International Research Journal of Natural and Applied Sciences
ISSN: (2349-4077)
Impact Factor 5.46 Volume 5, Issue 7, July 2018
Website- www.aarf.asia, **Email** : editoraarf@gmail.com

Vegetation in Urban Environment and Its Role in Management of Urban Heat Island

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Abstract

An urban heat island is a phenomena designated by a high temperature recorded within a city from which is subtracted the temperature that would be measured at that same location without the presence of the city. Urban development usually leads to alteration of land cover, as natural vegetation is removed and replaced by built up surfaces that trap incoming solar radiation during the day and then re-radiate it at night.An understanding of an UHI is central to urban micro-climatology and human environment interactions as it causes environmental discomfort and has adverse effect on human health.The present study focuses on classification of land cover using supervised fuzzy technique so that relationship between different land cover class and land surface temperature is correlated and impact of each land cover element in characterization of urban thermal landscape is established.The values of correlation are further used to develop a landscape index based on impact of different land cover in generating land surface temperature (LST) variations within an urban environment.UHI and its relationship with land cover reveal that there is a strong negative relationship between vegetation cover and the intensity of UHI implying that an increase in vegetation cover would tend to bring down the intensity of UHI effect.Anincrease in vegetation cover is proposed at places where open land is available and can be brought under vegetation cover. Increase in percentage of vegetation cover at places alters the value of Landscape index for UHI negatively indicating a decrease in intensity of UHI effect at such locations.

Key Words: *LANDSAT-8, Land cover, Land Surface Temperature, Source area, Sink area, Modified Landscape Index.*

Abbreviations:

UHI	Urban Heat Island
LST	Land Surface Temperature

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Introduction

The Urban Heat Island (UHI) is designated as an urban space around which surface temperatures are higher than those of the surrounding rural landscape (Pinho and Orgaz 2000; Shenlai X 2009).Urban development usually leads to a phenomenal alteration of the land cover, as natural vegetation is removed and replaced by non-evaporating, non-transpiring surfaces, (Park1986; Eliasson 1996; Goh and Chang 1999; Montavez et al. 2000) that trap incoming solar radiation during the day and then re-radiate it at night (Oke 1982). Ideally, an UHI is the difference in temperature recorded within a city that is subtracted from the temperature that would be measured at that same location without the presence of the city. As such measurement is not possible; the UHI intensity can be calculated by taking the temperature difference between an urban location and any nearby rural location with similar geographic features (Magee et al. 1999).The knowledge of the UHI is important to a range of issues in earth sciences central to urban climatology, global environmental change, and human environment interactions. Increase in UHI effect may exacerbate the health impacts of the higher temperatures that are already common in urban areas. As UHI effect has been found to be related to global warming (DeWitt and Brennan 2001) it may in case of climate change bring in the adverse impacts of warming directly to cities in form of further intensification of UHI effect.

One of the primary health concerns due to UHI is an increase in the intensity and frequency of heat waves, which have been linked with heat stroke, hyperthermia and increased mortality rates (Stott et al. 2004; Fouillet et al. 2006; Tan et al. 2007).Higher urban temperatures also mean increased consumption of energy, mostly for air conditioning, (Assimakopoulos et al.2007; Kolokotroni et al. 2007) and as power plants burn more fossil fuels, they drive up the pollution level that further leads to degradation of green spaces (Driscoll 1985; Myer 1991).In most cities around the world, the effect of urbanization on local climate, especially on outdoor temperature is alarming (Oke 1982; Rosenfeld et al. 1995; Sailor 1995; Taha 1997; Atkinson 2003; Giridharan et al. 2004)and is considered one of the major problems in the 21st century.Until recently the urban area accounted for only 2% of the earth surface (Grimm et al.2000); however, the urban landscapes have exerted significant impacts on the local and global ecosystems (Masek et al. 2000).Persistent worldwide expansion of urbanized areas are expected to accelerate in the next several decades (Miller and Small 2003)which will further transform urban landscapes and are expected to bring about unprecedented changes in urban micro-climate. In recent years, the rise in temperature from rapid development of urban centers has attracted attention of the scientists from world over (Wang et al. 1990)and in order to prevent the phenomena of UHI from intensifying and escalating it is necessary to understand its causes and consequences.

