Research article

Assessment of urban thermal field variance index and thermal comfort level of Addis Ababa metropolitan city, Ethiopia

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ABSTRACT

Land use land cover (LULC) conversion around urban areas is the root cause for the increasing trend of land surface temperature (LST) in many cities. The increase in LST is driven by the replacement of vegetation cover and other LULC by impervious surface. This study is aimed to assess the extent of urban thermal field variance index (UTFVI) and thermal comfort level of Addis Ababa city using geospatial techniques and linear regression model. Landsat image of 1990 TM, 2000 of ETM+ and 2020 of OLI/TIRS are used to analyze LST and Urban Heat Islands (UHI) for assessing UTFVI and urban thermal comfort level. The results showed that the UHI over Addis Ababa city is substantial increased over the past decades. The results reveled that LST has increased by 7.9 °C due to decline of vegetation cover and expansion of built-up area. Results show that about 225 km^2 (42.7%) is excellent comfort for urban resident while about 241.4 km^2 (45.8%) is categorized as worst ecological evaluation index, which results discomfort to the city dwellers. The key findings of from this study are crucial for informing city administrators and urban planners to reduce urban heat islands by investing on urban green areas and open spaces.

1. Introduction

The decrease of vegetation coverage and expansion of impervious surfaces lead to elevated temperatures in developed urban areas. Substantia studies documented that the declining of vegetation coverage and increasing of impervious surfaces are the drivers of environmental problems like land surface temperature (LST) in many cities (Nwakaire et al., 2020; Ayanlade et al., 2021; Garcia and Diaz, 2021; Ejiagha et al., 2022) and considered as the greatest challenge in the 21[th]c (Isioye et al., 2020). Other studies documented the negative impacts of land use land cover (LULC) change and urbanization on climate change (Kalnay and Cai, 2003; Rahman et al., 2021). Specifically, Kalnay and Cai (2003) found that urbanization and agriculture significantly increase the daily average surface temperature.

It is clear that our world is very dynamic and changing a lot for complex reasons. The role of LULC change plays an important role in this regard. Therefore, analysis of LULC change and its consequences are very crucial and how land use change is affecting various environmental issues such as LST, urban heat island (UHI), flood, drought, biodiversity loss, and degradation of ecosystem services. For instance, study by Song et al. (2018), and Yohannes et al. (2021) indicates that LULC change and affects provisions of ecosystem services.

Flood is another key environmental problem in urban areas, which is directly linked with LULC change, population growth, and road density (Rahman et al., 2021). Urban warming is the cumulative effects of dense population, absence of greenery area, and high presences of imperviousness in the cities (Dewan et al., 2021). Study conducted over Ibri city in Roman by Mansour et al. (2022) conclude that the declining of green areas will negatively affect ecosystem services. Study conducted by Tuladhar et al. (2019) in Bagmati catchment in Central Nepal revealed that the combined effect of climate change and human activities have resulted to river discharge changes.

The increasing trend of LST around big cities are remained as the major environmental problems that influences the life of the residents (Abulibdeh, 2021). The increasing of heat stress driven by UHI during the day time worsens human discomfort in big urban center (Pantavou et al., 2011; Oleson et al., 2015; Mandelmilch et al., 2020). Other study found negative changers in daytime temperature can occur with urbanization (Rasul et al., 2015). Built-up areas absorb heat during the daytime and release of it during nighttime which resulting in a weakening of nighttime cooling (Ayanlade et al., 2021; Kamal et al., 2015).

The UHI is pronounced mainly in the night time. Several studies have been conducted to investigate the effect of UHI during the night time, while the effect of UHI during the daytime is not get attention over the past decades. It is a topic of debate and a research topic whether UHI is more severe during the daytime or night time. For instance, Dewan et al. (2021) highlight that surface UHI is higher during the daytime than nighttime in large cities in Bangladesh. Of course, there are different factors that may affect temperature difference between daytime and nighttime temperature among cities which might be influenced by location, altitude, wind and the surrounding LULC. Feyisa et al. (2014) concluded that topographic variation significantly influences thermal variations among parks over Addis Ababa city.

The conversion of LULC results in warming of UHI (Wemegah et al., 2020; Yuvaraj, 2020) which influences local climate. Ibrahim (2017) conclude that LST and LULC have a strongly connected relationship. Wolteji et al. (2022) reported that LULC change is a key driver of LST and triggers climate change. Similar to LST, air temperature of particular area is influenced by LULC change. Transformation of LULC change is the main cause for significant increasing trends of mean minimum and maximum temperature in the wettest parts of Ethiopia (Gemeda et al., 2021, 2022).

Rapid urbanization substantially influences the city thermal environments by converting the natural surfaces into built up area (Khan et al., 2020; Qu et al., 2020; Naima and Kafy, 2021). The urban thermal comfort level was measured using the urban thermal field variance index (UTFVI). Substantial studies have used UTFVI to estimate the urban thermal comfort level to ensure sustainable urban health (Tomlinson et al., 2011; Fu and Weng, 2016; Kafy et al., 2020; Sobrino and Irakulis, 2020; Mondal et al., 2021; Naima and Kafy, 2021; Majumder et al., 2021) using UTFVI. Early study clearly indicates that the inner city is less comfortable for people. For instance, study by Isioye et al. (2020) in Abuja municipal city of Nigeria shows that the outside margins of the city are ecologically more comfortable than the inner of the city.

The rapid growth of Addis Ababa city modifies the urban microclimate through increasing surface heat intensity (Feyisa et al., 2014, 2016; Abebe and Megento, 2017). The rapid conversion of LULC change

particularly the decline of vegetation cover and increase of built-up area resulted in an increase of LST from 3 to 8 °C between the year 1985 and 2015 (Worku et al., 2021). Other studies by Aflaki et al. (2017) and Abulibdeh (2021) found that the air temperature around urban area can increase between 2 °C and 15 °C by UHI. In contrast, the presence of urban green space can minimize urban warming (Feyisa et al., 2014; Abebe and Megento, 2017).

