ADDIS ABABA UNIVERSITY

COLLEGE OF NATURAL AND COMPUTATIONAL SCIENCE

CENTER FOR ENVIRONMENTAL SCIENCE

URBAN LAND USE LAND COVER CHANGE AND ITS EFFECTS ON LAND SURFACE TEMPERATURE: THE CASE OF YEKA, BOLE AND AKAKI-KALITY SUB CITIES

Kinfe Kidanewald

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This is to certify that the thesis prepared by Kinfe Kidanewald entitled "Urban land use land cover change and its effect on Land surface temperature: the case of Yeka, Bole and Akaki-kality Sub cities" and submitted to the partial fulfillment of the requirement of the degree of Master of Science complies with the regulation of the University and meets the accepted standard with respect to originality and quality.

Signed by Examining committee:

Examiner Mekuria Argawe (PhD) Signature ______________Date____/___/____

Examiner Ermiase Teferie (PhD) Signature ______________Date___/_____/____

Advisor Gudina Legesse (PhD) Signature ______________Date___/____/____

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Chair of Department or Graduate Program Coordinator

Abstract

Urban land use land cover change and its effect on land surface temperature: the case of Yeka, Bole and Akaki-kality Sub cities

Kinfe Kidanewald

Addis Ababa University, 2018

This research is about the impact of urban land use land cover change on land surface temperature in Yeka, Bole and Akaki-kality Sub-City of Addis Ababa. The study examined the change of land use land cover in the past 20 years and analyzes its effect on the land surface temperature in the years 1998, 2010 and 2017 by applying remote sensing and GIS technologies. The LULC map of the study years was developed using Landsat image using support vector machine algorithm of supervised classification through ENVI 5.3 software and the land surface temperature was retrieved using the thermal band of Landsat image which was band 6 and band 10 for landsat 5 and 8 respectively. The study also examined different residential areas urban morphology types of land surface temperature. The UMT are condominium, villa and mud house. These UMT are extracted by digitizing from the Google earth explorer and converting into shape file using Arc GIS 10.3 software and the land surface temperature of each urban morphology type polygon were computed in zonal statistics using LST map of the study area. The result indicated that the study area is under extensive land use land cover change in the past two decades and showed that the land cover class of farm land /bare land declined by 34.20% whereas built-up increased by 28.70% respectively. Even if the vegetation is the smallest portion of the study area it shows a slight increment by 5.50%. The mean land surface temperature of the study area showed an increment from the period of 1998 to 2017 by 2.20^{0}C and among the land use land cover categories the built-up LST showed an increasing trend. The residential urban morphology types have a significant mean LST difference and the mean NDVI value of the UMT were-0.0726 (condominium),-0.0186 (villa) and -0.0388 (mud house) respectively. Average mean land surface temperature of the condominium has the highest than the other UMT because of its lowest NDVI value. Therefore, future expansion or urbanization without proper urban planning or management and considering environmental perspective, it will accelerate the modification of local climate and development of UHI. Therefore, any development activities should take in to account the future environmental condition of the area in order to make the environment suitable for living.

Key words: Land use land cover, Urbanization, Land Surface Temperature, GIS, Remote sensing, Urban Morphology Type

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Acronyms and Abbreviations

AAEPA	Addis Ababa Environmental Protection Agency
ANOVA	Analysis of Variance
CSA	Central Statistical Agency
DEM	Digital Elevation Model
DN	Digital Number
ENVI	Environment for Visualizing Images
FAO	Food and Agricultural Organization
GCP	Ground Control Point
GIS	Geographic Information System
GPS	Global Positioning System
ha	Hectare
ISA	Impervious surface area
LST	Land Surface Temperature
LU/LC	Land-Use/Land-Cover
m a. s. l	Meter above sea level
Mm	millimeter
NDBI	Normalize Difference Building Index
NDVI	Normalized Difference Vegetation Index
NMA	National Metrologic Agency
OLI	Operational Land Imager
QUAC	Quick atmospheric correction
SVM	Support Vector Machine
TIR	Thermal Infrared
TM	Thematic Mapper
UHI	Urban Heat Island
UMT	Urban Morphology Type
USGS	United States Geological Survey
UTM	Universal Transverse Mercator

1. Introduction

1.1 Background

Urban population is increasing at higher rate throughout the world since most people live in urban areas than in rural areas. World urbanization prospect report indicated that world's population's live urban areas were increased from 30 percent to 54 percent of the total world's population from 1950 to 2014. It will expect to be 66 percent in 2050 (Nations, 2014). This increment can be related with migration toward urban areas, natural increase, slow rate of technology change, drought which is caused by the climatic condition, an availability of infrastructure in their hometown and the reclassification of rural areas as urban centers (Henderson et al., 2017). This lead to extensive land acquisition for urban developmental infrastructure and it accelerates land use land cover change in our globe (Wang et al., 2018). And this urbanization induced land use land cover change rate is higher in developing countries (Arsiso et al., 2018). The term land use land cover change is the conversion of one type of land use land cover to another type that means from forest or farm land to built-up (Houghton, 1994).

According to McCarthy et al.,(2010) LULC change is one of the major global environmental problems mainly is caused by expansion of urbanization And the main environmental consequences of LULC change is changing local climate through the increment of urban land surface temperature (LST) than the nearby rural area. It is the main characteristics of land surface which directly influenced by land use land cover change (Wang et al., 2018). LST measures how hot land surface at a particular location which represents temperature recorded at the interface between earth surface and immediate atmosphere (Valiente et al., 2010). It influences the process of energy exchange between the land surface and the atmosphere and contributing to changing local environmental conditions (Chen et al., 2006).

The replacement of different land use land cover type to urban land cover with impervious surface type disturb the extent of solar radiation absorption, albedo, (Fu, 2003) which disturb evaporation rates, transmission of heat to the soil, storage of heat, wind turbulence, and mainly change environments of the near-surface atmosphere over towns (Mallick et al., 2008). The possibility of increasing land surface temperature, create drought, heat stress and urban heat island (UHI) phenomenon in urban centers (Takeuchi et al., 2010). Moreover, increases the air temperature in a long time period (Wang et al., 2018). These affect atmospheric state, thermal properties of the surface and subsurface mediums (Becker and Li, 1990) which disturb the ambient habitat for the human beings and other ecosystem members (Khandelwal et al., 2017).