Research on UHI and its relationship with land cover have shown that there is a strong negative relationship between vegetation cover and the intensity of UHI (Carlson et al. 1994; Gillies and Carlson 1995; Gillies et al.1997; Lo et al. 1997; Goward et al. 2002; Weng et al. 2004). A higher level of latent heat exchange was found in areas dominated by vegetation cover, while sensible heat exchange was more favored by urban built up areas (Oke 1982). This finding has encouraged more and more researchesto focus on the relationship between LST and vegetation abundance (Gallo and Owen 1998; Gillies and Carlson 1995; Weng 2001). In spite of these significant contributions, application of LST–vegetation abundance relationship to management of UHI has been rather limited (Qihao et al.2004). The relationship between LST and vegetation indices, such as NDVI, has been extensively documented in the literature (Carlson et al. 1994)but it has been observed that the relationship between NDVI and other measures of vegetation abundance is well known to be nonlinear(Gillies and Carlson 1995). This nonlinearity and the platform dependency suggest that NDVI may not be a good indicator for quantitative analyses of vegetation. As theNDVI does not measure the amount of vegetation (Small 2001) and its values can be influenced by many factors external to the plant leaf, including viewing angle, soil background, and differences in row direction and spacing in the case of agricultural crops (Qihao et al.2004), the present study adopts a supervised fuzzy classification approach to extract vegetation cover. Fractional vegetation cover extracted from supervised fuzzy class approach depicts the amount of vegetation cover within a pixel, and modulates the proportions of vegetation and other land covers.

The UHI effect has been the subject of numerous studies in recent decades and is exhibited by many major cities around the world (Wang et al. 1990; Kim and Baik 2004; Huang et al. 2005).As other factors like land use, physical morphology of the city and anthropogenic heat emissions are related if not dependent on land cover. The relationship between land surface temperature (LST) and land cover has been the focus of many studies on UHI(Gallo and Trapley 1996; Dousset and Gourmelon 2003; Chen et al. 2006;Li et al. 2009). Urban land cover characteristics have an influence on UHI(Bottyan and Unger 2003; Stone and Norman 2006) but in a complex heterogeneous urban environment, it is not well understood as to how much role different urban surfaces like built-up area, water bodies, vegetation cover and barren land have on the intensity of the UHI. Simply comparing the temperature in an urban area to that in the surrounding rural area is not adequate in terms of urban design and planning and sustainable urbanization.There is a pressing need to evaluate strategies to mitigate against further increases in temperatures in urban areas (Bowler et al. 2010)for which landscape index for UHI is prepared using the area of different land covers and their correlation coefficient with temperature intensity in an urban area.

Keeping the negative correlation coefficient between vegetation cover and UHI intensity into consideration, it is proposed that the open lands within the city be brought under vegetation cover that will change the values of landscape index for UHI and will help in modifying and mitigating the UHI effect.

Method and materials

Study area

Gorakhpur, located between Lat. 26º 13' N and 27º 29' N and Long. 83º 05' E and 83º 56' E is an important city of eastern Uttar Pradesh in north India**(Fig. 1).** The city covers an area of approximately 110 km^2 and has a population around 0.75 million. January is the coldest month with average temperature around 15^0C while June is the hottest month where maximum temperature may go up to 45^0C and average temperature can be as high as 32^0C. Most of the 150 cm rainfall occurs during the monsoon months of July to September. While Gorakhpur is not viewed as a city with prominent heat issues, on account of the presence of wetland surrounded by built up area and forest area along with agricultural fields in close proximity, the city provides an ideal setting to analyze the variation in intensity of UHI due to different combinations of land cover.

