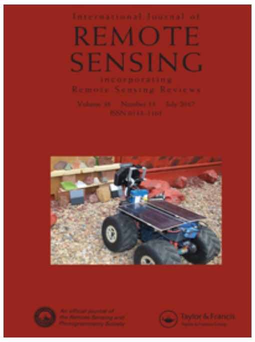

International Journal of Remote Sensing

ISSN: 0143-1161 (Print) 1366-5901 (Online) Journal homepage: http://www.tandfonline.com/loi/tres20

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To cite this article: Azad Rasul, Heiko Balzter & Claire Smith (2017) Applying a normalized ratio scale technique to assess influences of urban expansion on land surface temperature of the semi-arid city of Erbil, International Journal of Remote Sensing, 38:13, 3960-3980, DOI: 10.1080/01431161.2017.1312030

To link to this article: https://doi.org/10.1080/01431161.2017.1312030

Published online: 03 Apr 2017.

INTERNATIONAL JOURNAL OF REMOTE SENSING, 2017
VOL. 38, NO. 13, 3960–3980
http://dx.doi.org/10.1080/01431161.2017.1312030

Applying a normalized ratio scale technique to assess influences of urban expansion on land surface temperature of the semi-arid city of Erbil

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ABSTRACT

The difference between surface and air temperature within a city and its surrounding area is a result of variations in surface cover, thermal capacity, and 3-dimensional geometry. This research has examined and quantified the decreasing daytime land surface temperature (LST) in Erbil, Kurdistan region of Iraq, and the influence of rapid urban expansion on urban heat/cool island effect over a 20 year period. Land-use/land-cover change across this time period is also established using pixel samples. The current study proposes the application of the normalized ratio scale (NRS) to adjust the temperature of images acquired at different dates to the same range. Eleven satellite images acquired by Landsat 4, 5, 7, and 8 during the period 1992–2013 are used to retrieve LST. The results indicate that 55.3 km^2 of city land cover changed from bare soil to urban; consequently, the mean LST of the new urbanized area decreased by 2.28°C. The normalized difference vegetation index (NDVI) of Sami Abdul-Rahman (S.A.) Park increased from 0.09 ± 0.01 to 0.32 ± 0.11, resulting in a decrease of the mean LST by 7.29°C. This study shows that the NRS method is appropriate for detecting temperature trends from urbanization using remote-sensing data. It also highlights that urban expansion may lead to a decrease in daytime LST in drylands.

ARTICLE HISTORY
Received 28 May 2016
Accepted 20 March 2017

1. Introduction

The difference between surface and air temperature within a city and its surrounding area is a result of variations in surface cover, thermal capacity, and 3-dimensional geometry (Oke 1981; Robinson Peter and Ann 1999). Moreover, urbanization leads to a reduction of natural habitats, can modify energy flow, and can alter the local microclimate (Alberti and Marzluff 2004). Researching land-use/land-cover (LULC) changes in an area helps to assess the amount of man-made modification of the surface and other environmental changes related to human impacts (Xiao and Weng 2007).

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In an urban climate study, the surface temperature is very significant (Voogt and Oke 2003). Satellite sensors can be used to retrieve and study the surface temperature of urban areas and its spatial patterns (Watson 2012). Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) are widely used to assess the relationship between LST and LULC (e.g. Xu 2007; Li et al. 2011; Ukwattage and Dayawansa 2012). The correlation between LST and normalized difference vegetation index (NDVI) has been applied extensively (Weng, Lu, and Schubring 2004; Sun and Kafatos 2007; Weng and Lu 2008; Schwarz et al. 2012).

Vegetation is different from urban materials in terms of its radiative, aerodynamic, thermal, and moisture properties. The capacity of urban vegetation to produce shade, reduce air temperature, and improve air quality implies it is an appropriate strategy for urban environmental design (Oke et al. 1989). A key process of urban greening that reduces temperature is evapotranspiration; this cools the leaf and the air temperature surrounding it through energy consumption during the phase change of water (i.e. latent cooling) (Bowler et al. 2010). Moreover, trees can intercept solar radiation and reduce the surface and air warming through shading (Oke et al. 1989). Most studies on urban green areas and parks broadly confirm that green sites within cities can be cooler than non-vegetated areas. They act as cooling agents of daytime temperature, particularly if the green space is large and contains trees (Bowler et al. 2010).

In assessing the Urban Heat Island (UHI) in New York City, Susca, Gaffin, and Dell'Osso (2011) found that the temperature in the most vegetated areas was on average 2°C less than in the least vegetated areas. Results have also indicated that the cooling influence of green areas in the city exceed vegetated areas to influence temperatures in surrounding built-up and commercial areas (Ca, Asaeda, and Abu 1998; Yu and Hien 2006). Because vegetation such as trees, grass, forests, and parks have strong cooling effects in the city, it could be used to reduce temperatures and mitigate UHIs (Onishi et al. 2010). Qiu et al. (2013) suggested that urban temperature could be reduced from 0.5°C to 4.0°C through vegetation and urban agricultural evapotranspiration. In addition, the result of simulation by Taha (1997) suggests that air temperature could decrease 2°C as a consequence of increasing vegetation in the cities. This decrease may reach 4°C in some circumstances such as favourable meteorological conditions.

Numerous studies of cities situated in different environments indicate that urbanization leads to an increase in the surface and air temperature; Kalnay and Cai (2003) in the United States; Baker, Brazel, and Westerhoff (2004) in the Phoenix Metropolitan Area in the USA; Zhou et al. (2004) in southeast China; and Amiri et al (2009) in Tabriz urban area, Iran. In contrast, Trenberth (2004) indicates a cooling rather than warming influence of rural land-use change.

In terms of the effect of urban expansion in cities located in a subtropical climate zone, Weng (2001) found urban development and decreasing biomass in the Zhujiang Delta in China, during 1989–1997, increased surface radiant temperature by 13°C on average. Baker et al. (2002) examined the urbanization effect of Phoenix, Arizona (USA), as a city situated in a subtropical desert climate. The research indicated that as a result of urbanization, night-time minimum temperature and daily average temperature increased by 5°C and 3.1°C, respectively. Furthermore, when urbanization occurred in irrigated agricultural areas, maximum air temperature increased by 2°C–4°C, whilst replacing desert land with urban development only increased 1 K of daytime temperature (Grossman-Clarke et al. 2010).

In the literature, various techniques have been applied for analysing temporal changes of satellite-based LST. Some researchers directly compare two or more LST images without any modification (Abdullah 2012). This approach is open to critique because the climatic situation is not the same at the times of the two image acquisitions. Having high temperature in the second image compared to the first one, for example, does not mean the temperature has increased because it is possible at that time the temperature was higher for other reasons. Another technique that is used for establishing the UHI effect is normalizing the temperature based on the mean and standard deviation in high- and low-temperature areas (Streutker 2002; Zhang, Wang, and Wang 2007). This can minimize the effect of time; however, a small change may not be detectable, and with the increasing temperature, it may stay in the same category as the lower temperature. The third technique is common normalization of temperature based on the minimum and maximum LST of the same image in the same way as for NDVI (Khandelwal et al. 2011).