Different researchers tried to investigate the relation between LULC and LST by using remotely sensed thermal infrared (TIR) imagery because LST is a key variable to understand the impacts of urbanization induced land use and land cover (LULC) changes (Fu and Weng, 2016). The Study conducted in Nigeria, Lagos metropolis indicated that built-up area increase over 100 % which is from 38.276 % to 79.561 % and vegetation decreases very rapidly with the stated study year from 70 % to 10 % from 1984 to 2013. Due to this increment, LST ranged from 21 ^{0}C to 35 ^{0}C during the study period (Babalola and Akinsanola, 2016). Similar studies were conducted in different parts of Ethiopia; Debretabore district in Northeast part of Ethiopia experienced increment of urban land, cultivation land and bare land by 10.35 %, 10.05 % and 8.49 %, respectively and decline of shrub land and forest land by 17.44 % and 11.45 %, respectively. The increment of urban built-up resulted in increment of LST by 0.2714 ^{0}C within a 15-year time period of 1999 to 2014 (Kebede et al., 2017).

Urban expansion in Addis Ababa converted forests, agricultural lands, grass lands and bare lands to built-up areas because of these conversion significant LST increment showed from the period of 1986 to 2011 in different land use land cover types and LST increased about 3.32 ^{0}K, 1.65 ^{0}K, 1.27 ^{0}K and 0.29 ^{0}K, for the areas forests, agricultural lands, grasslands and bare lands respectively due to the transformation into Built-up areas, (Teferi and Abraha, 2017). Even if Satellite-based remote sensing data used for estimation and retrieval almost true kinetic energy of radiant temperature (Rani et al., 2018). But most studies neglect the effect of elevation or in studying the spatial distribution of land surface temperature. Beside other factors, elevation plays a significant role in LST dynamics. So there is need to solve the altitudinal effect and find out the LULC change and UMT effect on LST.

1.2 Statement of the problem and justification

World urban areas are experiencing dramatic rapid population growth (Cohen, 2006). Due to this existed land use land cover types are transformed to new land use land cover types. This rate is relatively high in developing countries (Hegazy and Kaloop, 2015). As a developing country Addis Ababa, the capital of Ethiopia is also facing high rate of land use land cover change due to urban development activities expansion led by government and private sectors mainly mass housing program like condominiums, single residential and real state constructions and other developmental activities such as construction of roads and railways For example, there are visible evidences from newly established woreda Ayat, Lebu, Bole bulbula, Bole arabesa, Gellane, Summit, etc.. Are areas that taken place developmental activities of mass housing programs. These expansion resulting declines of agricultural land and forest areas and more surfaces areas in cities are changed to buildings (Teferi and Abraha, 2017).

Even though different researchers try to asses land use land cover change and its impact on land surface temperature increment in Ethiopia even in Addis Ababa using Geographical Information System (GIS) and Remote Sensing techniques but they fail to consider the effect of altitude on temperature which is one of the major factor that affect temperature beside other factors. Increasing of altitude result decreasing of temperature this reduction is referred as environmental lapse rate. Environmental lapse rate is fall in temperature with altitude, at any location, along the same column of air above the ground surface, i.e. in the vertical direction (Khandelwal et al., 2017). To solve such problem studies should relate spatial distribution of LST such as urban heat island studies; climate change studies and effect of elevation should also be considered and the value should be rationalized based on elevation difference. So this study assessed the land surface temperature of different land use land cover types by removing the altitudinal effect. Moreover, there is no sufficient study regarding urban morphology type and its thermal effect in Addis Ababa and the study tried to examine the thermal effect of different urban morphology types by removing the effect of altitude because it is difficult to compare different UMT thermal properties that are found in different altitude.

1.3 Objective of the study

1.3.1 General objective

The main objective of this study is to assess temporal and spatial analysis of land use land cover dynamics through remote sensing and GIS and examine its impact on land surface temperature in Yeka, Bole, and Akaki-kality sub-city

1.3.2 Specific objectives

- To examine the change in land surface temperature due to land use land cover change
- To understand the relationship between LST, LULC and vegetation influences
- To examine the thermal variation among various urban morphology types

1.4 Scope of the study

This study was conducted in Yeka, Bole and Akaki-kality sub-cities of Addis Ababa; Ethiopia, it focuses on the impact of urban land use land cove change on land surface temperature. The study also examined different residential UMT land surface temperature of the study area.

1.5 Significance of the study

This study will provide valuable information on trend of land use land cover change and its associated land surface temperature LST in the study area. It will inform for different stakeholders for their decision making processes, urban and rural land management, natural resources managers and environmental experts. It will also be source of information for further study in same or other studies.

1.6 Limitation of the study

Difficulty to get high resolution images for better, high accuracy and precision result on mapping and classifying land use land cover map of the study area. Bureaucracy and limited accesses to get data from different organizations were the major limitation.

1.7 Structure of the thesis

This thesis consists of six major parts. First part focuses on background and statement of problem objectives, scope, significance and limitation of the study. Second part includes review of related literature and the third part is material and method. The result and discussion sections included in the fourth and fifth part respectively, finally Conclusion and recommendations included in the sixth part of the thesis.

2. Review of related literature

2.1 Remote sensing and GIS

Remote sensing is process of detecting and monitoring the physical characteristics about an object, a place, or phenomenon through the analysis of data acquired by a device without contacting the object, which is under exploration (Chipman et al., 2004) and geographic information system (GIS) is a computer-based system that is used for data capture and preparation, managing, visualize, analyze and interpret data and it helps to understand trends, patterns and relationships between different types go-referenced data . (Huisman and De By, 2009).

currently remote sensing and GIS techniques are the most useful tool to examine and forecast environmental changes with considerable decision making approaches (Choudhary et al., 2017). Because Remote sensing (RS) data can provide fundamental information on growth-related processes and their influence on the urban environment, as well as the spatial distribution of land use/land cover classes (Hussain et al., 2013). Different studies were used and approve the effectiveness of GIS and Remote sensing techniques for mapping of land surface temperature variation retrieved from Landsat thermal data (Weng et al., 2007). infrared remote sensing imagery has also been widely applied to retrieve land surface temperature; to study spatial pattern relationship between UHI and urban surface characteristics that are mainly affected by land use land cover characteristics of different land use because each land use land cover has its unique thermal, moisture, and optical spectral properties (Oke, 1982)

The reasons for the high demand of RS applications is the large area coverage it can offer for accessing of areas which are not accessible and it is always actual and timely (Muttitanon et al., 2004).

