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Spatial and Temporal Relationship between NDVI and Land Surface Temperature of Faisalabad city from 2000-2015

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Abstract

The study estimates the land surface temperature of Faisalabad city. For the current study Landsat ETM+ images of 2000, 2003, 2010 and OLI/TIRS 2015 were acquired from USGS of the study area. Normalized Difference Vegetation Index (NDVI) was developed and NDVI based classification were used to calculate the vegetation area. The digital number of thermal infrared band is converted in to spectral radiance using the equation supplied by the Landsat user's hand book. The effective at-sensor brightness temperature has been obtained from the spectral radiance using Plank's inverse function. The surface emissivity based on NDVI is used to retrieve the final LST. The research aims to investigate the spatial and temporal pattern of vegetation and land surface temperature and also to determine the correlation between land surface temperature and vegetation in study area from 2000 to 2015. The results reveal decrease in vegetation area results in increase in the LST. The vegetation area decreases from 34 to 14.3 percent with average increase in LST mean from 39.8 to 44 degree Celsius from 2000-2015. The research suggested that more studies should be conducted with images and sensors of higher resolution and seasonal variation can be assessed for the LST.

Keywords: ETM +, LANDSAT, LST, NDVI, OLI/TIRS

Introduction

The urban expansion impacts the climate at local, regional and global scale it is evident that there is a strong relationship between NDVI and climatic parameters such as temperature (Lim *et al.*, 2008). The most important anthropogenic impacts on climate are the emission of greenhouse gases, biomass burning aerosols and dust aerosols (Dirmeyer *et al.*, 2010; Xiao *et al.*, 2010, Forster *et al.*, 2007). Urban expansion modifies surface energy and moisture budgets through alterations in evaporation and fluxes of latent and sensible heat, unswervingly affecting precipitation and temperature (Wang *et al.*, 2014). Land Surface Temperature (LST) can be defined as the temperature felt when the land surface is touched with the hands or it is the skin temperature of the ground (Kant & Bharath, 2008). The urban temperature is steadily rising in all around the world due to decrease in the green areas this climatic condition is termed as urban heat island (UHI) (Kumar, 2015; Bechtel *et al*., 2012; Wei *et al.*, 2008, Vooget and oke, 2003). Change in LST is one of the most significant effects of land use changes. LST can provide information about the physical properties of the land surface and climatic conditions, as well as land use changes and human activities affecting the environment (Dehua *et al*., 2012, Weng, *et al*. 2004, Zhou *et al*., 2004). Normalized Difference Vegetation Index (NDVI) has been widely used in examining the dynamics of vegetation which can be defined as the ratio of the difference between near-infrared reflectance and red visible reflectance to their sum, is an indicator of vegetation productivity (Sun *et al*., 2011). The NDVI is one of the most commonly used vegetation indices because it provides the best results regarding variations in vegetation (Baihua & Isabela, 2015; Benkouider *et al.*, 2013; Kerr and Ostrovsky, 2003). Changes in vegetation are the main causes of the land surface temperature changes which are associated with vegetation density (klok *et al.*, 2012; Weixin *et al.* 2011). It has been finally shown that there is a logical relationship between NDVI and LST (Fathizad *et al*., 2017, Wei *et al*., 2015). The use of remote sensing is one of the direct methods applied to estimate the land surface temperature. Remote sensing data has great ability to investigate the temporal and spatial changes in vegetation, land use and estimating of LST (Schwarz *et al.*, 2012). Enhanced Thematic Mapper Plus (ETM +) of Landsat 7 with the assistance of infrared bands give the thermal data with high resolutions images. Furthermore, the latest generation of Landsat 8 series Thermal Infrared Sensor (TIRS) having two infrared bands with the similar spatial and temporal resolution as compare to previous Landsat. Remote sensing is significant tool in monitoring land surface temperature (Isa et al., 2016).

The current study aiming to calculate the vegetation area of Faisalabad city by using NDVI based classification and to investigate the spatial and temporal patterns of vegetation and land surface temperature changes from 2000 to 2015 and to analyze the correlation between land surface temperature and vegetation.