In this article, we propose a normalized ratio scale (NRS) technique to normalize the value of each pixel-based ratio to make the LST images from different time periods comparable, whilst simultaneously maintaining the original values. This technique compares the real value of each pixel with the entire image, then compares the values of the different images. Through multiplying the results by a constant number, the real temperature values can be illustrated.

Spatial variation of LST and Surface Urban Cool Island (SUCI) in Erbil during the dry season has been examined using Landsat 8 images before. The results of the research indicated that bare soil rural areas exhibited higher LST compared to densely built-up areas and the city, which act as cool islands during the daytime (Rasul, Balzter, and Smith 2015). Furthermore, the temporal variation of LST and SUCI/SUHI of the city was studied using the LST product from MODIS Aqua and Terra (Rasul, Balzter, and Smith 2016). Erbil experiences a SUCI during the daytime compared to the dry, bare surroundings; therefore, urban expansion is expected to correspond to a decrease in LST (Rasul, Balzter, and Smith 2015).

The current research extends these earlier results by quantifying the decreasing daytime LST as a consequence of urban expansion. It also examines different pixel samples of LULC change to show the influence of this change in more detail and illustrates what type of LULC change helps mitigate the night-time SUHI and makes the daytime SUCI more active in the summer-time.

The effect of LULC change on LST in cities located in semi-arid environments still needs more research to be better quantified and understood. The objective of this study was to quantify the effect of the LULC change on the LST patterns in Erbil. The objectives of the current study are to

- propose the application of the NRS to adjust the temperature of images acquired at different dates to the same range and
- quantify decreasing LST by expanding green area and urban expansion in Erbil as a case study for cities situated in semi-arid climates.

1.1. *Study area*

Erbil is the capital of Kurdistan region and the central city in the north of Iraq. The city is located 412 m above mean sea level (Sharif 1998). It is situated between 43° 57'E–44°03'E and 36°08'N–36°14'N (Figure 1). During the past two decades, the infrastructure and population of the city has experienced extensive growth. In

2015, the population of the Erbil Governorate was estimated to be 1,530,722 inhabitants (NCCIRAQ 2015). The annual growth rate of the population in Erbil is 2.9% (Dizayee 2014).

The city has a semi-arid continental climate and is classified as subtropical semi-arid (BSh) dry hot steppe in the Köppen classification of climate. It has a dry and warm summer and a rainy and cool winter. The amount of precipitation shows interannual variation but the average annual precipitation from 1993 to 2012 was 380.26 ± 108.88 mm with the majority occurring between December and March. The annual air temperature is 21.85°C and July and August are the hottest months of the year; air temperature during these months may reach 49°C (MSDEG 2014).

Residential land use is the dominant land use type in the city (approximately 70% of the area) comprising buildings built from concrete blocks. In the rural areas, winter grains such as wheat and barley are the most common form of land cultivation, and in general, agriculture in the study area depends on precipitation patterns, rather than irrigation water. Therefore, the majority of croplands are dry in the summer.

The ratio of the green area in Erbil is 12% (Erbiltourism2014). There are several gardens and parks in the city, for instance, Sami Abdul-Rahman Park (S.A. Park), Minare Park, and Shanidar Park (Figure 1). Sami Abdul-Rahman Park is located in the west of Erbil and is the biggest green area in the city (about 2 km^2). It is divided into gardens and forest. Its gardens consist of three types: lawns, a flower quarter, and a variety of trees.

Erbil is established on Erbil Plain, which has dark brown soil. The soil has a good structure, deep, and rich in organic matter, which makes it the best for agriculture (Kahraman 2004).

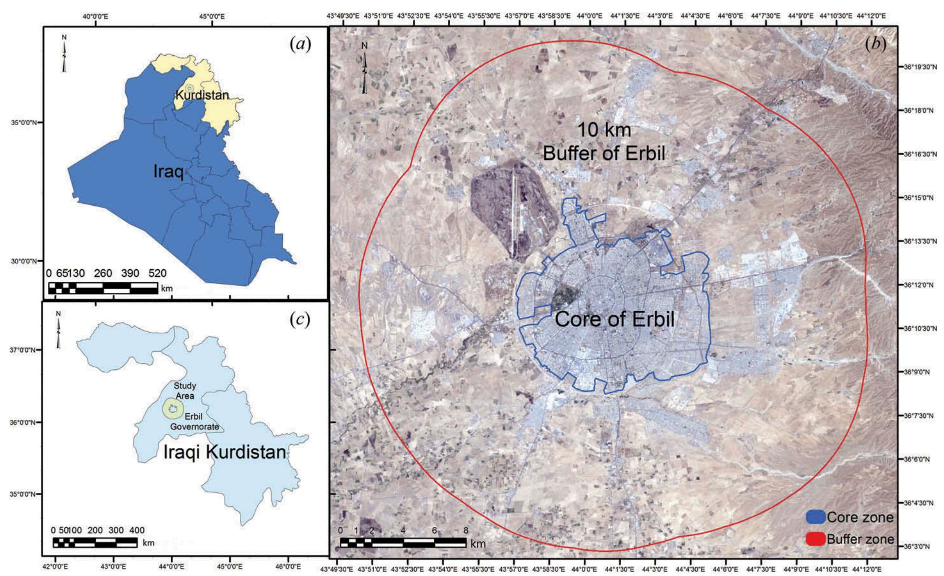

Figure 1. Map showing location of study area: (*a*) Iraq map, (*b*) Kurdistan Regional Government, and (*c*) true colour Landsat image of Erbil city, the study area.

2. Materials and methods

2.1. *Data and pre-processing*

Land surface temperature (LST) data were extracted from 11 Landsat images. To avoid seasonality of temperature, all were selected from the dry season (July, August, and September). Three images acquired in 1992 (Landsat 4 and 5), two images from 2002 (Landsat 7), and six thermal infrared radiometer images from 2013 acquired by Landsat TIRS (Landsat 8) from 1 July to 19 September 2013 were used. These images were resampled to 30 m spatial resolution by data provider to the same resolution of visible bands to make them comparable to each other and used to retrieve LST (Path 169, Row 035). The images were provided as level L1T data and were captured under clear atmospheric conditions (<1% cloud coverage) and in the dry season. The images are in UTM projection (zone 38 N). They were retrieved from the United States Geological Survey (USGS), Earth Explorer website (http://earthexplorer.usgs.gov/).

Composites of the Landsat images (thermal and multispectral bands) were produced for each year. They were produced by calculating the pixel-based mean of the images of each year. These composite images are used for all of the subsequent analysis. For the thermal bands of Landsat 4 and 5 that have one thermal channel, a scene-specific atmospheric correction was applied (Coll et al. 2010) whilst for the thermal bands of Landsat 7 and 8, a thermal atmospheric correction method was applied. Furthermore, quick atmospheric correction (QUAC) was performed that is appropriate for atmospheric corrections of Landsat multispectral bands.

A shapefile of S.A. Park and the urbanized area from 1992 to 2013 was digitized based on true colour Landsat imagery. Representative pixels of different LULC with the significant change in the study area were selected based on Landsat images for each year, and DigitalGlobe imagery with 0.5 m resolution (acquired on 5 July 2010) (Figure 2).

