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Identifying the relationship between land cover change and land surface temperature increase in Colombo City, Sri Lanka – A remote sensing and GIS approach

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Abstract

With the concentration of development activities and increase of built-up areas, Colombo City is experiencing considerable changes in its Land Cover (LC) as well as its temperature. As past records indicate, Colombo city was experiencing around 27^0C average temperature in past few decades which is recording a significant increase in recent years. Accordingly, this study attempts to identify the LC changes in Colombo City and its surroundings in respective three years 1995, 2005, 2015. LC was classified into basic 4 classes; water, vegetation, built-up and soil using Supervised Classification method. The technique employed was Maximum Likelihood Classification and it was performed for LANDSAT 4-5TM and LANDSAT 8 OLI/TIRS images in each year. Detected changes were compared with the calculated Land Surface Temperature (LST) using thermal band of all three images. The result shows a strong relationship between the reduction of vegetation cover and increased land surface temperature. Vegetation cover within the city limits of Colombo has been reduced up to 30% within past two decades. The areas converted from vegetated into built-up shows an elevated LST which has a trend of spreading towards the inland. Results illustrate the relationship between increasing trend of temperature within the city and LC change which should be of deep concern to the activities of city planning and decision making.

Keywords: Land cover change; suppervised classification; LST, Remote Sensing

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1. Introduction

With the rapid development and urban expansion, land cover and land use change could be identified in most of the urban environments especially in developing countries like Sri Lanka. Colombo is the commercial capital of Sri Lanka which is experiencing significant spatial changes over past few decades. Colombo is a coastal city with a high concentration of population and infrastructure networks. Increasing number of population and concentration of services in the city have directed to cause adverse environmental impacts such as concentrated development, waste management issues and traffic congestion etc. Moreover, reduction and replacement of vegetation cover for fulfilling the land demand for increasing urban activities that result more impervious surfaces have significantly impacted to accumulate heat energy in cities which creates an unlivable environment for inhabitants. This causes urban areas with raised temperatures than surrounding sub-urban or rural areas. Since Colombo is in a stage of rapid development that is attracting much more development projects, a broader understanding and consideration regarding its environmental aspect has become a timely need.

Consequently, this study is carried out to identify the temporal land cover changes and correspondent land surface temperature (LST) variation in Colombo city by a remote sensing approach. Remotely sensed data are commonly used for land cover change analysis to provide information on resource inventory and land use, and to identify, monitor and quantify changing patterns in the landscape (Fonji and Taff, 2014). Multi-temporal satellite imagery helps to understand land cover dynamics using digital change detection techniques. Remote sensing and GIS technologies were used in present study to identify land cover changes and to assess their impacts on land surface temperature in Colombo and its surrounding areas. Satellite data from Landsat 4-5TM and Landsat 8 OLI/TIRS were used to perform supervised classification, NDVI calculation and detect LST for three respective years 1995, 2005 and 2015 to determine land cover changes, quantifying urban expansion, vegetation cover extraction and corresponding temperature changes in Colombo.

2. Data used

The remote sensing data used for this study includes 3 Landsat images for 1995, 2005 and 2015. Landsat 4-5 Thematic Mapper (TM) images acquired on 1st January 1995 and 13th February 2005 were used for analyzing all three factors including land cover classification, NDVI and LST. Landsat TM images consist of seven spectral bands with a spatial resolution of 30 meters for Bands 1 to 5 and 7. Spatial resolution for Band 6 (thermal infrared) is 120 meters, but it is resampled to 30-meter pixels. For the year 2015, the image acquired on 8th January 2015 from Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) was used which consists of nine spectral bands with a spatial resolution of 30 meters for Bands 1 to 7 and 9. The resolution for Band 8 (panchromatic) is 15 meters. Thermal Infrared bands are Band 10 and 11 acquired at 100 m spatial resolution which are resampled to 30 meter in delivered data product.

