Urban Heat Island Analysis in Dar es Salaam, Tanzania

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Abstract

An urban heat island (UHI) occurs when a city center is substantially hotter compared to neighbouring countryside. In this study, UHI intensity is assessed using Landsat 8 data in Dar es Salaam, Tanzania. An ERDAS Imagine algorithm is used to acquire the land surface temperature (LST) from Landsat 8 data. The association of LST and normalized difference vegetation index (NDVI) as well as the normalized difference build-up index (NDBI) is also assessed. The outcome of the study shows that the influence of UHI in Dar es Salaam is situated mainly in built-up areas compared to the surrounding rural areas. The negative association of LST and NDVI shows that greenery can reduce the development of a UHI, while the positive association of LST and NDBI indicate that built-up areas can enhance the formation of UHI.

Keywords: NDVI; UHI; NDBI; Landsat 8

1. Introduction

Dar es Salaam is the main commercial city of Tanzania and a gateway for many landlocked countries (TIC, 2017). As Tanzania progresses to be one of the best performing and most stable economies in Africa, with the improvement and increase in trades, industries and farming, likewise, Dar es Salaam city is rapidly expanding. These developments will increase heat energy in the atmosphere and affect the weather, including rainfall (Kabanda, 2018). The development and enlargement of city centres necessitate the building of new roads, buildings, and other structures to accommodate the increasing population; this however results in the alteration of the natural land cover. The consequence of this is that roads and rooftops absorb the sun's heat and resulting in land surface temperatures (LST) of urban areas to be 10 - 20°C greater than the atmospheric temperatures (Golden; 2004; Taha *et al*, 1992). This phenomenon is called the urban heat island (UHI) effect and raises urban temperatures above those of adjacent rural areas. The increase in urban temperatures can have an effect on the manifestation of climatological events like greater rainfall, and heat waves, affects environmental quality, and possibly contributing to global warming (Kikegawa *et al*, 2006).

LST studies generally detect UHIs by measurements of air temperatures or surface temperatures (Streutker, 2002). Remote sensing allows the ability to detect surface temperature and a number of UHI studies have made use of it (Kaplan *et al*, 2018). Streutker, 2002 and Tomlinson *et al*, (2012) used MODIS data to study UHI by satellite image using LST measurement, while others (Ouaidrari *et al*, 2002 and Frey, 2016) used 1-km AVHRR data to estimate LST. Weng, 2012 and Chen *et al*

(2006) used Landsat TM and ETM to study UHI. Landsat is a medium resolution sensor and is appropriate for studying smaller regions. Owen *et al*, (1998) analysed the effects of different land cover types on LST, and this resulted in other studies such as Chen *et al*, (2006) and Weng *et al*, (2004) to particularly focus on the association between vegetation abundance and LST. Gombe *et al*, (2017) in a recent study of UHI over Dar es Salaam, used a MODIS time series, Normalized Difference Vegetation Index (NDVI) and LST to conduct a seasonal trend and principal component analysis (PCA) to delineate Dar es Salaam into two zones – rural areas and city centre. The NDVI is normally applied for vegetation detection while the Normalized Difference Built-up Index (NDBI) is used to detect urban areas (Kaplan *et al*, 2018). Identifying the association of NDVI and LST is important in understanding the urban climatology. UHI intensity, the correlation between LST, NDVI, and NDBI, are analysed for Dar es Salaam region in this study.

2. Study area

Dar es Salaam (Figure 1) covers an extent of 1624 sq. km and has 4.4 million people as of 2012. It is one of the rapidly urbanising regions in Africa (Roy *et al*, 2018). Accelerating population growth has also caused extensive spatial expansion through urban sprawl (Andreasen, 2013). This population growth increases the demand for built infrastructure. An enormous land cover conversion is ongoing in Dar es Salaam (Kironde, 2006), with no strategies in place to establish adequate urban green spaces (Roy *et al*, 2018).