2.2. *Methodology*

2.2.1 *Retrieval of LST*

The digital number of the thermal band of Landsat data was converted to at-sensor radiance, using Equation (1) (Chander and Markham 2003; USGS 2013; NASA 2011).

$$L_\lambda = \text{gain} \times (\text{DN}) + \text{offset} \tag{1}$$

where

L_λ = spectral radiance at the sensor's aperture (W m^{-2} sr^{-1});
gain = band-specific rescaling gain factor ((W m^{-2} sr^{-1})/DN);
offset = band-specific rescaling bias factor (W m^{-2} sr^{-1});
DN = quantized calibrated pixel value (Chander, Markham, and Helder 2009).

Afterwards, these values were converted to at-satellite brightness temperature using Equation (2):

$$\text{TB} = \frac{k_2}{\ln\left(\frac{k_1}{L_\lambda} + 1\right)} \tag{2}$$

where TB = effective at-sensor brightness temperature (K).

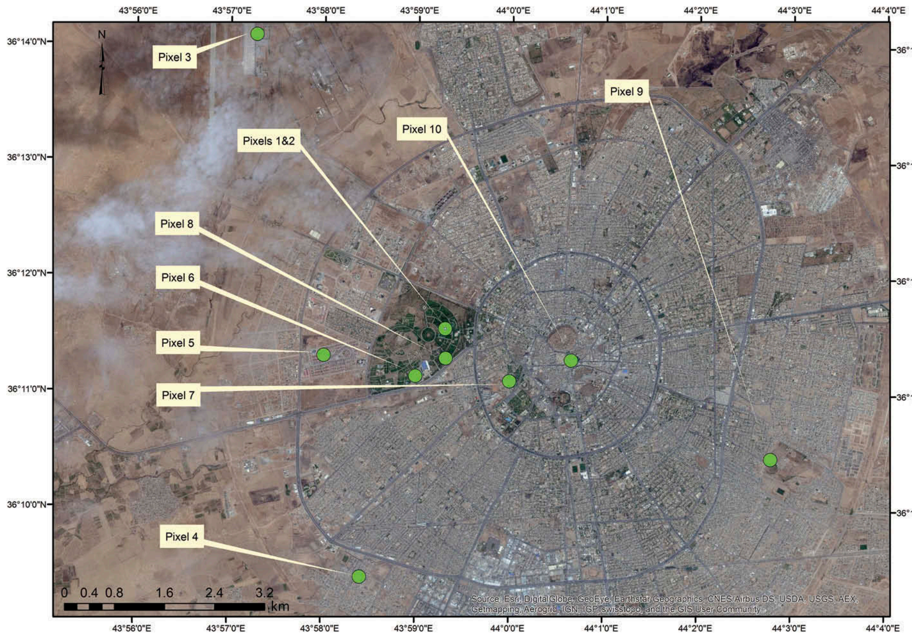

Figure 2. Location of pixel samples of LULC change (Image source: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogird, IGN, IGP, swisstopo, and the GIS User Community).

k_1 = calibration constant 1 (W m^{-2} sr^{-1}), Landsat 4: 671.62; Landsat 5: 607.76; Landsat 7: 666.09; Landsat 8: 774.89;

k_2= calibration constant 2 (K), Landsat 4: 1284.30; Landsat 5: 1260.56; Landsat 7: 1282.71; Landsat 8: 1321.08 (USGS 2013);

L_λ= spectral radiance at the sensor's aperture (W m^{-2} sr^{-1});

ln = natural logarithm (Chander, Markham, and Helder 2009).

2.2.2. *Emissivity correction*

An emissivity correction is required to accurately derive LST from satellite imagery (Srivastava, Majumdar, and Bhattacharya 2009). For Landsat 4 and 5, a typical emissivity of 0.95 was used and the emissivity normalization method was applied for Landsat 7 and 8. This method has been recommended by Li et al. (1999) to calculate emissivity. The approach calculates the emissivity of the highest temperature for each pixel (Zhang et al. 2008; Li et al. 2013). Equation (3) is then used to correct surface emissivity (Zhang et al. 2013).

$$T_s = \frac{(\mathrm{TB})}{(1 + (\lambda(\mathrm{TB})/\rho)\ \ln\varepsilon)} \tag{3}$$

where $T_s$is LST (in Kelvin); TB is brightness temperature (in Kelvin); λ is the wavelength of emitted radiance (11.5 μm); ρ is $\mathrm{h} \times \mathrm{c}/\sigma\left(1.438 \times 10^{-2}\mathrm{mK}\right)$; h is Planck's constant $\left(6.26 \times 10^{-34}\mathrm{Js}\right)$; c is the velocity of light (2.998 × 108 m s^{-1}); σ is Stefan Boltzmann's constant $\left(1.38 \times 10^{-23}\mathrm{JK}^{-1}\right)$; and ε is emissivity.

2.3. *Calculating impervious surface area (ISA) and vegetation indices*

NDVI is a simple and widely used vegetation index. It is a ratio-based index using two bands (red and near infrared) to identify healthy vegetation and changes in green biomass. The index relies on the fact that vegetation has a strong absorption in the red band and a strong reflection in the NIR band (Karnieli et al. 2010; Wu 2014). To calculate NDVI, Equation (4) was employed (Sobrino, Jiménez-Muñoz, and Paolini 2004).

$$\mathrm{NDVI} = \frac{\rho_{\mathrm{NIR}} - \rho_{\mathrm{Red}}}{\rho_{\mathrm{NIR}} + \rho_{\mathrm{Red}}} \tag{4}$$

where NDVI = normalized difference vegetation index, ρ_{NIR} is the surface reflectance of band 4, and ρ_{Red} is the surface reflectance of band 3 in Landsat 4, 5, and 7 (band 5 and band 4 in Landsat 8).

2.3.1 *Fractional vegetation and impervious surface cover*

$$F = N^{*2} \tag{5}$$

where N^* is a scaled NDVI from Equation (6):

$$N^* = \frac{(\mathrm{NDVI}) - (\mathrm{NDVI})_\circ}{(\mathrm{NDVI})_s + (\mathrm{NDVI})_\circ} \tag{6}$$

And $(\mathrm{NDVI})_s$ and $(\mathrm{NDVI})_\circ$, respectively, are values for dense vegetation and pure bare soil (maximum and minimum NDVI of the study area or the image).

ISA is calculated from the following equation (Carlson and Arthur 2000):

$$\mathrm{ISA} = (1 - F)_{\mathrm{dev}} \tag{7}$$

where dev indicates that the quantity is only defined for urban developed regions.

2.4. *Normalized ratio scale*

A common technique for normalizing LST is normalizing based on the minimum and maximum LST values (Khandelwal et al. 2011) (Equation (8)):

$$\mathrm{LST}^* = \frac{(\mathrm{LST}) - (\mathrm{LST})_\circ}{(\mathrm{LST})_s + (\mathrm{LST})_\circ} \times 100 \tag{8}$$

where LST^* is a normalized LST; LST_s and $\mathrm{LST}_\circ$, respectively, are the values of the maximum and minimum LST for the study area of that particular image. The range of LST^* is between 0 and 100.