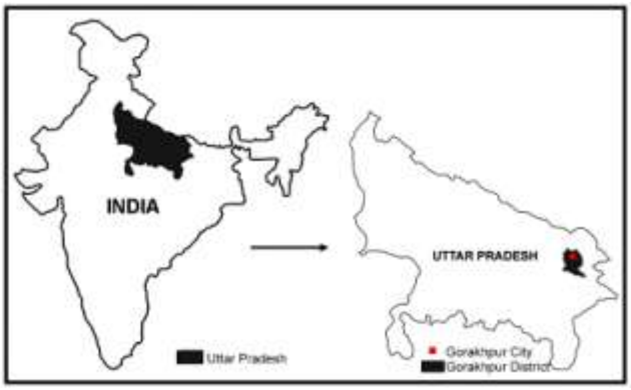

Fig. 1 Location of Gorakhpur City

Data

UHIs have long been studied by ground-based observations but it had proved difficult to monitor and measure UHI solely with in-situ instruments (Bendor and Saaron 1997).Ground based observations lack simultaneity and even large number of observations require interpolation which introduces errors. Satellite thermal data can effectively depict the patterns of the thermal environment of extensive urban areas(Streutker 2002).With the advent of thermal remote sensing technology, remote observation of UHI's became possible and has provided new avenues for the observation of UHI's and the study of their causation through the combination of thermal remote sensing and urban micrometeorology (Voogt and Oke 2003). In recent years, with the advance of the study on algorithm and the improvement of sensor, remotely sensed data is being used extensively in the field of urban climate and UHI(Dousset and Gourmelon 2003).In the present work LANDSAT-8 data has been used to extract the different land covers and to derive LST's which were used to find correlation between land cover, development of land cover index and formulation of management strategies for UHI in Gorakhpur city.

To quantitatively measure the LST and compare UHI intensity in the study area, LANDSAT-8 image (Path 141/Row 042), acquired on October 19, 2014 was used. The LANDSAT image acquired through the USGS Earth Resource Observation Systems Data Centerwas rectified to a common Universal Transverse Mercator coordinate system based on 1:24,000 scale topographic maps, and was resampled using the nearest neighbor algorithm with a pixel size of 30 m by 30 m for all bands including the thermal band.

Land Cover classification

Land cover classes are mapped from remotely sensed data through digital image classification where all pixels are categorized into land cover classes (Lillesand et al.2008). As the spatial resolution interacts with the heterogeneous urban land cover a special problem of mixed pixels is created, where several land cover types are contained in one pixel. Mixed pixels have been recognized as a major problem affecting the effective use of remotely sensed data in urban land cover classification and change detection (Fisher 1997). Traditional classifiers are per-pixel based, and cannot effectively handle the mixed pixel problem (Cracknell 1998). Use of high spatial resolution image data does not lead to high accuracy of classification (Clapham 2003) and as per-pixel based classification loses both spatial resolution and statistical information supervised fuzzy approach for land cover classification has been applied in the present study. Thapa and Murayama (2009) have shown that classification results can be improved using fuzzy supervised classification approach as it considers that each pixel might belong to several different classes without definite boundaries. The fuzzy supervised classification approach works using a membership function, where a pixel's value is determined by whether it is closer to one class than another (Jensen 2005; Wang 1990).

Homogeneous sample pixels were identified as training pixels in the image that were used as representative samples for each land cover category to train algorithm and to locate similar pixels in the image. In all four major land cover type were identified and five to ten region of interest were prepared that were used as signatures of training samples for different land covers. The ground reference data were used to prepare the training signatures. For supervised fuzzy classification of satellite data, PARBAT software had been used and for identification of different land covers, region of interesthad been created using ENVIsoftware.The fuzziness parameter was set between 1.5 and 2.0 as proposed by Zhang and Foody (2001). Fuzziness parameter with value 2.0 along with Euclidean distance was taken as it forms an ideal combination for lower resolution data like LANDSAT (Gopal and Woodcock, 1994). The membership value in fuzzy classified data pixels gives their degree of affinity with the centroid of the optimal class. Membership μ of the i^{th} object to the c^{th} cluster of n number of classes in ordinary fuzzy c-means, with d the distance measure used for similarity, and the fuzzy exponent q determines the amount of fuzziness, is defined as:

$$\mu^{ic} = \frac{(d_{ic})^{\frac{-2}{q-1}}}{\sum_{c'=0}^{n}(d_{ic'})^{\frac{-2}{q-1}}}$$

In the supervised fuzzy c-means, the class centroid is determined from the training data. Land covers in Gorakhpur city are depicted in **(Fig. 2)** where as the membership images for different land covers are shown in **(Fig. 3)**. Output of the supervised fuzzy classification had been used for further analysis.