2.2 Concept of land use land cover change

The term land use refers to land cover type planned to use and managed by human beings such as forestry, agriculture, and infrastructure. Whereas land cover is biophysical cover found above earth surface, including distribution of vegetation, water, bare soil and artificial structures (Meyer and Turner, 1992). According to Di Gregorio, (2005), Land use defined as the arrangement, activities and inputs (management) taking place by human being in a specific land cover type to maintain the land cover and produce goods. LULC change means conversion and modification of one LULC type to another LULC by changing the physical, functional attribute LULC for example forest converted to buildings.

land use land cover change is influenced by the different factor that is directly or indirectly related to human population growth, economic development, technology and environmental changes (Houghton, 1994). Agricultural intensification, urbanization, range land modification and globalization are the major causes of land use land cover change of the globe (Lambin et al., 2001). According to Ramankutty and Foley, (1999) finding almost 6 million km^2 of forests/woodlands and 4.7 million km^2 of savannas/grasslands/steppes were converted to crop land throughout the world. Urbanization contributed LULC change through transformation rural area and causes ecosystem fragmentation in an area due to the demand for conservation and recreational land uses (Areas, 1997). And it also puts pressures on natural resource (Hegazy and

Kaloop, 2015). Because LULC changes significantly affect central aspects of earth system functioning and aggravate vulnerability of places and people to climatic, economic, or sociopolitical perturbation (Kasperson et al., 1995).

2.3 Over view of land surface temperature

LST is a measure of how hot land surface at a particular location and it define as the skin temperature of the surface (Latif, 2014). It is an essential factor in many areas like global climate change studies, urban land use/land cover, geo-/biophysical and also an input for climate models (Reddy and Manikiam, 2017). Moreover, it drives from thermal band which is located in the thermal infrared region from geometrically corrected Landsat Thermal Infrared (TIR) band 6 and Landsat 8 thermal infrared (TIR) band 10 and 11 (Yu et al., 2014). In remote sensing image based land surface temperature retrieval land surface emissivity (LSE) is crucial (Li et al., 2013). Because the emissivity value significantly vary with vegetation, surface moisture, roughness, and viewing angles (Salisbury and D'Aria, 1992).

Emissivity is a ratio which compares the radiating capability of a surface to that of an ideal radiator or black body (Artis and Carnahan, 1982). Researches uses different method to determine the emissivity values, NDVI based is one of the method for driving land surface emissivity (Valor and Caselles, 1996).

LST is a key variable to understand the impacts of urbanization induced LULC changes (Fu and Weng, 2016), because it has a capacity to systematically characterize the thermal environment at a city-scale at a specific period of time (Li et al., 2011) as cited by (Guo et al., 2016). Rapid urbanization has caused significant land cover change (LCC) as well as changes in the land surface temperature (LST) because it has a direct correlation in between (Forman, 2016) and studies have also identified that physical processes, such as radiative fluxes, and land surface material characteristics (e.g., albedo, emissivity, thermal capacity, and conductivity) can clarify the correlations between land cover types and temperature (Yu et al., 2018) and different studies also shows that urbanization process has the capacity to rise the land surface temperature of an area because different land use land cover types that have a significant for cooling effect through the process of evapotranspiration has replaced with impervious surface type (Tayyebi et al., 2018; Madanian et al., 2018 &Wang et al., 2018).

2.4 Normalized difference vegetation index

NDVI is a single band product and calculated as a ratio between the red (R) and near-infrared (NIR) values used to distinguish vegetated area with non-vegetated area. It drives from NIR and Read infrared (USGS, 2014) and the value lies between -1 and 1 Higher NDVI value indicate healthiness of vegetation and how dense is the vegetation.

Vegetation coverage is one of the most important indicators of a regional ecological situation. Vegetation growth conditions determine the land surface temperature of a specific area because high NDVI value indicates low land surface temperature (LST) by the latent heat flux from the surface to atmosphere via evapotranspiration. Lower LSTs usually are found in areas with high NDVI (Li et al., 2015).

NDVI value and LST have an inverse relationship as shown in different studies. findings forward that there is need to be greenery area or urban vegetation cover in order to maintain urban climate, minimize urban heat island (UHI) effect and sustain of the urban ecosystem (Ibrahim and Rasul, 2017).

2.5 Urban heat island and its effect

Studies that are related to environment and climate use land surface temperature for different purpose from those for urban heat island forecasting can be mentioned (Quattrochi and Luvall, 1999). Urban heat island (UHI) is a climatic phenomenon when urban areas have higher air temperature and surface temperature than nearby rural area (Shahmohamadi et al., 2011). UHI affected cities are separated from surrounding natural and rural environments in terms of climatic elements, air, and surface and land use type (Feyisa, 2013). This have effect on ecosystem processes, biogeochemical cycles, biodiversity and human activities and it has also a probability to alter of precipitation pattern and decreased air conditioning urban area (López et al., 2001).

UHI effect aggravated by anthropogenic activates by generating heat from different sources such as traffic, domestic buildings, industries, densely constructed mass buildings. due to this attention is given on increasing trend of UHI, its effect in different Urban climatology studies (Yuan and Bauer, 2007).

Vegetation has a role to mitigate the effect of UHI as different studies recommend. planting trees in urban area has a very significant cooling effect, the study conducted on efficiency of parks in mitigating urban heat island effect in Addis Ababa by (Feyisa et al., 2014) explained that high intensity of tree canopy cover has higher cooling effect on daytime air temperature.

2.6 Effect of urban morphology types

The physical structure of urban built ups such as building height, size, density and pattern described as urban morphology. Building height increase solar radiation absorbed by building which contributed for UHI development (Yang and Li, 2015). Recently different studies analyzed urban morphology. The methods used to obtain morphological information's are one field measurement and satellite-based second approach. Field measurement is the most common method for obtaining urban morphological data; it can be implemented quickly and easily, and it is very accurate for small study areas but it needs more time and labor, whereas satellite technology is a fast and economical method for obtaining urban morphological information over large areas and help to study UMT and UHI relationship (Yu et al., 2010) as cited by (Xu et al., 2017).

According to Xu et al., (2017) urban areas with higher building density and more complex urban morphology exhibit strong heat islands and low urban air ventilation. It is important indicator for urban planning and urban climatic applications.

2.7 Research approaches on Land surface temperature and Land use land cover change relationship

There are different approaches used to investigate the impact of land use land cover change on land surface temperature, remote sensing and GIS can be mentioned (Chen et al., 2006). GIS and remote sensing are most widely used techniques to study land use land cover change analysis; detect and examine temporal changes of different land use land cover, mapping land surface temperature and analyze the relation with LULC change and to analyze the correlation between LULC change and Normalized difference vegetation index (Tarawally et al., 2018; Xiao and Weng, 2007). Different land use land cover categories indices also used to examine the impact of land use land cover change on land surface temperature which include normalize difference vegetation index (NDVI), normalized difference building index (NDBI) these indices indicate vegetation built up and bare land relation and high NDBI value indicate areas with high and intensive urban development (Shi et al., 2015).