Although, some efforts have been conducted to indicate the influences of impervious surface on LST in Addis Ababa city, less attention was given to the UTFVI to measure urban thermal comfort level. Therefore, the present study aims to overcome the previous research gap by incorporating the UTFVI to estimate the thermal comfort level of Addis Ababa metropolitan city using geospatial techniques and linear regression model. Finally, this study enhances public understanding of urban green space role in microclimate mitigation.

2. Materials and methods

2.1. Description of the study area

The study is conducted in Ethiopian national capital, Addis Ababa, which covers about 527 km^2 (Moisa and Gemeda, 2021). It lies between 8°51′15″ to 9°4′15″N and 38°38′0″ to 38°55′30″E. Addis Ababa city is home to more than 5 million people. Administratively, the city has 10 Sub-cities (Figure 1). Addis Ababa city is the most populous city in Ethiopia. It is one of the fast-growing cities from Africa (Arsiso et al., 2018). According to the Central Statistical Agency (CSA), 2007 of Ethiopia the city has a total population of 3, 384, 569 which was increased to about more than five million by the year 2021 and projected to swell to over 8.9 million by 2035.

2.2. Data sources

In the present study, three Landsat satellite image of 1990, 2000 and 2020 were downloaded from USGS website in the month of January and
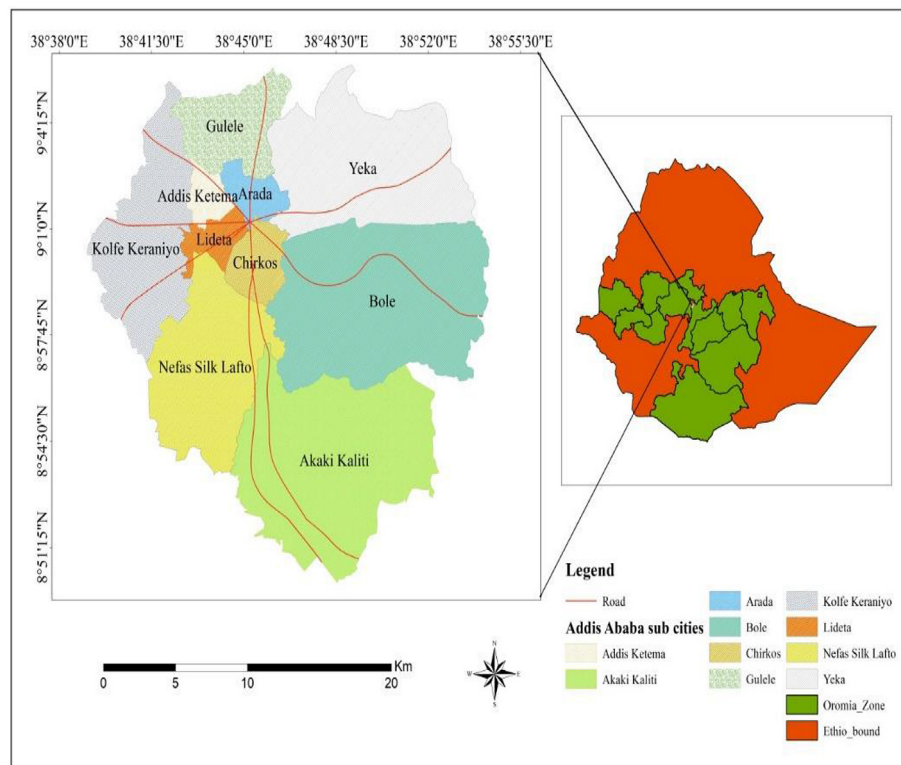

Figure 1. Map of the study area.

February (during the dry season) to minimize the impact of cloud on image accuracy (Table 1).

2.3. Image preprocessing and image classification

Image preprocessing such as layer stacking, and false color composting technique were applied using ERDAS IMAGINE 2015. In the present study, supervised image classifications techniques with maximum likelihood algorithm were applied (Abebe et al., 2019; Neg-assa et al., 2020). Finally, the LULC of the study area was classified into built-up, vegetation, agriculture, grassland and bare land.

2.4. Land surface temperature retrieval

The LST was retrieved from thermal bands of Landsat images of TM 1990, ETM+ 2000 and OLI/TIRS 2020 (Traore et al., 2021). A Mono window algorithm on Landsat -5 TM (band 6), Landsat 7 ETM+ (band 6) and the split window algorithm on Landsat 8 OLI/TIRS Thermal Infrared band (band 10) were used to calculate the LST (Qin et al., 2001; Athick et al., 2019; Sekertekin and Bonafoni, 2020). In this study, the LST represent the daily-average temperature. For LST retrieval, first the conversion of digital number ito radiance were performed as uggested by (Sekertekin and Bonafoni, 2020). The ETM+ digital number varies between zero and 255 (Kayet et al., 2016). The digital numbers of band 8 from Landsat 8 OLI was converted to into sensor radiance values (Mancino et al., 2020).

After conversion of digital number into radiance, the TM and ETM+ of Band 6 were converted from spectral radiance to a more physically useful variable to convert to brightness temperature (Yue et al., 2007). And finally, the land surface emissivity estimation was performed (Sobrino et al., 2004; Chibuike et al., 2018) based on the required vegetation proportion (Carlson and Ripley, 1997; Chibuike et al., 2018).

2.5. Normalized difference vegetation index

In the present study, NDVI value was computed from red bands and near infrared of Landsat 5 of 1990, Landsat 7 of 2000, and Landsat 8 of 2020.

2.6. The normalized difference built-up index

The NDBI is calculated from multispectral bands of Landsat 8 and computed from band 5 and 6 as shown in (Eq. (1)).

$$NDBI = \frac{Band6 - Band5}{Band6 + Band5} \tag{1}$$

2.7. Urban heat island (UHI)

In the present study, UHI effect was extracted for daytime based on daily-average temperature. Urban heat island is occurred when the temperature of urban center is higher than its surrounding. To compare variation of UHI from different years, LST is calculated following (Abu-taleb et al., 2015) by using (Eq. (2)).

$$UHI = \frac{LST - LSTmean}{STD} \tag{2}$$

where UHI is urban heat island; LST is mean land surface temperature, and STD is standard deviation.