3. Methodology

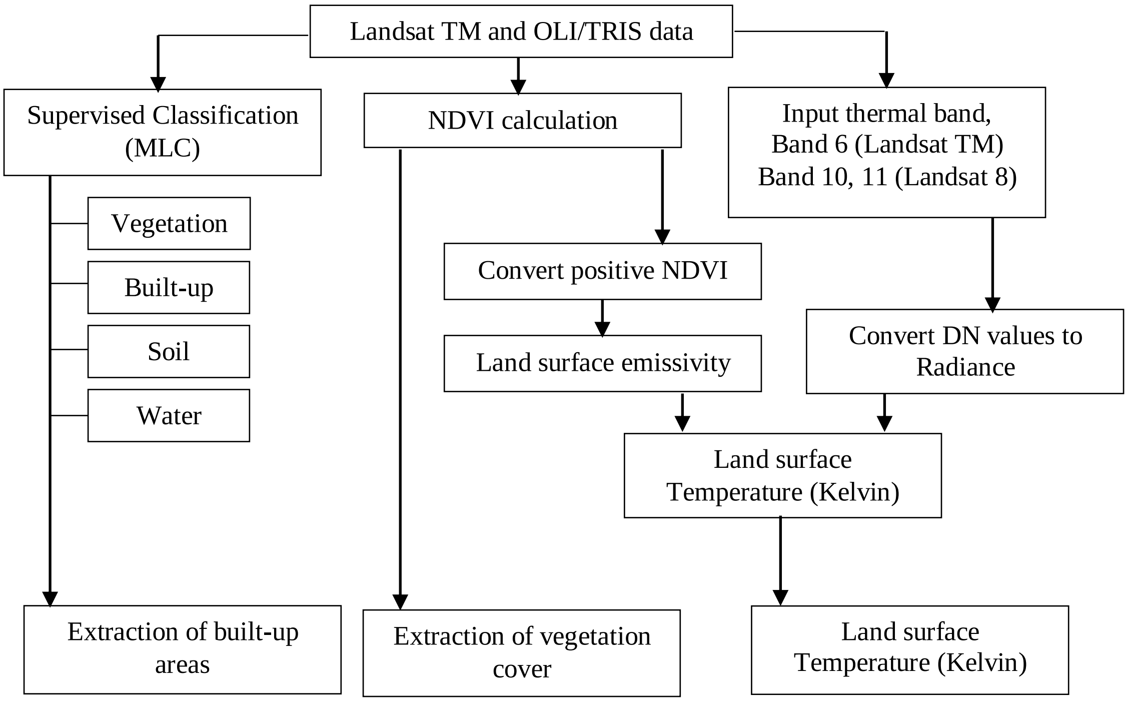


Fig. 1. Flow chart showing the workflow of methodology

3.1. Land cover classification

Colombo city and its surrounding area was selected as the study area for regional analysis to get a better and broader understanding on land cover change and to determine the pattern of changing with new emerging features. Supervised Classification which group satellite image pixels with the same or similar spectral reflectance features into the same information categories (Campbell and Wynne, 2011) was performed to identify four major classes, built-up, vegetation, water and soil using Maximum Likelihood Classification (MLC) technique for all three Landsat images in respective years. Ten ground truth reference polygons were created based on Bing map and each polygon contained more than 50 pixels except few polygons in soil class. To improve the classification, results were visually compared with Bing map image and confusing reference polygons were discarded and created new ones and repeated the process until the results become observably accurate. (Fonji and Taff, 2014). Land cover classification of three years are shown in figure 2 (a), (b), (c). Built-up areas were extracted from classified results of all three years to determine the changes of built pattern. For this study, an accuracy assessment was carried out based on visual observation of few know ground points by comparing them with Bing map imagery.

3.2. NDVI Calculation

Spectral signature difference of vegetation areas due to photosynthesis by absorption of red light (RED) from 0.4μm to 0.7μm wavelengths in visible region and high reflection in 0.7μm to 1.1μm Near Infra-Red (NIR) region (from 0.7μm to 1.1μm) is used to calculate the Normalized Difference Vegetation Index. Following formula (1) is used to calculate NDVI value for green vegetation.

$$NDVI = \frac{NIR - RED}{NIR + RED} \tag{1}$$

This can be used to differentiate green vegetation from other land cover classes based on their value. NDVI value falls between -1.0 to +1.0 where very low values (0.1 and below) correspond to barren areas such as rock, sand, or soil. Moderate values represent shrub and grassland (0.2 to 0.3), while high values indicate temperate and tropical rainforests (0.6 to 0.8) (earthobservatory.nasa.gov, 2016). Accordingly, vegetation cover was extracted based on NDVI value to identify the changes over the two decade period.