Impervious surface area (ISA) can be also mentioned as most important techniques used to quantify the degree of urbanization impact on land surface temperature. It is mainly associated with transportation (streets, highways, parking lots and sidewalks) and building rooftops in remote sensing (Yuan and Bauer, 2007). The Degree of urbanization has a capacity to affect land surface temperature by altering the sensible and latent heat fluxes (Yang et al., 2003). Using ISA the relationship between land surface temperature and urban characteristics can be quantified (Chen and Zhang, 2017).

3. Material and methods

3.1 Study area description

3.1.1 Location

The study area is located in the South Eastern part of Addis Ababa which include Bole, Yeka and Akaki-kality sub cities, these parts of the city is the most rapidly expanding and growing in Addis Ababa due to massive housing programs for residential purpose, industrial expansion and other infrastructural activities. The study area lies between 38 ^{0}45’ E-39 ^{0}E and 8^{0} 45’45” N- 9^{0}7’30”N (Figure 1). The area covers a total area of 32634 ha.

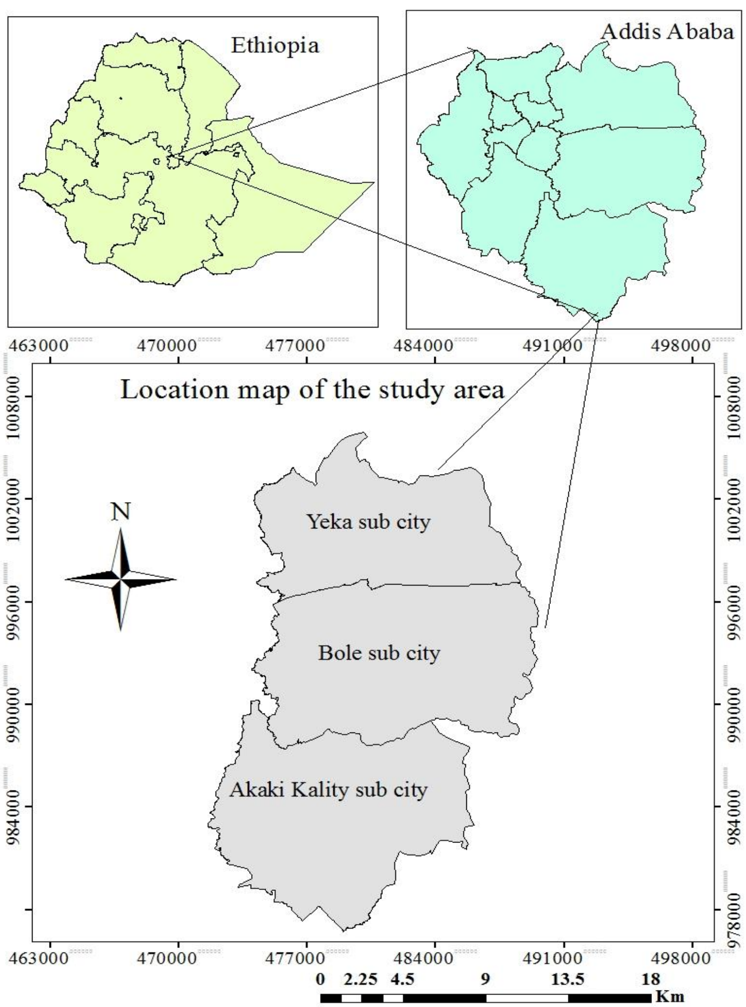


Figure 1: location map of the study area

3.1.2 Topography

The study area has characterized by mixed topography with an altitude difference ranging from 2054-3126 m.a.s.l .The slope of the area varies significantly from one area to another, generally the study area dominated by flat area, which was mostly agricultural land, from the three sub cities Yeka sub city is the hilly side of the study area and the slopes ranging lies between 25 and 48 degree (Figure 2and 3).