2.8. Urban thermal field variance index (UTFVI)

The UTFVI, the extent of urban thermal comfort is calculated using (Eq. (3)) to describe the urban health and heat distribution (Liu and Zhang, 2011; Ahmed 2018; Wemegah et al., 2020; Abir et al., 2021; Al-kafy et al., 2021).

$$UTFVI = \frac{TS - Tmean}{TS} \tag{3}$$

where UTFVI is urban thermal field variance index; TS is the LST of a pixel (°C or °K), and Tmean is the mean LST of the study area (°C or °K). Thermal comfort level or ecological evaluation index of Addis Ababa city is categorized into six different ecological evaluation indices (Liu and Zhang, 2011) as indicated in (Supplementary Material (SM), Table 1).

2.9. Accuracy assessment

Accuracy assessment was conducted to compare the LULC classification to understand the percentage of correctly classified pixels. For this purpose, both Overall accuracy and Kappa statistics (Congalton, 1991) were done. Kappa statistics is used to calculate the extent of agreement between two maps stacking into account all elements of confusion matrix (Moisa and Gemeda, 2021).

3. Results

3.1. Land use land cover change

In this research, the LULC of the Addis Ababa city is classified into built-up, vegetation, agriculture, bare land and grassland from Landsat images of 1990, 2000 and 2020 (Figure 2). Results show that, the share of the built-up area is increasing overtime, which covers a total area of 164.7 km^2 (31.3%), 175.6 km^2 (33.3%) and 208.3 km^2 (39.5%) in 1990, 2000 and 2020, respectively while the agriculture, and vegetation cover declined tremendously (Table 2).

During the study period, the built-up area was substantial increased. Bare land is another land cover class that experiencing an increasing trend over time. For instance, in 1990 the bare land covers about 3% and increased to 11.2% and 15.2% by the year 2000 and 2020, respectively. In 1990 the share of agriculture and vegetation cover accounts about 44.8% and 4.5%, respectively and later declined to 29.5% and 1.7% in the year 2020, showing a decreasing by 15.3%, and 2.8% from agricultural land and vegetation cover.

In the present study, accuracies assessment for LULC classes were performed. Accordingly, the overall accuracy assessment results for the year 1990, 2000, and 2020 are 81.6%, 80%, and 85%, respectively while the Kappa statistics assessment results for 1990, 2000, and 2020 is 0.81%, 0.84%, and 0.86%, respectively (SM Table 2).

3.2. Land surface temperature

The results revealed that, LST was increased over the study period (1990–2020) because of decline in vegetation coverage and increase of impervious surface mainly the built-up area. The mean maximum LST was 30.4 °C, 34.2 °C, 36.5 °C, 37.3 °C, 37.9 °C and 38.2 °C in 1990, 1995, 2000, 2005, 2010, 2015, and 2020, respectively (Figure 3). The mean daily maximum LST was 30.4 °C in 1990, and it increased to 38.2 °C, which indicates an increment of daily average LST by almost 8 °C (7.8 °C) over the past three decades. The mean daily minimum LST is also increasing significantly over the past three decades. Accordingly, the mean minimum LST was 11.4 °C, 12.6 °C, 14.9 °C, 15.7 °C, 16.8 °C, and 18.7 °C in 1990, 1995, 2000, 2005, 2015, and 2020, respectively. This

Table 1. Details of acquired satellite images.

Satellite	Sensor	Acquisition data	Path/row	Spatial resolution
Landsat5	TM	January 25 1990	168/54	30 m/120 m
Landsat7	ETM+	February 20 2000	168/54	30 m/60 m
Landsat8	OLI/TIRS	February 16 2020	168/54	30 m/100 m
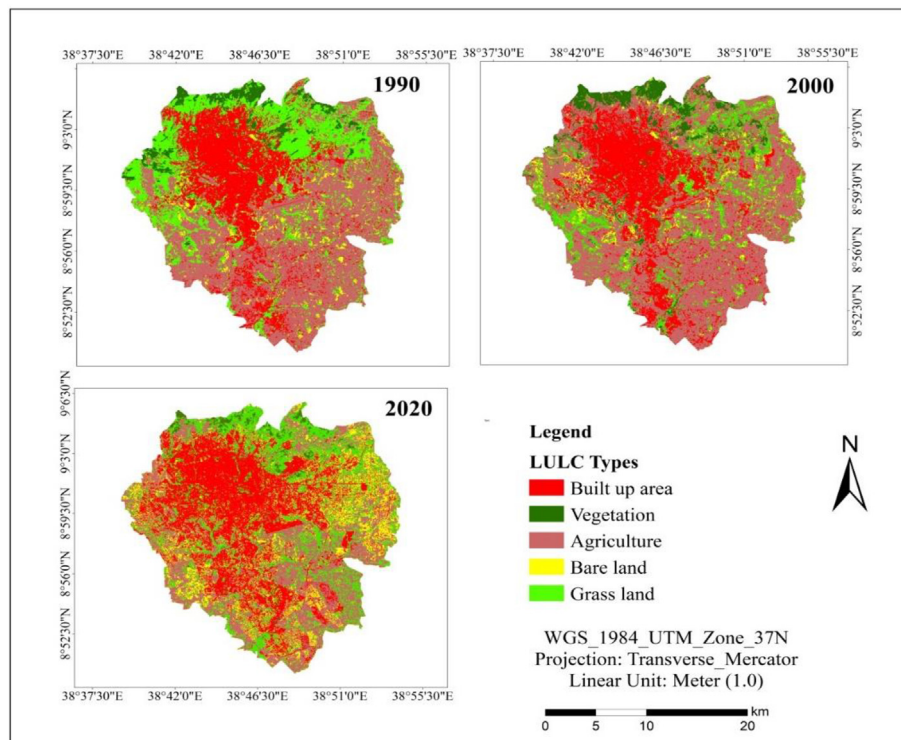
Figure 2. LULC map of Addis Ababa city.

