zone. The analysis also exhibits the huge growth in city periphery and most of the new built areas are developed near and along the major roads or highways in North West and eastern direction of the city.

B. Land use/land cover change impact on Land Surface Temperature

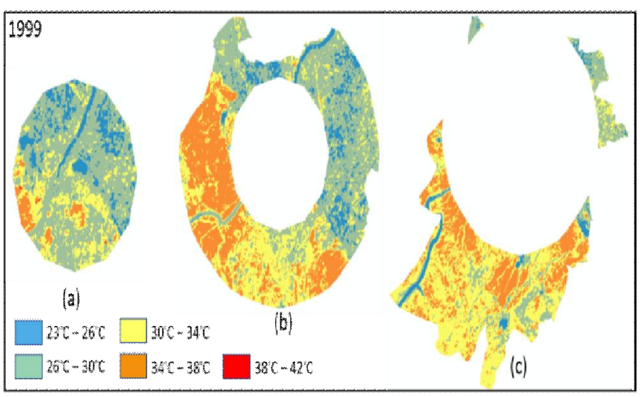

Fig. 4: Land Surface Temperature changes in different buffer zones during 1999

Spatio-temporal distribution of surface temperature is shown in Figure 4 and Figure5 for the year 1999 and 2016. Table 3 depicts the variations in LST during 1999 and 2016 for the Kota urban area. High LST values correspond to built-up and barren land, while the low LST values were observed over vegetative surfaces and waterbody. This could be attributed to the fact that urban impervious surface has a warming effect on urban land surface temperature [24]. Increase in impervious surfaces result into increase in surface temperature [25]. LST result implies that the average surface temperature of the study area has increased by 4.4°C during 1999 to 2016.

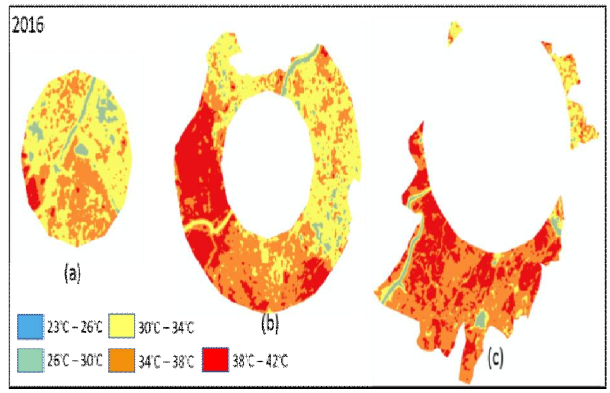

Fig. 5: Land Surface Temperature changes in different buffer zones during 1999

Table 3: Variation in Land Surface temperature from city centre

	1999				2016			
Buffer Zone	Min	Max	Mean	S.D.	Min	Max	Mean	S.D.
0-5 Km	23.59	39.6	28.87	2.52	27.74	41.38	33.29	2.08
5-10 Km	23.16	37.26	30.7	3.34	27.7	41.79	35.08	3.02
> 10 Km	22.72	37.26	32.04	2.61	26.947	41.09	36.457	2.51

Figure 6 reveals the change in LST during last 18 years (1989-2016). The analysis implies that vegetative land dropped in the city during the period while the built-up lands constantly rose. Spatial distribution results (Figure 5) also infer that along with urbanized area; the rocky, barren and elevated land in southern part of cityis also warmer and enhancing the UHI effect in the city.

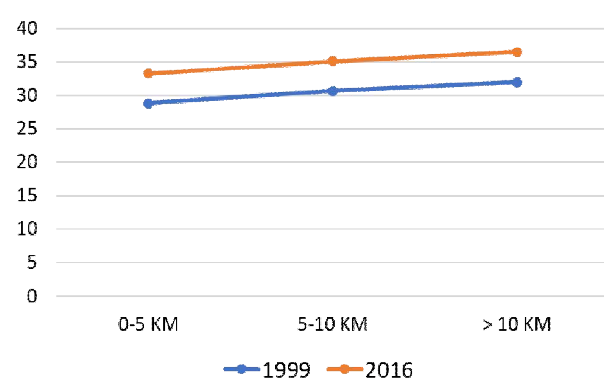

Fig. 6: AverageL and Surface Temperature (in °C) during 1999 and 2016

4. CONCLUSIONS

This study was focused to detect LULC changes and associated LST changes from 1999 to 2016, using Landsat ETM+/OLI images in Kota City, India. The unprecedented increase in population and large scale land transformation was observed in 5-10 and >10 km buffer zone area of the city during the study period.LST results indicate that average surface temperature of the study area has increased by 4.4˚C during 1999 to 2016. LST analysis reveals that built-up area and barren land has the highest temperatures among the land use types. The lowest temperatures are found in the vegetation area and waterbody as expected. Thus, increase in non-evaporating surfaces such as settlement, bare soil and rocky land have contributed to increase in land surface temperature of the study area. This study enables to understand the influence of LULC change on local climate change. Different mitigation measures should be introduced to reduce UHI effects in Kota city and for the purpose of sustainable urbanization.

5. ACKNOWLEDGEMENT

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