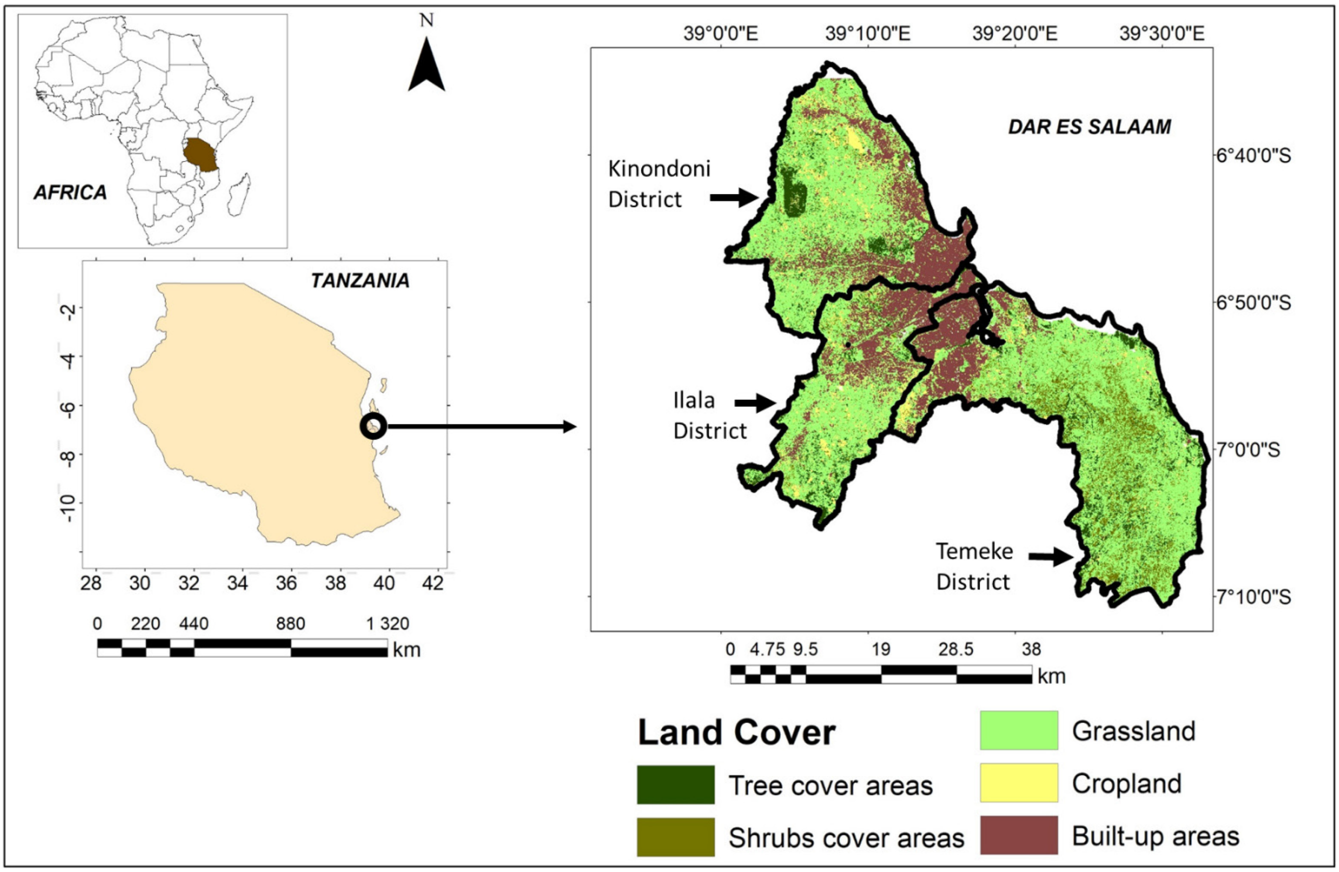

Figure 1. Study Area: the city of Dar es Salaam.

Dare es Salaam has tropical conditions, characterised by warm and humid weather during much of the year due to its proximity to the warm western Indian Ocean. Annual rainfall is nearly 1,100 mm and there are two rainy seasons "the long rains" (March to May) – known locally as Masika – and "the short rains" (October to December), known as Vuli (Kabanda, 2018), as indicated in Figure 2.

