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Urban Green Areas to Mitigate Urban Heat Island Effect: The Case of Addis Ababa, Ethiopia

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ABSTRACT

Land surface temperature (LST) changes have been studied using different parameters and data sets to assess the heat effects in urban areas. Depending on landsat data, single window algorithm and split window algorithm are applied to generate LST output to assess the influence of urban green areas. During the present study, both these methods were used to retrieve LST from landsat TM, ETM+ and landsat 8 images. Correlation between LST and NDVI revealed that the latter is a good indicator of the former and that over 76% LST variability is due to randomly scattered distribution of the vegetation. The four base years, 1985, 1995, 2006 and 2015 showed a gradual increase in maximum LST as well as its expanse, but for a slight decrease in 1995. Out of the total area of 526.47 km^2, very low (<17°C) or low (17–21°C) to moderate (22–26°C) LST prevailed in 34.90% (183.71 km^2) of the area, while high (27–31°C) or very high (>31°C) temperatures existed in 65.10% (342.76 km^2) of the area in 1985. Subsequently, though very low, low and moderate temperature classes increased through 1995, 2006 and 2015, high and very high temperature classes became dominant in expanse. The R^2 value between NDBI and LST was direct and positive. The higher the NDBI value, the higher was the LST. Temperature measured in the selected Public Parks compared to the surroundings disclosed up to 5° difference, indicating that Urban Public Parks play a vital role in mitigating urban heat island effects.

Key Words: Land Surface Temperature; NDVI; NDBI; Urban Public Parks; Urban Heat Island.

INTRODUCTION

Urban green spaces including parks contribute to mitigate imparts of urbanization over a short period of time. Land cover is an important component of urban environment, which provides ecosystem services (Bradley 1995, Lütz and Bastian 2002). Earth's surface temperature is a result of the balance between incoming solar energy and outgoing radiation energy (Ries 2002, Baccini et al. 2008, CRGE 2011, Roja et al. 2017). Like all other physical objects, earth reacts to any increase in the incoming energy by warming up. The warmer the earth gets, the more the energy it radiates out. Earth has been experiencing a warmer atmosphere since the pre-Industrial era and its average surface temperature rose by 0.89% during 1902 and 2012 (IPCC 2014). Climate change is impacting many communities and disrupting sustainable development right from food security to economic growth of several countries. Climate change is mainly caused by greenhouse gases that retain radiating energy in the atmosphere (Frumkin 2001, 2006, Velarde et al. 2007, Rajeshwari and Mani 2014). This phenomenon is particularly accelerated by the increase of gases resulting from human population explosion and resulted development process. Methane and Carbon dioxide contributed through human activities are the primary greenhouse gases in Ethiopia which account for 52% and 26%, respectively, of the total emissions equaling to 0.3% of the global releases (MEF 2015). As development continues in the Ethiopian capital city,

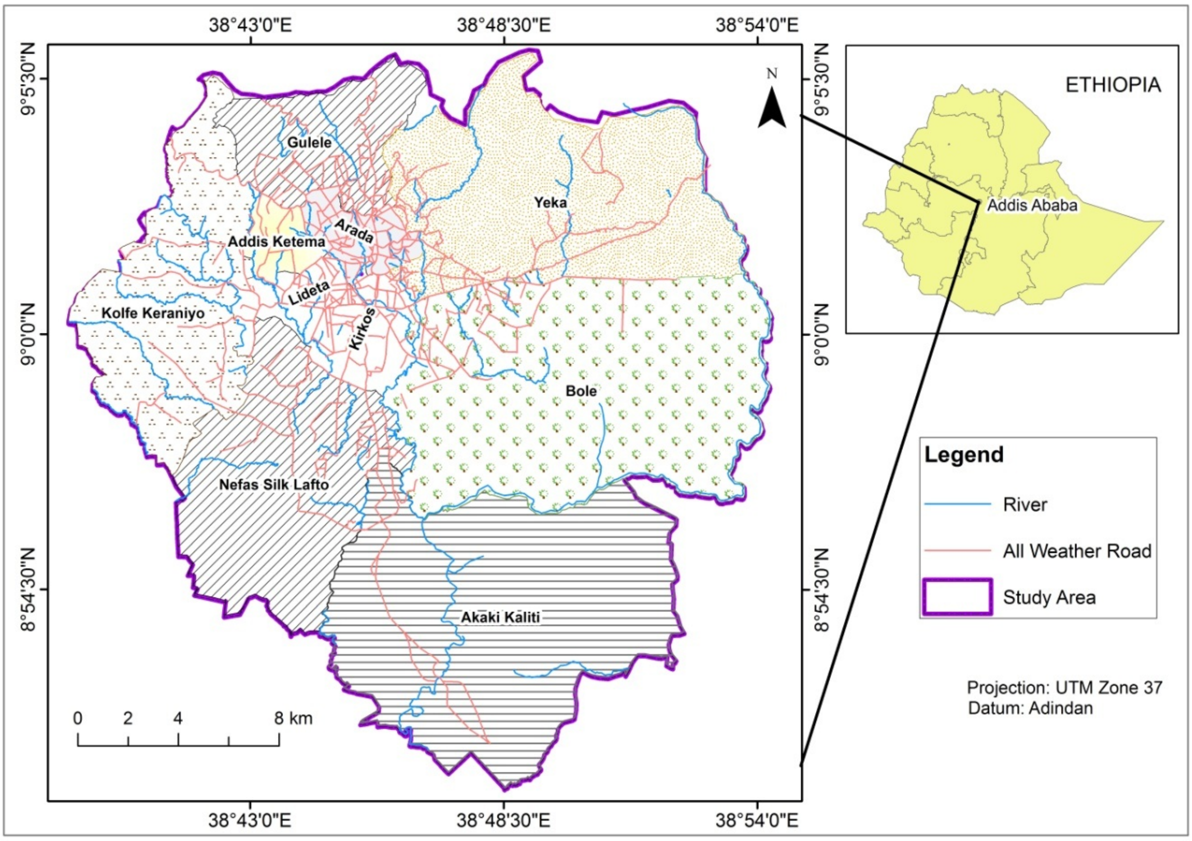

Figure 1. Map of the study area.

Addis Ababa, natural habitats are being converted to non-vegetated covers, which results in the development of urban heat island (UHI).

Green spaces are defined as partly or completely vegetated places such as parks, community gardens, school yards, cemeteries and picnic areas accessible to the public (USEPA 2008, AACBPCDAA 2015). The warmed up atmospheric condition of urban vicinities relative to the rural surroundings is termed as Urban Heat Island (UHI) (Shahmohamadi et al. 2011). Roads, business houses, residential buildings and other constructions reduce urban vegetative cover (Siti et al. 2013). Heat absorbing radiating roofs, concrete structures, payments and other impervious surfaces in urban areas cause urban heat island effect (Voogt and Oke 2003). Geographic information system and Remote Sensing technologies are widely used in analyzing land surface temperature, identifying green spaces, determining the extent of green cover and processing of meteorological data to generate valuable information required for effective decision making.

Green areas provide clean air to the public, clean environment, improve ground water holding, promote biodiversity, reduce heat during dry seasons and offer societal services for the well-being of urban dwellers (Bell et al. 2008, Maller et al. 2002, Chiesura 2004, Tzoulas et al. 2007, Roja et al. 2017). Addis Ababa, the capital city of Ethiopia, located in semiarid zone is devoid of enough natural recreational centers. Functional public parks in Addis Ababa spread over 957,650 m^2, which is insignificant, having only an extent of 0.3 m^2 per head (Yeshitla 2013, AACBPCDAA 2015). In this context, the impact of public parks in mitigating Urban Heat Island Effect in Addis Ababa is addressed to reveal the cooling effect of the sampled parks in the city utilizing remote sensing and GIS technologies.

STUDY AREA

Addis Ababa city is extended to an area of 526.92 km^2 lying between 38°39 03″E–38°54 19″ E and 8°50 10″N–9°06 01″ N at elevations ranging from +2015 m to +3152 m asl. It is bounded on the north by Entoto

Mountain, east by Yerer Mountain, south by Wechecha Mountain (Figure 1). The population to the city is 3.352 million (CSA 2015). Being a highland city, Addis Ababa experiences rainfall varying from 7 mm in boreal winter (December–February) to 290 mm in boreal summer (July–August). Average monthly temperature ranges from 10ºC to 20ºC.