3.3. Calculating Land Surface Temperature

For calculating LST the thermal infrared bands of Landsat 4-5 TM (for 1995 and 2005) and L8OLI/TIRS (for 2015) were used. Landsat sensors acquire temperature data and store information as digital numbers (DN) in their Thermal Infrared band. These DN values are possible to convert in to degrees Kelvin/Celsius by two-step process (Kayet et al., 2016). Thermal energy that is emitted by different forms of land surfaces are vary from one to another which can use as a factor for differentiating the surface temperature of various land cover classes. DN values of each thermal infra-red bands can be converted in to spectral radiance using following accepted formula. (Kayet et al., 2016), (Landsat.usgs.gov, 2016).

$$L_\lambda = M_L Q_{cal} + A_L \tag{2}$$

where, L_λ = TOA spectral radiance (Watts/($m^2 \times srad \times \mu m$)), M_L = Band-specific multiplicative rescaling factor, A_L = Band-specific additive rescaling factor, Q_{cal} = Quantized and calibrated standard product pixel values (DN).

For Landsat 4-5 TM, $M_L = 0.055375$, $A_L = 1.18243$ and DN value band 6 was used for Q_{cal}. For Landsat 8, $M_L = 0.003342$ and $A_L = 0.1$ for both TIRS bands 10 and 11. DN values for band 10 and 11 were used separately to calculate the radiance value for both bands. After converting the DN values into radiance, it is converted to at-satellite brightness temperature values using Planck function (Kayet et al., 2016), by (3),

$$T_b = \frac{K_2}{ln\left(\frac{K_1}{L_\lambda} + 1\right)} \tag{3}$$

where, T_b = Brightness Temperature, K_1 = Band-specific thermal conversion constant, K_1 = Band-specific thermal conversion constant, L_λ = TOA spectral radiance (Watts/($m^2 \times srad \times \mu m$)). Kelvin values were calculated for both band 10 and 11 for 2015 Landsat 8 image which needs to be averaged to compute one value for 2015. To quantify the average value for brightness temperature, mean value was taken by calculating cell statistics.

Since the output values are satellite brightness temperatures, the values then be corrected using emissivity values of land use classes to estimate the actual Land Surface Temperature (T_s) using equation (4),

$$T_s = T_b / 1 + \left(\lambda \times \frac{T_b}{\rho}\right) \ln \varepsilon \tag{4}$$

where, T_b is the brightness temperature, λ is the wave length of emitted radiance, $\rho = hc K^{-1}$ (1.438×10^{-2} mK), h = Planck's Constant ($6.626 \times 10^{-34} J s^{-1}$), c is the velocity of light ($2.998 \times 10^{8} ms^{-1}$) and K is Boltzman constant

(1.38×10^{-23} J K^{-1}), ε is surface emissivity which can be calculated converting positive NDVI using following two (5), (6) formulas (Carlson and Ripley, 1997)

$$P_v = \left[\frac{NDVI - NDVI_{min}}{NDVI_{max} + NDVI_{min}}\right]^2 \tag{5}$$

$$\varepsilon = 0.004 \cdot P_v + 0.986 \tag{6}$$

where, T_b is the brightness temperature, λ is the wave length of emitted radiance, $\rho = hc\,K^{-1}$ (1.438×10^{-2} mK), h = After calculating the land surface temperatures corrected for spectral emissivity (ε), the computed Kelvin values then converted into Celsius by equation (7),

$$T_c = T - 273 \tag{7}$$

After performing classification, NDVI and LST analysis in regional scale, then the study has narrowed down to identify the spatial changes and temperature differences of Colombo city limits in past two decades. Ten DSD (Divisional Secretariat Division) administrative boundaries in western province which are adjacent to city of Colombo were selected to analyse further (Figure 2).

