Urban weather assessment using LST, NDBI and NDVI of Kolhapur city, Maharashtra

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Abstract
Normalized difference built-up index (NDBI) and normalized difference vegetation index (NDVI) are considered indicators of surface urban heat island effects and urban weather assessment. The relationship among LST (Land Surface Temperature), NDBI, and NDVI of Kolhapur city was determined by considering LST as a dependent variable on NDBI and NDVI. NDBI, NDVI, and LST were retrieved from Landsat5 data of March 2009. The regression analysis represents a strong positive relationship between the LST and NDBI, whereas LST and NDVI denoted a strong negative correlation. The R square value in regression statistics between LST and NDBI was 0.997883 indicating a 99% change in LST driven by the change in NDBI (Positive Coefficient= 29.40534). The significance F value was 0.00000000297 representing strong regression, and P-value (0.00000000297) indicates the reliability of correlation. The regression statistics between LST and NDVI signify that a 91 % change in LST was driven by the change in NDVI (Negative Coefficient=-24.2613) and had strong regression and greater reliability with 0.000233 F value and P-value.

Hence, it is clear that the land surface temperature was affected by the built-up area and vegetation cover. It denotes that land surface temperature is high where the proportion of built-up area increases and vegetation cover reduces and vice-versa. So, this investigation helps to find out urban heat pockets, accordingly plantation process and related planning strategies can be prepared to control the phenomena of the urban heat island.

Keyword: Normalized difference built-up index (NDBI), Normalized Difference Vegetation Index (NDVI), Land Surface Temperature (LST), Regression Statistics, Landsat 5 TM.

Introduction

The increased proportion of artificial alterations on the earth's surface and accelerated energy consumption by human beings augment Land surface temperature. On the other hand, deforestation and reduction in water bodies hastened the land surface temperature.[11] Remote sensing is a useful technique in the collection of radiant surface temperature and reflecting energy data. Hence, it ultimately employed for the studies of urban vegetation and built-up area changing scenarios.[24] For the urban climate studies, much emphasis was given on studying the correlation between NDVI and Land surface temperature.

The linear relationship between NDVI and LST represents a negative correlation.[1] There is a slightly stronger negative correlation between vegetation and LST.[23] Even different land-use patterns represent different mean LST and NDVI values.[24] There is comprehensive literature on the studies of the relationship between the LST and NDVI.[23,24] The relationship between changing an urban land cover pattern, modified materials on urban areas, and increased land surface temperature plays a significant role in understanding environmental and human health.[20]

The thermal attributes of the land cover categories are connected with distinctive patterns of land surface temperature. Therefore, land surface temperature represents urban land use and material changes to a certain extent.[13,22] The surface energy stability, physical, chemical processes over a surface, soil, hydrological, biological and geochemical characteristics of land etc. are effectively studied using Land surface temperature (LST) as a significant parameter.[6,21] The energy and water budgets at the surface-atmosphere interface are formulated using LST.[4]

The ground and atmosphere energy fluxes, physical properties of the land surface, and surface-atmosphere interactions are also studied using land surface temperature (LST) as a key factor.[25] Generally, the relationship between LST and vegetation is associated with a normalized difference vegetation index (NDVI), a vegetation indicator. It maps the vegetation on a pixel basis.[10,18] Most urban climate studies deal with LST and NDVI because of high NDVI areas denoted by Low LST values (negative correlation).[25] LST and NDVI relationship is very complicated; it was affected by many factors.

Hence, further study is required to understand the relationship better.[2,16] Most of the studies associated with LST and NDVI depend on the mean values of the growing season. All the related studies by Gurney, Goward, Hope, Memani, Smith, etc. reveal the strong negative correlation between LST and NDVI. These studies elaborate on the relationship between LST– NDVI globally and explained Spatio-temporal variability in LST and NDVI.[3,5-8,15] After the vegetation, built-up areas are playing an essential role in the alteration of LST values. Therefore, the normalized difference built-up index (NDBI) is also one of the key indexes in urban climate analysis. As compared to the built-up areas, vegetation and water body have a lower temperature.

For the present investigation, NDBI, NDVI, and LST maps were retrieved from Landsat 5 data of March 2009 to find out the relationship among LST, NDBI, and NDVI by considering LST as a dependent variable on NDBI and NDVI. The regression analysis was carried out by using class break values which represent a strong positive relationship between the LST and NDBI.

In contrast, LST and NDVI denoted a strong negative correlation. Therefore, the present investigation helps correlate the land surface temperature, the proportion of built-up area, and vegetation cover. Finally, urban heat pockets are recognized to prepare related planning strategies, which can further control the urban heat island phenomena.

Data Sources and methods

Data Sources: The images for LST preparation, NDBI, and NDVI maps were obtained from Landsat thematic mapper (TM) captured on 22/03/2009. The seven bands were acquired from Landsat TM denoted in table 1. The investigation was based on the preparation of NDVI, NDBI maps, retrieval of land surface temperature, and regression statistics.

Normalized Difference Vegetation Index (NDVI): The amount of green vegetation cover was assessed by quantification of the red and near-infrared band. Hence, a standard process of the Normalized Difference Vegetation Index (NDVI) was employed to estimate vegetation cover. The formula used for the calculation of NDVI is as follows:

NDVI= (NIR - R) / (NIR + R)

where NDVI= Normalized Difference Vegetation Index, NIR= Near-Infrared Band and R= Red Band.