LULC types	1990		2000		2020	
	km^2	%	km^2	%	km^2	%
Agriculture	235.9	44.8	190	36.1	155.6	29.5
Bare land	15.6	3	59	11.2	80.3	15.2
Built up area	164.7	31.3	175.6	33.3	208.3	39.5
Grassland	87	16.5	81.4	15.4	73.6	14
Vegetation	23.7	4.5	21.1	4	9.2	1.7
Total	527	100	527	100	73.6	100

indicates the mean minimum LST has increased from 11.4 °C in 1990 to 18.7 °C in 2020, that means the mean minimum temperature was increased by 7.3 °C over the past three decades. Results indicates that the central and southern parts of the city experienced the highest LST. The highest LST was observed in low vegetation area particular on built-up area, agriculture and bare land.

3.3. LST regression analysis

In this analysis, the NDBI and NDVI are independent, while LST is dependent variable (Table 3). Results show that a decreasing of NDVI and increasing of NDBI values were the main causes for increasing of LST. The LST in the city increased by 7.9°C due to decline of vegetation cover (NDVI), and expansion of built-up area (NDBI) based on adjusted R^2 values. Results of coefficient of determination between LST, NDVI and NDBI was (R^2 = 0.99) for the year 1990–2020.

3.4. Correlation between LST and NDBI

The results show that LST had a positive linear relationship with NDBI (R^2 = 0.97). The LST of the city have been increased due to rapid urbanization and loss of vegetation cover (Table 4). NDVI has negative

strong relationship with LST (R^2 = 0.98) and NDBI (R^2 = 0.99). Higher LST has low NDVI values and high NDBI values (Figure 4). Lower LST has higher NDVI values and lower NDBI values.

3.5. Urban heat island of Addis Ababa City

The results of the study showed that the spatial pattern of UHI increased from center of the city towards all directions. Particularly in 2020, the variation of UHI in central and southeastern part of the city was very high due to the expansion of built-up and loss of vegetation. This spatio-temporal variation was associated with urban expansion, which enhance UHI.

The result showed that, the maximum UHI increased from 22.9 °C in 1990 to 25.3 °C in 1995, 27.4 °C in 2000. After fifteen years, i.e., in 2005 the UHI increased to 27.8 °C. The UHI is increasing over the past decades since 1990. Accordingly, the mean maximum UHI over Addis Ababa was 28.1 °C in 2010, 29.1 °C in 2015 and 29.5 °C in 2020. The lowest maximum UHI value (22.9 °C) was observed in 1990, while the highest maximum UHI value (29.5 °C) was in 2020. Similarly, the minimum UHI also increased over the study period. Results show that the mean minimum of UHI over Addis Ababa city was increased from 9.3 °C in 1990 to 10.7 °C, 12.5 °C, and 12.7 °C, respectively during the year 1995, 2000, and 2005, respectively. In 2010 the mean minimum UHI was about 13.2 °C and increased to 13.8 °C and 14.1 °C, respectively in the year 2015, and 2020, respectively (Figure 5). Consequently, mean maximum UHI of Addis Ababa city was increased by 6.6 °C from 1990 to 2020 while the mean minimum UHI was increased by 4.8 °C between the year 1990 and 2020 over Addis Ababa city.

The replacement of green spaces by the impervious surface such as built-up area and road constructions are the key drivers for the increasing of UHI over Addis Ababa in the past three decades and expected to increase in the future under business as usual. This increasing of UHI from time to time has impacts on urban thermal comfort for people live in the city. This study found that the highest value of UHI is observed in the central part of the city where there is a complex building and high coverage of non-reflective surface.
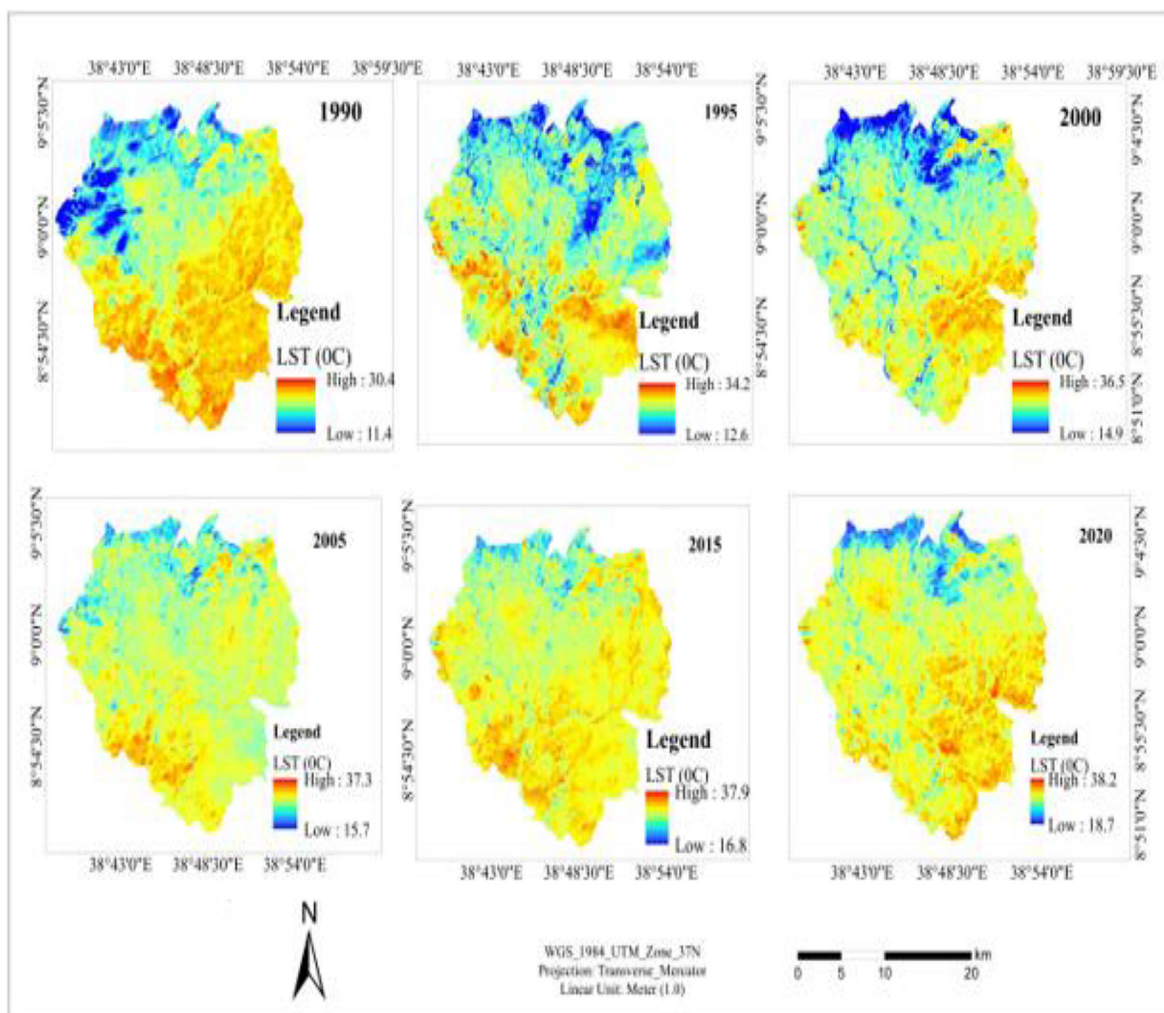
Figure 3. Land surface temperature over Addis Ababa city between 1990 and 2020.