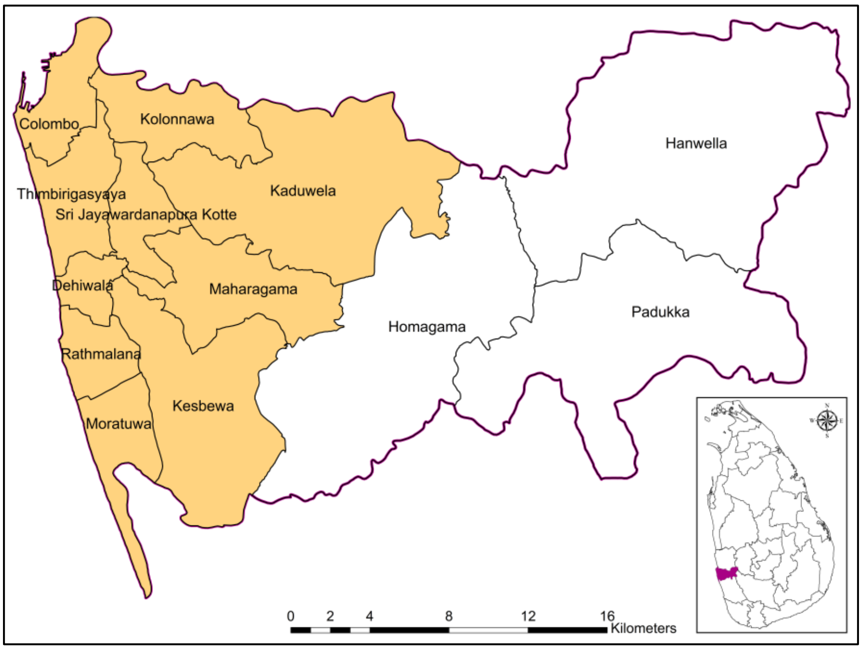


Fig. 2. Study area

Those are the areas that were subjected to rapid land cover conversion within past two decades which determined by observing land cover classification results. Vegetation cover change within the selected areas were quantified and it was compared with temperature changes to distinguish the relationship of vegetation cover reduction and increase of land surface temperature.

4. Results and Discussion

4.1. Land cover classification

Land cover classification was performed using supervised classification for all three years 1995, 2005 and 2015 to identify the pattern and distribution of four classes namely, built-up, vegetation, soil and water. Figure 3 (a), (b), (c) shows the result of supervised classification.

Using classification results, built-up areas were extracted to compare the pattern of urban expansion and to distinguish newly emerged urban areas. From 1995 to 2015 20 years period, urban areas have been rapidly expanded towards the inland. Results indicate the annual percentage increase of built-up areas from 1995 to 2005 is 2.64% while it is 14.16% from 2005 to 2015. This shows the accelerated urban growth from 2005 to 2015 where the total built-up area in 1995 ($97.73 km^2$) has become tripled up to $298.52 km^2$ in 2015 according to the classification results for selected study area. Extracted built-up areas for each year shows in Figure 3 (d), (e), (f). The result of built-up area extraction clearly illustrates the growth of urban patches, emergence of new built-up areas, and expansion of built-up areas towards the newly emerged urban patches. Subsequently, land surface temperature analysis was carried out to determine the temperature changes of the areas in respective years.

4.2. *Land Surface Temperature*

Comparing the built up areas and land surface temperature distribution, it clearly shows the dispersion of areas with high land surface temperature towards the inland correspondent to the development of new built-up areas. Land cover classification results and comparison of built-up areas with temperature changes along the 20 years period gives a clear representation of overall spatial changes.