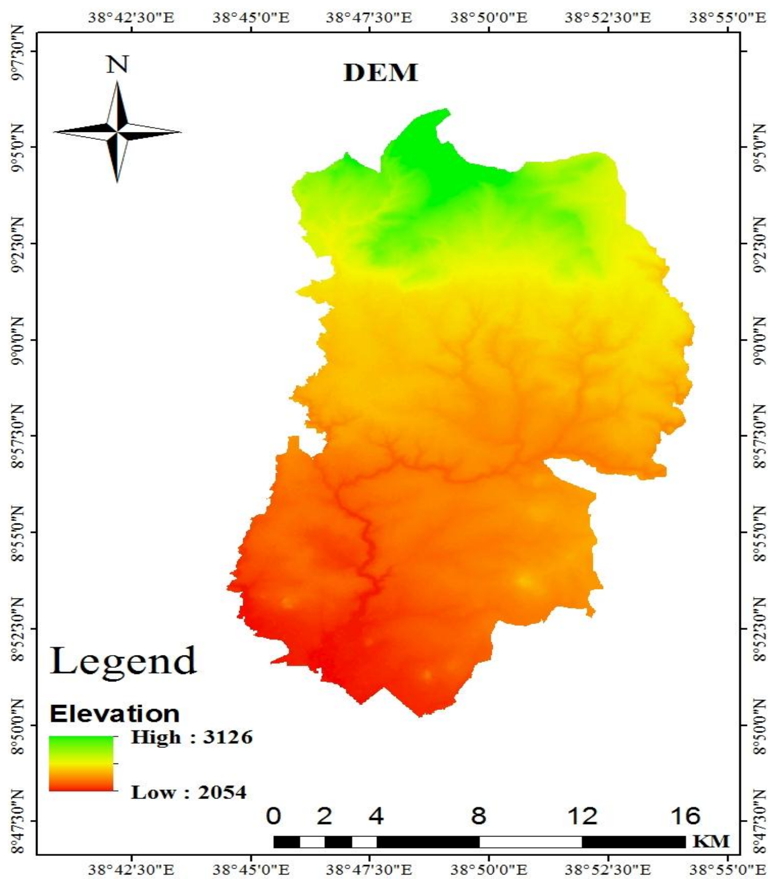


Figure 2: Digital elevation model (DEM) of the study Area

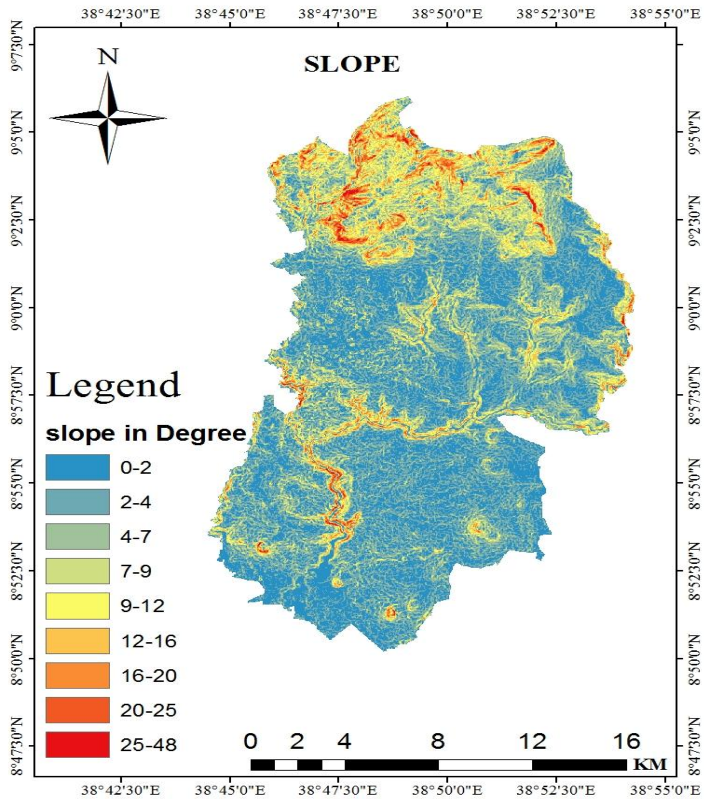


Figure 3: Slope map of the study area

3.2 Climate

3.2.1 Rain fall

Addis Ababa has dry and wet season ,the wet season is from June to August which receives maximum rainfall and the driest season is from December to April (Conway et al., 2004) Based on the national metrological agency mean monthly rainfall from the period of 1998 to 2017 in three stations which are at Koteb, Bole and Akaki-kality show that the mean annual rainfall at Kotebe (at an elevation of 2755 ma.s.l.), Bole (at an elevation of 2354 m.a.s.l), and Akaki (at an elevation of 2057m.a.s.l.) are 960mm, 998mm and 955.mm, respectively. From this, the study area receives average annual rainfall of about 971.mm.

The study area, monthly total rainfall records of the three stations for the year between 1998 and 2017 is used to analyze monthly mean rainfall and annual mean rainfall. And the mean maximum rainfall for the three stations is recorded in the month of August, The mean monthly rainfall of National Meteorological Agency stations located at Bole, Kotebe and Akaki are shown in (Figure 4).

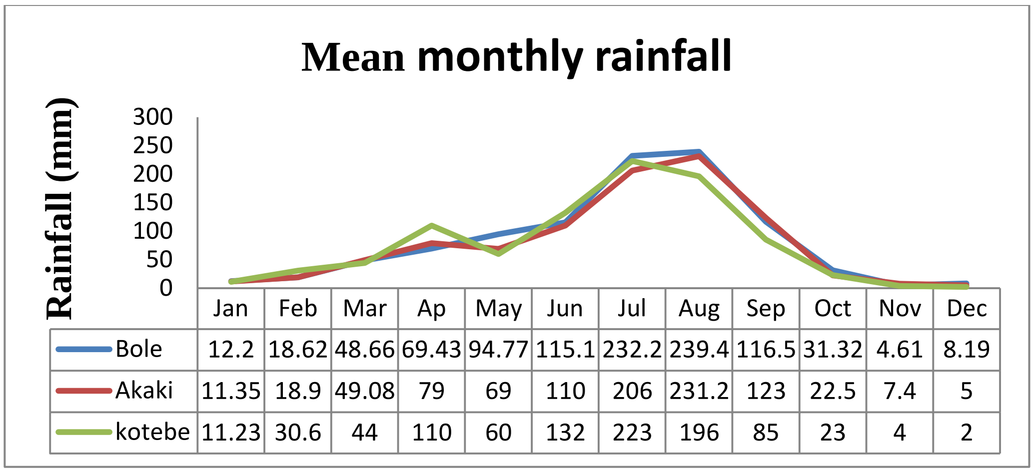


Figure 4: Mean monthly rainfall from 1998-2017(Data source: National Metrological Agency (NMA) of Ethiopia, 2017)

3.2.2 Temperature

Monthly Mean Minimum and Maximum temperature that are recorded at Bole and Akaki station for the year between 1998 and 2017 was used to analyze mean monthly temperature. The calculated average maximum and minimum temperature are given in (Figure 5 and 6).

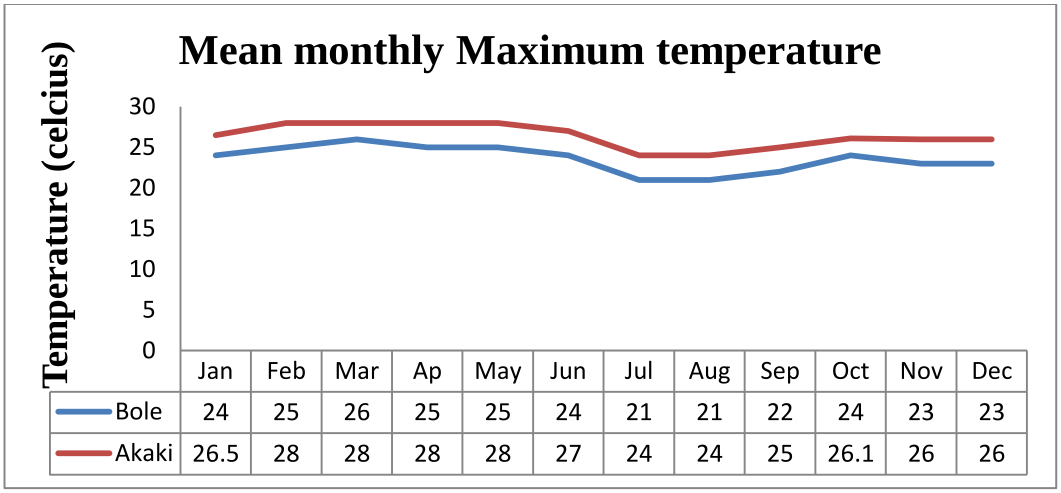


Figure 5: Mean monthly maximum temperature from 1998-2017 (Data source: National Metrological Agency (NMA) of Ethiopia, 2017)