Table 3. Correlation coefficients between LST, NDVI and NDBI.

	Coefficients	Standard error	t stat	p-value	Lower 95%	Upper 95%
*LST	44.12501314	2.560353794	17.233952	5.44E^{-07}*	38.07074	50.179288
NDVI	-100.337839	17.49438401	-5.735431	0.00070896*	-141.705	-58.97019
NDBI	-67.9575833	16.64354532	-4.083119	0.00467128*	-107.313	-28.60185

*Dependent variable: LST. *Statistically significant at p < 0.01.

Table 4. Correlation between LST, NDVI and NDBI.

Factors	LST	NDVI	NDBI
LST	1		
NDVI	-0.98396*	1	
NDBI	0.972815*	-0.99808*	1

* Indicates correlation values between them.

3.6. Estimation of ecological evaluation of Addis Ababa city using UTFVI

In this study, the UTFVI is classified into six classes based UHI to identify thermal comfort level and discomfort zone for human life. The result revealed that, about 225 km^2 (42.7%) excellent comfort for human life whereas 241.4 km^2 (45.8%) has strongest UHI, which is categorized as the worst zone for human life because of heat and warming (Table 5).

The ecological evaluation of Addis Ababa city was determined using UTFVI, which was driven from UHI values. At sub-city level, Yeka, Gulele and Kolfe-Keraniyo indicates more comfort zones and best suitable for human life. However, Addis Ketema, Bole and Akaki-Kaliti has lower comfort zone for life (Figure 6).

4. Discussions

The findings of this study provide clear evidence that LULC around big metropolitan cities are affected as increase in UHI, biodiversity loss, and ecosystem degradation that significantly affect the life of the residents. Most principally identified impacts included declining of vegetation coverage, increasing of minimum and maximum temperature which directly contributes for change in urban thermal environment. Rapid urbanization has a significant negative impact on biodiversity and
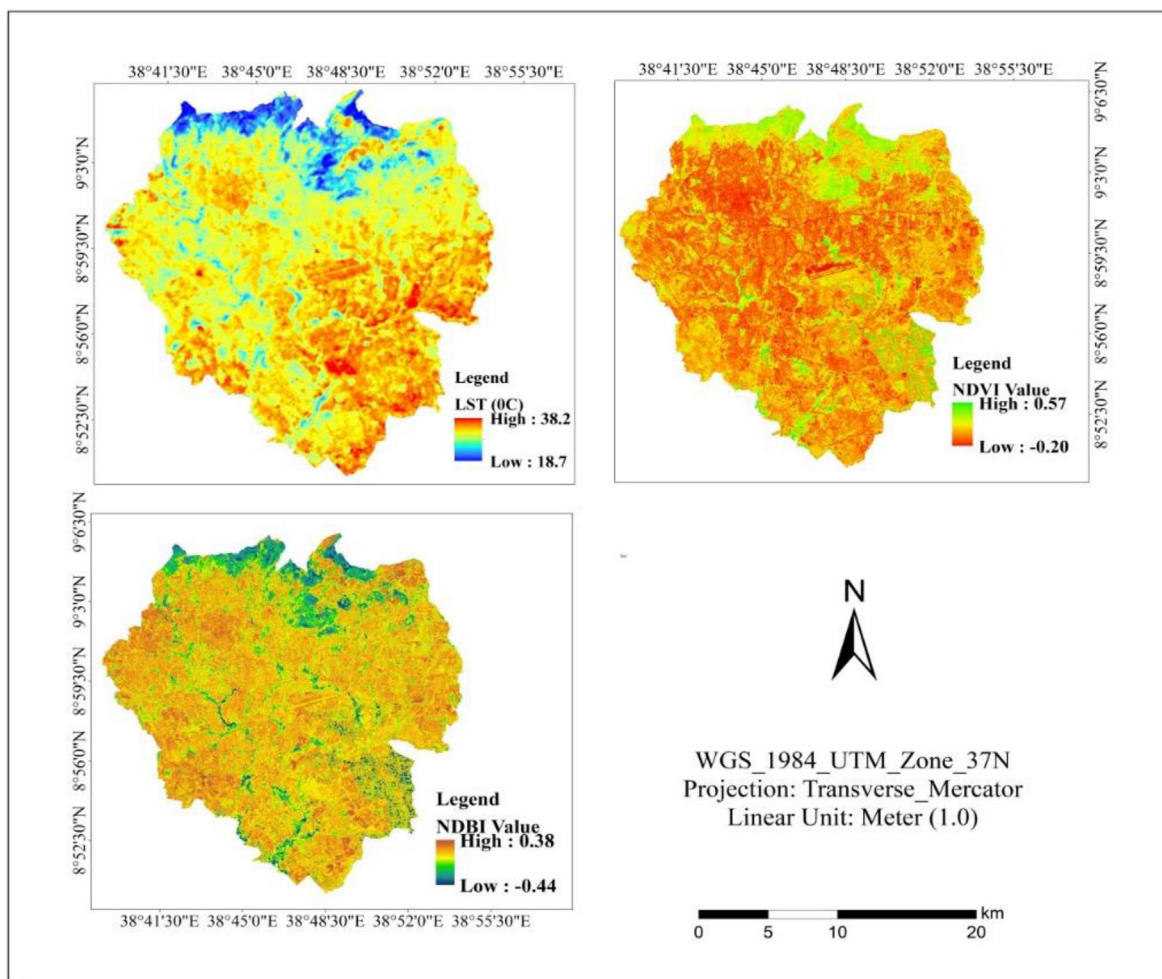
Figure 4. LST, NDVI, and NDBI map of Addis Ababa city in 2020: LST, NDVI and NDBI map of Addis Ababa city.