Materials and Methods

Study area

Faisalabad city is major urban center in Pakistan with the global coordinate 30°42' and 31°47' North latitudes and 72°40' and 73°40' East longitudes with an area of 213 square Kilometer (Mazhar and Jamal, 2011). The city ranked third largest industrial city of Pakistan with estimated population over two million (CDGF, 2010).

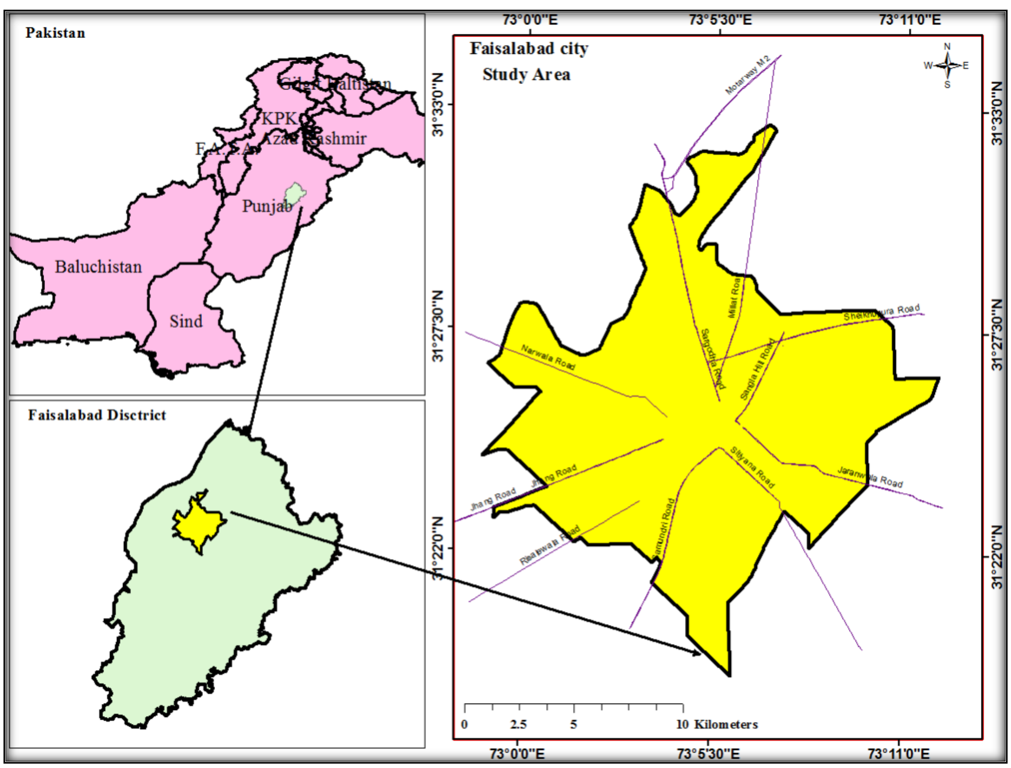

Figure 1: Study area map

This study used to calculate the spatiotemporal variation of NDVI and LST of different temporal maps of years 2000, 2003, 2010 and 2015 using the Landsat imageries of Faisalabad city Table 1. The relationship between the vegetation and land surface temperature was shown with each year increase and decrease was obtained for the 15-years. NDVI based classification were used to calculate the agricultural area in the Faisalabad city. The software used includes the ERDAS IMAGINE 2014, ARCMAP 10.3 and MS Excel 2016.

To calculate approximately the land surface temperature from satellite images it contain of various process and step that been explained by NASA and described below as

Radiometric Calibration

The calibration parameters can be retrieved from the image head files and the NASA website

Lλ= GAIN*DN*BAIS (Eq. 1)

Lλ is the normalized atmospheric reflectance at a particular wavelength.