There are various statistical methods which can be used to normalize variables and make them comparable to each other, such as nominal scale variables, ordinal scale, interval scale, ratio scale, difference scale, and absolute scale. Ratio scale preserves four properties including equality, ordinality, interval ratios, and value ratios. Because the ratios of the intervals between the numbers are not affected by congruence transformations, ratio scales are unique up to a congruence or proportionality transformation. This means that if you measure a group of objects on a ratio scale and then multiply each value by a constant, the resulting values are equally as valid as the original values. For instance, in the following example, the measurements M1, M2, and M3 are equally valid measures of a given object property, but M4 is not measuring the same thing (Borgatti 2016):

Object	M1	M2	M3	M4
A	22	220	11	12
B	22	220	11	12
C	22	220	11	12
D	23	230	11.5	13
E	24	240	12	14

A ratio scaled normalizing the variables above would produce the following:

Object	M1	M2	M3	M4
A	0.44	0.44	0.44	0.43
B	0.44	0.44	0.44	0.43
C	0.44	0.44	0.44	0.43
D	0.45	0.45	0.45	0.46
E	0.47	0.47	0.47	0.50

In this study, we propose a NRS, which rescales a set of images on a ratio scale, and then multiplies each value by a suitable number in order to produce a result close to the real temperature. In this method, the output values are as valid as the original values (Stevens 1946; Borgatti 2016). We divide each pixel value by the square root of the sum of squares of all the original pixel values (Equation (9)):

$$\mathrm{LST_{NRS}} = \frac{(\mathrm{LST})}{\sqrt{\sum (\mathrm{LST})^2}} \tag{9}$$

where $\mathrm{LST_{NRS}}$ is normalized LST based on the ratio scale and LST is the value of each pixel in the image. To return the values similar to original LST values, $\mathrm{LST_{NRS}}$ is multiplied by the results of Equation (10):

$$N = \frac{\mathrm{mean}(\mathrm{LST})}{\mathrm{mean}(\mathrm{LST})_{\mathrm{NRS}}} \tag{10}$$

where $\mathrm{mean}(\mathrm{LST})$ is the mean LST of one image before normalizing and $\mathrm{mean}(\mathrm{LST})_{\mathrm{NRS}}$ is the mean of the same image after normalizing (from Equation (9)).

To test the capability of NRS for LST change detection, it was compared visually with other methods (Figure 3). Mean LST, standard deviation, and variance of each method were compared (Table 1). LST measurements of the study area from 1992 (before urbanization), 2002, and 2013 (after urbanization) are unavailable. In its place, LST derived from Landsat data from 1992 was used as reference (referring to 330 pixels within the same land cover, bare soil). The results of the different normalization methods compared with these estimated references are shown in Figure 4.

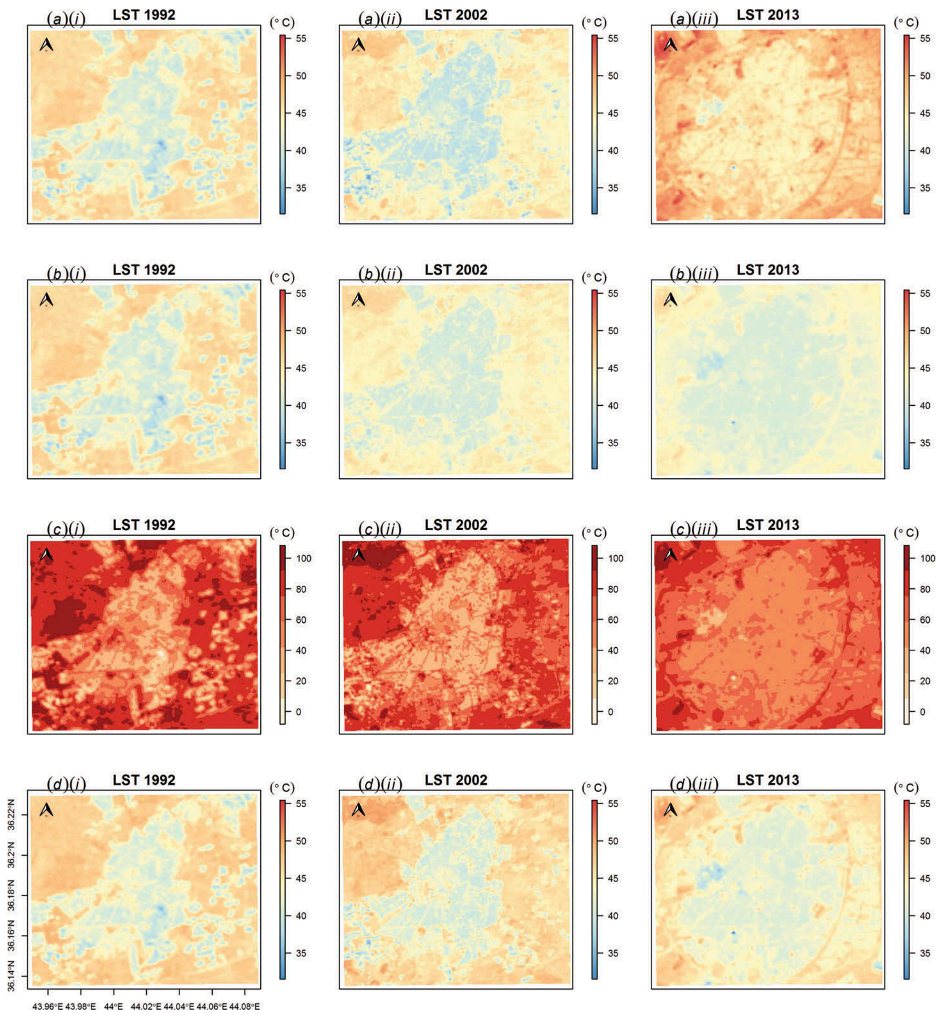

Figure 3. LST of Erbil based on the different methods of normalizing Landsat images. (*a*) without normalization, (*b*) LST in rescaling images to the same minimum and maximum in 1992, (*c*) NLST method, and (*d*) normalized based on NRS. The purpose of different scale of c method is to show how the output of the method looks like.

Table 1. Mean, SD, variance and Δ LST in degree Celsius for different method from Landsat images.

Methods	Mean LST 1992	SD mean LST	Variance LST 1992	Mean LST 2002	SD mean LST	Variance LST 2002	Mean LST 2013	SD mean LST	Variance LST 2013	ΔLST (1992, 2002)	ΔLST (1992, 2013)
A*	45.01	2.28	5.18	43.84	1.85	3.43	46.92	1.72	2.95	−1.17	1.91
B**	45.01	2.28	5.18	43.76	1.22	1.49	42.1	1.04	1.08	−0.95	−2.91
C***	73.28	15.67	245.5	68.93	11.62	134.94	60.74	8.12	65.91	−4.35	−12.54
D****	45.86	2.32	5.38	45.71	1.93	3.73	43.56	1.59	2.54	−0.15	−2.3

*Without normalization.
**LST in rescaling images to the same minimum and maximum in 1992.
***NLST method.
****Normalized based on NRS.