natural ecosystems (Mansour et al., 2022) and increases urban thermal stress (Mondal et al., 2021; Fu and Weng, 2016). Other study also documented the negative effects of land pattern change on ecosystem functions and systems (Yohannes et al., 2021).

Change and modification of LULC change particularly the declining and degradation of forest ecosystem played a key role in urban climate. Previous studies from different countries clearly indicate the negative impact of LULC change on urban environment (Kalnay and Cai, 2003; Song et al., 2018; Ayanlade and Howard, 2019; Tuladhar et al., 2019; Isioye et al., 2020; Nwakaire et al., 2020; Ayanlade et al., 2021; Dewan et al., 2021; Garcia and Diaz, 2021; Hong et al., 2021; Rahman et al., 2021; Yohannes et al., 2021; Ejiagha et al., 2022; Mansour et al., 2022). It can be argued that LULC change are likely the key drivers of environmental problems, in particular the increasing trends of urban thermal environment in metropolitan cities.

The results of this study indicated that there is a high conversion of LULC change around Addis Ababa metropolitan cities which might be driven by the rapid population growth and migration of people from countryside for better life. This assumption reconfirms earlier study by Selod and Shilpi (2021), whose work described that rural to urban migration is mainly due to higher incomes and labor market opportunities in urban areas as compared to the country side. Labor migrants have increased the local population, which is crucial to sustain services and restore the economy (McAreavey and Argent, 2018). The increasing of urban population for muti-factors accelerate rapid conversion of LULC from one type to another. From LULC types the built-up area is substantial increasing while other land cover classes like vegetation and agricultural land is rapidly declined. These reconfirmed results of Moisa

and Gemeda (2021) who reported that the built-up area was the dominant LULC types over Addis Ababa between 1990 and 2020.

The declining of vegetation cover on one hand, and the increasing of built-up area and impervious surface on the other hand highly contributed for the increasing trend of LST around metropolitan city. Over the past three decades the average daily maximum LST was increased almost by 7.8 °C (Which was increased from 30.4 °C in 1990 to 38.2 °C by the year 2021). Results indicates that highest LST was observed around clow vegetation cover area particular on built-up area, agriculture and bare land. This finding is in line with previous study by Feyisa et al. (2014) who concluded that inter-urban variation in altitude contributes for thermal variation within a city. Other study by Ibrahim et al. (2016) used the mean surface temperatures and inferential statistics to evaluate the impact of LULC change on temperature. The LULC change also aggravate climate extremes like flood as reported by Rahman et al. (2021) in Bangladesh. The other climate extremes, drought is also aggravated due LULC change (Wolteji et al., 2022).