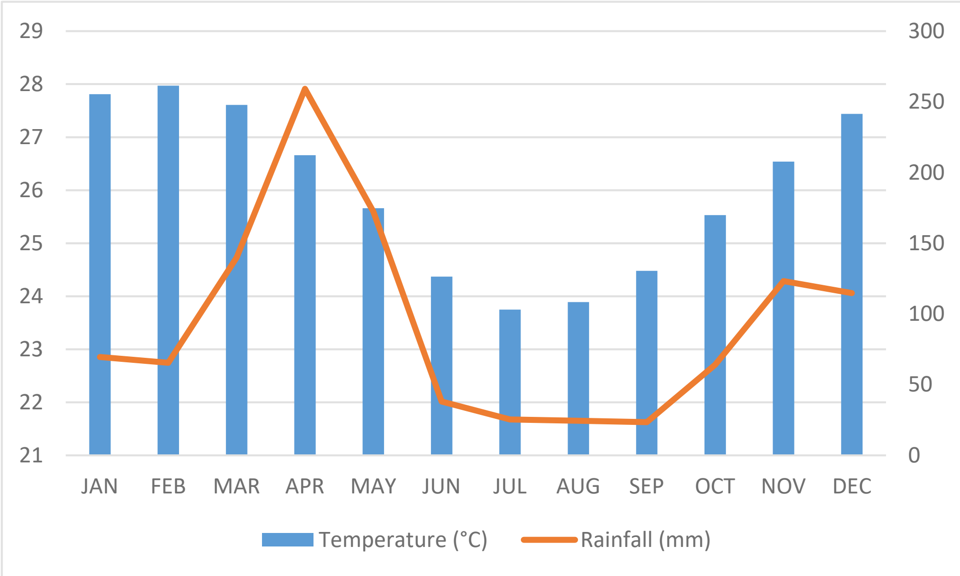

Figure 2. Monthly rainfall and temperature for Dar es Salaam

Mean yearly temperature is 25.9°C, with monthly temperatures > 25°C in most of the year except for June to September when temperature are < 25°C as illustrated in Figure 2.

3. Methodology

To study the UHI in Dar es Salaam (Figure 1), Landsat 8 satellite image (Path 166 and Row 65) for June 21 2017 was acquired from the United States Geological Survey. Table 1 provides metadata of the bands such as thermal constant, radiance multi band value etc., which used for calculation of LST. Air temperature data from weather station 638940 (Latitude: -6.86; Longitude: 39.2) of the day the satellite image was taken was 24.2°C for average temperature and 30.5°C for maximum temperature. June was chosen because it is the first month of the year when Dar es Salaam has clear skies; other months (Jan – May) are seriously affected by clouds. In addition, June is when the mean monthly temperatures start to drop.

Table 1. Metadata values used for LST calculation

RADIANCE_ADD_BAND_10	0.10000
RADIANCE_MULT_BAND_10	0.0003342
Landsat 8 Band 10 K_1 Constant	774.8853
Landsat 8 Band 10 K_2 Constant	1321.0789

3.1. Retrieving LST

Two steps are taken in retrieving LST using the algorithm developed by Avdan and Jovanovska (2016) from Landsat 8 data. Firstly, the digital number (DN) values are transformed to spectral radiance by means of the spectral radiance scaling technique as expressed in equation (1).

$$L\lambda = ((LMAX - LMIN)/(QCALMAX - QCALMIN)) * (DN - QCALMIN) + LMIN \quad (1)$$

where:

$L\lambda$ = is the cell value as radiance, LMAX = spectral radiance scales to QCALMAX, LMIN = spectral radiance scales to QCALMIN, QCALMAX= the maximum quantized calibrated pixel value (typically = 255), QCALMIN = the minimum quantized calibrated pixel value (typically = 1)

Secondly to convert radiance to kelvin using equation (2)

$$T_B = K_2/\ln((K_1)/L\lambda+1) - 273.15 \quad (2)$$

where:

T_B is the effective at-satellite temperature (°C), K_1 and K_2 are calibration constants, $L\lambda$ is the spectral radiance from equation (1).

3.2. NDVI calculation

NDVI is measured using the pixel values from the near infra-red (IR) band and pixel values from the red (R) band to measure healthy vegetation.

$$NDVI = ((IR - R) / (IR + R) \quad (3)$$

3.3. NDBI calculation

According to Zha *et al,* (2003), NDBI is measured using the middle infra-red (MIR) and NIR (equation 4).

$$NDBI = ((MIR - NIR) / (MIR + NIR) \quad (4)$$

3.4. Correlation between LST and NDVI, and LST and NDBI

The correlation coefficient between LST and NDVI, and LST and NDBI is measured using the Band Collection Statistics tool in ArcGIS that produces statistics for the multivariate analysis of a set of raster bands. The correlation between two layers (Equation 5) is the ratio of the covariance between the two layers divided by the product of their standard deviations (Peters, 2001).

$$Corr_{ij} = \frac{Cov_{ij}}{\delta_i \delta_j} \quad (5)$$

3.5. UHI intensity

The UHI intensity is calculated by the relative LST as Equation (6) (Table 2) (Weng, 2004; Weng *et al*., 2012):

$$Tr = \frac{Ts - \overline{Ts}}{\overline{Ts}} \quad (6)$$

where:

Tr is the relative LST, Ts is the LST (°C), $\overline{Ts}$ is the mean LST (°C).

