Study of Urban Heat Island Phenomena for Baghdad City using Landsat- 7 ETM+ Data.

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Abstract

Urban areas have well documented effects on climate, such as the urban heat island effect, reduction of wind speeds, enhanced turbulence and boundary layer heights, and changes in cloud cover and precipitation. The objective of the present work is to study the Urban Heat Island in Baghdad city, by finding out the spatial variation of four indicators, Normalized Difference Vegetation Index (NDVI), soil adjusted vegetation index (SAVI), Leaf Area Index (LAI) and Land Surface Temperature (LST) using Landsat-7 ETM+ imagery. Land use/ Land cover map for the study area were retrieved using supervised classification by ERDAS(9.1) software. This paper classifies Baghdad city area as five type of land built up area with trees, built up area without trees, water area, low vegetation and high vegetation. The results shows that the maximum difference of land surface temperature between the built-up and the surrounding area reach to 11.97 ºC. The maximum value of the land surface temperature appeared in the built-up area without trees in the downtown of the city (29.96 ºC),while the water and high vegetation area show 17.93 ºC of minimum land surface temperature values. The result of the spatial analysis of the NDVI, LAI and SAVI indicated that there is a negative correlation with the built-up area and positive correlation with vegetation area.

Key words: Urban heat island, land surface temperature, normalized difference vegetation index, Landsat-7, Land use land cover, Baghdad.

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Study of Urban Heat Island Phenomena for Baghdad City using Landsat- 7 ETM+ Data.

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دراسة ظاهرة الجزيرة الحرارية الحضرية في مدينة بغداد بأستخدام بيانات القمر الصناعي لاندسات-7 (ETM+)

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الملخص

ان للمناطق الحضرية تأثيرات موثقة على المناخ مثل ظاهرة الجزيرة الحرارية الحضرية وتقليل سرعة الرياح والزيادة في الاضطرابات الجوية وارتفاعات الطبقة المحاددة والتغيرات في الغطاء الغيمي والتساقط. ان الهدف من هذا البحث هو دراسة ظاهرة الجزيرة الحرارية في مدينة بغداد من خلال حساب التغيرات المكانية في اربع مؤشرات وهي مؤشر الفرق الخضري (NDVI)، مؤشر مراعاة التربة للنبات (SAVI)، مؤشر الكثافة الخضرية (LAI) ودرجة حرارة سطح الارض (LST) باستخدام بيانات القمر الصناعي لاندسات-7 (ETM+).في هذه الدراسة تم وضع خارطة للاستخدامات الارضية في مدينة بغداد باستخدام تقنية التصنيف المراقب في برنامج الايرداس 9.1، حيث تم تصنيف منطقة الدراسة الى خمسة اصناف وهي مناطق حضرية بدون اشجار، مناطق حضرية مع الاشجار، مساحات مائية، غطاء خضري قليل وغطاء خضري كثيف.اظهرت النتائج ان اقصى فرق لدرجة حرارة سطح الارض بين المناطق الحضرية والمناطق المجاورة لها وصل الى 11.97 درجة مئوية. اقصى قيمة لدرجة حرارة سطح الارض ظهرت في المناطق الحضرية بدون اشجار وكانت 29.96 درجة مئوية، بينما سجلت المساحات المائية والمناطق الخضراء اقل قيمة وكانت 17.93 درجة مئوية. نتائج التغير المكاني للمؤشرات (NDVI,SAVI and LAI) اشرت الى علاقة عكسية مع المناطق الحضرية وعلاقة ايجابية مع المناطق الخضرية.

الكلمات المفتاحية: الجزيرة الحرارية الحضرية، درجة حرارة سطح الارض، مؤشر الفرق الخضري, لاندسات-7، الاستخدامات الارضية، بغداد.

Introduction

Urban areas are one of the most obvious examples of human modification of the Earth's surface. Despite covering only 1.2% of the Earth's surface [1, 2], it is estimated that in 2003 about 48% of the World's population resided in urban settlements [3]. By 2030 it is expected that 61% of the World's population will be living in urban areas. Urbanization is an extreme example of human land use modification, since it radically alters the physical properties of the Earth's surface and may also affect the thermal, radiative and aerodynamic character of the surface [4]. Urban areas have well documented effects on the environment, such as changes to the local winds and turbulence [5], changes in cloud cover and precipitation [6] and the urban heat island phenomenon.