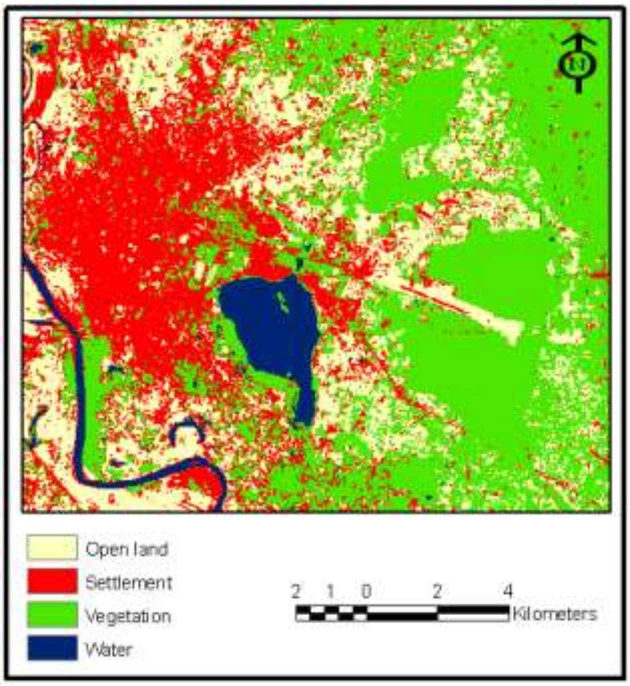

Fig. 2 Land cover, Gorakhpur (October 2014)

Land cover map generated for Gorakhpur **(Fig. 2**) shows dense settlements in the central core of the city from where areas of high density of settlements radiate out towards the fringe area following the transport arteries. The fringe area is dotted with patches of settlements intercepted with open land and vegetation. A large wet land (Ramgarh Tal) lies to the east of the city while a large area under vegetation cover (Khushmi forest) lies further east.

Land Surface Temperature Generation

Estimating LST, at sensor Brightness temperature was derived from LANDSAT band 6 (with an effective wavelength of 11.457µm). The Land Surface emissivity was derived by NDVI technique proposed byJime´nez-Mun˜oz and Sobrino (2003), Kant and Badrinath (1998) using derived NDVI (NDVI = NIR – R / NIR + R) and vegetation cover (p_v) image. Using this information,LST had been derived with help of Mono – window Algorithm as proposed by Qin et al. (2000).

Algorithm for LST estimation:

$$T_6 = [a_6(1 - C_6 - D_6) + (b_6(1 - C_6 - D_6) + C_6 + D_6)T_6 - D_6T_6]C_6$$

Where:

a_6 and b_6 are the coefficients. For the possible temperature range *0 – 70⁰C (273 – 343 K)* in most cases,

a_6 = -67.355351

b_6 = 0.458606

$C = \varepsilon\tau$

$D = (1 - \tau)[1 = (1 - \varepsilon)\tau]$

ε = Land surface emissivity

τ = Total atmospheric transmissivity

T_{sensor} = (T_6) at sensor brightness temperature

T_a = Mean atmospheric temperature

T_a = 16.0110 + 0.92621 T_o

T_o = near surface air temperature

τ = 0.974290 – 0.08007w (high T_o)

τ = 0.982007 – 0.09611w (low T_o)

w = atmospheric water vapor content for the range 0.4 – 1.6 gm/cm^2

Value of Land surface emissivity had been taken from derived emissivity image. The computation of LST from band 6 data is depended on determination of atmospheric transmittance τ_6 and effective mean atmospheric temperature (T_a).