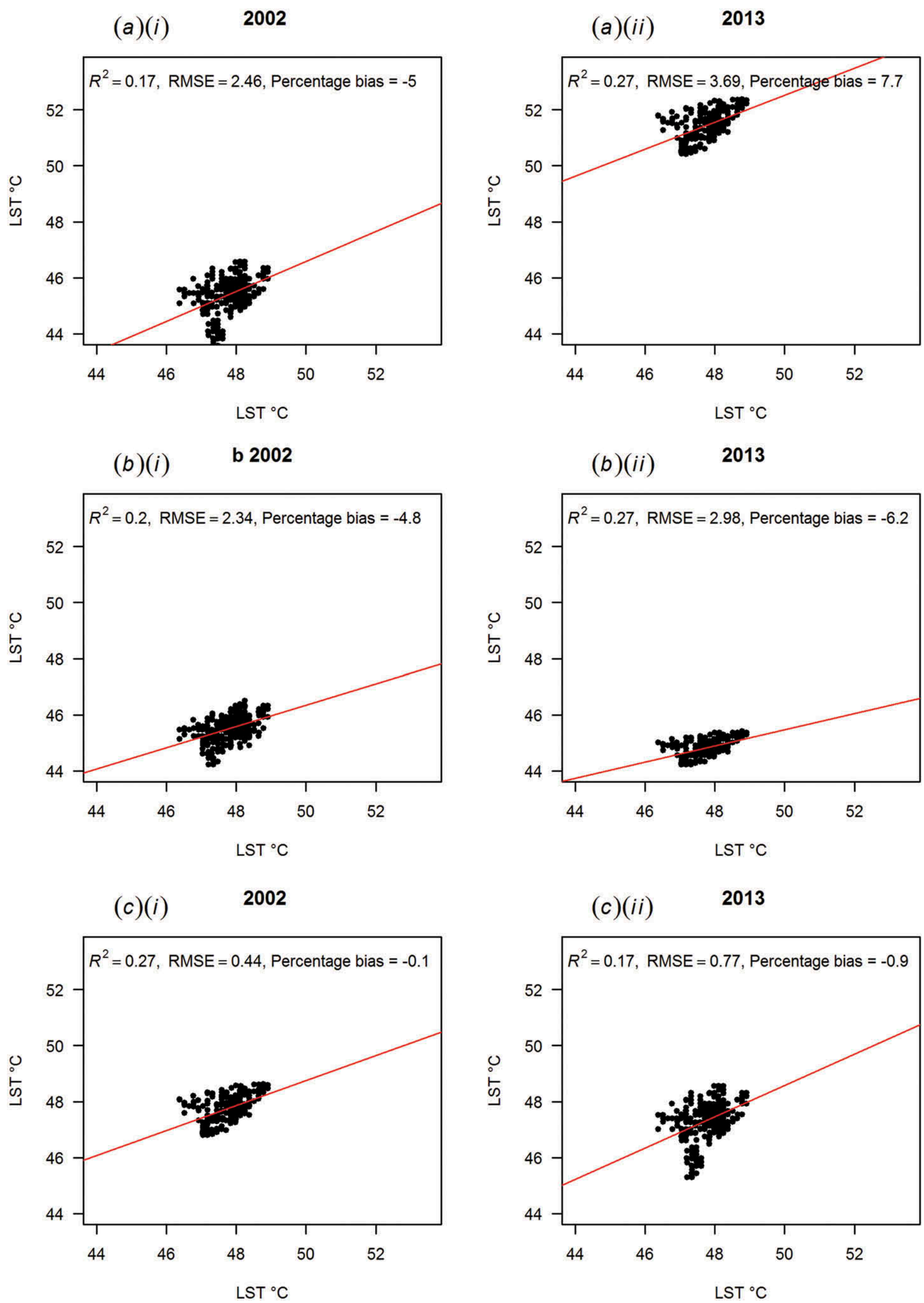

Figure 4. Compare LST of Erbil based on the different methods of normalizing Landsat images. (*a*) LST without normalization, (*b*) LST in rescaling images to the same minimum and maximum in 1992, and (*c*) normalized based on NRS. X data is LST 1992 of 330 pixels with the same land cover from 1992 to 2013.

3. Results

3.1. Normalized ratio scaled land surface temperature

In order to understand the characteristics of the new method, LST_{NRS} method (D) was compared with the non-normalized method (A), rescaling images to the same minimum and maximum in 1992 (B) and NLST (C). The results indicate that method (A), non-normalization, was unable to show real LST change of an area at different times. As illustrated in Figure 3, the method shows a decrease of LST by −1.08°C in 2002 and an increase in LST by 2.98°C in 2013 compared to 1992 while in reality LST decreased in both periods (Table 1, Figure 3). Result of method (C) produced a wide range of LST values, indicating a change of up of to −12.54°C (1992–2013). Figure 4 and Table 1 suggest that Methods B and D (LST_{NRS}) are capable of illustrating the change in LST at a specified location. For 2002 and 2013, respectively (Figure 4), RMSE (0.44, 0.77) and bias of LST_{NRS} (−0.1, −0.9) are relatively low. Therefore, results indicate that NRS is an appropriate technique for detecting temperature trends using remote-sensing data.

3.2. Effect of vegetated land on land surface temperature

Sami Abdul-Rahman Park is the biggest park in Erbil and the whole of Iraq. The location of the park is a former army base that was taken out of use in 1991. The period studied here starts in 1992 before the park was created. Most parts of this area were used for winter grain cultivation such as wheat and barley depending on precipitation seasonality; it was bare soil or cropland without vegetation during the dry season. In 1992, the mean NDVI of S.A. Park was 0.09 ± 0.01 and the mean of LST was 47.67 ± 0.73°C (Table 2, Figures 5 and 6).

In 2002, the park was partially vegetated and its NDVI increased slightly to 0.11 ± 0.08. This change led to a decrease in mean LST to 46.07 ± 2.65°C (a 1.6°C decrease). By 2013, the majority of the park had been converted to a green space and its mean NDVI increased to 0.32 ± 0.11, a 0.23 increase compared to 1992. In contrast, the mean LST of the park decreased to 40.38 ± 1.91°C. Compared to 1992, its LST decreased by 7.29°C. Consequently, a decreasing LST as a result of the increased vegetation coverage leads to the park appearing as a cool island between the other LULC classes in the city.

Table 2. Land surface temperature and NDVI in S.A. Park in 1992, 2002, and 2013.

Year	Min NDVI	Max NDVI	Mean NDVI	SD NDVI	Min LST (°C)	Max LST (°C)	Mean LST (°C)	SD LST (°C)
1992								
*	0.05	0.18	0.09	0.01	44.21	48.66	46.78	0.71
**					45.05	49.58	47.67	0.73
2002								
*	−0.05	0.47	0.11	0.08	39.89	46.15	43.92	1.46
**					39.30	49.70	46.07	2.65
2013								
*	−0.02	0.54	0.32	0.11	36.92	42.79	40.03	1.25
**					35.64	44.64	40.38	1.91
Change								
*	−0.07	+0.36	+0.23		−7.29	−5.87	−6.75	
**					−9.41	−4.94	−7.29	

*LST in rescaling images to the same minimum and maximum in 1992.
**LST in NRS technique.