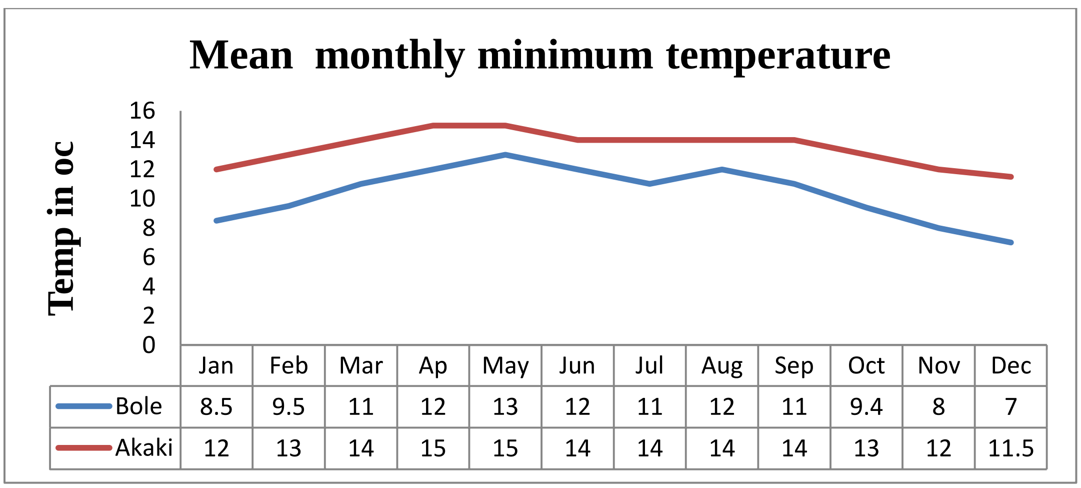


Figure 6: Mean monthly minimum temperature from 1998-2017 (Data source: National Metrological Agency (NMA) of Ethiopia, 2017).

The highest mean monthly maximum temperature in both stations found in the months of March and the lowest is in the month of July. The mean monthly minimum temperature in the stations is in December and the highest in May. Therefore the average temperature of the study area (for the period 1998-2017) is 18.4^{o}C.

3.3 Population

Total population of Addis Ababa is estimated 3,434 000 and from this, the study area or these three sub cities occupies 30.5 % of Percent of the total population of the city and the total population of each sub-cities which are, Yeka, Bole and Akaki-kality are 434,599, 387,355 and 227,182, respectively (CSA, 2013) according to CSA population and housing census of Ethiopia Addis Ababa population was 2,211,737 in 1994 and 2,757,729 in the year of 2007 and projected 2017 is 3,434000 (Figure 7and 8) shows the trend of population growth in Addis Ababa and in the study area from the period of 1994 to 2017.

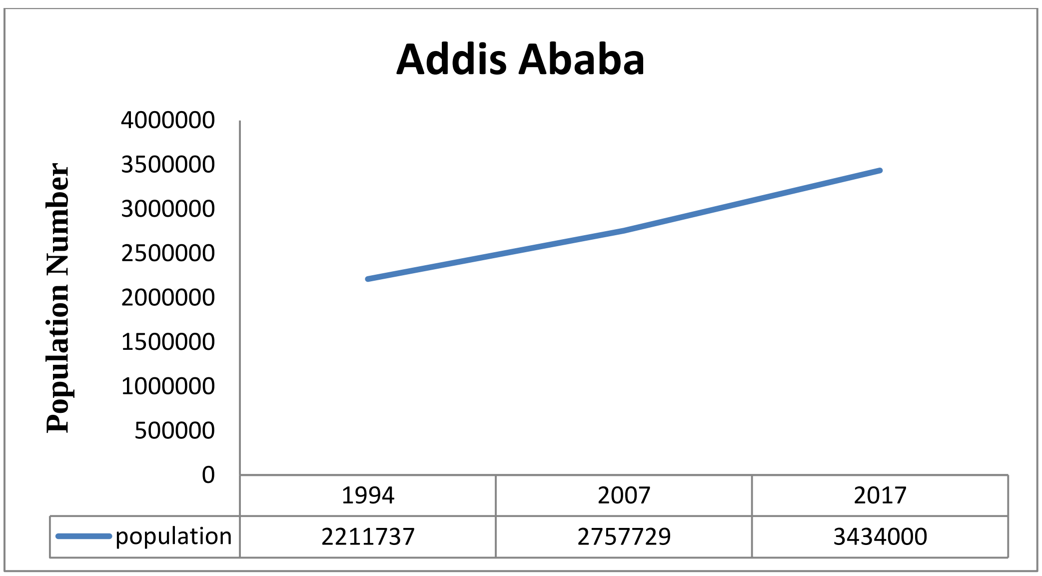


Figure 7: Total population trend in Addis Ababa from 1994-2017 (Data source: CSA1994; 2007and 2017 projection).

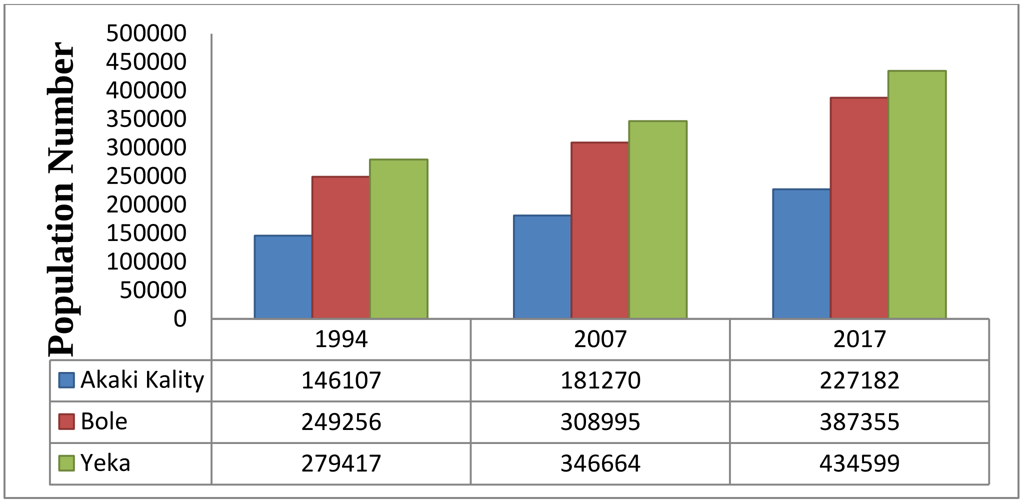


Figure 8: Total population trend in Akaki-Kalit, Bole and Yeka sub-cities from 1994-2017 (Data source: CSA, 1994, 2007and 2017 projection).