The urban heat island (UHI) is a particularly important example of how the urban area can influence climate and the most obvious climate manifestation of urbanization [4, 7 and 8]. It is caused by a variety of factors which contribute to higher temperatures in the urban centre, either of the surface or the atmosphere, compared to the surrounding rural areas. The UHI can be particularly significant in exacerbating the effects of summer heat-waves, with consequent problems such as increased mortality [9] and marked air pollution events [10]. A UHI can also affect the regional scale flow by means of a thermodynamically driven circulation pattern [11, 12 and 13] caused by the UHI modifying the local pressure field and the stability. Under best conditions the Urban Heat Island may be up to 10-15 ºC [14].

Urban heat island mainly appeared in the spatial distribution of land surface temperature (LST),

which is governed by surface heat fluxes and obviously affected by urbanization [15,16].

Consequently, acquiring LST is the primary and key step to the urban heat island analysis. The LST difference is usually larger at night than during the day. Seasons influence the LST difference, too. Heat island cities located in the mid latitude usually are strongest in the summer seasons. In tropical climates, the day season may affect the large island magnitudes. Thus, there are differences in day, night and seasonal measurements of LST.

The concept of urban heat island was described by Luke Howard [4], and since then this research topic has received ever more attention. Recently, with the development of society and acceleration of the process of urbanization, the urban heat island has become more and more significant and has had severe impact on urban development and human living environments.

Urban Heat Island can be marked by in situ measurement of the air temperature in the city or by using remote sensing techniques, which needed information about the overlying atmosphere and the surface heat radiation flux properties. Several relevant researches i.e. [17-19], estimated Urban Heat Island using remote sensing techniques.

The aim of the present study is to assessment the specific characteristics of Urban Heat Island in Baghdad city, by analyzing the spatial variation of Normalized Difference Vegetation Index (NDVI), Leaf Area Index (LAI), Soil adjusted vegetation index (SAVI) and Land Surface temperature. (LST), using Landsat-7 ETM+ imagery and digital image processing techniques.

Area of study

Baghdad is the largest and most heavily populated city in Iraq with an area of about 900 Km^2, whereas the total area of Baghdad Governorate reaches 5159 Km^2 [20]. The estimated population is in the order of 6 million [21]. Baghdad lies in the middle of Iraq within the Mesopotamian Plain. The Tigris River passes through the city dividing it into two parts; Karkh and Rasafa. The area is bounded from the east by Dyala River which joins the Tigris River southeast of Baghdad. The Army Canal, 24 km long, recharges from the Tigris River in the northern part of the city and terminates in the southern part of Dyala River [22]. The study area is restricted to latitudes (33º 15′ -33º 28′N) and longitudes (44º 15′- 44º31′E) with an area of about 540 km^2 approximately(Figure 1). Several land uses can be noticed from Baghdad maps, specifically those prepared by Baghdad Environment Directorate [23], According to these statistics the percentages of the urbanized, agricultural, and industrial areas from the total area are 72.69%, 25%, and 2.31% respectively.

Material and Methods

For the present study the following methodology is adopted (Figure 2) ,which involves satellite data collection, classification of the imagery, development of land use/cover maps, preparation of (NDVI) maps, (LAI)map, (SAVI) map and retrieval of (LST) maps. These are briefly outlined here.

Data preparation

Landsat satellite data of 2001 for the study area has been downloaded from United States Geological Survey (USGS) Earth Explorer website. All the remote sensed data were pre-processed and geometrically corrected in the datum WGS84 and projection UTM zone N38. The details of the satellite data collected are shown in the Table.1. The multispectral image data consists of seven spectral bands and has a spatial resolution of 30 meters for the reflective bands and 60 meters for the thermal bands. The overpass time is about 10 o'clock A.m., and the sun elevation angle is 48.035°.

The data pre-processing is performed using ERDAS Imagine 9.1 software. Each ETM+ file is composed of the independent single-band images. Thus, it is firstly used to combine the single-band images to a multi-bands image of ETM+ using a layer stacking tool. Secondly, the geometric correction was made for the ETM+ images, by which each point on the image would have only latitude or longitude geographical coordinates. This is the most important step in pre-processing. Thirdly, after geometric correction, the image subset tool was used to clip our study area. After the pre-processing, the study area images of Baghdad were obtained for the data processing and analysis of urban heat island.