Based on the above mentioned algorithm, LST image was generated for study area **(Fig. 3).** To locate the extent of UHI, the average temperature in rural hinterland (24^{0}C) was subtracted from the temperature in the urban area that gives the extent and intensity of UHI in Gorakhpur city**(Fig. 4).**

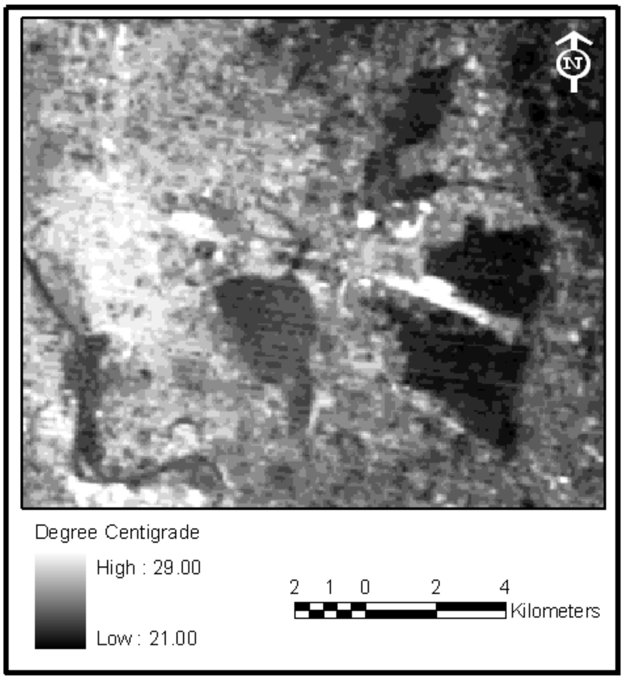

Fig. 3 Land Surface Temperature, Gorakhpur (October 2014)

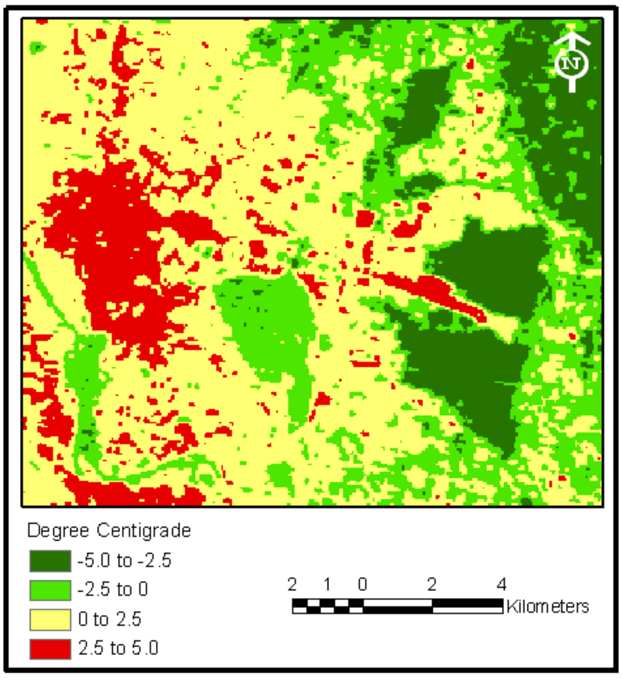

Fig. 4 Intensity of Urban Heat Island, Gorakhpur (October 2014)

Identification and Distribution Characteristics of UHI

From the LST map generated**(Fig. 3),** it is observed that temperature in the central core of the city and its surrounding areas varies between 22^{0}C to 30^{0}C while the average temperature in the rural areas around the city is 25^{0}C. It was observed that large areas in the central part of the city had intense heat island effect where temperatures were 2^{0}C to 5^{0}C higher than the rural areas**(Fig. 4).** It is interesting to observe that some part of the study area was actually cooler than the rural landscape that surrounds it. Temperatures above the large wetland to the south east of the central core and along the river bed in the south west **(Fig. 2)**were up to 2^0C lower than the temperatures of rural areas**(Fig. 4)**. Temperatures over the forest area along the eastern borderswere 2^0C to 3^0C lower than the temperatures of the rural landscape beyond. The overall pattern of temperature indicate that high intensity of UHI effect was associated with high built up density while areas with high density of vegetation and water surfaces were actually cooler than the rural locations around them.