Table1.Basic characteristics of the Landsat-7/ETM+ and Landsat 8 scenes used in the Study

Data	Resolution	Sensor	Scene Time	Scene Date	Sun Azimuth	Sun Elevation	Cloud Cover
Landsat 7	30	ETM	5:35	14-06-2000	105.7	67	0
Landsat 7	30	ETM	5:25:17	31-06-2003	105	66	0
Landsat 7	30	ETM	5:34:57	26-06-2010	105	66	0
Landsat 8	30	OLI/TIRS	5:35	25-06-2015	107	68	0.87

Source: (http://earthexplorer.usgs.gov/).

Conversion to At Sensor Spectral Radiance (Qcal -to- Lλ)

The digital number (DN) converted in to spectral radiance (Lλ) by means of the equation

Lλ= (LMAX –LMIN/QCALMAX - QCALMIN)(QCAL- CALMIN)+LMIN- (Eq. 2)

Where

LMAX = the spectral radiance that is scaled to QCALMAX in W/(m2 * sr * μm)

LMIN = the spectral radiance that is scaled to QCALMIN in W/(m2 * sr * μm)

QCALMAX = the maximum quantized calibrated pixel value (corresponding to LMAX) in DN = 255

QCALMIN= the minimum quantized calibrated pixel value (corresponding to LMIN) in DN = 1

Conversion to At-sensor Brightness Temperature (L λ -to- T)

The thermal band data (Band 6 on ETM+ and band 10 and 11 on OLI/TIRS) converted from at-sensor spectral radiance to effective at-sensor brightness temperature.

T= K2/Ln(K1/ Lλ +1)-------------------- (Eq.3)

Where:

T = Top of Atmosphere Brightness Temperature, in Kelvin.

Lλ = Spectral radiance (Watts/ (m2 * sr * μm))

K1 = Thermal conversion constant for the band (K1_CONSTANT_BAND_n from the metadata)

K2 = Thermal conversion constant for the band (K2_CONSTANT_BAND_n from the metadata)

Temperatures can be converted from degree Kelvin into degree Celsius by subtracting 272.15 from the result.

Derivation of NDVI Image

The NDVI image was computed for 2000, 2003, and 2010 from the band 3 and band 4 reflectance data whereas band 4 and band 5 for 2015, using the formula below:

NDVI= NIR−R/NIR + R

Where,

NIR = the near infrared

RED = the red reflectance

Estimation of Land Surface Temperature (LST)

The final Land Surface Temperature (LST) estimated using following equation:

LST=TB/1+(λ+TB/ ρ)*Ln e

λ is the wavelength of the emitted radiance which is equal to 11.5µm. ρ h.c/σ, σ Stefan Boltzmann's constant which is equal to 5.67 x 10-8 Wm-2 K -4, h Plank's constant (6.626 x 10 -34 J Sec), c = velocity of light (2.998 x 108 m/sec) and ε is the spectral emissivity. Spectral emissivity canbe calculated by means of the following equation

e= 0.004pv+0.986

Where

Pv = proportion of vegetation which can be calculated by using following formula

Pv= (NDVI-NDVIMIN/NDVIMAX-NDVIMIN)2

All the procedures for estimating land surface temperature and NDVI calculation were computed using map algebra function in Spatial Analyst in ArcGIS 10.3 software Figure 2. (Isa et al. 2016, Kumar and Shekhar 2015)