The raster image of NDVI is helpful to obtain information about green vegetation present in each pixel. Therefore, it is also used to find out the emissivity values.

Proportional Vegetation: The Pv represents the pixel's emissivity and vegetation present within a pixel. The following formula determines it:

$Pv = \{(NDVI – NDVImin) / (NDVImax – NDVImin)\}^2$
where Pv = Vegetation Proportion, NDVI= Normalized Difference Vegetation Index, NDVImax= Maximum value of NDVI and NDVImin= Minimum value of NDVI.

Land Surface Emissivity: Using NDVI and Pv as input raster images, Sobrino et al[19] have derived a formula to determine emissivity. The Land Surface Emissivity was derived from the following formula:

$^{\varepsilon}TM6 = 0.004Pv + 0.986$

where $^{\varepsilon}TM6$= Land Surface Emissivity and Pv= Vegetation Proportion.

Conversion of DN to Radiance: From the thermal band, radiance values were obtained by converting DNs. For calculation of radiance, values gain, and bias, method was used.

L_{λ}= 0.05518* (thermal band 6) + 1.2378

where 0.05518 and 1.2378 = constant and Thermal band 6= thermal band 6 image.

Computation of Land Surface Temperature: Based on radiance and emissivity raster values, land surface temperature was calculated:

$T(K)= \{[K2/\log ((k1^* {}^{\varepsilon}TM6)/ (L_{\lambda})+1)]\} – 273$

where K1= 607.76 and K2= 1260.56 (K1 and K2 are Calibration constants), L_{λ}= Spectral radiance and $^{\varepsilon}TM6$= Emissivity.

Normalized Difference Built-up Index (NDBI): It is used to obtain the built-up features on the surface. It was used for TM data by Zha et al.[26]

NDBI= (MIR - NIR) / (MIR + NIR)

where NDBI= Normalized Difference Built-up Index, MIR= Band-5 of Landsat 5 TM and NIR= Band-4 of Landsat 5 TM.

After obtaining raster images for LST, NDBI, and NDVI class break values were used to gain regression statistics values (figure 1).

Study Area

Absolute Location: Kolhapur city lies between 16º 39' 0" north to 16º 46' 0" north latitude and 74º 10' 30" east to 74º 17' 0" east longitude.

Relative Location: The investigation is limited to Kolhapur city. The city is well linked by rail and road with the important cities of India viz; Mumbai, Bengaluru, New Delhi and other important cities of Maharashtra like Pune, Sangli, and Miraj. Kolhapur city is 240 km from Pune, whereas it is situated to the south of Mumbai at a distance of 395 km (figure 2).

Results and Discussion

Obtaining surface temperatures and using them in further analysis is essential to determine the environment's problem[14]. The correlation and regression coefficient between LST, NDBI, and NDVI were determined by considering LST as a dependent variable on NDBI and NDVI. The analysis denotes a strong positive relationship between LST and NDBI whereas a strong negative relationship was observed between LST and NDVI.

Table 1
Landsat TM Bands

Band Resolution	**Band-1**	**Band-2**	**Band-3**	**Band-4**	**Band-5**	**Band-6**	**Band-7**
	Visible			NIR	MIR	TIR	MIR
Spatial Resolution (m)	30	30	30	30	30	120	30
Spectral Resolution (µm)	0.45-0.52	0.52-0.60	0.63-0.69	0.76-0.90	1.55-1.75	10.40-12.50	2.09-2.35