Studying the rate of LST in response to LULC change is very important for environmental protection and life urban residents. Investigation the extent of change of urban thermal condition is very crucial, for both biodiversity and urban dwellers (Ayanlade and Howard, 2019). It is argued that the declining of vegetation cover which is detected by NDVI results to an increasing trend of NDBI and LST during the study period. Substantial scholars highlighted that the LST had a negative linear relationship with NDVI (Weng, 2004; Zhou et al., 2014; Wemegah et al., 2020; Yang et al., 2020). In contrast, LST has a positive relationship with LST. Kumar and Shekhar (2015) found that NDBI and LST has positive correlation. High reflectance in the near infrared (NIR) shows that
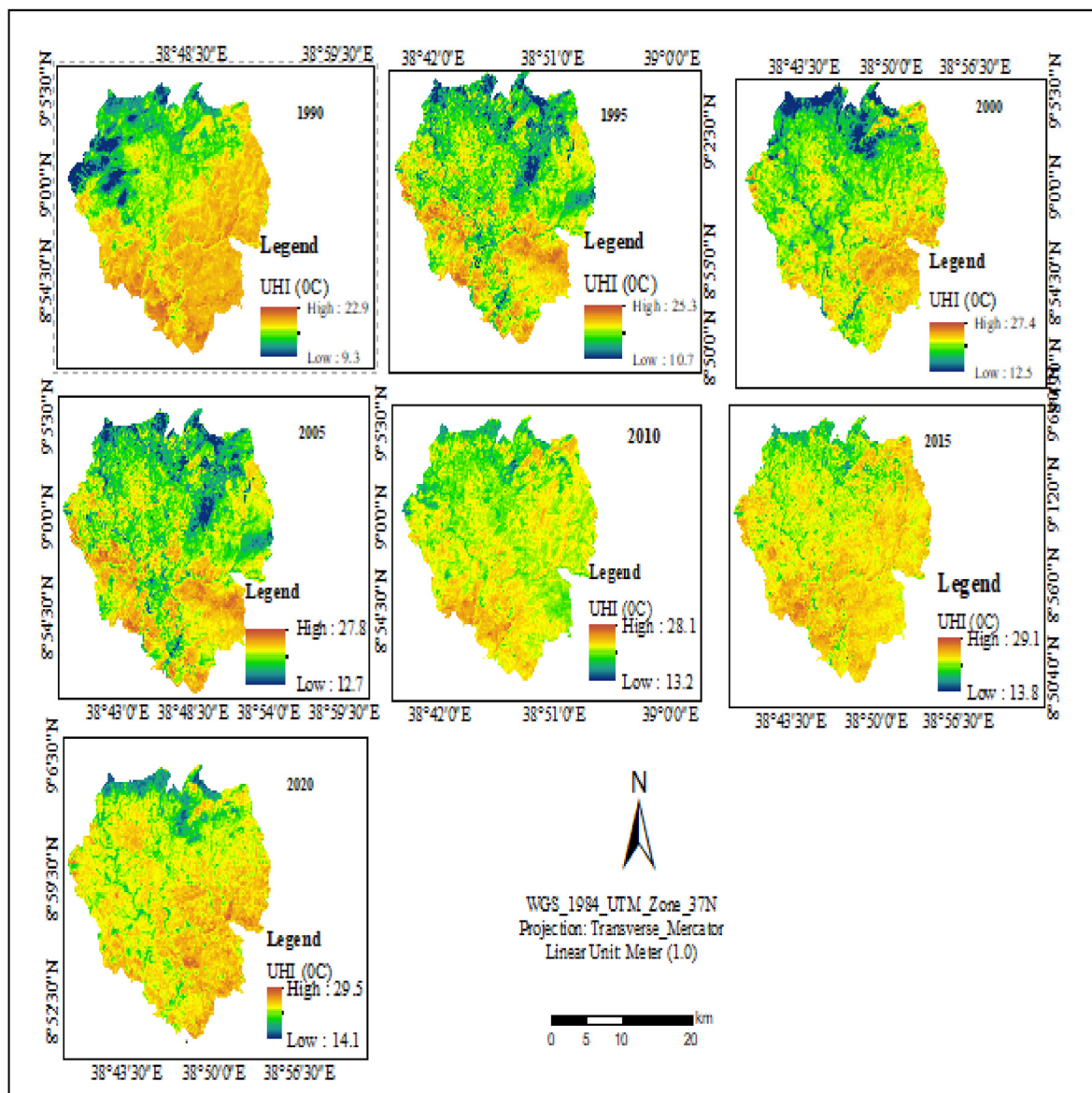
Figure 5. UHI effect map of Addis Ababa city between 1990 and 2020.

Table 5. UHI phenomenon and ecological evaluation index.

UTFVI range	Urban thermal field variance index (UTFVI)	Urban thermal comfort level (UTCL)	Area (km^2)	Area (%)
<0	None	Excellent	225.0	42.7
0–0.005	Weak	Good	14.8	2.8
0.005–0.01	Middle	Normal	15.3	2.9
0.01–0.015	Strong	Bad	15.7	3.0
0.015–0.02	Stronger	Worse	14.9	2.8
>0.02	Strongest	Worst	241.4	45.8

healthy vegetation and less reflectance in the red band indicates unhealthy vegetation (Isioye et al., 2020). There is an inverse relationship between NDVI and LST and NDVI values (Pu et al., 2006; Ibrahim et al., 2016). NDVI has a cooling effect on LST and mitigate urban heat islands (Sun et al., 2011; Zhou and Wang, 2011; Abebe and Megento, 2017; Isioye et al., 2020).

Investigating the trend of UHI is very helpful to design appropriate adaptation strategies. Previous study by Moisa et al. (2022) found that urban thermal environment is highly influenced by change in LULC. We evaluate the trends of UHI by using daily average temperature at five years intervals from 1990 to 2020. Substantial scholars detected UHI during nighttime (Kamal et al., 2015; Rasul et al., 2016; Peng et al., 2018; Ayanlade et al., 2021). However, study by Dewan et al. (2021) highlighted that daytime surface UHI is higher than nighttime in large cities in Bangladesh. Thus, little information is available concerning the daytime UHI in many cities and our studies contributes some understanding for urban dwellers and urban administration. The findings of the study clearly indicated that the spatial pattern of UHI increased from center of the city towards all directions. This spatio-temporal variation was associated with urban expansion, which enhance UHI. This study documented that the UHI over Addis Ababa city was increased by 6.6 °C over the past three decades. Accordingly, the UHI was increased from 22.9 °C in 1990 to 29.5 °C in 2020. Similarly, the minimum UHI also increased by 4.8 °C between the year 1990 and 2020. Previous studies by Moisa et al. (2022) over Jimma city in Ethiopia, and Mallick et al. (2008) over Delhi city in India found that the UHI was substantial increased due to the replacement of green space by impervious surfaces.