Results and Discussions

The Correlation Analysis of UHI and Land cover

Correlation analysis was carried out to establish the relationship between land cover and observed pattern of variation in temperature over Gorakhpur city where correlations coefficient between image for temperature and membership images of different land covers was carried out separately. A correlations coefficient value of $r_b = 0.5$ was calculated between LST image and membership value for built up area which reflect the effects of urbanization and associated anthropogenic activities on the intensification of the UHI while a correlations coefficient value of $r_o = 0.3$ was calculated between LST image and open land as it comprised of sparse vegetation and exposed bare soil and built up structures in scattered patches. A negative correlation $r_w = -0.3$ was calculated between LST image and membership value for water thatindicates towards the importance of water surface in moderating the city's air temperature. Area under forests showed a considerably negative correlation of $r_v = -0.5$ with surface temperature as dense vegetation reduces the amount of heat stored in the soil and surface structures through transpiration. The results of correlation analysis point towards the relative significance of different land covers towards formation and mitigation of UHI effect.

Landscape index for UHI

The proposed landscape index for UHI is based on percentage of different land cover and their correlationswith LST. To construct the landscape index for UHI, values of membership images for different land covers are multiplied by the respective correlation coefficient value that the different land cover classes have with temperature. Finally the individual products of values of membership image and correlation coefficient are added to give the value of landscape index for UHI.

The landscape index for UHI is given by the following expression:

$$LI = (A_b \times r_b) + (A_o \times r_o) + (A_w \times r_w) + (A_v \times r_v)$$

Where

LI= Landscape index for UHI

A=Area

r = Correlation coefficient

b=Built up surface; o=open land; w= water body; v=vegetation

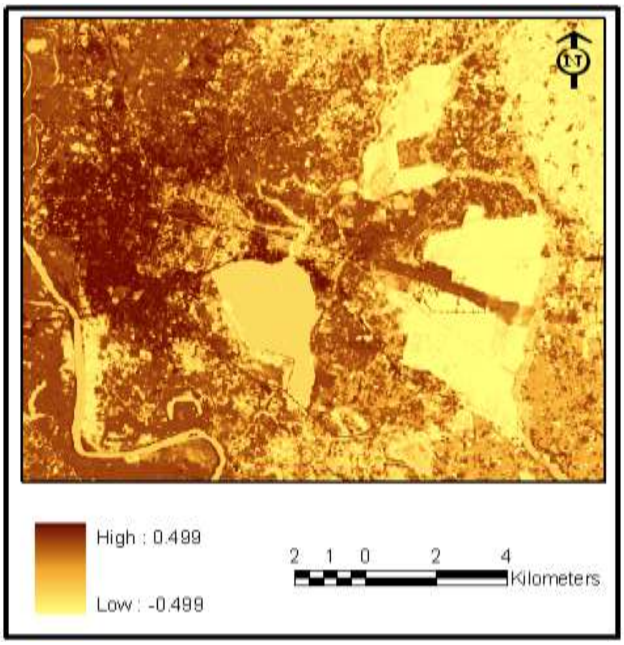

Fig. 5 Landscape Index for Urban Heat Island, Gorakhpur (October 2014)

Areas with high density of built up areas have an index value of more than 0.25 while urban areas with comparatively less percentage of built up area have an index ranging between 0.25 and 0.01which implies that open lands and patches of grass and trees have lowered the value of index. Landscape index over water surface ranged between -0.01 to -0.25 while the value of landscape index over vegetation cover was less than -0.25**(Fig. 5)** indicating the relative importance of the two sink areas. As the built up area and open land have a positive correlation with temperature, their presence in an area would tend to increase the values of landscape index for UHI for that area. Water bodies and vegetation cover have a negative correlation with temperature due to which their presence in an area would tend to bring down the value of on landscape index for UHI for that area. Areas dominated by built up structures and open land have positive value of landscape index for UHI effectand will act as source areas for UHI effect while areas with abundance of vegetation cover or water bodies will have a negative value of landscape index for UHI and will act as a sink areas for UHI effect **(Fig. 6).**