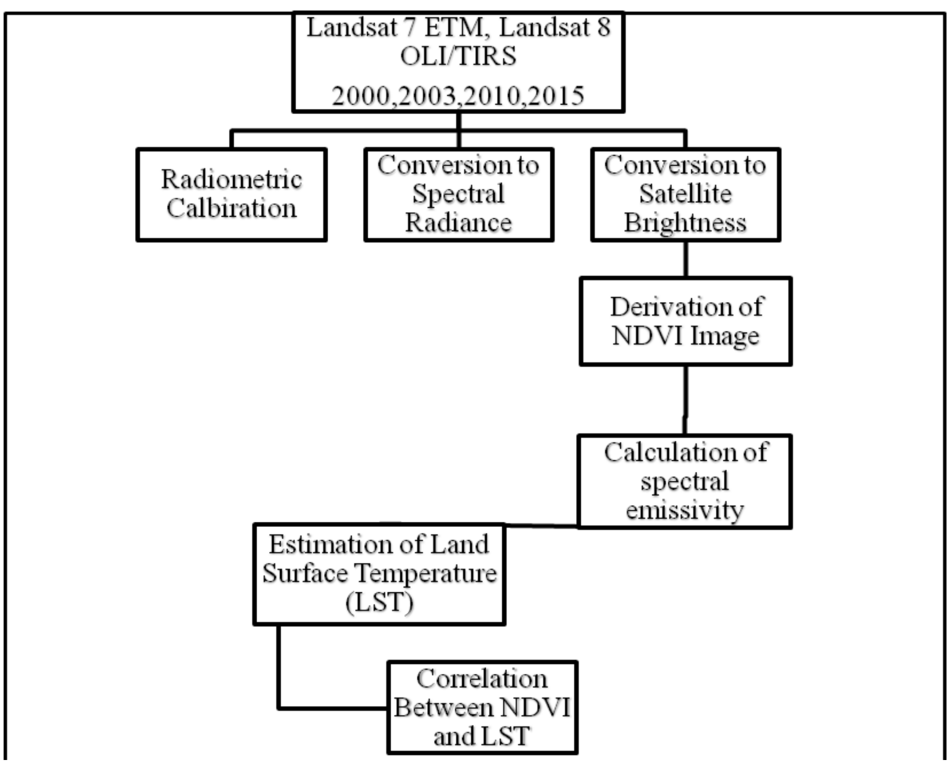

Figure 2 Flow chart of Methodology

Results and Discussion

Using remote sensing, this study investigated the relationship between NDVI and LST Change. Figure 3 shows the LST maps 0f 2000, 2003, 2010 and 2015 for the study area and display the minimum and maximum temperature of the region that has been calculated between 29 and 49 degree Celsius in the studied years. Figure.4 showing the maps of NDVI index application. It is clearly shown that in all the images the outer boundary and central part of the city has the lowest temperature because of the good vegetation density presence there.