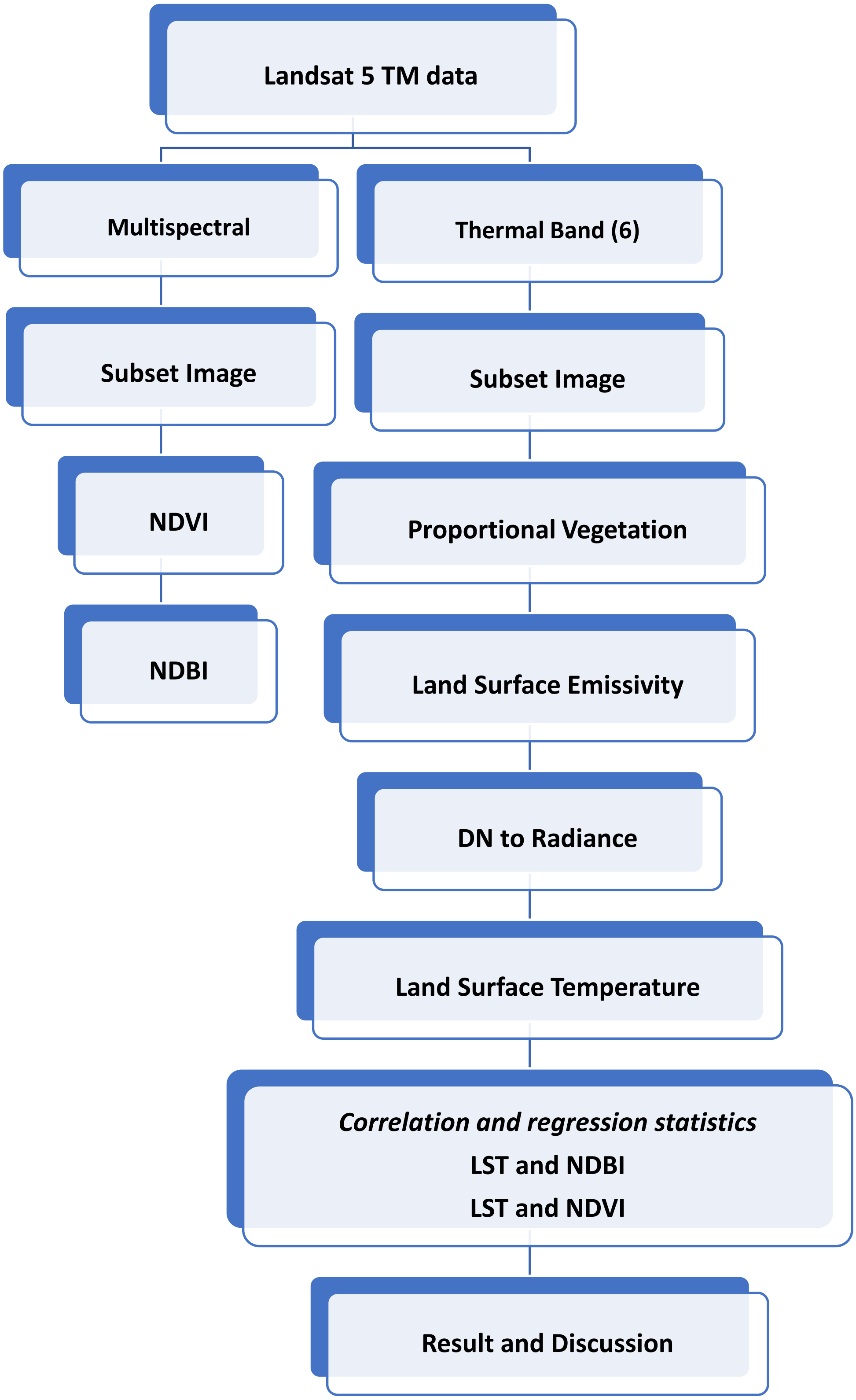

Fig. 1: Flow Chart of the Methodology

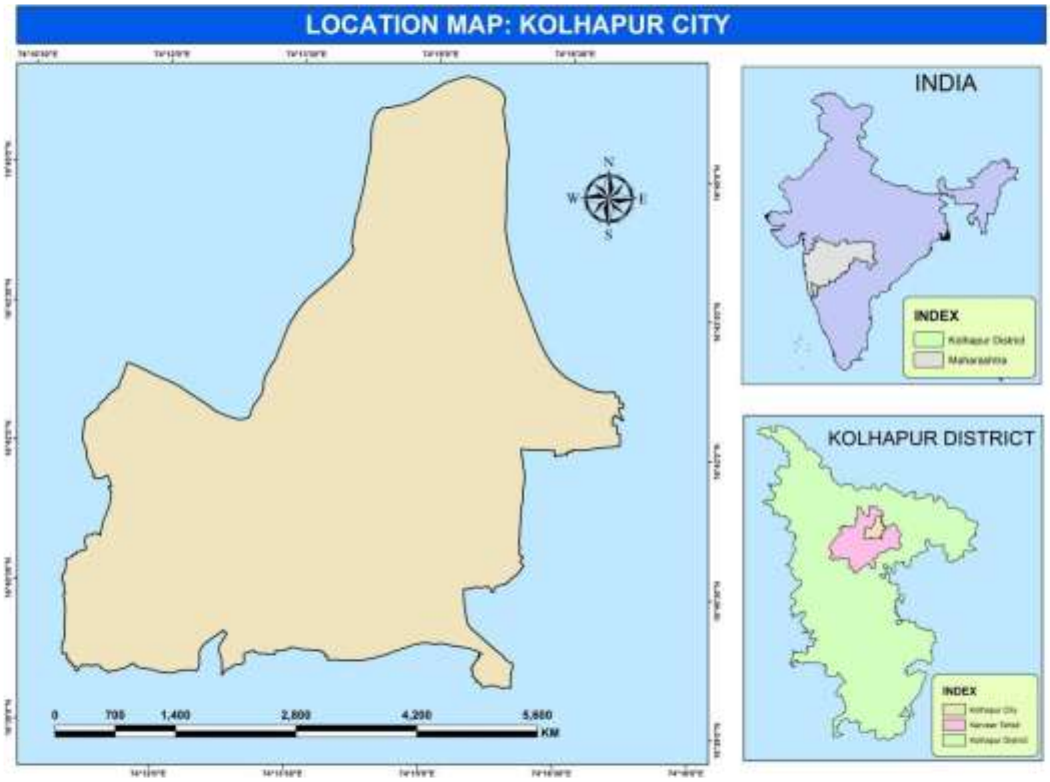

Fig. 2: Location of Study Area

Table 2
Landsat 5 TM data

Satellite/ Sensor	Projection/Path/Row	Date
Landsat 5 TM	UTM-43N/147/48	22/03/2009

Relationship between LST and NDBI (2009): The R square value between LST (Figure 3, Figure 4, Table 3) and NDBI (Figure 5, Table 3) obtained by regression statistics is 0.997883 indicating that the change in NDBI drove a 99 % change in LST. The LST and NDBI relationship was denoted by a strong positive correlation (0.99) and a positive regression coefficient (29.40534). The significance F value is 0.00000000297 representing strong regression and P-value shows the reliability of correlation (Table 5). Hence, it was concluded that settlement areas or urban land surfaces have more significant land surface temperature values than areas with vegetation cover.