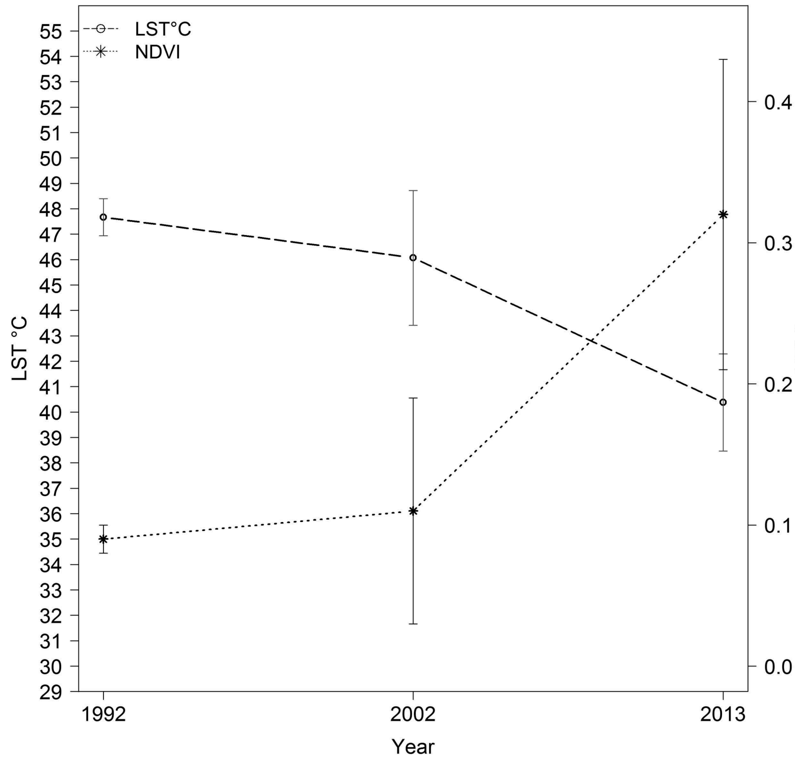

Figure 5. Mean LST_{NRS} and mean NDVI of S.A. Park from 1992 to 2013 from Landsat images.

3.3. *Decreasing LST of urbanized area from 1992 to 2013*

In 1992, the area of Erbil city was 38.1 km^2, the mean LST of the city was 44.56 ± 2.71°C, and the mean LST of this area before urbanization was 45.85 ± 2.31°C (Table 3 and Figure 7). The LST of this area was 1.29°C higher than the mean LST of the city. Rapid urbanisation led to 55.3 km^2 around the city being transformed mostly from 'bare soil' and 'field without vegetation' to 'urban' between 1992 and 2013. During the first decade of this period, the city only expanded by approximately 6.4 km^2. In the second decade, especially after 2003, the city expanded rapidly. In this period, after the political change, the government changed the investment law to help investment in the building sector. In 2013, the area of the city increased by 48.9 km^2 compared to 2002 (Table 4). In this year, the mean LST of the new urbanized area decreased to 43.57 ± 1.6°C indicating that from 1992 to 2013 the LST of the new urbanized area decreased by 2.28°C. This result shows that the LULC change from barren soil to urban areas in cities located in semi-arid climates can lead to a decrease in daytime LST.

3.4. *Changes in LST for different types of LULC change*

The previous sections indicate a decrease of LST caused by vegetation and urbanization. Here, 10 pixels are selected as exemplars of different LULC changes to identify in more detail how LULC change affects LST in Erbil city as an example of cities in semi-arid

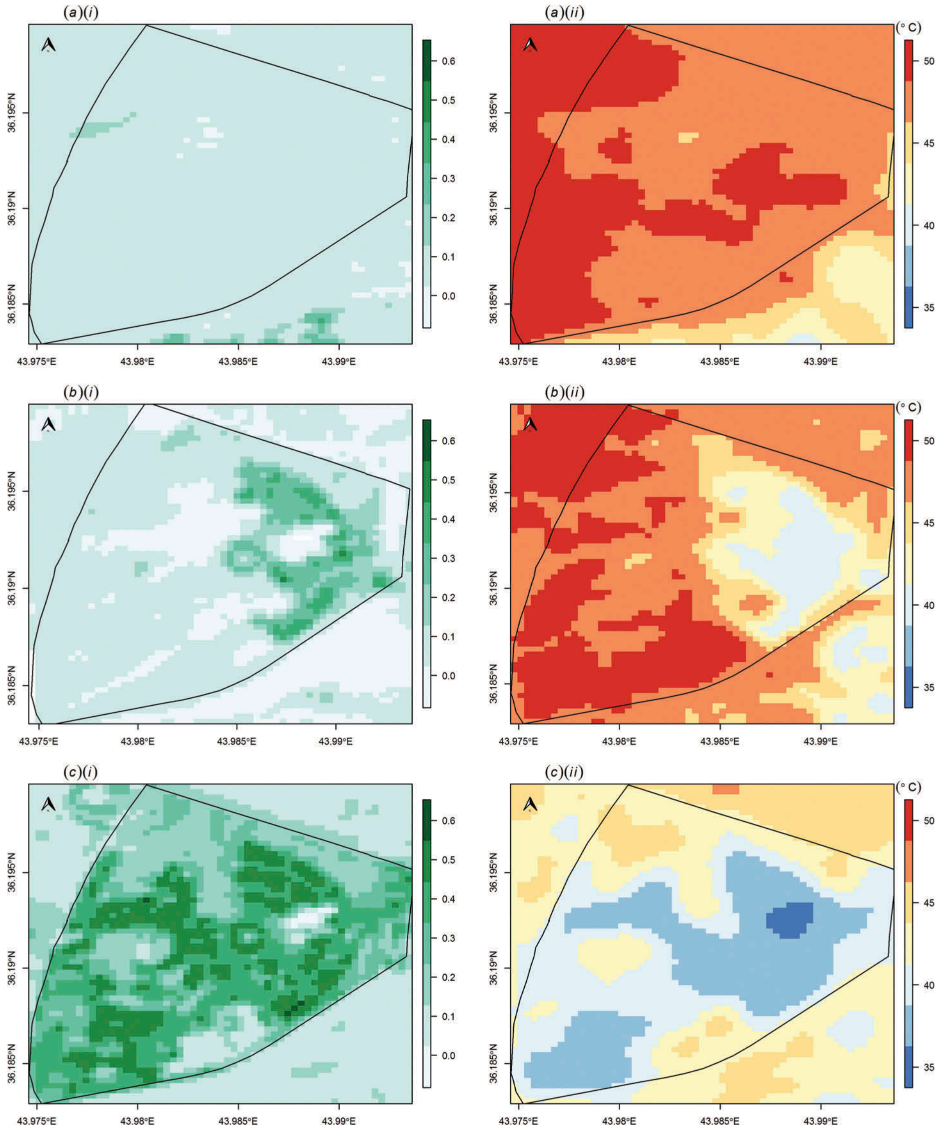

Figure 6. The change of NDVI and LST_{NRS} of S.A. Park from 1992 to 2013 from Landsat images. (*a*)(i) NDVI 1992, (*a*)(ii) LST 1992. (*b*)(i) NDVI 2002, (*b*)(ii) LST 2002. (*c*)(i) NDVI 2013, (*c*)(ii) LST 2013.

climate. The first group of pixels in Table 5 (1–8) changed from bare land or fields without vegetation to buildings and other purposes in the residential area whilst pixel number 9 changed from green to bare soil and pixel number 10 changed from buildings to vegetation.