Table 2. The classification of UHI intensity.

Relative LST	UHI Intensity
< 0	non-UHI
≥ 0	UHI

4. Results

4.1. NDVI

Landsat 8 data for the date 21-06-2017 (path/row: 166/65) is used for the present study. After transformation of DN values to spectral radiances, NDVI index of each dataset is calculated (Figure 3). The NDVI index outputs values between −1 to +1. Low values (0.1 and below) indicate barren rock, moderate values (0.2 – 0.3) represent shrubs and grassland while high values (0.6 and above) represent forest.

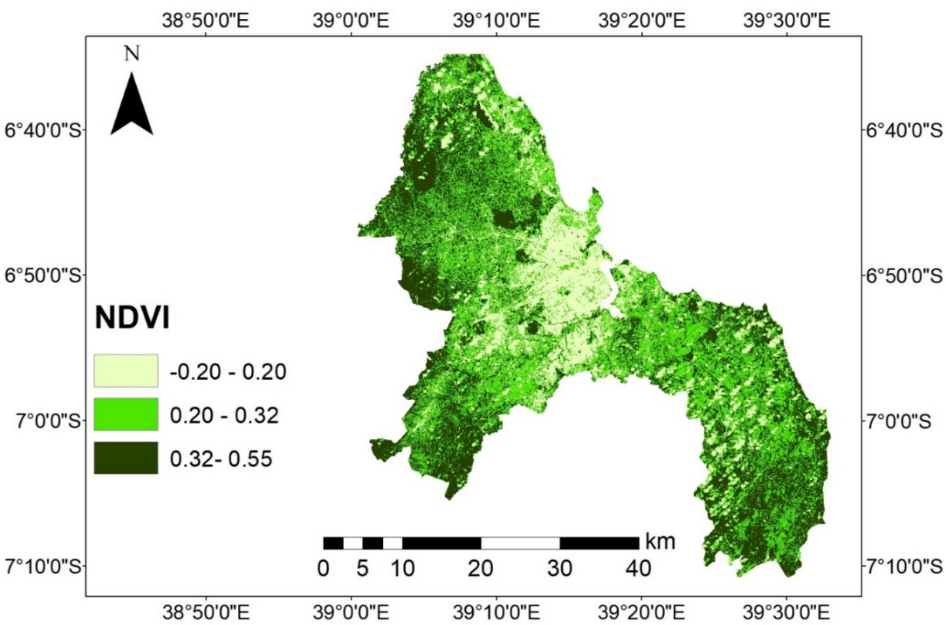

Figure 3. NDVI map for 21-06-2018.

4.2. LST

The land surface temperature analysis (Figure 4) represents the lowest and highest temperatures in Dar es Salaam for 21-06-2017. It is found that mean surface temperature (Mean ± S.D.) for Dar es Salaam region is 25.28°C ± 1.4, while the minimum temperature is 15°C and the maximum 31°C.

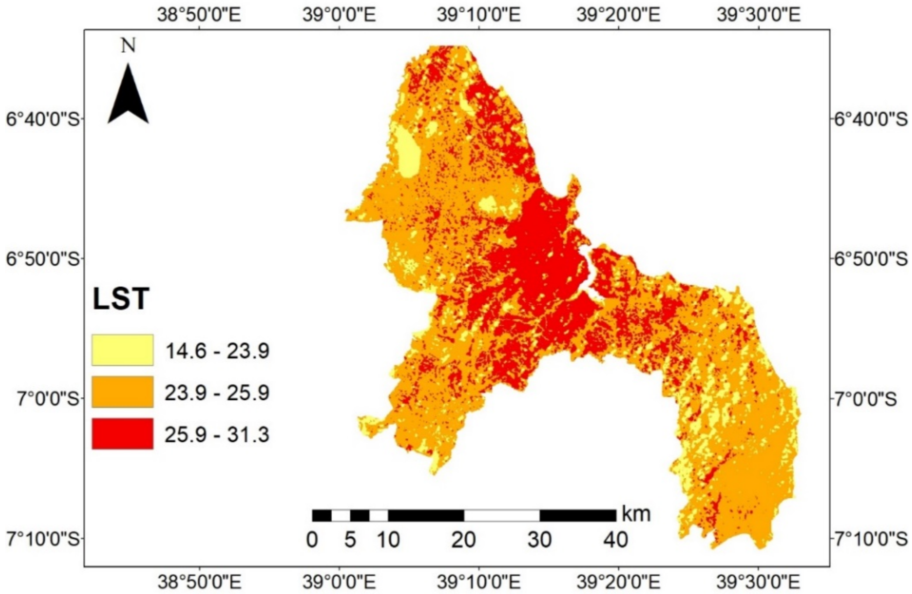

Figure 4: LSTs derived from Landsat 8 imagery for 21-06-2018.