Land-cover and Public Parks in Addis Ababa

Main land-cover in the study area comprises of farmland, grasslands, woodlands, and shrub/bush lands. Farmlands are with trees of species such as *Acacia albida*, *Cordia african* and of *Croton* sp. *Eucalyptus camendulensis* is seen in homesteads. Depending on the landscape and topography of the watershed, different types of indigenous vegetation exist in the area. The woodlands consist of evergreen and semi–evergreen bushes, small trees and occasional by large trees. Indigenous trees are common along the ridges, of rivers and protected areas. Nineteen public parks covering a total area of 931, 086 m^2 are present in Addis Ababa city (Figure 2). Out of these, 13 parks (68.42%) are committed to give recreational services to the public, whereas the other six parks are not able to give the desired services over due to re-development and re-assignment. Among the 13 functional parks, eight are randomly chosen for the present study (Table 1).

Table 1. Geographical extent of the sampled parks in Addis Ababa City.

Park	Location (Sub-city)	Area (m^2)	Area (%)
Africa	Kirkos	45,707	14.12
Ambassador	Arada	9,393	2.90
Bihere Tsige	Nefas Silk Lafto	142,726	44.10
Gedame Eyesus	Addis Ketema	4,128	1.28
Gola	Lideta	9,625	2.97
Kolfe	Kolfe Keraniyo	20,000	6.18
Sheger	Gulele	70,000	21.63
Yeka	Yeka	22,081	6.82
	Total area	323,660	100

METHODS

Data were acquired from 1985 to 2015 approximately at 10 yr intervals, considering 1985, 1995, 2006 and 2015

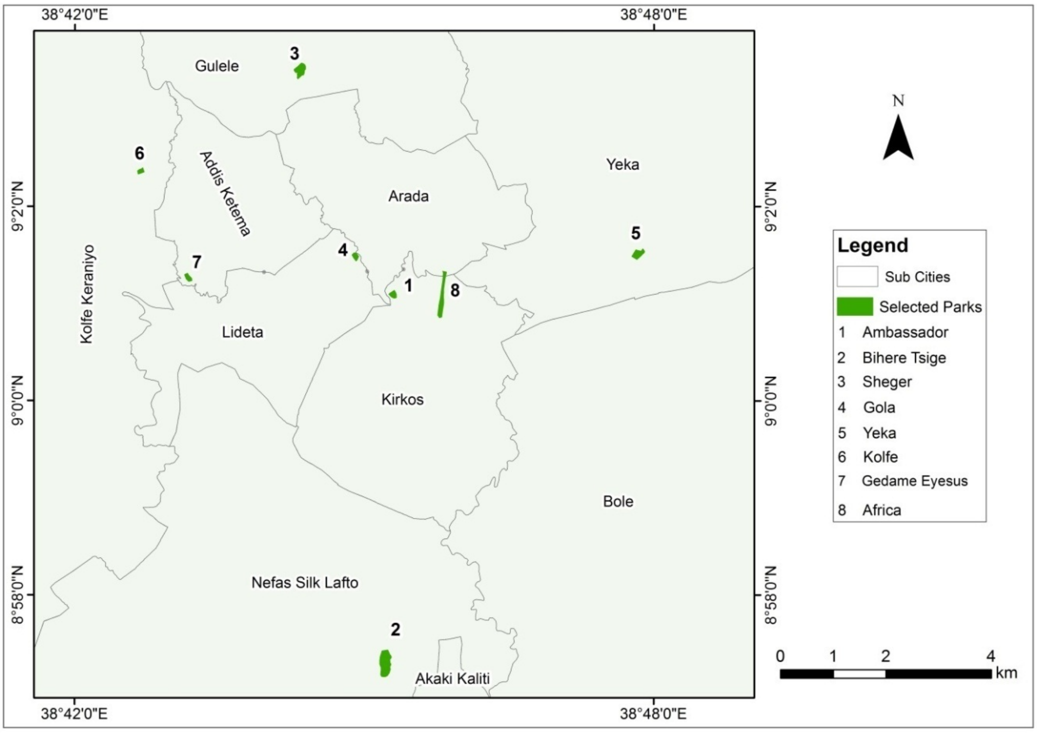

Figure 2. Location of the selected parks in Addis Ababa.

as base years to assess and interpret changes in Urban Green Areas UGAs) and Urban Heat Islands (UHI). To facilitate ease in data processing, analyses and interpretation, LST was distinguished under five classes, *viz*., 17ºC (very low), 17ºC−21ºC (low), 22ºC−31ºC (high) and >31ºC (very high). Cloud free Landsat TM for the years 1985 and 1995, Landsat ETM+ for 2006 and Landsat 8 image for 2015 of the Addis Ababa city with path 168 and row 054 were acquired from the United States Geological Survey (USGS). The acquired data with WGS84 were projected to Universal Traverse Mercator (UTM) projection and Adindan datum, specific to Ethiopia.

Normalized Difference Vegetation Index (NDVI)

The principle behind NDVI is that 'green' leaves absorb radiation at Red wavelengths due to the presence of chlorophyll pigments while scattering radiance at Near Infrared wavelengths due to their internal structure (Farooq 2012). This was expressed as a standard algorithm to characterize vegetation cover of the area. However, NDVI can only work effectively in the area with plant cover above 30% (Ray 1994). For landsat data, the NDVI formula (Zha et al. 2003, Saad and Nitin 2014) shows as:

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

where, NIR is the reflectance value of Near Infrared, and R is the reflectance value of red.

Normalized Difference Built-up Index (NDBI)

Remote Sensing time series data are useful to illustrate urban development over time through mapping built-up changes (Varshney 2013) of information extracted using the algorithm (Varshney 2013, Zha et al. 2003). The NDBI is often mixed with plant noise. Therefore, NDVI is used to filter out the noise. The NDBI is developed based on the unique spectral response of built-up area that has higher reflectance in the MIR wavelength range than in the NIR wavelength range. The NDBI value was obtained using the following equation and applied to identify urban built area

$$NDBI = \frac{(MIR - NIR)}{(MIR + NIR)} \quad (2)$$

where, MIR is the reflectance of mid infrared (Band 5), and NIR is the reflectance of near infrared (Band 4).

Land Surface Temperature (LST)

A single window method was used to retrieve LST values from Landsat TM and ETM+ images as the method is less sensitive to the uncertainties in optical properties of the atmosphere, simple and computationally efficient. Split window algorithm was used to retrieve LST from Landsat 8 data that had two bands (Band 10: 10.6µm to 11.2µm, Band 11: 11.5µm to 12.5µm) (Wan and Dozier 1996, Rajeshwari and Mani 2014, Cheng et al. 2015). Split-window algorithm uses brightness temperature of the two bands of Thermal Infrared (TIR), mean and difference in land surface emissivity for estimating LST. The process of acquiring LST values follows conversion of thermal infrared Digital Numbers (DNs) (Bands 10 and 11) to radiance Top of Atmosphere (TOA) and at-satellite brightness temperature. Top of Atmosphere Spectral Radiance was calculated using the following formula (Rajeshwari and Mani (2014) :

$$L\lambda = MLQcal + AL) \quad (3)$$

where, L_λ is the TOA special Radiance (watts $(m^2*srad*\mu m)^{-1}$), and M_L is the Band specific multiplicative rescaling factor from metadata (Radiance_Mult_Band_ x where x is band number), A_L is the Band specific additive rescaling factor from metadata (Radiance_Add_Band_x where x is band number) , and Q_{cal} is the Quantized calibrated pixel value in DNs.

Park Cooling Distance

Temperature measurements were taken from the center of each of the eight selected parks and outside from five locations from the park periphery up to a linear distance of 150 m at 30 m intervals during 12:00 noon and 14:00 hours in March when clear sky radiation devoid of cloud cover and precipitation persists and that inclination of the sun produces minimal shadow of the ground objects bearing little or no influence over the temperature. In the case of Gedame Eyesus and Yelea parks, temperatures could not be measured beyond 60 m and 90 m, respectively, because of hindrances. In the Sheger park, the temperature was measured during three different periods, viz., 06:00-07:00 h, 12:00-14:00 h and 16:00-19:00 h.