More importantly, this study contributes further understanding on the impact of LULC change on UHI phenomenon and ecological evaluation
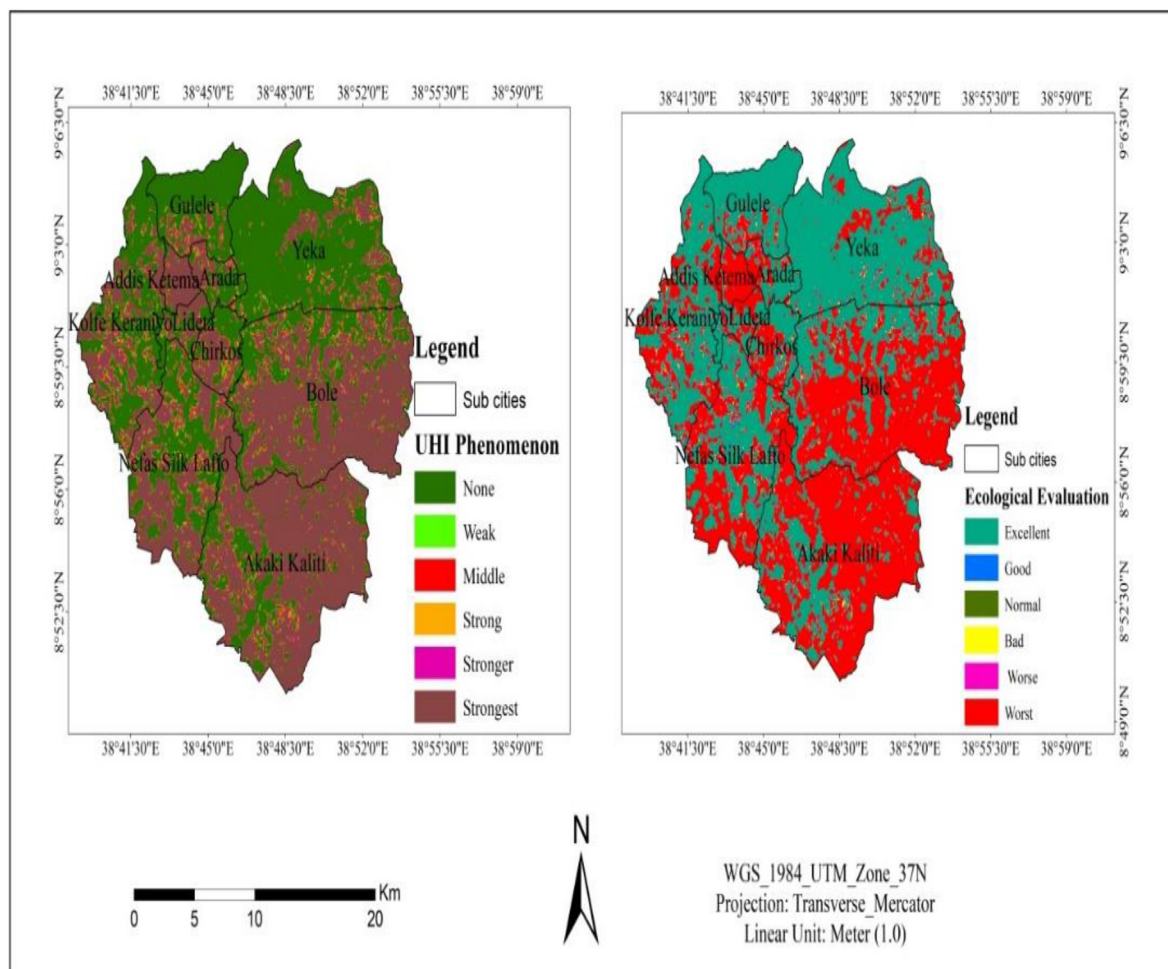
Figure 6. UTFVI and UTCL of Addis Ababa city.

index. The ecological evaluation in this study referee to the UTFVI. The ecological evaluation of Addis Ababa city was determined using UTFVI, which was driven from UHI values. In the present study, both the UHU phenomenon and, ecological evaluation index (UTFVI) are classified into six classes based UHI to identify thermal comfort level and discomfort zone for urban dwellers. Previous study by Abir et al. (2021) describes the UHI quantitatively.

This study assessed the UTFVI based on UHI phenomenon. Our results indicated that about 45.8% is categorized under the worst, while 2.8%, and 3% of the city categorized under worse and bad ecological evaluation index, which is not favorable for urban dwellers. Recent studies in various countries have confirmed that the climate around large cities are very different from the usual. The urban climate significantly changed due to the decline of forest cover and increasing of impervious surfaces. Moreover, the existing green spaces and parks are not proportional to the number of residents. More than half (51.6%) of Addis Ababa city categorized under worst to bad, which indicates that substantial areas in the city are not comfortable for city residents due to high UTFVI.

5. Conclusions

The LST of Addis Ababa city is increasing from year to year which has been attributed to the replacement of green and open spaces by impervious surfaces. The vegetation and agricultural land cover have decreased, while built-up area has increased tremendously over the past 30 years. In this study we found that there is a positive relationship

between LST and NDVI while a negative relationship between LST and NDVI. By analyzing the average daily average LST at five years intervals in 1990, 1995, 2000, 2005, 2010, 2015, and 2020, the authors found that an increase in built-up area, which contributes for the increasing trends of the LST and UHI could significantly increase the UTFVI. The UHI Phenomenon and UTFVI are used to assess the urban health over Addis Ababa metropolitan city and the results indicates that more than half of the city is categorized under worst to bad thermal comfort level, which need urgent attention from city administration and other concerned stakeholders.

Analysis of UHI reveals significant difference among the sub-cities which is directly associated with the physical land features. The ecological evaluation index of Addis Ababa metropolitan city is measured using UTFVI. From the total, only 42.7% and 2.8% of the city is categorized under excellent, and good condition, respectively. A high proportion, which is about 45.8% is categorized under worst UTFVI category, while 2.8% and 3.0% are under worse, bad UTFVI Category. The results conclude that Yeka, Gulele and Kolfe-Keraniyo sub-cities are more comfortable while Addis Ketema, Bole and Akaki-Kaliti are less comfortable for human life because of higher UTFVI. All stakeholders need to work hand in hand to improve the problem of climate change in the urban environment. More specifically, it is very important to conserve trees in cities and expand parks for green spaces to make cities more suitable for human life. Thus, decision makers and urban planners should consider the importance of urban green and open spaces to mitigate the potential impacts of UHI over city dwellers.

Declarations

Author contribution statement

Mitiku Badasa Moisa: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Dessalegn Obsi Gemeda: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Data availability statement

Data will be made available on request.

Declaration of interest's statement

The authors declare no conflict of interest.

Additional information

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