Development of Land use/Land cover map

Using bands 1-6 and 7 of the pre-processed images the land use / cover pattern was mapped by supervised classification with the maximum likelihood classification algorithm of ERDAS software. The Five classes considered for the study area are built up area with trees, built up area without trees, water area, low vegetation and high vegetation. The supervised classification involves pixel categorization by Training, Classification and Output.

NDVI map preparation

The normalized difference vegetation index (NDVI) is one of the most widely applied vegetation indices. Doing ration calculation between the near infrared (NIR) band and the red (R) band can strengthen the vegetation information and the ratio is the main idea of NDVI [24]. The reason NDVI is related to vegetation is that healthy vegetation reflects very well in the near infrared part of the spectrum. Green leaves have a reflectance of 20 % or less in the 0.5 to 0.7 range (green to red) and about 60 % in the 0.7 to 1.3 μm ranges (near infrared). The value is then normalized to

$-1 <= NDVI <= 1$ to partially account for differences in illumination and surface slope. In order to calculate the NDVI, Equation (1) can be used as:

$$NDVI = \frac{NIR\ Band - R\ Band}{NIR\ Band + R\ Band} \quad (1)$$

SAVI and LAI map preparation

The SAVI is an index that attempts to "subtract" the effects of background soil from NDVI so that impacts of soil wetness are reduced in the index. It is computed as [24]:

$$SAVI = \frac{(1 + L) \times (NIR\ Band - RBand)}{(L + NIR\ Band + RBand)} \quad (2)$$

Where L is a constant, a value of 0.5 frequently appears in the literature for L.

The LAI is the ratio of the total area of all leaves on a plant to the ground area represented by the plant. It is an indicator of biomass and canopy resistance, is calculated from the empirical equation [24]:

$$LAI = -\frac{ln\left(\frac{0.69 - SAVI}{0.59}\right)}{0.91} \quad (3)$$

Retrieval of Land Surface temperature map

The digital number (DN) of thermal infrared band is converted in to spectral radiance (L_λ) using the equation supplied by the Landsat user's hand book. [25]

$$L_\lambda = \left(\frac{L_{MAX} - L_{MIN}}{QCAL_{MAX} - QCAL_{MIN}}\right) * DN - 1 + L_{MIN} \qquad (4)$$

L_{MAX} = the spectral radiance that is scaled to $QCAL_{MAX}$in (W m^{-2} sr $^{-1}$ µm^{-1})

L_{MIN} = the spectral radiance that is scaled to $QCAL_{MIN}$ in (W m^{-2} sr $^{-1}$ µm^{-1})

$QCAL_{MAX}$ = the maximum quantized calibrated pixel value (corresponding to L_{MAX}) in DN = 255

$QCAL_{MIN}$ = the minimum quantized calibrated pixel value (corresponding toL_{MIN}) in DN = 1

L_{MAX} and L_{MIN} are obtained from the Meta data file available with the image and they are given in the Table 2.

The effective at-sensor brightness temperature (T_B) also known as black body temperature is obtained from the spectral radiance using Plank's inverse function.

$$T_B = \frac{K_2}{ln\left(1 + \frac{K_1}{L_\lambda}\right)} \qquad (5)$$

K1 and K2 are calibration constants for Landsat-7 ETM+ thermal band. Their values are K_1 =666.09 W m^{-2} sr $^{-1}$ µm^{-1} and K_2=1282.71 $^{\circ}$K.

The final Land Surface Temperature (LST) is estimated by the following equation.

$$LST = \frac{T_B}{1 + (\lambda + T_B/\rho) * ln\varepsilon} \qquad (6)$$

Where, λ is the wavelength of the emitted radiance which is equal to 11.5μm. $\rho - \frac{h.c}{\sigma}$, 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. In this study spectral emissivity coefficient is taken as unity.

Results and Discussions

The land use land cover map of the study area developed for the Landsat-7 ETM+ imagery dated 18^{th} Mar. 2001 using supervised classification method is given in Figure 3. The total area of the rectangular area of interest (AOI) is (545) square kilometers. The details of the land cover of the area under study are given in the Table 3. From the table it's clear that the built-up area without trees represent 54.78% of total area of study while the built-up area with trees, low vegetation, high vegetation and water area covered 26.37%, 9.45, 7.41 and 1.99% respectfully of the area of study. The center of Baghdad city is characterized by, high density of built- up structures with various institutions, commercial and industrial constructions and roads network, leading to increase in the anthropogenic activities a companied with alteration of natural surface characteristics. The vegetation area in the area of study concentrated in the northeast and southeast parts of the city.