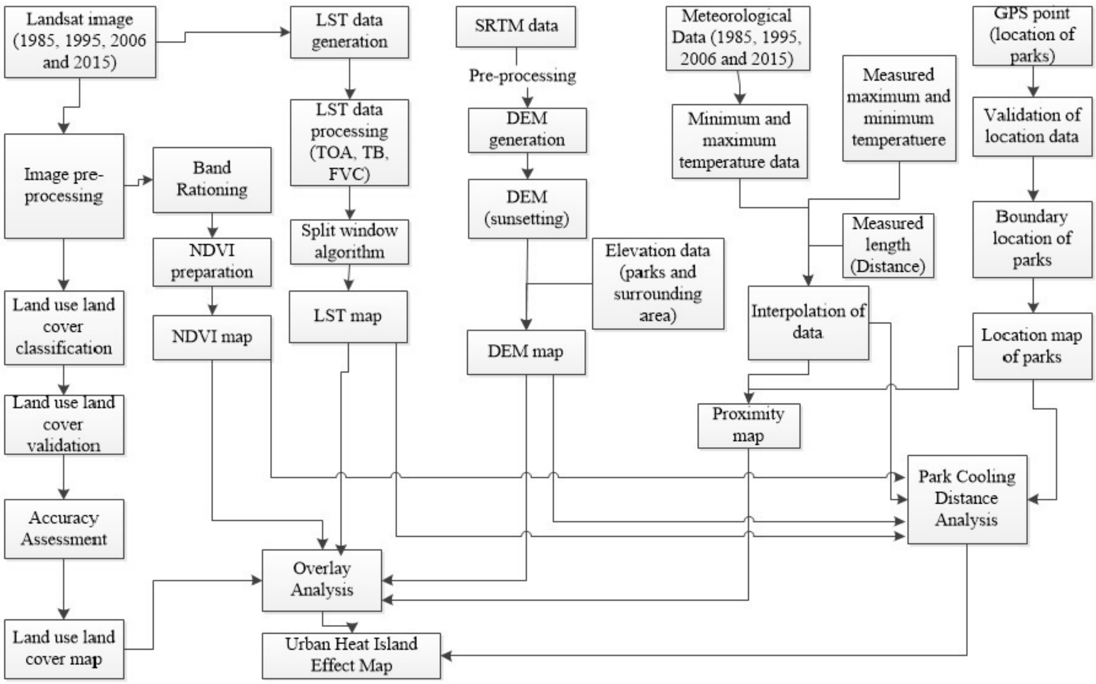

Figure 3. Framework of the methodology

Table 2. Normalized Difference Vegetation Index of the Parks for 1985 (A), 1995 (B), 2006 (C) and 2015 (D).

Park Name	Minimum				Maximum				Mean				Standard Deviation			
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
Ambassador	0.2	0.2	0.3	-0.1	0.4	0.4	0.5	0.4	0.3	0.3	0.4	0.2	0.1	0.1	0.1	0.1
Bihere Tsige	0.2	0.2	0.3	-0.2	0.6	0.6	0.7	0.5	0.5	0.4	0.5	0.2	0.1	0.1	0.1	0.2
Sheger	0.2	0.2	0.3	-0.1	0.6	0.5	0.7	0.2	0.4	0.4	0.5	0.1	0.1	0.1	0.1	0.1
Gola	0.2	0.2	0.1	-0.01	0.3	0.4	0.4	0.3	0.2	0.2	0.3	0.1	0.04	0.1	0.1	0.1
Yeka	0.2	0.2	0.2	-0.1	0.5	0.5	0.5	0.2	0.3	0.3	0.4	0.1	0.1	0.1	0.1	0.1
Kolfe	0.2	0.2	0.2	-0.2	0.5	0.4	0.4	0.2	0.4	0.3	0.3	0.1	0.1	0.1	0.1	0.1
Gedame Eyesus	0.2	0.2	0.1	-0.1	0.3	0.4	0.5	0.3	0.2	0.3	0.3	0.1	0.02	0.1	0.1	0.1
Africa	0.1	0.04	0.1	-0.2	0.5	0.4	0.5	0.4	0.3	0.2	0.3	0.2	0.1	0.1	0.1	0.1

A free-standing instrument, namely, Psychrometer that measures the relationship between air temperature recorded by conventional surface instruments and true air temperature was used to note field temperatures over 1.25 m high from the ground adopting standard response time as 20 seconds (WMO 2008). In urban segments, measurements were also taken 5 to 10 m away from the buildings in open spaces between buildings. Correlation between cooling distance and LST around the parks were found out based on Zonal statistics and regression models further to correlation between public parks and NDVI/LST. Framework of data acquisition and output generation during the study is schematically represented in Figure 3.

RESULTS

Public Parks and Normalized Difference Vegetation Index

Of the eight selected parks, Bihere Tsige with 142,726 m^2 (44.10%) is the largest followed by Sheger with 70,000 m^2 (21.63%) and Gedame Eyesus with 4128 m^2 (1.28%) followed by Ambassador with 9393 m^2 (2.90%) and Gola with 9625 m^2 (2.97). The other three (Africa, Yeka and Kolfe) are of intermediary in area (Table 1). The NDVI for the four base years were in the range of 0.1 (Africa) -0.7 (Bihere Tsige, Sheger 0.04 (Africa) -0.6

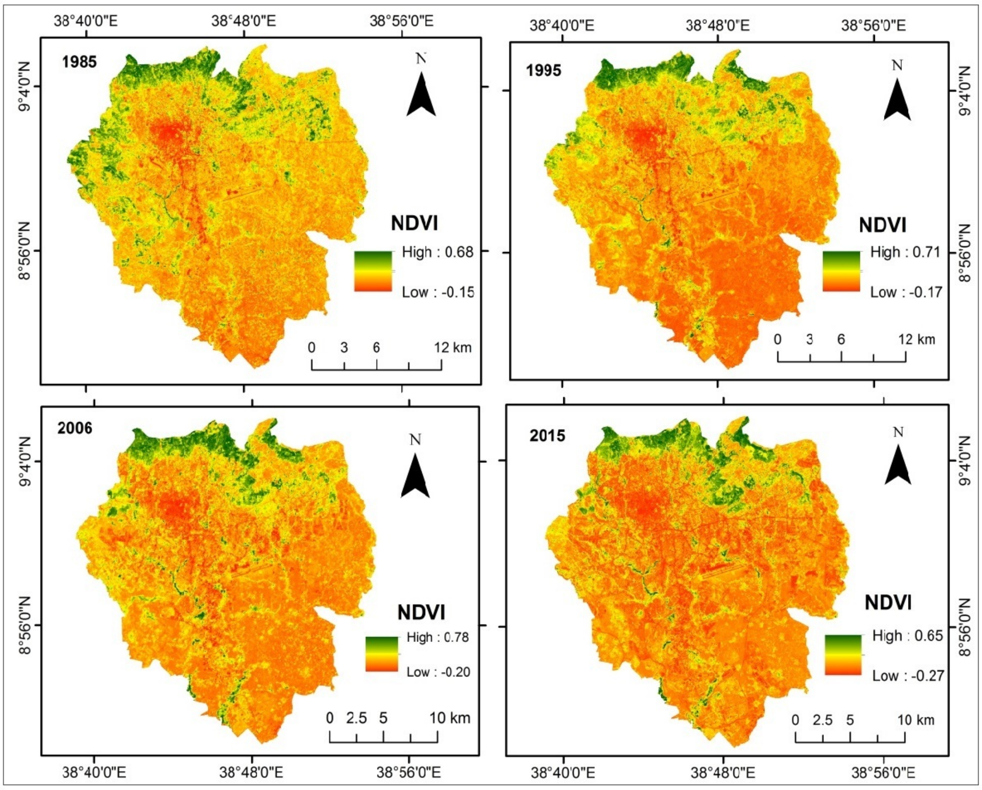

Figure 4. Normalized Difference Vegetation Index map of the study area.