4.3. NDBI

NDVI shows the vegetation coverage, while NDBI is useful in indicating urban areas and are both linked to surface temperature (Ahmed, 2018). NDBI represents one of the major land cover types, that is, built-up lands, which could describe the spatial pattern of urban impervious surfaces (buildings, roads, parking, and other paved surfaces). NDBI index (Figure 5) has been analysed to explore the effect of vegetation cover and the urban area on UHI.

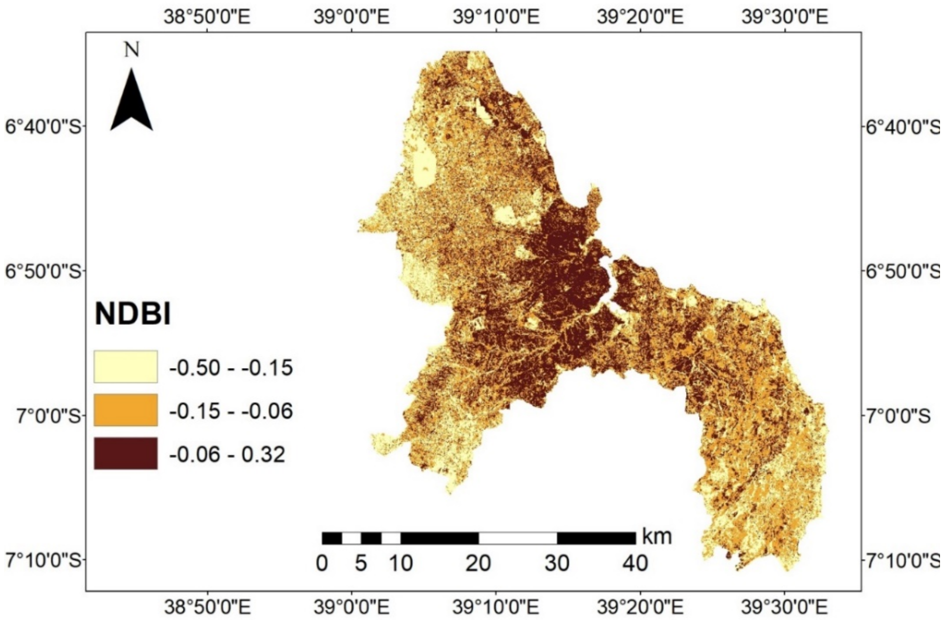

Figure 5: The NDBI map for 21-06-2018.

4.4. Correlation between LST and NDVI, and LST and NDBI

Correlation measurement between LST and NDVI on one hand, and LST and NDBI on the other, are analysed to observe their influence on UHI. NDVI has a negative correlation with LST whereas NDBI displays positive correlation with LST. It is observed that the cooling effect of vegetation on LST is stronger A negative slope trends with Pearson correlation -0.3 was observed during the day. This indicates that more cooling is possibly arising in the outer areas of the city via active evapotranspiration. Table 3 shows the outcome of statistical analysis.

Table 3: Results of the correlation

LST and NDVI	LST and NDBI
-0.35800	0.51853

4.5. UHI intensity

Figure 5 shows that temperatures are markedly higher in the UHI, with LST ranging from 15°C – 23°C in the non-UHI areas, and from 23°C – 31°C in the UHI. This difference in temperature between UHI and non-UHI is known as UHI intensity (Guha *et al*, 2018). The magnitude of UHI intensity in the urban areas of Dar es Salaam (Figure 6) is higher than the surrounding areas. The results imply that higher temperatures in urban areas may increase demands for air conditioning, generate more pollution and modify precipitation patterns (Zeng, 2018).