NDVI is one of the most widely used index of which applicability in satellite analysis and in monitoring of vegetation cover was sufficiently verified in the last two decades. The NDVI value of the pixels varies between -1 and +1. Higher values of NDVI indicate the richer and healthier vegetation. Vegetation affects the latent thermo flux of the surface intent to the atmosphere through the evapotranspiration. Lower LST (except water bodies) is usually measured in areas with higher NDVI values. The Normalized Difference Vegetation Index (NDVI) image developed is shown in the Figure 4. The spatial distribution of normalized difference vegetation index (NDVI) ranged from -0.86 at area of no vegetation cover and water bodies to 0.83 at area covered by high density of vegetation cover. The water bodies and area of high vegetation cover play an important agent in reducing the radiation heat flux of the earth surface by consuming most of the radiation energy during the evapotranspiration process, which resulted in reducing the LST.

The spatial variation of LAI (Figure 5) shows that, the values are ranged from negative values of -1.312 at the area of no vegetation cover and water bodies to positive values of 9.022 at area characterized by dense vegetation cover.

Figure 6 shows the spatial distribution of (SAVI), the values are ranged from 1.24 at area covered by high density of vegetation cover to -1.25 at the area of no vegetation cover and water bodies.

From brightness temperature (TB) the final Land Surface Temperature image was obtained by developing a model in ERDAS Imagine 9.1. The Final LST image is shown in the Figure 7.

From the LST image it was observed that highest temperatures of about 29.93 º C exist at urban built- up areas and lowest temperatures of about 17.96 º C are existing at water and vegetative areas. That means, the maximum urban /suburban land surface temperature difference is approximately reaches 11.97 ºC. The urban development raised the temperature by replacing natural environment (forest, water and pasture) with non – evaporating, non – transpiring surfaces.

Table (4) shows the statistic values (minimum, maximum and mean) for the NDVI, SAVI, LAI and LST over the five land use land cover classes at the area of study. The maximum values of the NDVI, SAVI and LAI appeared in the high vegetation class, while the water area shows the lower values of these indices.

Conclusions

In this work Landsat ETM+ images of Baghdad city were collected from USGS earth explorer web site. The land use land cover maps of the study area are developed by supervised classification of the images. Land use classes have been identified as Built-up area with trees, built-up area without trees, Water area, low Vegetation and high vegetation land. LST, NDVI, SAVI and LAI, Four indicators are using to evaluate the urban heat island effect for Baghdad city. From the LST images it is clearly understood that surface temperature is more in urban area compared to rural areas, the difference reach to 11.97 ºC, the results also shows that the LST is strongly and negatively correlated with NDVI, SAVI and LAI. The physical properties of urbanization structures play a main factor for transferring the land surface thermal properties to the air through the vertical exchange of surface radiation heat flux, when compared to the sub- urban surrounding areas for the difference in temperature, where the vegetation cover and water bodies play a major role in reducing surface temperature.

References

1. Lamptey, B. L., E. J. Barron and D. Pollard, Impacts of agriculture and urbanizationon the climate of the Northeastern United States. Global and Planetary Change 49, 2005 203-221.
2. Shepherd, J., A review of current investigations of urban-induced rainfall and recommendations for the future. Earth Interactions 9, 2005, 1-27.
3. UN. World urbanization prospects: The 2003 revision. United Nations Population Division. New York, USA, Department of Economic and Social Affairs, United Nations Secretariat**:** 2004, 335.
4. Oke, T. R., Boundary layer climates. 2nd ed., Methuen, London. 1987, 435.
5. Roth,M.. Review of atmospheric turbulence over cities. Quarterly Journal of the Royal Meteorological Society 126, 2000, 1941-1990.
6. Changnon, S. A., Inadvertent Weather Modification in Urban Areas: Lessons for Global Climate Change. Bulletin of the American Meteorological Society_73(5), 1992,619-627.
7. Arnfield, A. J., Two decades of urban climate research: A review of turbulence, exchanges of energy and water, and the urban heat island. International Journal of Climatology.23, 2003, 1-26.
8. Fan, H. L. and D. J. Sailor, Modeling the impacts of anthropogenic heating on the urban climate of Philadelphia: a comparison of implementations in two PBL schemes. Atmospheric Environment_39(1), 2005, 73-84.