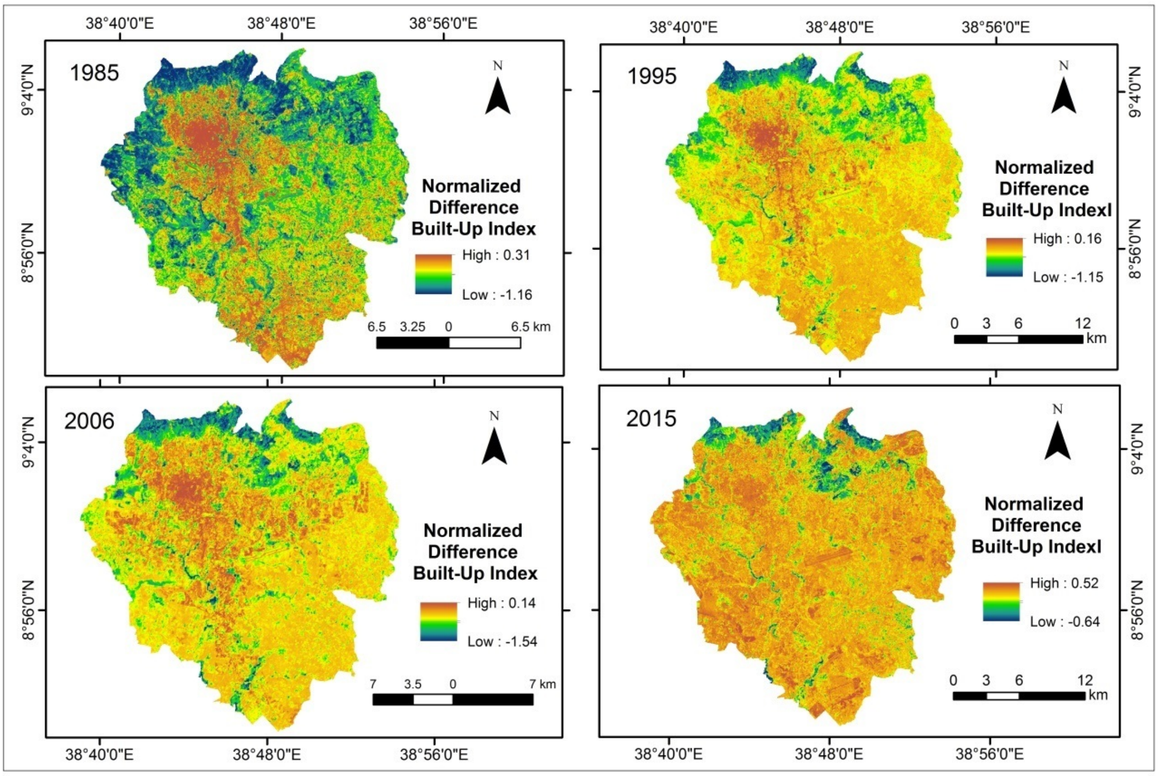

Figure 5. Normalized Difference Built-Up Index map of Addis Ababa for different years.

(Bihere Tsige), 0.1 (Africa, Gedame Eyesus, Gola) -0.7 (Bihere Tsige, Sheger) and -0.01 (Gola) -0.5 (Bihere Tsige) with the mean varying form 0.2 ± 0.02 to 0.5 ± 0.1 in 1985, 0.2 ± 0.1 in 1985, 0.2 ± 0.1 to 0.4 ± 0.1 in 1995, 0.3 ± 0.1 to 0.5 ± 0.1 in 2006 and 0.1 ± o.1 to -0.2 ± 0.2 in 2015 (Table 2 and Figure 4). Over all, NDVI for the four base years was 0.55.

Normalized Difference Built Up Index

The built-up index shown in Figure 5 indicates that the positive values defining the area under built-up is strong. The area under red to yellow color depicts built-up areas, and the area under dark blue indicates no-built-up existence. The high reflectance of surface structures contributes to rise in temperature and the LST in turn. The areas dominated by built-up, agriculture and bare land exhibited high surface reflectance. The color contrast visible in the Normalized Difference Built-Up Index map of 1985, 1995 and 2006 clearly show the extent and concentration of the built-up areas.

Land Surface Temperature

Figure 6 shows Land Surface Temperature variations in 1985, 1995, 2006 and 2015. Minimum temperatures for all the four years were noticed in northern part of the study area with high vegetation cover in the Parks and along the river banks. Tabulated LST values for the four base years narrate these results (Table 3). A large part of Addis Ababa was dominated by LST in the range of 27 ºC to 31ºC in 1995, 2006 and 2015, but by 22ºC–26ºC during 1995.

Metrological data and LST ranges

Meteorological monthly temperature of the four stations in Addis Ababa, from 9.3ºC to 24.1ºC, with a mean of 16.7ºC in 1985, 10.6ºC to 25.6ºC with a mean of 18.1ºC in 1995, 11.1ºC to 26.1ºC with a mean of 18.6ºC in 2006 and 11.7ºC to 26.3ºC with a mean of 19.0ºC in 2015. The LST ranged from 13.00ºC to 36.83ºC with a mean of 28.1±1.88ºC in 1985, 11ºC to 32.86ºC with a mean of 23.61±2.25ºC in 1995, 9.00ºC to 37.75ºC with a mean of 28.52±2.60ºC in 2006 and 15.00 to 39.75ºC with a mean of 31.64±2.02ºC in 2015. Similarly, LST of 17ºC–21ºC extended over an area of 22.94 km^2 in 1985, 113.84 km^2 in 1995 15.30 km^2 in 2006 and 13.25 km^2 in 2015. Likewise, LSTs of 22ºC–26ºC prevailed over an area of 159.82 km^2 in 1985, 355.89 km^2 in 1995, 102.35 km^2 in 2006 and 41.85 km^2 in 2015. Land surface temperature

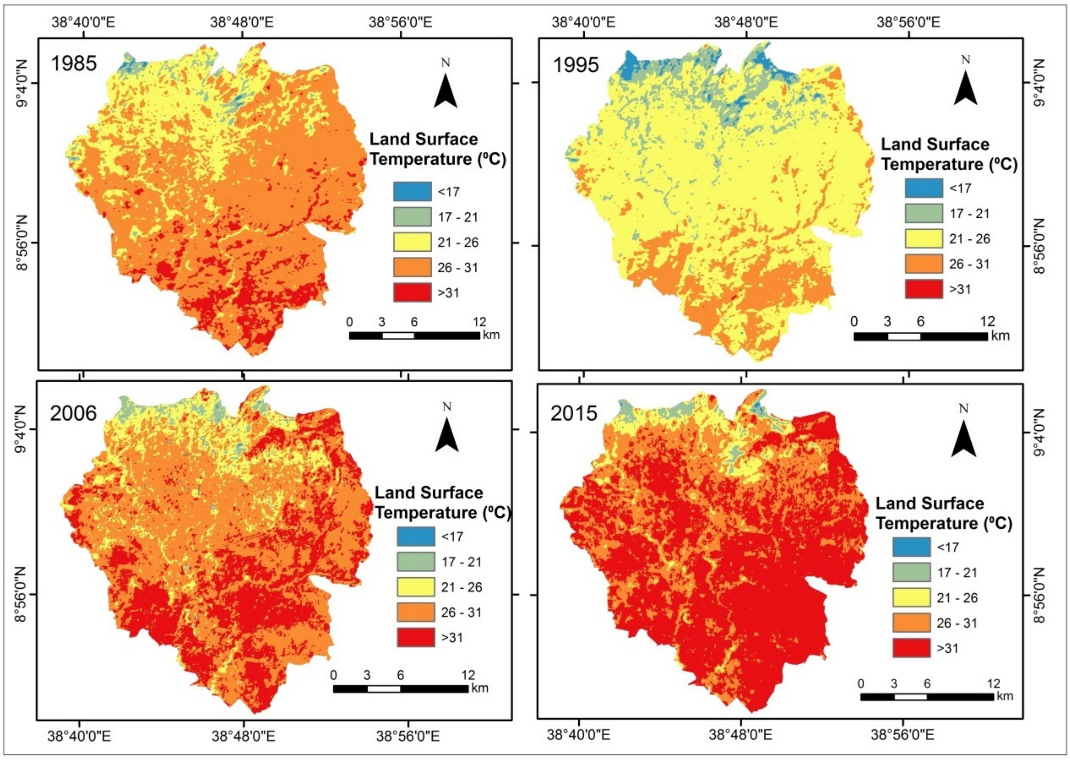

Figure 6. LST maps of different years of Addis Ababa.