The high NDBI index values (0.22 to 0.47) were observed at the southeastern and southwestern part leading to high land surface temperature (37.31^{o}C to 44.64^{o}C) of the Kolhapur city. Hence, to reduce the urban heat island effect, it is necessary to create urban green corridors in such areas.

Relationship between LST and NDVI (2009): The regression statistics between LST and NDVI (Figure 6, Figure 7, Table 4) indicates a 91 % change in LST driven by the change in NDVI (Negative Coefficient= -24.2613) and also had strong regression and greater reliability with 0.000233 F value and P-value (Table 6). The strong negative correlation (-0.91) and negative regression coefficient was observed between LST and NDVI denoting that areas with the least vegetation were experiencing greater land surface temperature values and vice-versa.

Table 3
Raster Output Values-LST and NDBI, March 2009

Y	X
LST	**NDBI**
27.3943	-0.11809
30.4572	-0.01382
32.4722	0.057677
34.0843	0.117259
35.7769	0.173861
37.3083	0.227484
39.6458	0.281108
44.6431	0.474747

Source: ArcGIS rasteranalysis

Table 4
Raster Output Values-LST and NDVI, March 2009

Y	X
LST	**NDVI**
27.3943	0.617834
30.4572	0.382308
32.4722	0.28279
34.0843	0.20981
35.7769	0.146782
37.3083	0.087071
39.6458	0.033994

Source: ArcGIS raster analysis

Table 5
Regression Statistics between LST and NDBI, March-2009

LST vs NDBI (March- 2009)								
Regression Statistics								
Multiple R	0.998941							
R Square	0.997883							
Adjusted R Square	0.99753							
Standard Error	0.269494							
Observations	8							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	1	205.3836	205.3836	2827.922	2.97E-09			
Residual	6	0.435762	0.072627					
Total	7	205.8193						
	Coefficients	Standard Error	t stat	P value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	30.81112	0.126336	243.8833	3.21E-13	30.50198	31.12025	30.50198	31.12025
NDBI_09	29.40534	0.552958	53.17821	2.97E-09	28.0523	30.75838	28.0523	30.75838

Source: LST and NDBI Raster Output, March 2009

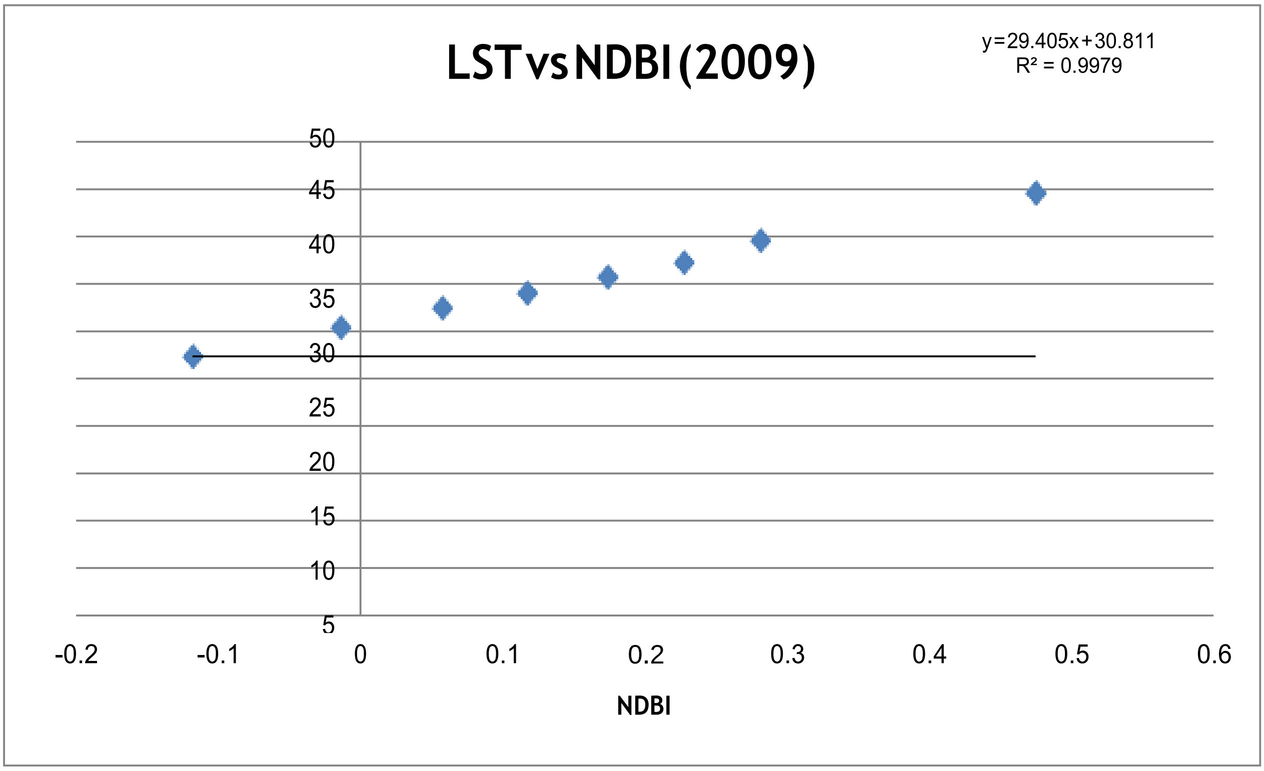

Fig. 3: Scatter Plot, Linear Regression between LST and NDBI, March 2009
Source: LST and NDBI Raster Output, March-2009