9. Johnson, H., R. S. Kovats, G. McGregor, J. R. Stedman, M. Gibbs and H. Walton, The impact of the 2003 heatwave on daily mortality in England and Wales and the use of rapid weekly mortality estimates. Eurosurveillance. 10(7-8), 2005, 168-171.

10. Stedman, J. R., The predicted number of air pollution related deaths in the UK during the August 2003 heatwave. Atmospheric Environment 38, 2004. 1087-1090.

11. Oke, T. R., The Heat Island of the Urban Boundary Layer: Characteristics, Causes and Effects. Wind Climate of Cities. J. E. e. a. Cermak. Dordrecht, Boston, Kluwer Academic Publishers**.** 1995, 81-107.

12. Bornstein, R. D. and Q. Lin, Urban heat islands and summetime convective thunderstorms in Atlanta: three case studies. Atmospheric Environment **34**, 2000, 507-516.

13. Collier, C. G.. The impact of urban areas on weather. Quarterly Journal of the Royal Meteorological Society 132, 2006, 1-25.

14. Adinna E. N., Enete Ifeanyi Christian and Arch. Tony Okolie,. Assessment of urban heat island and possible adaptations in Enugu urban using landsat-ETM,Journal of Geography and Regional Planning . 2(2), 2009, 030-036.

15. Dousset, B.; Gourmelon, F., Satellite multi-sensor data analysis of urban surface temperatures and landcover. ISPRS J. Photogram. Remote Sens., 58, 2003, 43-54.

16. Sun, Q.; Tan, J.; Xu, Y., An ERDAS image processing method for retrieving LST and describing urban heat evolution: A case study in the Pearl River Delta Region in South China. *Environ. Earth Sci.*, *59*, 2010, 1047-1055.

17. Salah, A. H. S., Impact of urban expansion on surface temperature in Baghdad, Iraq using remote sensing and GIS techniques. Journal of AL-Nahrain university, 13(1), 2010, 48-59.

18. Laosuwan, T. and Sangpradit, S., Urban heat island monitoring and analysis by using integration of satellite data and knowledge based method. International Journal of Development and Sustainability. 1 (2), 2012, 99–110.

19. Xu, L.U., Xia, X.D. and Li, S., Correlation analysis of the urban heat island effect and the spatial and temporal distribution of atmospheric particulates using TM images in

Beijing. Environmental Pollution 178, 2013, 102-114.

20. Nussaif, H. and Qamar, T., Environmental guide of Baghdad City, Ministry of Environment, Baghdad Environmental Directorate , 2007, 205.
21. Humantation information center for Iraq (HIC), Iraq population forcasting for year 2005 . Minstery of planning and development cooperation, Iraq, 2006.
22. Al-Hiti, B.M.,Groundwater quality within Baghdad area, M.Sc. thesis, College of Science, University of Baghdad, 1985, 235,(in Arabic).
23. Baghdad Environmental Directorate, Environmental situation of Baghdad City report, 2010,267, (in Arabic).
24. Allen, R. G., W. Bastiaanssen, R. Waters, M. Tasumi, and R. Trezza,. SEBAL Surface Energy Balance Algorithm for Land – Advanced Training and Users Manual Version 1.0, University of Idaho, USA, 2002.98
25. NASA, Landsat Project Science Office: Landsat 7 Science data users hand book, Chapter: 11, Data Products. http://www.gsfc.nasa.gov/IAS/handbook/handbook_htmls. 2004

Table 1: Details of Landsat data collected

Date of Image	Satellite/Sensor	Reference system/ Path/Row
18/03/2001	Landsat 7 /ETM+	WRS-II/168/37

Table 2: L_{MAX} and L_{MIN} values of Landsat data

Band No.	Satellite/Sensor	L_{MAX}	L_{MIN}
6.2	Landsat7 /ETM +Low gain	12.65	3.2

Table 3: Details of land use land cover classes.

No.	Land cover class	Area in Km^2
1	Built-up area with trees	143.7281
2	Built-up area without trees	298.5281
3	Water area	10.85076
3	Low vegetation	51.50181
4	High vegetation	40.39125

Table 4: statistics (Minimum, Maximum and Mean) of land use land cover classes for the area of study.