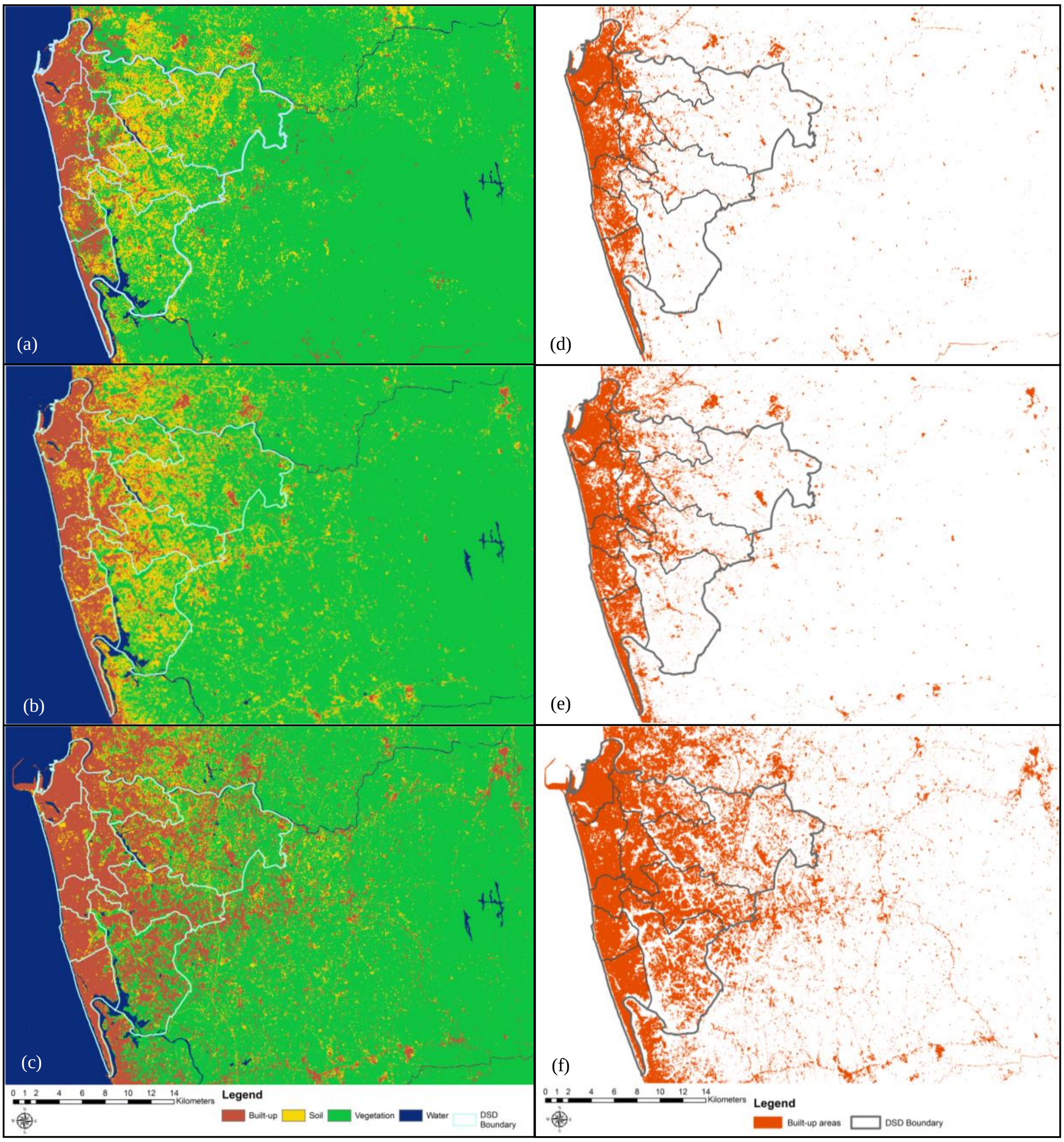


Fig. 3. Land cover classification results in (a) 1995; (b) 2005; (c) 2015; Extraction of built-up areas in (d) 1995; (e) 2005; (f) 2015

4.3. *Changes around Colombo city limits*

In order to identify the changes within city limits of Colombo where the significant changes could be observed, 10 DSD boundaries out of 13 in Western Province were selected as the study area for further analysis (Figure 2).

Within the selected boundary, the extracted vegetation cover using NDVI analysis shows a substantial decline from 1995 to 2015 quantitatively from 151.63 km^2 to 105.22 km^2 which is a 30.6% decrease which shows an 8.98% decrease in first 10 years (1995 to 2005) and accelerated decline of 21.63% in next ten years. From 2005 to 2015 the vegetation cover has reduced from 138.02 km^2 to 105.22km^2 quantitatively.