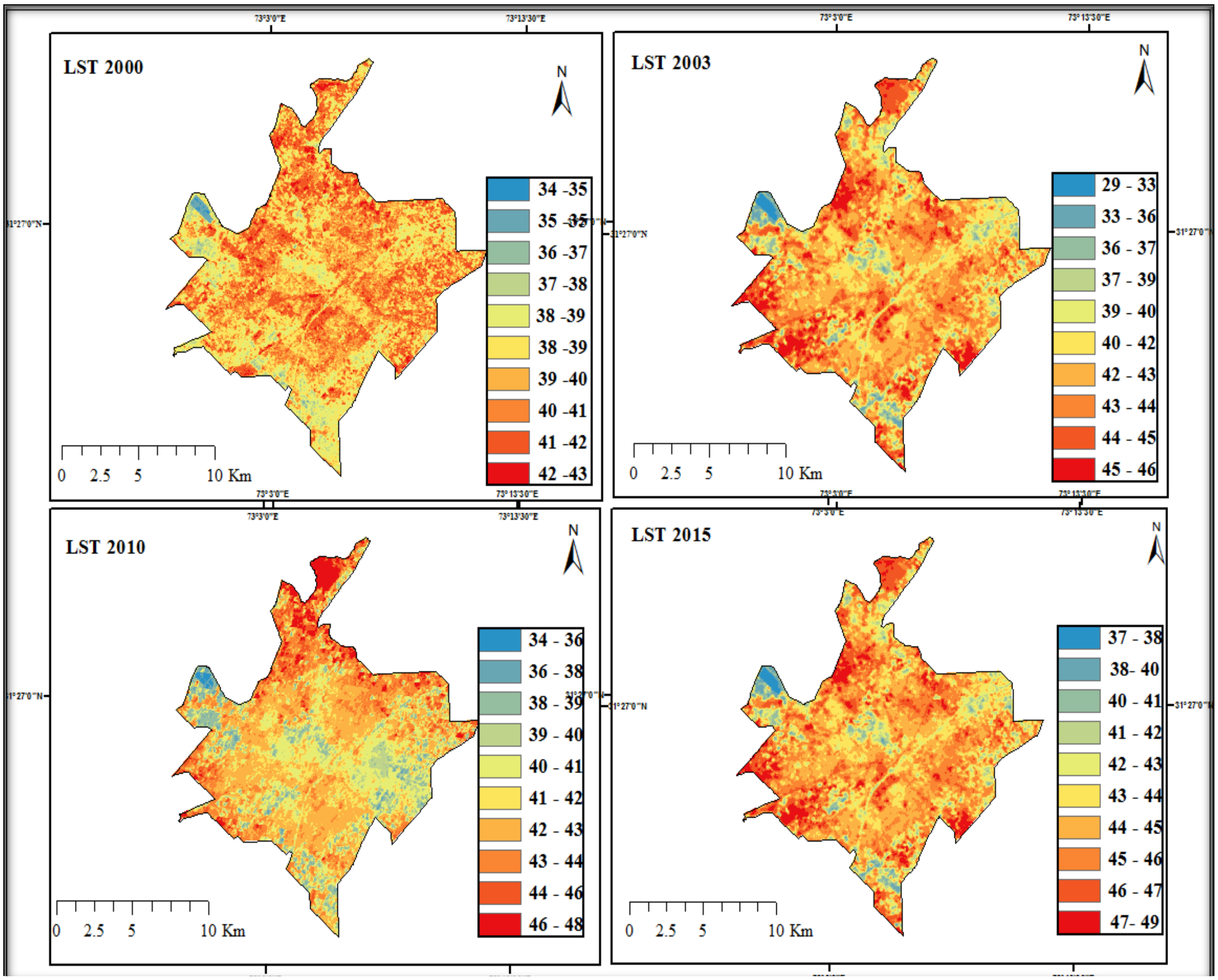

Figure: 3. LST Maps of Faisalabad City (2000, 2003, 2010 and 2015)

Table 2. Statistical characteristics of LST maps of years 2000, 2003, 2010, 2015

Year	Mean	Minimum	Maximum	Count	Standard Deviation
2000	39.8	34	43	237156	1.03
2003	41	29	46	237156	1.7
2010	42	34	48	237156	1.86
2015	44	37	49	237156	1.4