4. Data type and source

In this study Landsat satellite image of Thematic Mapper (TM) 1998 and 2010; Operational Land Imager/Thermal Infrared (OLI/TIRS) of 2017 which were obtained from USGS (http://earthexplorer.usgs.gov/) were used. All the images were taken in dry season between January and December in order to resolve the seasonality predisposition. The satellite images were projected to Universal Transverse Mercator (UTM) projection with datum of WGS 1984, zone 37N. Furthermore, Digital Elevation Model (DEM) data with the resolution of 30*30m was also used for mapping the elevation and slope of the study area. To supplement the image data field observation about urban land use types;

GPS points (GCP) which was used for ground truth points (training sites) for land use and land cover mapping. Finally Metrological data also used in order to identify minimum, maximum temperature and precipitation of the study area from National Meteorological Service Agency of Ethiopia. The Landsat data source and acquisition date is summarized in (Table 1).

Table 1: Land sat data type and acquisition date

Satellite Image	Sensor	Date of acquisition	path and row	Cloud cover
Landsat 5	TM	1998-12-24	168/054	0.00
		2010-12-09	168/054	1.00
Landsat 8	OLI	2017-01-10	168/054	0.01

4.1 Software

ENVI v5.3: used for digital image processing and spatial modeling and retrieve LST

Arc GIS v10.3: used to analyze correlation between land surface temperature; land use land cove change and to calculate land surface temperature of the study area. .

R statistical package v. 3.3.2: used to analysis correlation relation and test of significant.

4.2 Image analysis

4.2.1 Landsat image preprocessing

The satellite images were distorted due to noise, haze problems and need image correction hence, before proceeding to extracting of information, image preprocessing activities has taken place because it is mandatory. These includes Atmospheric correction, clipping, layer stacking and image enhancement preprocessing activities were applied using the software ENVI v5.3.

Atmospheric correction is the process is applied to reduce influence of atmospheric effects on images, improve quality of true surface reflectance values and to retrieve physical parameters of the Earth's surface, including surface reflectance, by removing atmospheric effects from satellite images and it is the most important part of the pre-processing of satellite image data (Hadjimitsis et al., 2010). For the present study atmospheric correction process was undertaken using ENVI 5.3 software with algorithm of Quick Atmospheric Correction (QUAC). And image enhancement activities also undertaken.

Image enhancement is a process of improving the interpretability or perception of information in images for the user and providing good input for other image processing techniques. The aim of image enhancement is to modify attributes of an image to make it more suitable for a given task and a specific user this activity which include image sharpening (Maini and Aggarwal, 2010). Image enhancement was also done using ENVI 5.3 software.

4.2.2 Image Classification

Digital image classification is the process of allocating pixels that represent a specific land use land cover class. Each pixel is treated as an individual unit composed of values in several spectral bands by associating pixels to one another and to pixels of known distinctiveness or identity. It is possible to assemble groups of similar pixels into classes that are associated with the informational categories of interest to users of remotely sensed data. These classes form regions on a map or an image (Campbell and Wynne, 2011). Image classification also used for land use/land cover mapping , there are main steps in classification processes majors are finding proper training samples, selection of a class scheme suitable for the current region and classification theme, classification itself and post-classification with accuracy assessment (Bobrinskaya, 2012).

In this study supervised classification with support vector machine algorithm (SVM) was used. Supervised classification is a process of assigning sample pixels in an image that are representative of specific class and then direct the image processing software to use these training sites as references for the classification of all other pixels in the image. For this study Band 1 to 5 and band 7 were used for classification of TM 1998, 2010 while Band 1 to 7 was for OLI, 2017 Images. The land use land cove classification was performed by applying SVM algorithm because SVM is suitable for remote sensing applications, SVM are particularly appealing in the remote sensing field due to their ability to generalize well even with limited training samples. And in recent years there has been a significant increase in SVM works on remote sensing (Mountrakis et al., 2011) At least 100 pixels in an average were taken from spectrally enhanced images for each class as training samples. The land use land cover classes of the study area were Farm Land / Bare Land, Vegetation and Built up. Ground truth activities also carried out for validation for each type of land use land cover type of the study area. The land use land cover descriptions of the study area are below.

Farm Land/ Bare Land: are areas which are cultivated and growing different types of crops and unused farm land/free and grazing land is bare land.

Vegetation: It is an area which covers sparse trees, and dense forest and shrubs

Built-up: is an area which includes settlement, commercials, roads and different infrastructures.

4.3 Urban morphology type

Urban morphology has wider definition and types, it reflects physical characteristics of different residential areas which are urban form and function (Cavan et al., 2014). Urban morphology information is important for planning, information management, and urban climatic applications (Xu et al., 2017). Both satellite-based and Field measurement were utilized to extract information about urban morphology of the study area. The study area was classified in to condominium, villas and mud house. These basic urban morphological types are the most dominant one in the study area.

Satellite based information was extracted from Google earth by digitizing morphology types and converting into shape file using Arc GIS 10.3. A total of 45 samples plots were taken i.e. for each type of morphology five samples with three replications were taken within each sub-city. The sampling technique was supported by ground truth field measurement (GPS reading). Comparative assessments of land surface temperature were made for the three morphology types of residential area. The general descriptions of the morphology types in the study area are shown below.

Condominiums is a multi-stories housing type and made up of concrete and the roofs are colored metal sheet and there is a road in between the block which is asphalt and graveled road in most sites there is a space for green area but most of them are bare land. (Figure 9, a)

Mud house is a type of house is made with mud and wood and the roof are metal sheet. Most of site has no any space for green area but there is sparsely planted trees, and the houses are built densely while the road type are graveled road or coble stone.(Figure 9,b)

Villas a type of houses categorized under single stories and made up of concrete and the roof is corrugated sheet. Further, there is a road in between which are asphalt and cobblestone and there is also a green area in each house. (Figure 9, c)

a

b

c

Figure 9: Image of morphology types of condominium (a), mud house (b) and villa (c)

4.4 Post classification processing

4.4.1 Accuracy assessment

Accuracy assessment is closeness of results of observations, computations or estimates to the true values or the values accepted as being true. Its mandatory for classification results is because LULC maps contain some errors due to several factors that range from initial data acquisition procedure to the implementation of classification technique (Foody, 2002). For this study accuracy assessment was done by comparing the classified image with a reference to GPS data collected from field and remotely sensed images by using error matrix or confusion matrix. It is One of the most common methods of accuracy assessment and contain a category comparison of relationship between known ground-truth data and classification results for the same category (Salla et al., 2018). The basic accuracy measures are the overall accuracy, producer's accuracy, user's accuracy and Kappa coefficient (Fathizad et al., 2017).