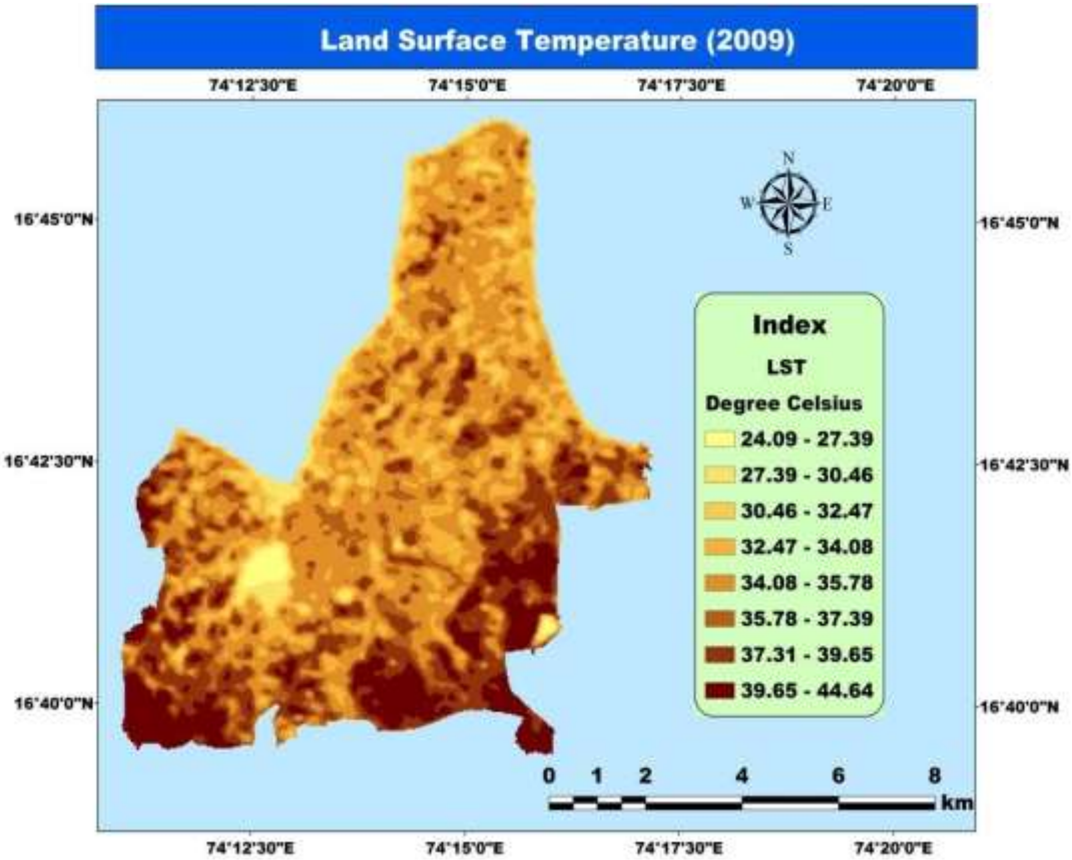

Fig. 4: Land Surface Temperature, Kolhapur City, March-2009

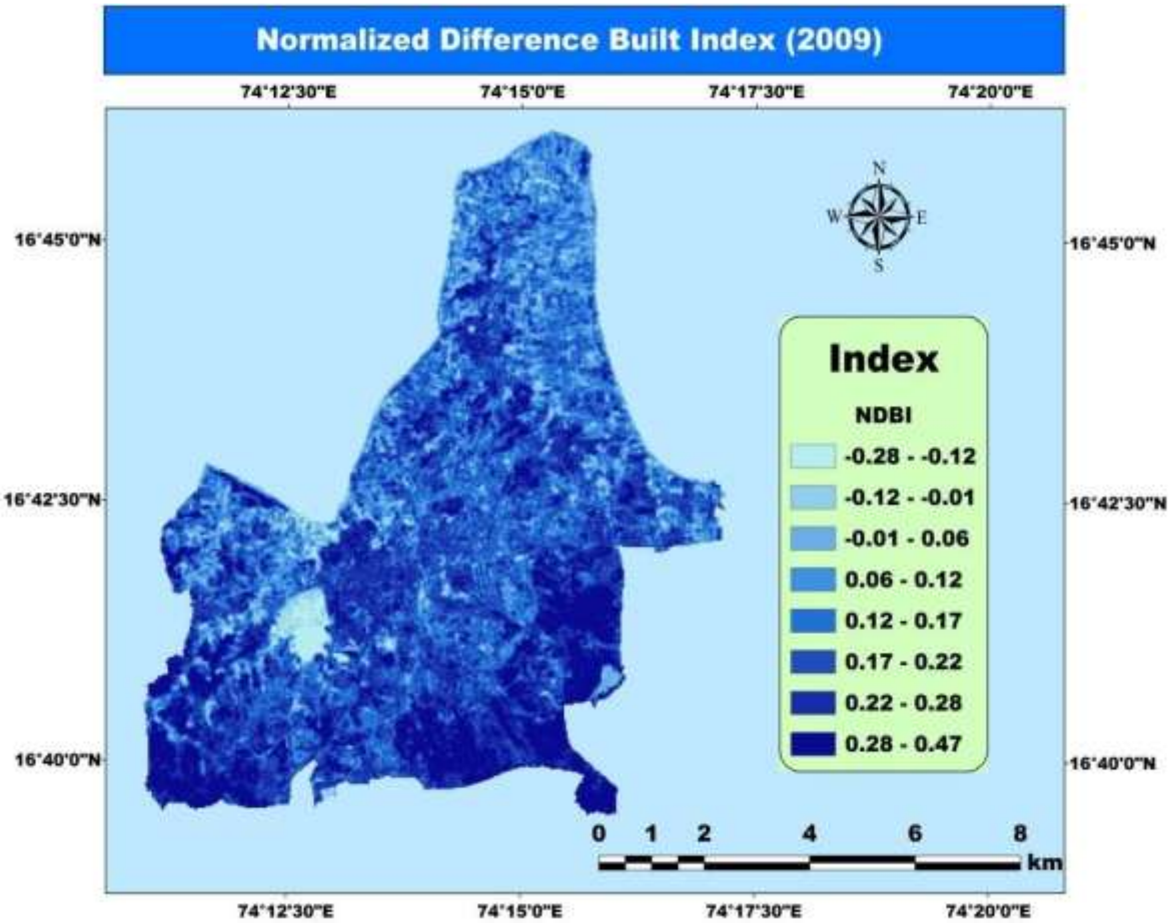

Fig. 5: NDBI of Kolhapur City, March 2009

Table 6
Regression Statistics between LST and NDVI, March-2009

LST vs NDVI (March- 2009)								
Regression Statistics								
Multiple R	0.954129							
R Square	0.910362							
Adjusted R Square	0.895422							
Standard Error	1.753531							
Observations	8							
ANOVA								
	df	SS	MS	F	Signicficance F			
Regression	1	187.3701	187.3701	60.9359	0.000233			