	LU/LC Class	Min.	Max.	Mean
NDVI	Built-up area with trees	-0.164	-0.067	-0.1192
	Built-up area without trees	-0.12	-0.054	-0.0928
	High vegetation	0.25	0.837	0.5270
	Low vegetation	0.130	0.437	0.275
	Water area	-0.866	0.449	-0.2205
SAVI	Built-up area with trees	-0.247	-0.098	-0.1897
	Built-up area without trees	-0.21	-0.077	-0.1467
	High vegetation	0.49	1.240	0.8220
	Low vegetation	0.256	0.648	0.429
	Water area	-1.250	-0.64	-0.919
LAI	Built-up area with trees	-0.46	-0.289	-0.3825
	Built-up area without trees	-0.45	-0.33	-0.384
	High vegetation	0.923	9.022	4.8827
	Low vegitation	0.302	2.950	1.596

	Water area	-1.312	-0.92	-1.2858
LST	Built-up area with trees	24.00	27.00	25.680
	Buit- up area without trees	24.86	29.966	27.635
	High vegetation	18.09	21.5	20.283
	Low vegetation	20.147	22.919	21.621
	Water area	17.936	18.3	18.433

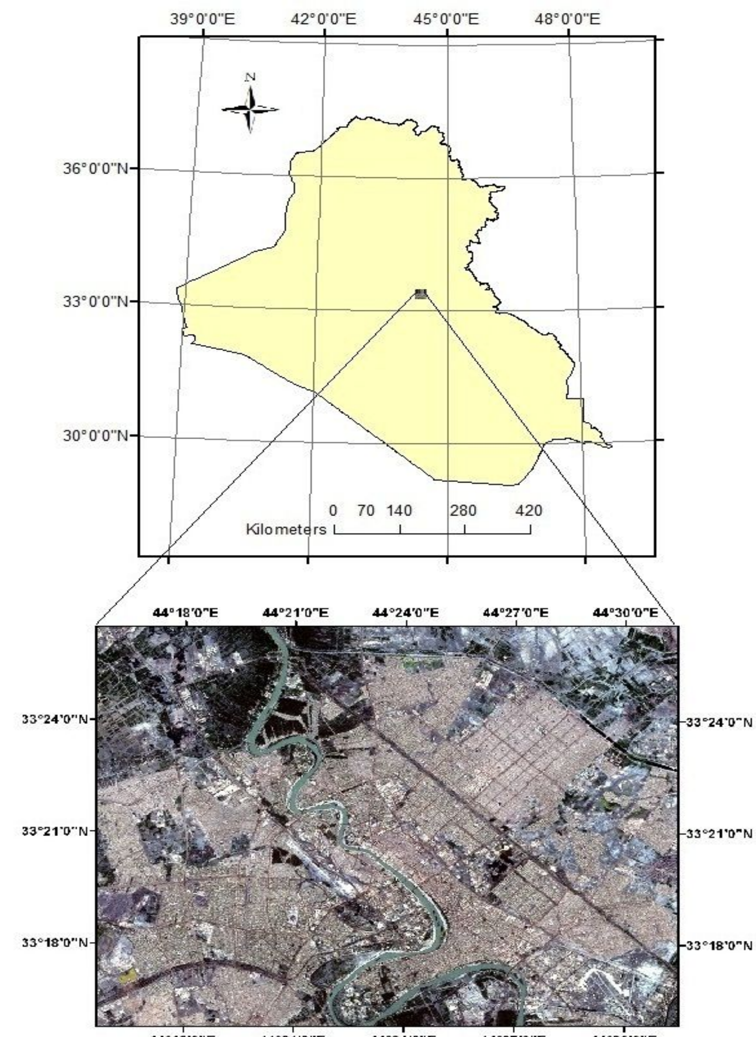

Figure 1: Location of the study area.