Table 3. LST of the parks for the base years 1985 (A), 1995 (B), 2006 (C) and 2015 (D).

	LST (°C) for parks 1985				LST (°C) for parks 1995				LST (°C) for parks 2006				LST (°C) for parks 2015			
Park Name	Min	Max	Mean	StD	Min	Max	Mean	StD	Min	Max	Mean	StD	Min	Max	Mean	StD
Ambassador	25.0	27.1	26.2	0.7	19.7	21.5	20.5	0.6	26.9	28.8	27.2	0.6	25.4	30.3	28.0	1.6
Bihere Tsige	21.9	27.5	23.9	1.3	17.5	23.7	19.2	1.4	21.3	29.3	24.3	2.3	22.4	29.2	24.6	1.7
Sheger	19.3	26.3	22.5	1.8	17.9	21.5	19.5	1.0	20.3	27.8	23.4	2.2	23.3	30.5	26.1	1.7
Gola	25.0	25.4	25.0	0.2	21.1	22.8	21.7	0.6	24.4	28.3	26.2	1.2	29.5	32.4	30.6	1.0
Yeka	25.4	28.4	26.6	0.8	21.1	22.4	21.8	0.4	23.4	30.8	25.9	2.1	26.9	32.9	29.0	1.6
Kolfe	23.7	24.5	24.2	0.3	19.7	20.6	20.3	0.3	23.4	26.4	24.8	1.0	26.6	30.5	28.3	1.1
Gedame Eyesus	24.1	26.7	25.9	0.8	20.6	21.9	21.3	0.5	23.9	26.4	25.1	0.9	27.0	30.0	28.1	0.8
Africa	22.8	26.7	24.3	0.7	19.7	21.9	20.5	0.6	22.8	29.8	26.5	1.9	24.6	31.0	28.3	1.8

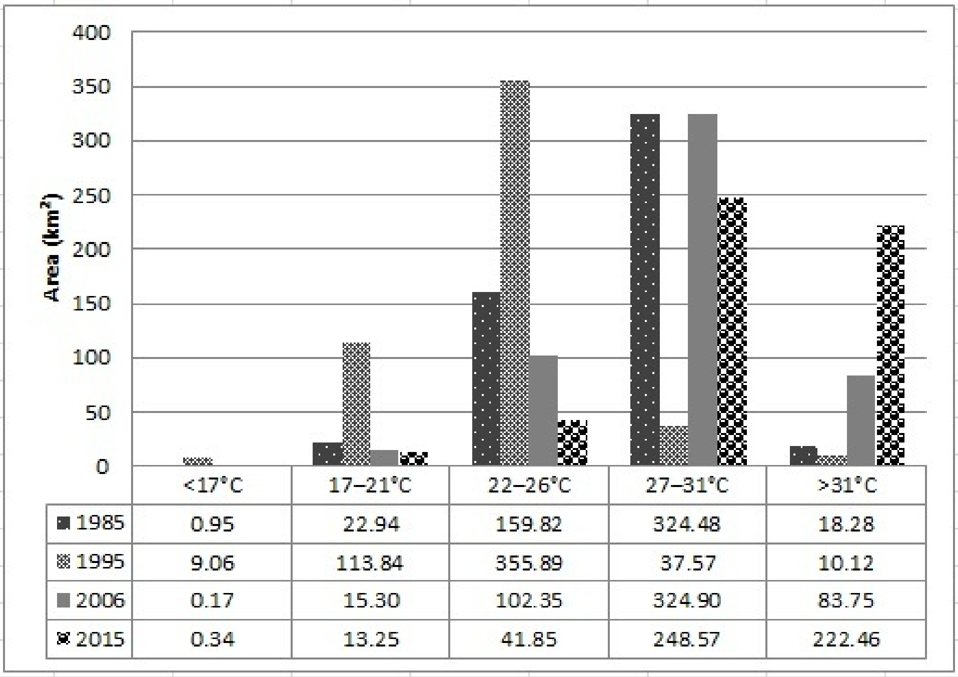

Figure 7. Geographical areas covered by various LST classes during different years.

27ºC–31ºC existed over an area of 324.48 km^2 in 1985, 37.57 km^2 in 1995, 324.90 km^2 in 2006 and 248.57 km^2 in 2015. Similarly, LSTs of >31ºC were spread over 18.28 km^2 in 1985, 10.12 km^2 in 1995, 83.75 km^2 in 2006 and 222.46 km^2 in 2015 (Figure 7).

Park-wise LSTs in Addis Ababa

Park-wise, LSTs varied from <20ºC in Sheger to 28.4ºC in Yeka with a mean of 26.15± 0.71ºC in Ambassador, 23.93±1.32ºC in Biher Tsige, 22.53±1.84ºC in Sheger, 25.04±0.15ºC in Gola, 26.57±0.79ºC in Yeka, 24.20 ±0.32ºC in Kalfe, 25.85±0.83ºC in Gedame Eyesus and 24.26±0.75ºC in Africa during 1985. Park-wise LSTs during 1985, 1995, 2006 and 2015 are given in Table 3, and the mean LST of these parks during the above years are shown in Figure 8. Similarly, LST during 1995 in different parks ranged from <18ºC in Sheger to 23.68ºC in Bihere Tsige with a mean of 20.52± 0.63ºC in Ambassador, 19.20±1.44ºC in Biher Tsige, 19.46±0.96ºC in Sheger, 21.74±0.56ºC in Gola, 21.75±0.38ºC in Yeka, 20.26 ±0.33ºC in Kalfe, 21.30±0.45ºC in Gedame Eyesus and 20.49±0.59ºC in Africa. Like-wise, the LST varied from 20.26ºC in Sheger to 30.75ºC in Yeka with a mean of 27.24 ± 0.61ºC in Ambassador, 24.25 ± 2.34ºC in Bihere Tsige, 23.39 ± 2.20ºC in Sheger, 26.15 ± 1.22ºC in Gola, 25.94 ± 2.07ºC in Yeka, 24.76 ± 1.05ºC in Kolfe, 25.13 ± 0.88ºC in Gedame Eyesus and 26.50 ± 1.85ºC in Africa during 2006. In the same way, LST during 2015 in different parks ranged from 22.44ºC in Bihere Tsige to 32.92ºC in Yeka with a mean of 28.04 ± 1.60ºC in Ambassador, 24.57 ± 1.69ºC in Bihere Tsige, 26.10 ± 1.75ºC in Sheger, 30.62 ± 0.99ºC in Gola, 29.03 ± 1.58ºC in Yeka, 28.30 ± 1.15ºC in Kolfe, 28.12 ± 0.77ºC in Gedame Eyesus and 28.28 ± 1.79ºC in Africa.

Land-use/land-cover-wise LSTs

In the instance of different land-use/land-cover classes during 1985, LSTs were between 13.78ºC to 33.66ºC with a mean of 24.8 ± 2.96ºC for vegetation, 19.28ºC to 36.83ºC with a mean of 28.1±1.88ºC for bare land, 16.10ºC to 36.44ºC with a mean of 27.8±2.58ºC for built-up, 18.38ºC to 36.83ºC with a mean of 28.9 ± 1.74ºC for grassland, 17.93ºC to 36.05ºC with a mean of 30.03±1.59ºC for agricultural land and 20.18ºC to 23.68ºC with a mean of 21.8±0.78ºC for water body (Figure 9).

Similarly, in the case of different land-use/land-cover categories during 1995, LSTs varied from 11.41ºC to 30.01ºC (20.67 ± 2.94ºC) for vegetation, 12.36ºC to 32.46ºC (24.60 ± 1.81ºC) for bare land, 13.31ºC to 32.86ºC (23.61 ± 2.25ºC) for built-up, 17.02ºC to 32.46ºC for grass land and agricultural land with means of 24.84 ± 1.65ºC, and 25.74 ± 1.35ºC, respectively and 17.48ºC to 26.25ºC (21.32 ± 2.48ºC) for water body.