Residual	6	18.44923	3.074872					
Total	7	205.8193						
	Coefficients	Standard Error	t stat	P value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	40.41361	0.909145	44.45233	8.68E-09	38.18901	42.63821	38.18901	42.63821
NDVI_09	-24.2613	3.107971	-7.80614	0.000233	-31.8662	-16.6563	-31.8662	-16.6563

Source: LST and NDVI Raster Output, March-2009

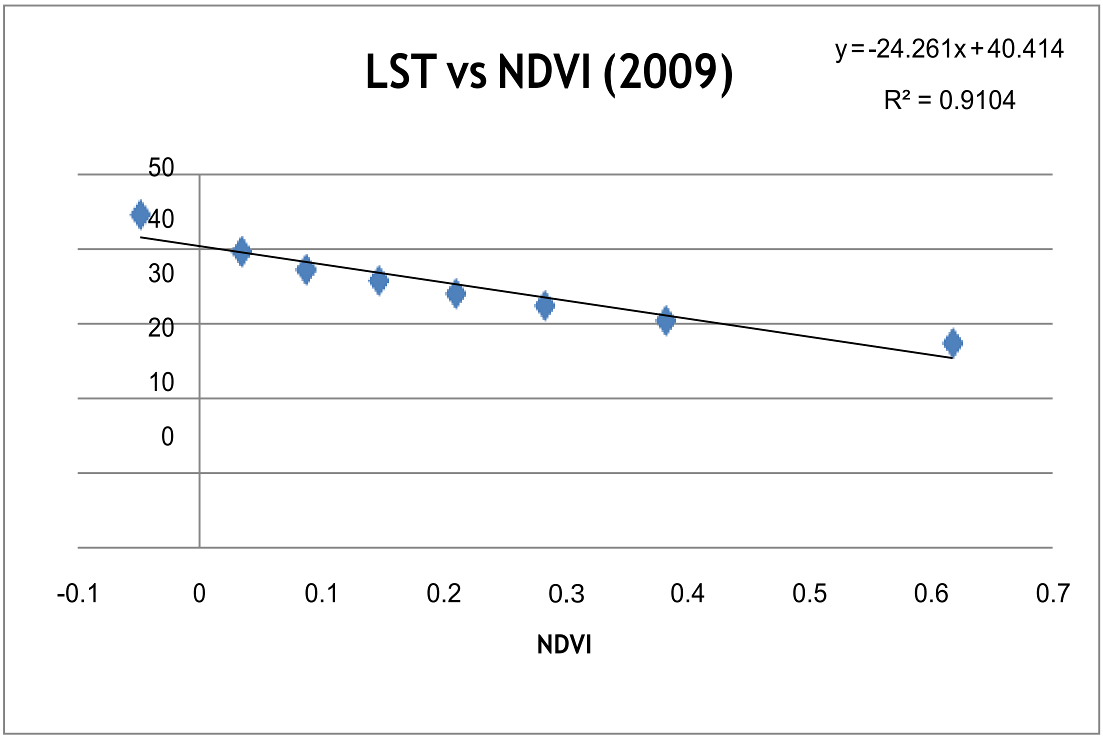

Fig. 6: Scatter Plot, Linear Regression between LST and NDVI, March 2009
Source: LST and NDVI Raster Output