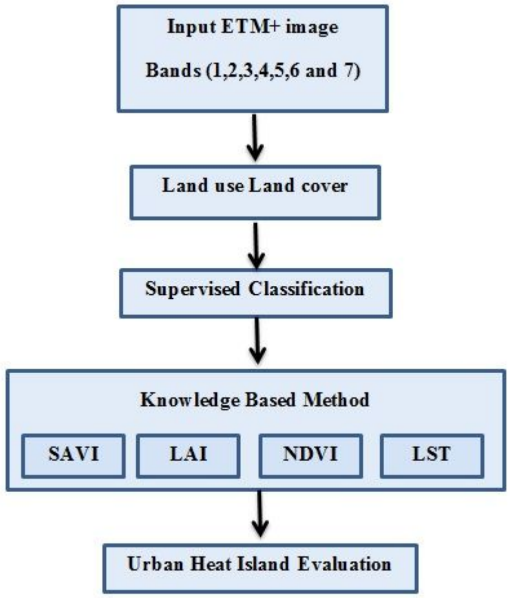

Figure 2: Flow chart of evaluation of urban heat island from Landsat 7 ETM+ image for the study area

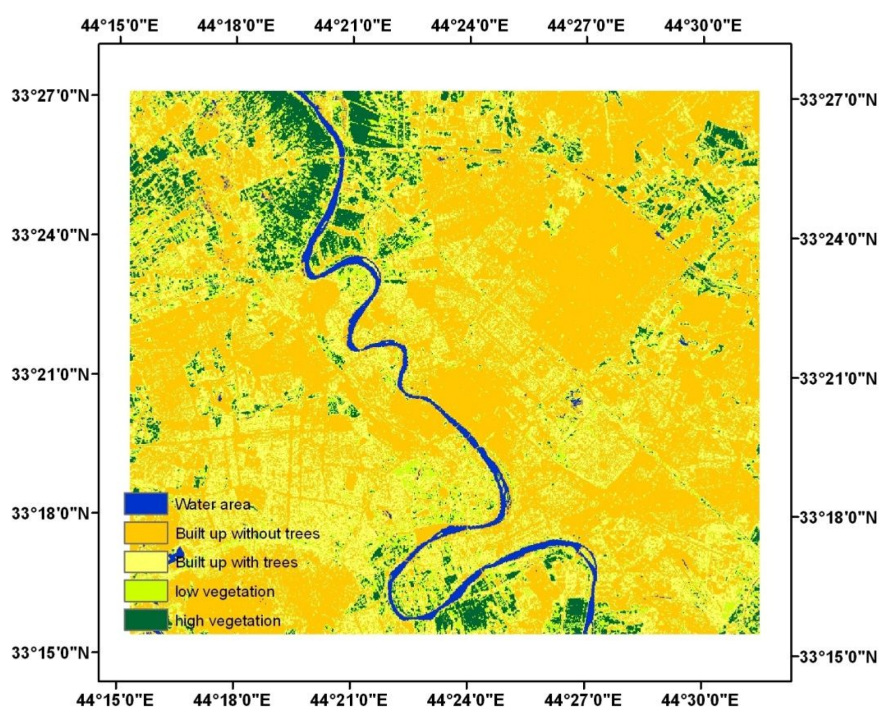

Figure 3: Land use land cover map of the study area.

NDVI

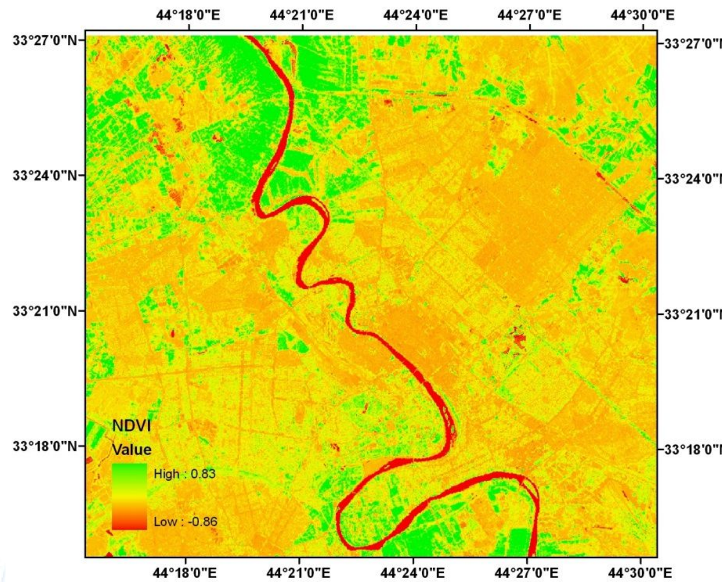

Figure 4: NDVI map of the study area.