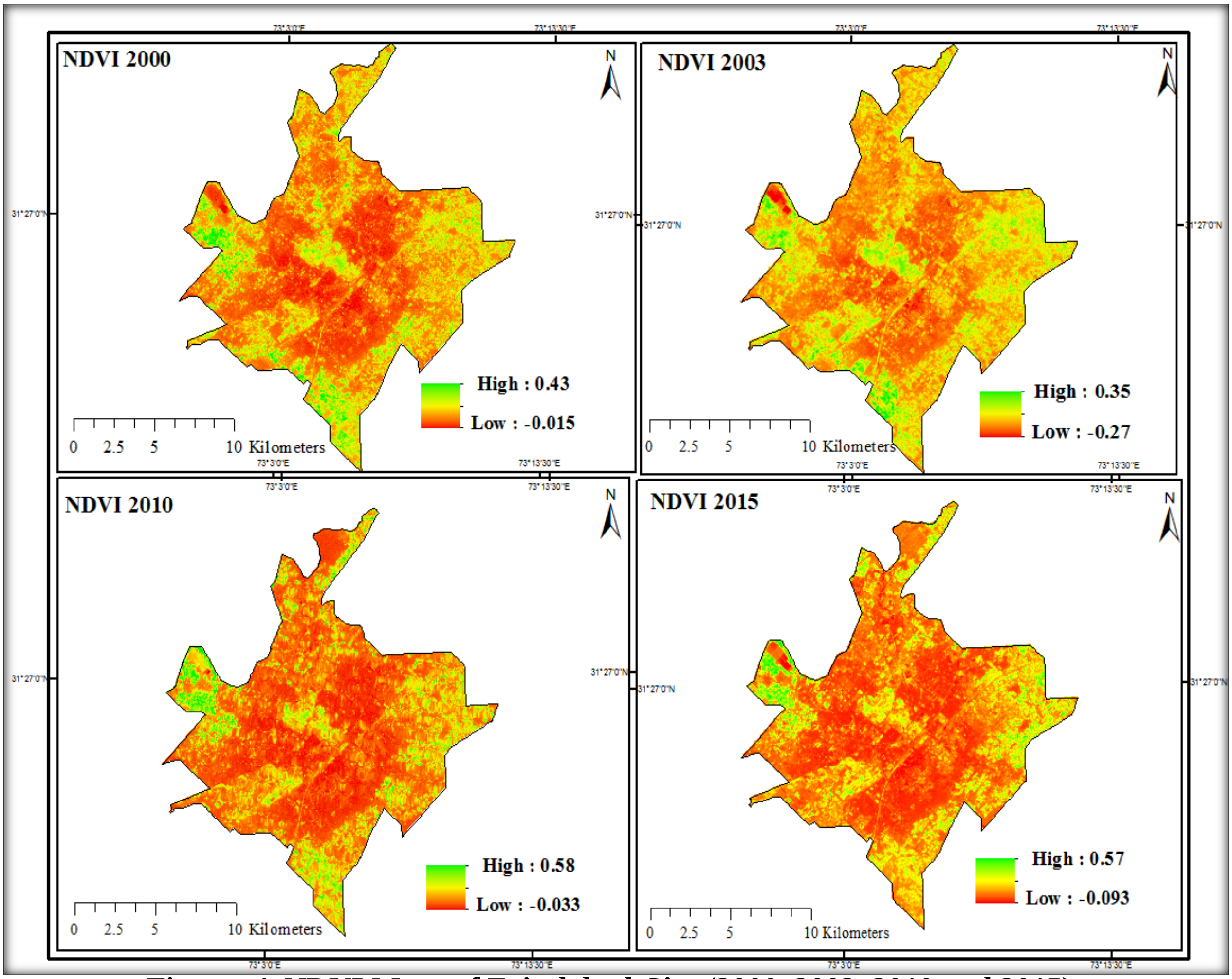

Figure: 4. NDVI Maps of Faisalabad City (2000, 2003, 2010 and 2015)

Table 3. NDVI Maps statistical characteristics for the year 2000, 2003, 2010, 2015

Year	Mean	Maximum	Minimum	Counts	Standard deviation
2000	0.139	0.43	-0.015	236955	0.063
2003	-0.055	0.35	-0.27	237156	0.066
2010	0.142	0.57	-0.033	236955	0.86
2015	0.150	0.57	-0.09	237156	0.09

Table 4: Mean LST in Celsius and Vegetation area

Year	Vegetation Area in Sq Km	Percentage of Area	LST Mean
2000	82	34	39.8
2003	73.71	30	41
2010	51.6	21.4	42
2015	34.5	14.3	44