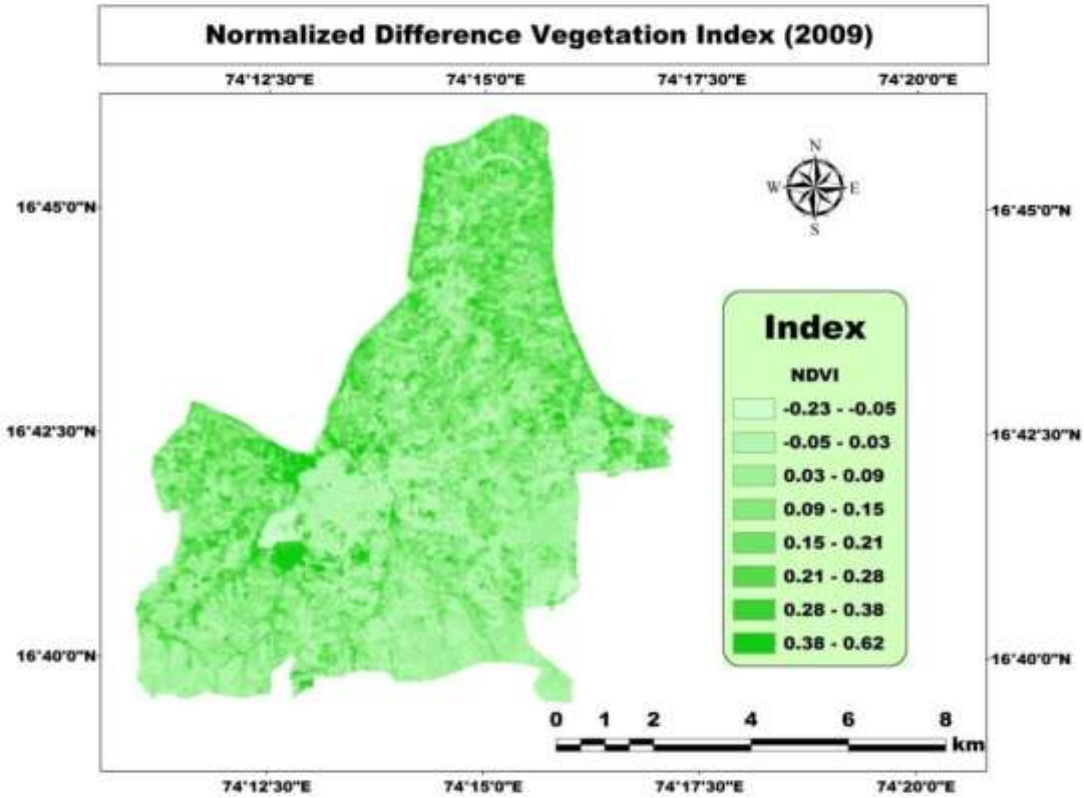

Fig. 7: NDVI of Kolhapur City, March-2009

Most of the northern part of Kolhapur city and the central part near the Rankala Lake are occupied by agricultural fields representing high vegetation index values (0.28 to 0.62), therefore associated with low-temperature values (20.09^{o}C to 30.46^{o}C).

Conclusion

The correlation and regression coefficient of LST, NDBI, and NDVI by considering the LST as a dependent variable on NDBI and NDVI represent a strong positive relationship between LST and NDBI and a strong negative correlation between LST and NDVI. The strong positive correlation (0.99) and positive regression coefficient (29.40534) between LST and NDBI denote settlement areas or urban land surfaces with greater land surface temperature values. The strong negative correlation (-0.91) and negative regression coefficient (-24.2613) between LST and NDVI indicate that the areas with the least vegetation were experiencing greater land surface temperature values and vice-versa. Hence, it is clear that the land surface temperature was affected by the built-up area and vegetation cover.

The above analysis reveals that most of the built-up areas in Kolhapur city are representing temperature above 37 ^{o}C whereas the vegetation covers reduce the land surface temperature by 10^{o}C to 20^{o}C. Therefore, by employing figures (figures 4, 5, and 7), it is easy to identify the Kolhapur city's urban heat island pockets' absolute location. It is easy to control the urban heat island effect through the urban green corridor creation, urban agriculture etc.