Pixel 1 was bare soil with LST = 47.67°C and in 2013 it became a part of an artificial lake (Lake 2) inside S.A. Park. This change leads to a significant decrease in LST (35.64°C), a drop of 12.03°C in 2013. Pixel 2 changed from bare soil with ISA = 0.61 to a built-up area of Erbil International Airport with ISA = 0.94. Its LST decreases slightly from 47.54°C in 1992 to 46.92°C in 2013 (Table 5).

Table 3. Change in LST of the area urbanized from 1992 to 2013.

Year	Min LST (°C)	Max LST (°C)	Mean LST (°C)	SD LST (°C)
1992				
*	36.38	48.89	45.01	2.28
**	37.06	49.82	45.85	2.31
2002				
*	37.15	46.50	43.76	1.22
**	34.25	50.23	45.69	1.94
2013				
*	36.92	46.04	42.10	1.04
**	35.64	49.65	43.57	1.6
Change				
*	+ 0.54	−2.85	−2.91	
**	−1.42	−0.17	−2.28	

*LST rescaled based on minimum and maximum.
**LST based on NRS method.

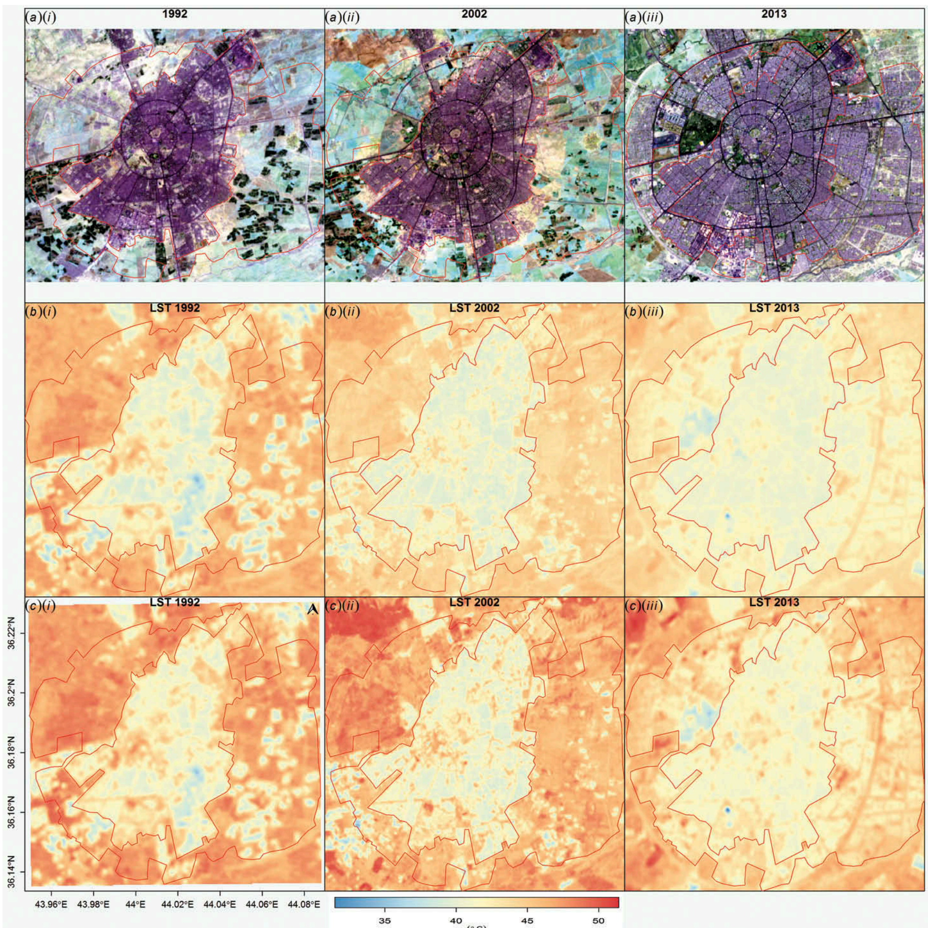

Figure 7. Decrease in LST in the area that was urbanized from 1992 to 2013. (*a*) bands 7, 6 and 4 as false colours from Landsat 8 (bands 7, 5 and 3 Landsat 5 and 7) showing urban areas in brown, vegetation in dark blue, water in black and barren land in sky blue and wheat colour. (*b*) LST rescaled with min and max, (*c*) LST from the NRS method. The red line is the boundary of the urbanized area.

Table 4. Urban expansion in the study area.

Year	Area (km^2)
1992	38.114
2002	44.461
2013	93.398
Urbanized	55.284

Table 5. Pixel samples of LULC change with LST_{NRS}, NDVI and ISA.

	Pixel 1	Pixel 2	Pixel 3	Pixel 4	Pixel5	Pixel 6	Pixel 7	Pixel 8	Pixel9	Pixel 10
(1992)										
LST_{NRS}	47.67	47.54	46.03	48.36	47.27	45.86	47.4	46.84	40.1	42.37
NDVI	−0.11	0.1	0.13	0.09	0.1	0.07	0.09	0.08	0.44	0.05
ISA		0.61	0.41	0.65	0.58					0.83
(2002)										
LST_{NRS}	40.91	50.23	44.91	47.49	49.45	46.76	42.28	40.2	42.26	42.53
NDVI	0.01	0.04	0.09	0.05	0.07	0.05	0.28	0.46	0.21	0.01
ISA		0.99	0.97	0.99	0.99					1.0
(2013)										
LST_{NRS}	35.64	46.92	42.27	44.52	43.98	40.67	38.02	38.38	45.94	41.41
NDVI	0.16	0.05	0.1	0.12	0.1	0.38	0.47	0.51	0.13	0.21
ISA		0.94	0.89	0.88	0.89					0.76

Pixel 1: bare to water, Pixel 2: bare to airport, Pixel 3: dry field to houses, Pixel 4: bare to western houses, Pixel 5: bare to asphalt parking lot, Pixel 6: bare to mix grass-tree, Pixel 7: bare to tree, Pixel 8: bare to grass, Pixel 9: farm to bare soil, and Pixel 10: commercial to grass-water.

Pixel 3 changed from field without vegetation with ISA = 0.41 and LST = 46.03°C in 1992 to houses within flat roofs (in the Shadi district) with ISA = 0.89 and LST = 42.27°C in 2013. During these two decades, LST of this pixel decreased by 3.76°C as a result of the urban expansion. Pixel 4 changed from bare soil with ISA = 0.65 and LST = 48.36°C in 1992 to western style housing within pitched roofs (in Italian Village) with ISA = 0.88 and LST = 44.52°C in 2013. The transformation from bare soil to a residential area had the consequence of reducing LST by 3.84°C. This result shows that change from bare soil to urban built-up areas in cities located in the semi-arid climate can lead to a decrease in its daytime LST.

Asphalt parking lots have their own microclimate due to their albedo and thermal low conductivity. Impervious surfaces such as asphalt and concrete absorb, store, and reradiate more heat energy than vegetated surfaces (Celestian and Martin 2004). Pixel 5 was also bare soil in 1992 with ISA = 0.58 and LST = 48.36°C which was later transformed to an asphalt parking lot with ISA = 0.89 and LST = 44.52°C in 2013. During this period, its LST decreased by 3.29°C as a result of the LULC change.