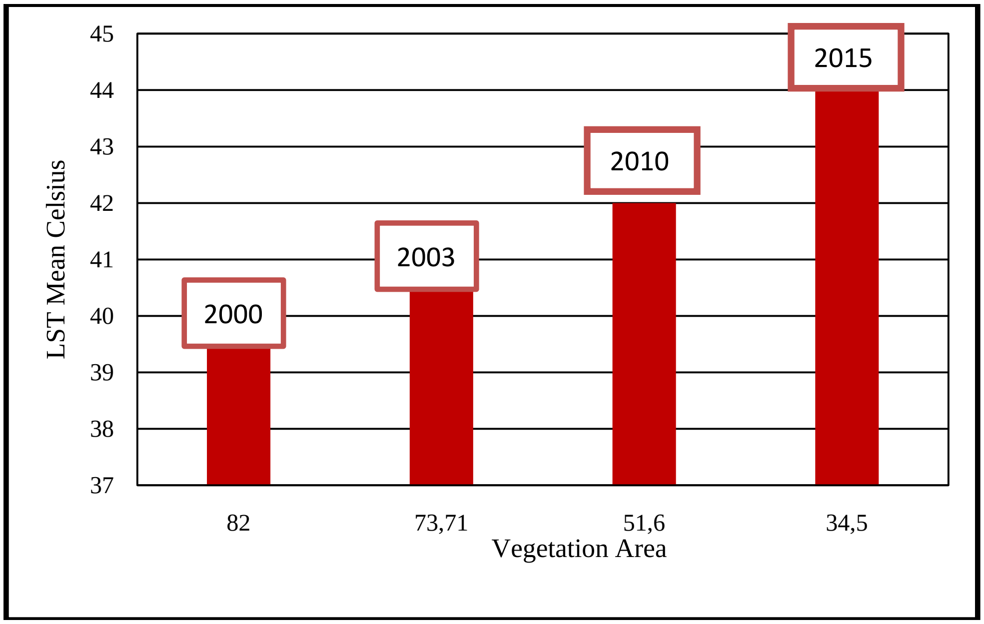

Figure 5: LST mean and vegetation area

NDVI has been used to estimate the LST of 2000, 2003, 2010 and 2015.The NDVI maps of 2000, 2003, 2010 and 2015 are shown in Figure 4. NDVI is calculated between 0.43 and 0.015 for the year 2000 outskirts of city are screening rich vegetation some area in center of the study area presenting good vegetation index in 2000. Whereas the NDVI value ranges from -0.27 to 0.35 and for 2010 it is 0.03 to 0.58. Moreover, in 2015 NDVI was calculated between 0.57-0.09 (Table 3). According to the Table 2, the range of LST is estimated between 34 and 43 in 2000, with an average of 39.8and a standard deviation of 1.03. While 2003 have range 34-46 with mean vale 41 and standard deviation 1.7 in addition 2010 temperature ranges between 34-48 Celsius having 42 mean value and 1.86 standard deviations. LST is calculated between 37 and 49 degree Celsius in 2015, with a mean of 44 and standard deviation of 1.4. The results illustrate that standard deviation is increased with average temperature.

Table 4 depicts In 2000 the vegetation area was 82 sq km and Average land surface temperature was 39.8 degree Celsius and in 2003 the decrease in vegetation area from 34 percent to 30 percent results in steady increase in land surface temperature to 41 degree Celsius with 1 degree increase of LST while in 2010 the vegetation in city decreases to 21.4 percent of 30 percent of the year 2003 with 1 degree increase in land surface temperature moreover 2015 the month of the June observed the average land surface temperature increases to 44 degree Celsius with decrease in vegetation area to 14.3 percent from 21.4 of the previous year Figure 5. The correlation between NDVI and LST has been revealed in Figure 5 in the year 2000 there is increase of land surface temperature with decrease in vegetation with NDVI range 0.47-0.27 temperature remain between 34-37 degree Celsius for the year 2003the temperature range 29-46 degree Celsius with NDVI value of -0.27-0.35 while for the range 0.07 to 0.027 temperature average increases from 39.8 of 2000 to 41 degree Celsius in 2003 with range between 29- 46 of previous37 to 43 degree Celsius. Furthermore, the NDVI for the year 2010 for class 0.33-0.57 the land surface temperature remained between 37-43degree Celsius at the same time as temperature increase shown with the decrease in the NDVI value 0.33 to -0.09 between 43-49 degree Celsius for the year 2015. Figure 6 demonstrates the clear inverse correlation between NDVI and LST for the each year from 2000 to 2015.