Change in land cover will bring about a change in landscape index which will have its impact on the UHI intensity of the urban area. Increase in proportion of source area will increase the value of index indicating further increase in intensity while an increase in proportion of sink areas will tend to bring the value of landscape index for UHI down indicating decrease in intensity of UHI. Vegetation cover can be used for management of UHI effect as it has a negative correlation with temperature and acts as a sink for UHI. Open lands are the only areas within the city that could be conveniently brought under vegetation cover as, neither built up areas can be removed nor can the water bodies and their area be altered. A new landscape index is prepared where in the total area under open lands was converted to vegetation cover and the values of landscape were classified into positive and negative classes i.e. source and sink areas. It is observed that the percentage of source area for UHI effect in landscape index with open land was 58 % and after bringing the open land under vegetation cover the percentage of source area is reduced to 30 %. This implies that sink area for UHI effect increased from 42 % to 70 % by bringing open lands under vegetation cover (Fig. 7) thereby appreciably reducing the heat island effect.

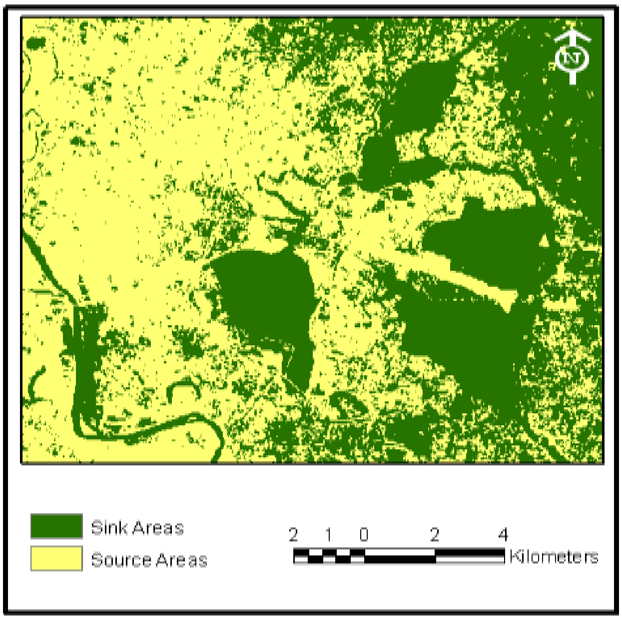

Fig. 6 Source and sink areas for Urban Heat Island, Gorakhpur (October 2014)

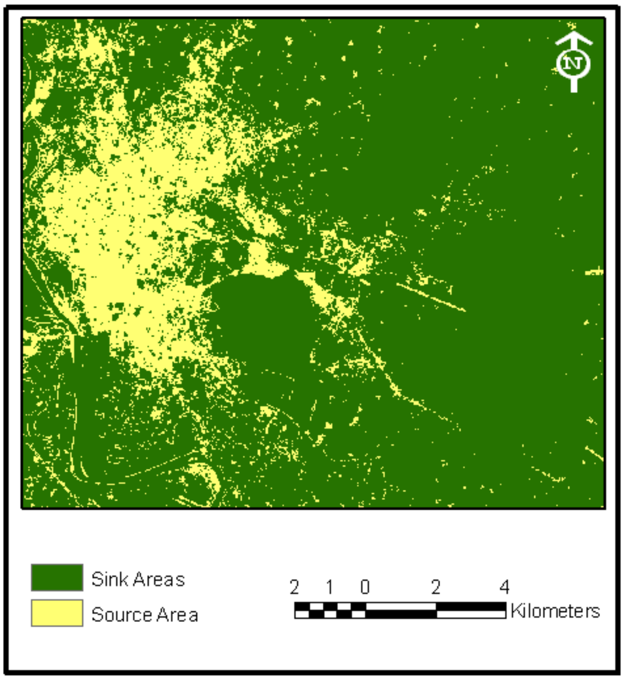

Fig. 7 Modified Source and Sink areas for Urban Heat Island, Gorakhpur (October 2014)