LAI

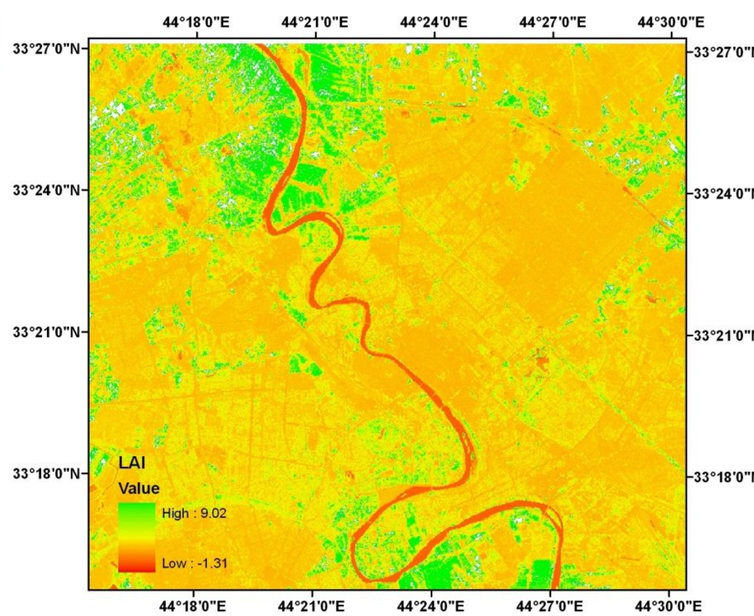

Figure 5: LAI map of the study area.

SAVI

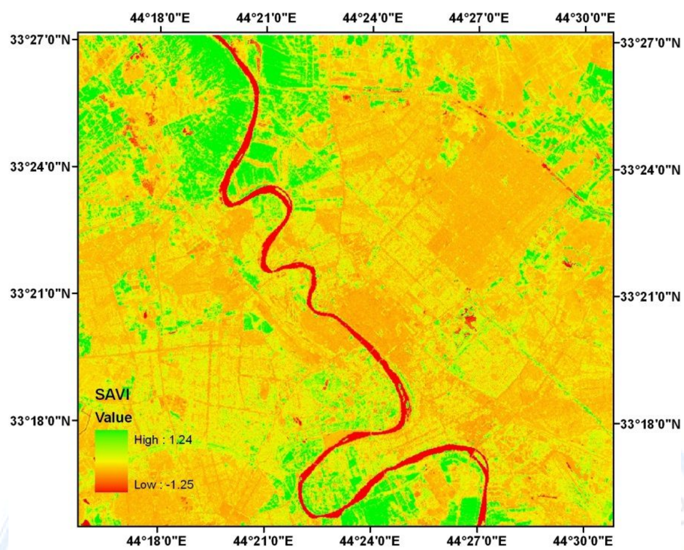

Figure 6: SAVI map of the study area.

LST

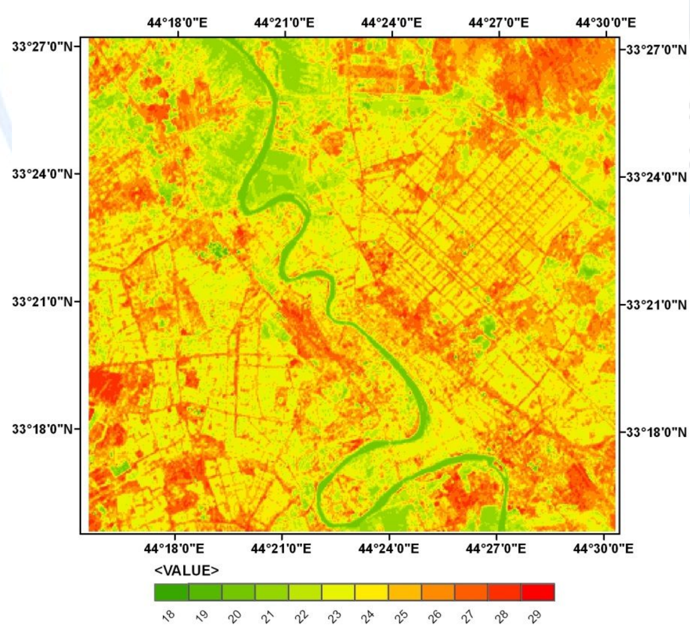

Figure 7: LST map of the study area.