Like-wise, in the instance of different land-use/land-cover groups in 2006, LSTs ranged from 15.47ºC to 34.53ºC (23.16 ± 2.89ºC) for vegetation, 19.74ºC to 36.38ºC (29.89 ± 2.02ºC) for bare land, 9.89ºC to 37.75ºC (28.52 ± 2.60ºC) for built-up, 21.30ºC to 36.84ºC (31.52 ± 1.67ºC) for grass land, 19.74ºC to 37.75ºC (31.15 ± 1.58ºC) for agricultural land and 21.30ºC to 26.86ºC (23.17 ± 1.09ºC) for water body.

For 2015, LSTs were 15.63ºC to 37.35ºC averaging at 24.49±3.50ºC for vegetation, 26.76ºC to 34.24ºC (31.58±1.32ºC) for bare land, 18.67ºC to 39.75ºC (31.64±2.02ºC) for built-up, 25.53ºC to 37.19ºC (32.95±1.78ºC) for grass land, 18.28ºC to 39.30ºC (32.36±2.90ºC) for agricultural land and 22.15ºC to 35.94ºC (24.99±2.12ºC) for water body.

Temperatures across the transects laid away from different parks

Except in Yeka park, temperatures across the transects of each of the eight in general was more than that of center and gradually increased from the center of the Park along with increasing distance barring certain minor observations (Figure 10). Across the transect, Ambassador park registered a step up in temperature at each interval, while the Park Africa experienced equal temperatures at 60 m, 90 m and 120 m distance, Yeka at centre, 30 m and 90 m distances. Temperatures at 90 m and 150 m of Bihere Tsige, at 120 m of Gola, 150 m of Kolfe, 90 m and 150 m of Sheger parks were slightly lesser than the preceding landmarked distances.

Perceptions of the public

Among the sampled public visiting Parks, 37% tend to visit once in a weak, 24% sometimes, 18% during weekends, 12% every day, 6% holidays and 3% once in a month. Further, of the total respondents, 90.9% recognized the difference between being inside the Park and outside, while the rest (9.1%) failed to sense any difference (Fig. 11). Among the positive respondents, 43.33% believed the existence of fresh air inside Parks while 26.67% realized refreshing of their minds and 30.00% felt pleasant air in the Park. Among the respondents, 50% experienced hotness of the air outside the Parks, whereas 36.67% felt that outside air as polluted and 13.33% as harmful. The final over layed urban heat island map of Addis Ababa is given in Figure 12.

DISCUSSION

Normalized Difference Vegetation Index is used as an indicator of LST in several research studies. The NDVI value close to or trend towards -1 indicate a bareland, open area or water body, whereas the value close to or trending towards indicate vegetative cover. The area under vegetation cover could be identified in the northern part of Addis Ababa in the Entoto mountain area, along the river banks and in urban green areas. Higher NDVI maximum (0.5−0.7) was found in while lower NDVI maximum (0.31−0.5) was noticed in Gedame Eyesus park with 1.28% of the total area of the selected parks indicating Bihere Tsige park with 44.10 % of the total area of the selected parks that park extent and shape have an impact NDVI value. Thus, the larger the

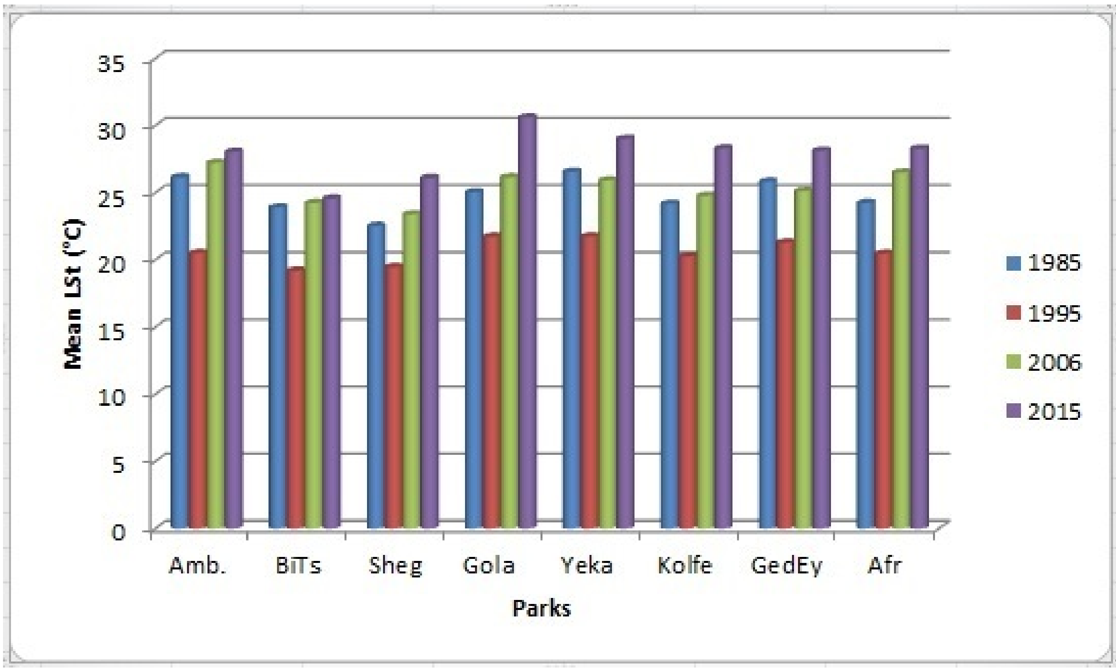

Figure 8. Mean LST of various public parks during different years.

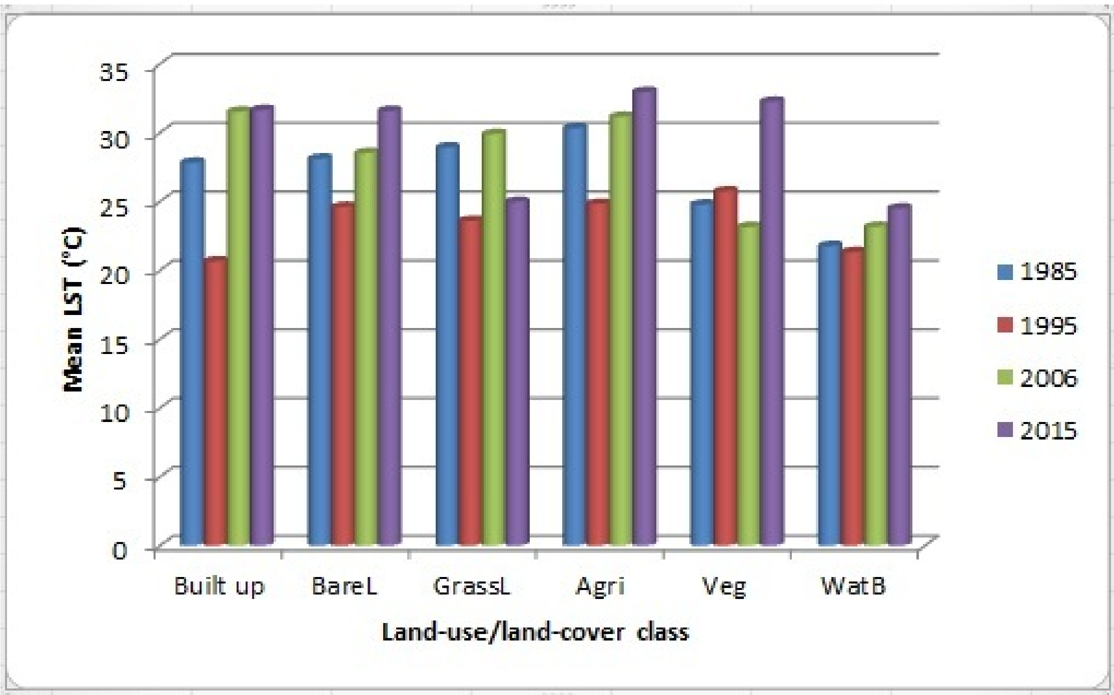

Figure 9. Mean LST of various land-use/land-cover classes during different years.