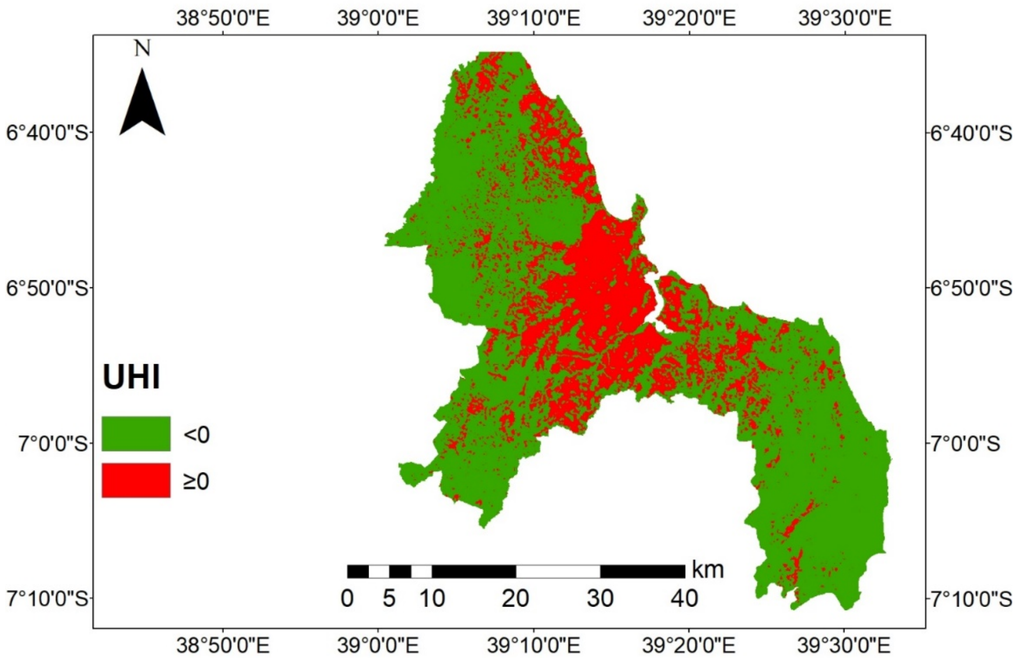

Figure 6: The UHI intensity distribution for 21-06-2018.

5. Discussion

The association of land cover (particularly NDVI and NDBI) and UHI was studied in Dar es Salaam. The outcomes indicate that the influence of UHI in Dar es Salaam is situated in the city centre. The mean LST is 27°C in the UHI areas and 19°C in the non-UHI, while low NDVI at the city centre is observed compared to the outer part. The negative correlation between LST and NDVI shows that the vegetated areas decrease the intensity of UHI, whereas the positive correlation between LST and NDBI indicates that the built-up land can enhance the influence of UHI in the study area. The results are in a strong agreement with the relevant published studies on UHI (Gombe *et al*, 2017)), which used various study approaches. Generally, built-up areas show lower NDVI values, leading to higher LST. The NDVI map (Figure 4), shows that the values range from -0.2 to 0.2 in the city centre, and from 0.2 to 0.5 in the neighbouring areas.

6. Conclusion

In this study, Landsat 8 OLI and TIRS data were used to examine the UHI intensity effect in Dar es Salaam and to understand the correlation between LST with NDVI and NDBI. The results provide empirical evidence of UHI in Dr es Salaam. It is observed that the temperature variance within the built-up areas is considerably different from the temperature variance within the non-built-up areas (in other words that temperature fluctuates more in the built-up areas). This study has revealed that the built-up areas have a significant impact on radiant surface temperature and increase urban heat in the study area. LST has a pronounced negative correlation (−0.35) with NDVI; and perfect positive correlation (0.51) with NDBI. The abundance of vegetation significantly affects LST while the lack of it results in an increase in temperature in the built-up areas and also the intensity of the UHI. The UHI intensity is estimated by the relative LST and indicates that the amount of UHI in the built-up area of Dar es Salaam is higher than the surrounding areas. The results offer remote sensing guidance on UHI conditions relative to the built areas and areas covered by vegetation over Dar es Salaam Region.

As the World Urbanisation Report of 2018 points out, more people live in urban areas than in rural areas, with 55% of the world's population living in urban areas, a proportion that is expected to increase to 68% by 2050. With Tanzania projected to become a middle-income economy by 2025 and continuing rapid urbanisation, this study recommends planting trees and other vegetation along the roadside. In addition, it also recommends urban planning to preserve some green spaces as the city expands to reduce heat island effect by providing both direct and ambient cooling effects.

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