Three pixels represent vegetation-related LULC change. Pixel 6 changed from bare soil with NDVI = 0.07 to a mixed pixel of tree and grass with NDVI = 0.38 and a reduction in LST from 45.86°C in 1992 to 40.67°C in 2013. Pixel 7 changed from bare soil with LST = 47.4°C in 1992 to tree cover with LST = 38.02°C in 2013, whilst pixel 8 was converted to grassland and increased its NDVI from 0.08 to 0.51 and decreased its LST from 46.84°C to 38.38°C over the same time. Transforming bare soil to dense tree cover decreased the LST by 9.38°C whilst changing bare soil to grassland in S.A. Park led to a decrease in LST by 8.46°C.

In contrast, pixel 9 changed from farmland vegetation to bare soil. Its LST was 40.1°C in 1992 and increased to 42.26°C in 2002 and 45.94°C in 2013. Pixel 10 represents a change from commercial buildings to a mixed pixel of ornamental grasses and a water fountain. Its LST was 42.37°C in 1992 which slightly decreased to 41.41°C in 2013.

4. Discussion

To show the changes in LST for urbanized and vegetated areas, the NRS method was proposed and the results showed that it is an appropriate technique to examine temperature change from remote-sensing data. Vegetation cover cools the temperature through transpiration, creating a shadow and retaining rainwater. LULC change from green areas such as forest and irrigated agriculture to built-up urban cover types leads to an increase in air temperature and LST, as other authors have shown (Weng 2001; Amiri et al. 2009; Grossman-Clarke et al. 2010). In contrast, increasing the fractional cover of green spaces in the city is an active strategy for reducing temperatures. Our analysis of the effects of establishing S.A. Park in Erbil on the local LST matched similar findings by other researchers related to vegetated areas in different environments. According to our analysis, the relationship between NDVI and LST during the period was an inverse relationship. Consequently, the surface of the park showed a cooling of 7.29°C in LST.

Furthermore, expanding waterbodies such as artificial lakes and rivers in urban areas leads to a decreasing local LST. Our analysis of pixel 1 (Section 3.4) agree with Tonkaz and Cetin's (2007) research on the South Eastern Anatolian Project (GAP) area in Turkey. Increasing water and vegetation are good procedures to reduce temperatures and the night-time SUHI in Erbil.

From 1992 to 2013, 55.3 km^2 were urbanized around Erbil city, especially in the last decade when the area of the city increased more than twofold. Consequently, the mean LST of these new urbanized areas decreased by 2.28°C. In the published literature, some authors point out that urbanized areas cool the surface in comparison to their rural surroundings, for instance, by reducing the incident solar radiation (Trenberth 2004), through higher thermal inertia in the built-up area, by casting shadows from high-rise buildings and because of the moisture difference between the urban and rural areas (Buyantuyev and Wu 2010). In some cities, convection is more efficient compared to their rural surroundings, and cooling from evaporation from trees and lawns planted in the city occurs (Zhao et al. 2014). The soil moisture in Erbil is the main factor causing the high SUCI value in the study area compared to the surrounding 10 km of rural area (Rasul, Balzter, and Smith 2015).

LULC change in the 55.3 km^2 urbanized area of the rapidly growing city of Erbil has led to a transformation of the surface to materials that reduce sunlight more than natural soil and increasing green spaces, waterbodies, and soil moisture content. To control the local LST in Erbil and make living more comfortable, city planners of the Erbil Master Plan should be using light-coloured materials for new buildings. Another technique is to direct the future expansion of the city to areas covered by bare soil and rocks that are not suitable for agriculture in order to control the temperature of the city and not lose green land.

5. Conclusions

This research has assessed and quantified the decreasing daytime LST in Erbil and the influence of rapid urban expansion on urban heat/cool island effect over a 20 year period. LULC change across this period is also established using pixel samples. The current study proposes the application of the NRS to adjust the temperature of images acquired at different date to the same range.

By 2013, the majority of the S.A. Park had been converted to a greenspace and its mean NDVI increased by 0.23 compared to 1992. In contrast, the mean LST of the park decreased by 7.29°C. During the same period, 55.3 km^2 around the city was transformed principally from 'bare soil' and 'field without vegetation' to 'urban'. The mean LST of the new urbanized area decreased by 2.28°C. This result demonstrates that the LULC change from barren soil to urban areas in cities located in a semi-arid climate can cause a decrease in daytime LST. At the pixel level, we concluded that the mean daytime LST of the urbanized zone decreased as a result of transformation from bare soil and soil without vegetation to waterbody, vegetation, building, and asphalt parking. In contrast, daytime LST increased due to a change from vegetation to bare soil by 5.84°C. In addition, this study demonstrates that the NRS method, which is proposed in this research, is appropriate for detecting temperature trends from urbanization using remote-sensing data. The importance of the NRS technique is to normalize the value of each pixel-based ratio to make the LST images from different times comparable, while at the same time maintaining the original values. Further research is required to confirm the results of this research regarding the capability of NRS for LST change detection.

The results of Rasul, Balzter, and Smith (2015) indicated that bare soil rural areas exhibited higher LST compared to densely built-up areas and the city, which act as surface cool islands during the daytime. The current research extends these earlier results by quantifying the reduction of the daytime LST as a consequence of urban expansion. It is important to assess different pixel samples of LULC change to demonstrate the influence of this variation in more detail and to illustrate what type of LULC changes contribute to mitigation of the night-time SUHI and make the daytime SUCI more active in the summer time.

This article is limited to changes of the SUHI/SUCI effect in the urban expansion zone in a semi-arid city during the dry season (summer). The reader should bear in mind that this research mainly relied on remotely sensed data while field measured data were utilized in the selection of land use classes and pixels. The data used in this research is limited to the morning time around 7 and 8 o'clock (the pass time of Landsat 4, 5, 7, and 8 over the study area). Temporal variations of SUHI/SUCI including seasonal and diurnal variation in Erbil have been assessed by researchers (Rasul, Balzter, and Smith 2016).

The result from this research has indicated a decrease in LST in vegetated areas but the variation in cooling potential between tree types remains unquantified. Moreover, the area needs the development of more research on techniques to reduce LST in rural areas surrounding the city such as the effect of irrigated vegetation in the dry season and increased soil moisture through artificial streams. The application of higher-resolution remote-sensing data is particularly valuable for facilitating studies on UHI characteristics.

Acknowledgments

The authors would like to thank the HCDP Scholarship Programme and Soran University for their financial support of this research. Many thanks go to the USGS, for providing the research with

Landsat images of the study area. We would also like to acknowledge the R Development Core Team for continuously improving and supporting this freely available software. H. Balzter was supported by the Royal Society Wolfson Research Merit Award, 2011/R3 and the NERC National Centre for Earth Observation.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

The authors would like to thank the HCDP Scholarship Programme and Soran University for their financial support of this research. H. Balzter was supported by the Royal Society Wolfson Research Merit Award, 2011/R3, and the NERC National Centre for Earth Observation.

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