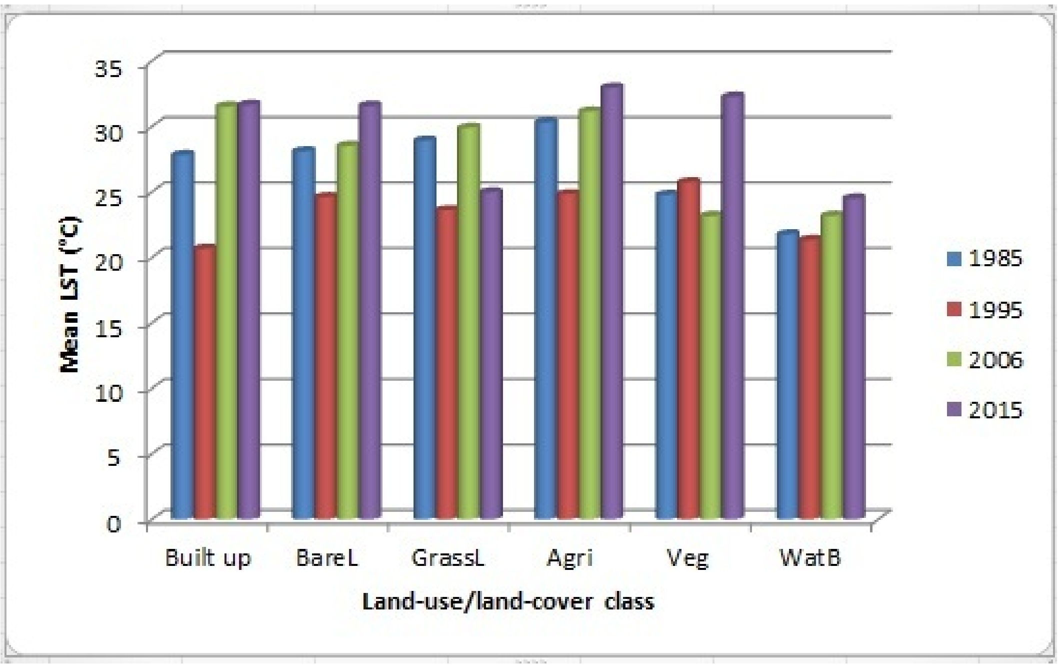

Figure 10. Average temperature at specific distances away from the parks.

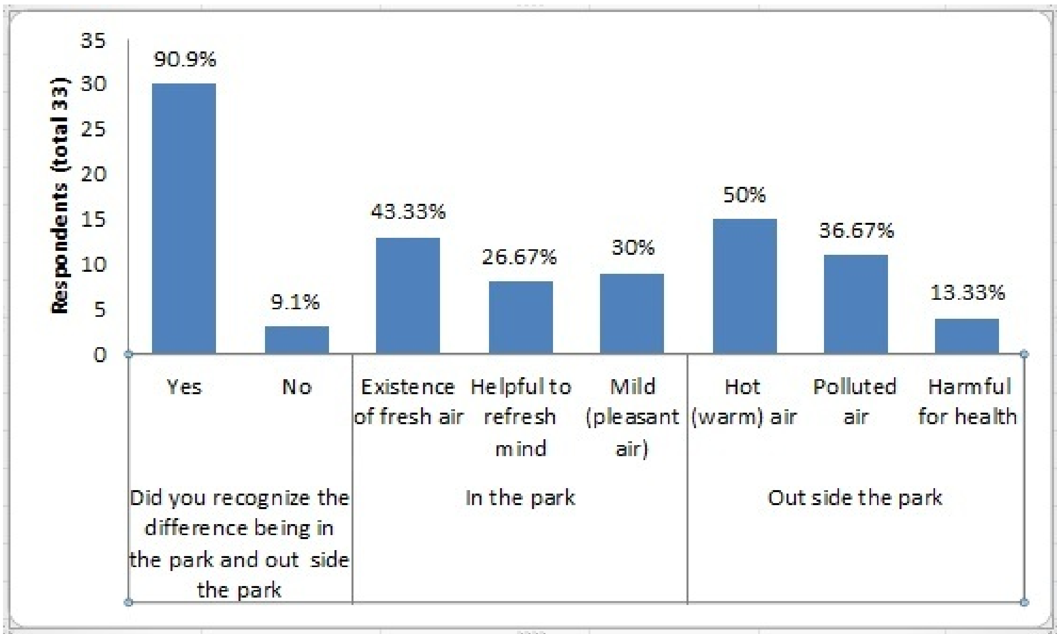

Figure 11. Response of visitors to various aspects related to the parks.

extent and vegetation cover, positive and closer the NDVI to 1. According to Weng et al. (2004), NDVI is as an acceptable indicator of LST, where, the coefficient of determination of NDVI accounted for 74.18% of variance in distribution. The 1985, 1995, 2006 and 2015 NDVI and LST correlations for Addis Ababa green area parks indicate that coefficient of determination of NDVI accounted for 75.9%, 76.3%, 79.2% and 84.1% of the LST distribution, respectively (Figure 13).

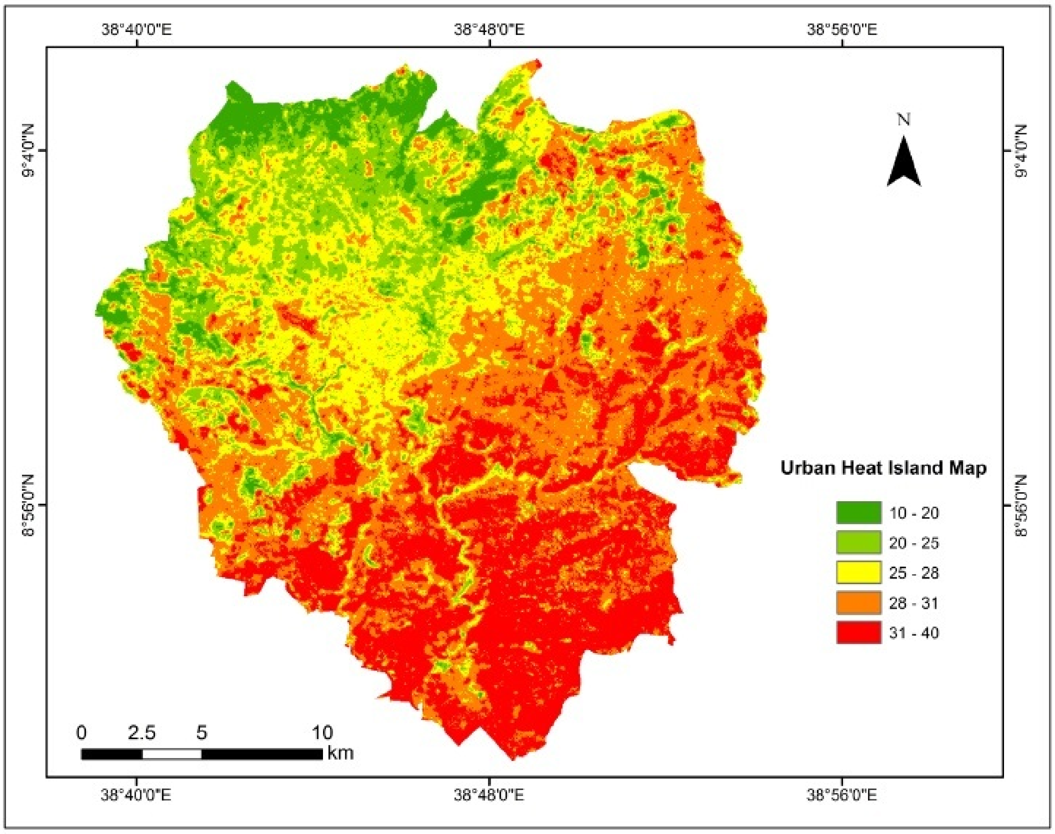

Figure 12. Urban Heat Island map for 2015.