Besides change in nature of surface from source to sink areas (Location 'A' in **Fig. 8**), the intensity of UHI effect within source area is also reduced (Location 'D' in **Fig. 8**) as is evident from the profile depicting values of Landscape index for UHI drawn along a line before and after modification of Landscape index by converting open lands to vegetation cover. Comparison of the two Landscape index maps show that large areas have remained as source area for UHI as in such areas, very high density of built up structures had left almost no place that could have been brought under vegetation and hence have remained as an important source areas (Location 'C' in **Fig. 8**). Large patches of vegetation cover had remained the way they were as they already had a high percentage of vegetation and water bodies have also remained as a source of sink as they could not be modified (Location 'B' in **Fig.8**).

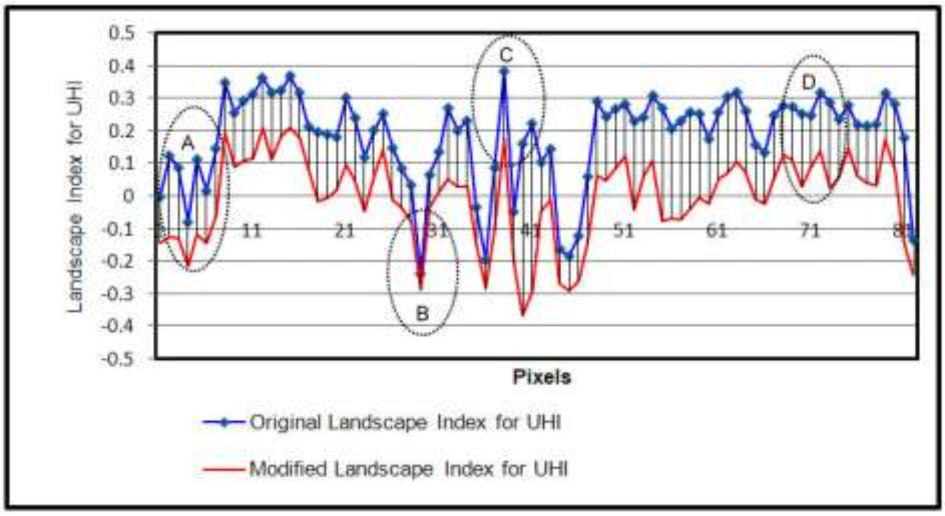

Fig. 8 Comparison of Landscape Index for UHI before and after modification

Conclusions

It was observed that land cover and LST information can be derived from remotely sensed data where errors in classification of land cover due to mixed pixels in heterogeneous urban environment could be rectified using supervised fuzzy classification technique. It was concluded that the intensity of UHI depends on the proportionand nature of different land covers in an urban environment. Areas dominated by built up structures and open land act as source areas for UHI effect as they are positively correlated with temperature while areas with abundance of vegetation cover and water bodies act as a sink area for UHI effect due to their negative correlation with temperature. The landscape index for UHI effect is prepared using the area of different land cover surface and their value of correlation coefficient at pixel level so that value of landscape index is retrieved for all pixels. Landscape index values for areas dominated by built up structure and open land have a positive value indicating that these surface act as a source area for UHI while landscape index value for areas under water and vegetation cover are negative indicating that these surfaces behave as a sink area for UHI effect. The most effective surface in modifying the UHI effect is vegetation cover and for management purposes, open lands are very significant for they are the only space available that can be brought under vegetation coverin an urban environment. Conversion of open land to area under vegetation cover transforms many source areas of UHI to sink areas and in areas where such transformation could not be achieved, a reduction in intensity of UHI effect within source areas is observed.

Acknowledgement

The authors would like to convey their thanks to USGS for providing with the LANDSAT imageries. Prof. R. P. Mishra is gratefully acknowledged for providing many good ideas in this work. Many thanks are given to all the reviewers for their constructive comments and suggestions.

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