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References

1. Carlson T.N., Gillies R.R. and Perry E.M., A method to use thermal infrared temperature and NDVI measurements to infer surface soil water content and fractional vegetation cover **(1994)**

2. Ghobadi Y., Pradhan B., Shafri H.Z.M. and Kabiri K., Assessment of the spatial relationship between land surface temperature and land use/cover retrieval from multitemporal remote sensing data in South Karkheh Sub-basin, Iran, *Arabian Journal of Geosciences*, **8**, 525–537 **(2014)**

3. Goward S.N., Cruickshanks G.D. and Hope A.S., Observed relation between thermal emission and reflected spectral radiance of a complex vegetated landscape, *Remote Sens. Environ.*, **18**, 137–146 **(1985)**

4. Gutman G.G., Towards monitoring droughts from space, *J. Climate*, **3**, 282–295 **(1990)**

5. Gurney R.J., Ormsby J.P. and Hall D.K., Observed relation between thermal emission and reflected the spectral radiance of a complex vegetated landscape, Permafrost: Fourth Int. Conf., Fairbanks, AK, University of Alaska and National Academy of Sciences, 401–404 **(1983)**

6. Hao X., Li W. and Deng H., *The oasis effect and summer temperature rise in an arid regions-case study in Tarim Basin, Sci Rep*, https://doi.org/10.1038/srep35418, **6**, 35418 **(2016)**

7. Hope A.S., Estimation of wheat canopy resistance using combined remotely sensed spectral reflectance and thermal observations, *Remote Sens. Environ.,* **24**, 369–383 **(1988)**

8. Hope A.S. and McDowell T.P., The relationship between surface temperature and a spectral vegetation index of tallgrass prairie: Effects of burning and other landscape controls, *Int. J. Remote Sens.,* **13**, 2849–2863 **(1992)**

9. Joshi J.P. and Bhatt B., Estimating temporal land surface temperature using remote sensing: a study of Vadodara urban area, *Gujarat International Journal of Geology, Earth and Environmental Sciences,* **2(1)**, 123-130 **(2012)**

10. Julien Y., Sobrino J.A. and Verhoef W., Changes in land surface temperatures and NDVI values over Europe between 1982 and 1999, *Remote Sensing of Environment,* **103**, 43–55 **(2006)**

11. Kumar K.S., Bhaskar P.U. and Padmakumari K., Estimation of land surface temperature to study urban heat island effect using Landsat ETM+ image, *International Journal of Engineering Science and Technology,* **2**, 771-778 **(2012)**

12. Lambin E.F. and Ehrlich D., Combining vegetation indexes and surface temperature for land-cover mapping at broad spatial scales, *Int. J. Remote Sens.,***16**, 573–579 **(1995)**

13. Lo C.P., Quattrochi D.A. and Luvall J.C., *Application of high resolution thermal infrared remote sensing and GIS to assess the urban heat island effect, International Journal of Remote Sensing,* **18**, 287-303 **(1997)**

14. Orhan O., Ekercin S. and Dadaser-Celik F., Use of Landsat Land Surface Temperature and Vegetation Indices for Monitoring Drought in the Salt Lake Basin Area **(2014)**

15. Prihodko L. and Goward S.N., Estimation of air temperature from remotely sensed surface observations, *Remote Sens. Environ.,* **60**, 335–346 **(1997)**

16. Qu C., Ma J.H., Xia Y.Q. and Fei T., Spatial distribution of land surface temperature retrieved from MODIS data in Shiyang River Basin, *Arid Land Geography,* **37**, 125–133 **(2014)**

17. Schultz P.A. and Halpert M.S., Global analysis of the relationships among a vegetation index, precipitation and land-surface temperature, *Int. J. Remote Sens.,* **16**, 2755–2777 **(1995)**

18. Smith R.C.G. and Choudhury B.J., On the correlation of indices of vegetation and surface temperature over south-eastern Australia, *International Journal of Remote Sensing,* **11**, 2113–2120 **(1990)**

19. Sobrino et al, Land surface temperature retrieval from LANDSAT TM 5 -Author links open overlay panel, Sobrinoa Jose A., Juan C. and Jiménez-Muñoza, *Leonardo Paolinib Remote Sensing of Environment*, **90(4),** 434-440 **(2004)**

20. Stone B. and Rdgebers M.O., Urban form and thermal efficiency: how the design of cities influences the urban heat island effect, *Journal of the American Planning Association,* **67**, 353-366 **(2001)**

21. Tomlinson C.J., Chapman L., Thrones J.E. and Baker C., Remote sensing land surface temperature for meteorology and climatology: a review, *Meteorological Applications,* **18**, 296–306 **(2011)**

22. Weng Q., A remote sensing-GIS evaluation of urban expansion and its impact on surface temperature in the Zhujiang Delta, China, *International Journal of Remote Sensing,* **22**, 1999-2014 **(2001)**

23. Weng Q., Lu D. and Schubring L., Estimation of land surface temperature-vegetation abundance relationship for urban heat island studies, *International Journal of Remote Sensing of Environment,* **89**, 467-483 **(2004)**

24. Yue W., Xu J., Tan W. and Xu L., The relationship between land surface temperature and NDVI with remote sensing: application to Shanghai Landsat & ETM+ data, *International Journal of Remote Sensing,* **15**, 3205-3226 **(2007)**

25. Yuan F. and Bauer M.E., Comparison of impervious surface area and normalized difference vegetation index as indicators of surface urban heat island effects in Landsat imagery, *International Journal of Remote Sensing of Environment,* **106**, 375-386 **(2007)**

26. Zha Y., Gao J. and Ni S., Use of normalized difference built-up index in automatically mapping urban areas from TM imagery **(2003)**.

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