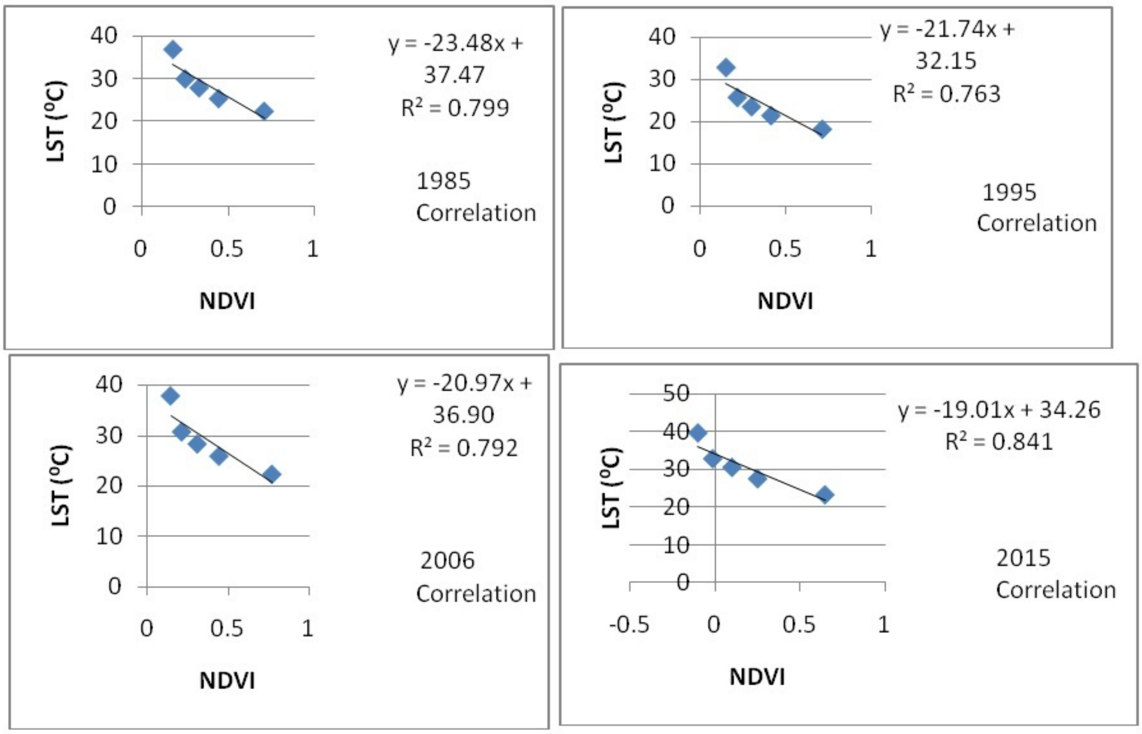

Figure 13. LST as a function of NDVI during different years.

Land surface temperature is an important factor in climate change and vegetation growth Md Shahid (2014). A study conducted in Patna Municipal Corporation in India by Ashraf (2015) focused on analyzing LST of the municipal area during 1989–2014 for six base years and the result showed that the minimum temperature of 19.584°C prevailing in February 1993 had increased gradually to 22°C by February 2014. During the present study it was found that the minimum LST of 13°C prevailed in 1995 gradually, decreased to the level of 11ºC by 1995 and further to 9ºC in 2006, but suddenly rose up substantially to 15°C by 2015. In 1995, LST more than 85% of the parks received above 20 ºC of surface temperature. Minimum as well as maximum surface temperatures were noticed in Bihere Tsige Park. The effect of vegetation cover over an area is clearly reflected in the measured maximum and minimum temperatures. Where the extent of vegetated cover over an area decreased, the highest was the LST with little difference between the maximum and minimal surface temperatures.

A comparison of the measured temperatures in the park and outside revealed the influence of vegetation cover in the park on the LST that gradually increased in tune with the increase in distantance from the park. With the increasing distance from parks, cooling effect gradually decreased. Cheng et al. (2015) recorded the highest mean LST of 36.15ºC in the smallest park while the lowest mean LST of 31.25ºC was recorded in the second largest park. In the present study, the highest mean temperature of 20.5ºC was observed in Gola, Gedame Eyesus and Africa park, whereas the lowest temperature of 18.5ºC was recorded in Sheger park. It was also noticed that the larger the size of the park, the smaller the amount of temperature received and the larger are likely to be cooler or efficient in cooling the surrounding areas. The statistical correlation between the land-use/land-cover classes and LST in 1985 indicated the lowest mean temperature of 22ºC in a water body, while the highest mean temperature of 30ºC in agricultural land.

Temperatures above 35ºC were exhibited within the built up areas, bare land, grassland and agricultural land. As the satellite image was taken in January 1995 during the period characterized by dry weather, surface reflectance in agricultural areas was higher due to which the LST rose up. A little decrease in the LST was seen in 1995 though this also still high (Figure 9). The land-use/land-cover class that received the highest maximum temperature was built-up area. Relatively lowest LST was recorded in water body and green vegetation class. In analyzing the land-use/land-cover and LST relationship lesser mean temperature was recorded in the classes vegetation and water body, showing 23.16ºC and 23.17ºC, respectively. The highest mean temperature of 31.52ºC was recorded by grassland and 31.15ºC by cropland. However, built-up and bare land areas respectively recorded 28.52ºC and 29.89ºC surface temperature.

Similar to the NDVI indices, the NDBI indices to notice the changes in built-up environment. Varshney (2013) applied the NDBI algorithm to detect changes between the years 2000 and 2010 in built-up environment. Xu (2007) also applied NDBI for analyzing the built-up area using the NIR and Red bands. Rapid urbanization has been bringing out many environmental problems such as development of UHI and change in land-use/land-cover patterns (Feinzizadeh and Blaschke 2013). Even if the reflectance of built-up area and bare land is similar and that NDBI treats both as same, the former has an advantage to show high reflectance for LST (Zha et al. 2003). During the present study also, NDBI values for the years were positive indicating the area under built-up. During spatio-temporal analysis of urban temperature in Bandung City, Ramdani and Setiani (2014) used NDBI as a tool to indicate the urban temperature and found a positive correlation between the two implying that NDBI has an additive effect in recognizing urban temperature due to increased reflectance of structural surfaces in urban areas (Wickop 1998, Souza 2015).

Analysis of LST of Addis Ababa showed that hot spot areas are located in the center of the city where settlements are congested and also along the road side, where business complexes are built. Weng et al. (2004) showed that hot spot areas in Indianapolis are in central business districts and small hot spot areas or urban heat islands along the roads where commercial and industrial built up areas were decrease. Thus, the efficiency of parks in mitigating the UHI effect is found to be enormous. Out of the total respondents, 90.9% recognized the difference being in the park and outside the park. The data indicate that people are aware of the benefits of the existence of parks in the community. While defining the condition within the park, 43.33% of respondents believed that the existence of fresh air is necessary for health. On the other hand, the respondents identified a warm and polluted air outside the park. Though the visiting times of respondents varied, all visitors recognized the importance of visiting parks.

Urban parks are considered as urban green belts with diversified benefits to the urban dwellers. Chiesura (2004) studied the role of urban parks for building up a sustainable city and stated that important environmental services such as air and water purification, wind and noise filtering, microclimate stabilization, provision of social and psychological services are of crucial significance for the wellbeing of urban dwellers. Baccini et al. (2008) suggested that higher temperatures in cities influence human wellbeing and health. Public response during the present study also confirmed that public parks have the ability to moderate temperature and refresh air, which are natural remedies for better health and to relives mental tension and stress.

CONCLUSION

Interest in executing research work to analyze UHI effects based on LST in urban built-up environment has gained momentum now-a-days. Expansion of urban areas leads to micro-climate change supplemented by LST increase. As Addis Ababa is a fast growing metropolitan city, issues of LST and UHI are very sensitive due to the expansion of the built environment, deterioration of vegetative cover and relatively small extent of urban green spaces like public parks mentioned. Therefore, the efficiency of public parks in coping up with the effect of LST increase and UHI effects plays a crucial role in decision making and development of smart green cities for the benefit of the present as well as future dwellers of this city.

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