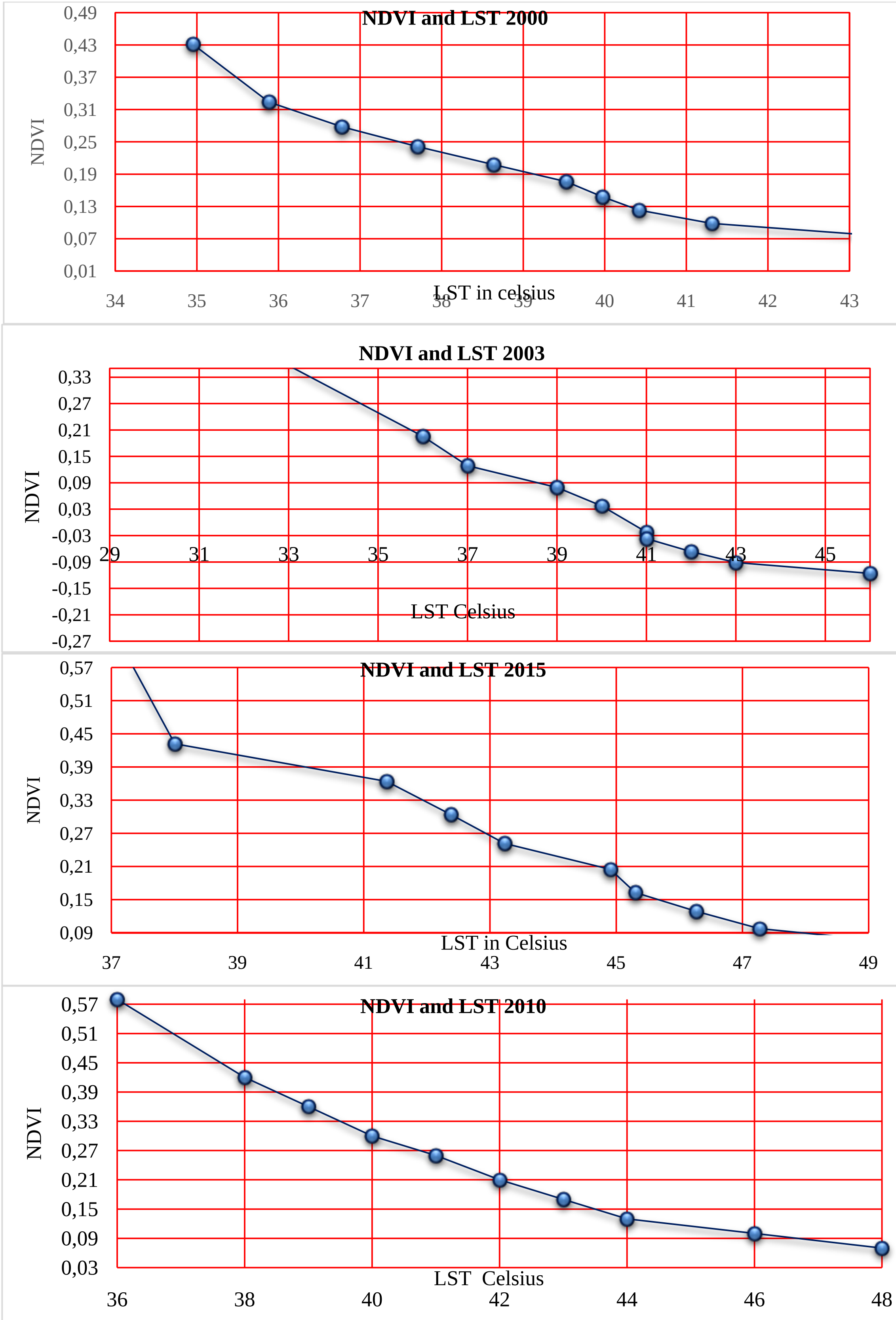

Figure:6. Correlations between NDVI and LST 2000, 2003, 2010 and 2015

Conclusion

The results of studying showing the relationship between parameters of vegetation density and surface temperature demonstrate that the decrease in vegetation will increase LST. NDVI based classification was used to calculate the vegetation area. The vegetation area decreases from 34 to 14.3 percent with average increase in LST from 39.8 to 44 degree Celsius from 2000-2015. It is suggested that further studies should be carried out in this area in different seasons and conditions. Furthermore, the sensor images with higher spatial resolution should be used to achieve better results, particularly more accurate estimates of the land surface.

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