Since LST and vegetation have a negative correlation, (Kayet *et al.*, 2016) the temperature change analysis results were compared with the correspondent vegetation distribution. Comparison clearly illustrate the areas where vegetation cover faded away especially Kaduwela, Kolonnawa and Maharagama have resulted an elevated land surface temperature correspondingly those of higher temperature areas are subjected to be dispersed. Changes of vegetation cover and temperature change analysis for the study area for each sequential 3 years are shown in Figure 4 and Figure 5.

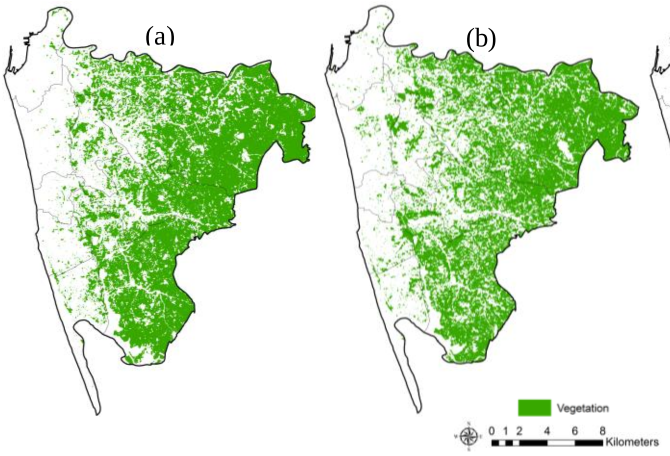
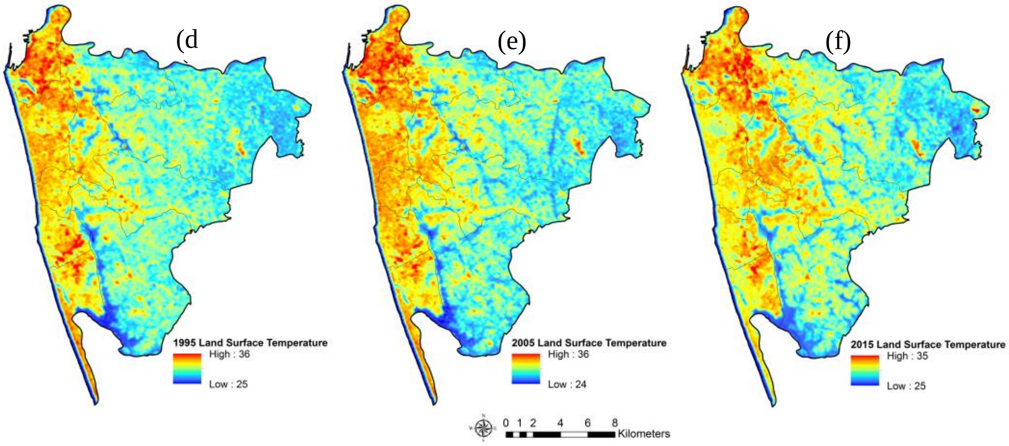


Fig. 4: Vegetation cover in (a) 1995; (b) 2005; (c) 2015

Fig. 5. Land Surface Temperature in (d) 1995; (e) 2005; (f) 2015

5. Conclusion

The attempt of this study is to identify temporal the land cover change and correspondent land surface temperature variation in Colombo city by a remote sensing approach. Land cover classification results of supervised classification indicated the rapid expansion of built up areas in regional scale and NDVI calculation clearly illustrated up to 30% decrease of vegetation cover in Colombo and adjacent areas. As a whole, the analysis results showed the consequences of vegetation cover decrease which caused an adverse impact on increase of land surface temperature and its distribution along a wider area. The results of this study can be effectively used for developing spatial planning initiatives for creating an environmentally compatible city. Corrective measures can be used to reduce the adverse impacts from LST increase by expanding greenery within the city. Further, study reveals the importance and possibility of using remote sensing analysis for effective quantification of temporal spatial change detection with a better accuracy.



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