The overall accuracy assessment of LU/LC for the years 1998, 2010 and 2017 is 91.50 %, 87.25 %, and 91.904 %, respectively. The classification Kappa coefficient for 1998 is 0.87 for the years, 2010 and 2017 are 0.80 and 0.88, respectively. The detailed information of producers and users accuracy is indicated in the (Appendix 8).

4.5 Data analysis

4.5.1 Change detection

Land-use/land-cover (LULC) change detection is an important factor in the dynamic study of ecosystems and developmental activities and it involves multi-temporal remote sensing information in order to provide potential and reliable information related with land use land cover change (Ahlqvist, 2008).

The study applied post classification change detection method by applying the classified land use land cover map of 1998, 2010 and 2017 as input to detect how individual classes had changed from one type to another type. This produces a two-way cross-matrix of LULC changes was created and a thematic layer containing different combinations. All the process of post classification detection was carried out in ENVI 5.3 software.

4.5.2 Percent surface cover analysis of UMT

The percent surface cover was determined in each UMT polygon by using random sampling point using Arc GIS 10.3; in order to quantify the percent land cover of each morphology type and to compare the land cover percent between each morphology type and the determined land cover type in each polygon are asphalt, graveled road, roof, vegetation and bare land.

4.5.3 Land surface temperature retrieval

Land surface temperature was retrieved from the thermal infrared band of band 6 for Landsat 5 and band 10 for Landsat 8. Through consecutive steps the thermal band pixel values were in digital number (DN) by using the ENVI 5.3 software, this DN was converted to radiance ,after converting to radiance according to the formulas that provided by Landsat Data Users Handbook published by USGS (USGS, 2016) first the satellite brightness temperature was calculated then the land surface temperature was retrieved. The steps were summarized below

1. The spectral radiance converts to brightness.

$$T_B = \frac{K_2}{\ln(\frac{K_1}{L_\lambda}+1)} \qquad \text{Eq.1}$$

Where:

T_B=Brightness

$K_{1=}$ CONSTANT_BAND_6 = 607.76

$K_{2=}$ CONSTANT_BAND_6 = 1260.56 these constant value is for Landsat 5

For Landsat 8: $K_{1=}$ CONSTANT_BAND_10 = 774.8853

$K_{2=}$ CONSTANT_BAND_10 = 1321.0789

L λ = is spectral radiance in W/ (m^2 ster Am)

2. Land Surface Temperature retrieval

$$LST = \frac{\boldsymbol{T_B}}{(\mathbf{1}+\left(\lambda\frac{\boldsymbol{T_B}}{\boldsymbol{\rho}}\right)*\boldsymbol{ln\epsilon})} \text{...Eq.2}$$

Where:

LST= land surface temperature

T_B=Total Brightness

λ = is the central band wavelength of emitted radiance (11.45 μm) For Landsat 5and (10.895 μm) For Landsat 8 of Band 6 and 10.

ρ = h * c/ σ (1.438*10-2m*K) with: h is the Planck's constant (6.62* 10^{-34})

c = is the velocity of the light (2.998*108 m/s)

σ =is the Boltzmann constant (1.38*10-23 J/K)

lne=emissivity

The emissivity value was assigned for each land use type the emissivity values are adopted from (Stathopoulou et al., 2007).

3**.** Convert land surface temperature value from Kelvin unit to degree Celsius

LST (^{0}C) = LST (Kelvin) – 273.15……………………………………………….Eq.3

4.5.4 Lapse rate

It is known that altitude is the major factor for temperature variation besides other factors and it also plays a significant role in LST dynamics(Khandelwal et al., 2017). In order to make rationalized land surface temperature value environmental lapse rate is used for this study purpose, environmental Lapse rate is a rate at which temperature is decreasing or increasing with respect to altitude variation. It is difficult to compare to different LULC types land surface temperature without considering altitudinal factor so to fill this gape this study was used lapse rate. The lapse rate value where temperature decreases with an increase of altitude and there is 0.67 ^{0}c temperature variation in every 100 meters altitude difference (Eq.4). This lapse rate difference value was adopted from (Jain et al., 2008). So in order to fill the elevation difference of the study area first compute the DEM difference because the study area has maximum elevation of and minimum 2054. Subtracting the minimum elevation of the study area which is 2054m from the maximum elevation of the study area which is 3126 and compute land surface temperature difference.

LST difference =Elevation diff*0.67 ^{0}C/100………………..Eq.4.

Altitude corrected LST = LST+LST difference…………..….Eq.5

4.5.5 Normalized difference vegetation index (NDVI)

NDVI is an index used to differentiate vegetated area from non-vegetated and it is the difference between from reflectance measurements in the near infrared (NIR) and red portion of the spectrum (USGS, 2014). The NDVI value is between -1 and 1and the negative value indicate the absence of green vegetation in specific area (Beck et al.,

2006) and the positive value indicate the vegetated surface reflectance of the area and the reason for higher NDVI value is that due to relatively higher reflectance value in NIR and lower in the red band (Tomar et al., 2013).For this study purpose Normalized difference vegetation index (NDVI) was acquired from spectral reflectance measurements in the visible (Reddy and Manikiam) and near infrared regions (NIR) in the software ENVI 5.3 and the formula is :

$$\text{NDVI}=\frac{NIR-RED}{NIR+RED}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eq.6}$$

Where; NDVI=Normalized deference vegetation index

NIR= is the near infrared band 4, RED= is the red band 3 of Landsat thematic sensor TM for the year 1998and 2010.

OLI for 2017 of Landsat 8 and in this case the NIR is Band 5 and band 4 for RED (USGS, 2014).

4.5.6 Relationships among land surface temperature, land use land cover and vegetation intensity

To evaluate the mean land surface temperature of each land use category Zonal statistic function of Arc GIS 10.3 were used. Zonal statistic function used to summarize the values of a raster within the zones of another dataset (either raster or vector) and reports the results in table form. LULC Maps of 1998, 2010 and 2017and LST was prepared same years to examine analyze the average LST in different LULC types. Similarly, Zonal statistic function was used to evaluate average LST of NDVI category zonal statistics algorithm of the year 1998, 2010 and 2017 LST and NDVI. In order to understand the relationship between the dependent variable (land surface temperature) and independent variable (Normalized difference vegetation index) linear regression model was applied using R Software v3.3.2.

4.5.7 Land surface temperature and urban morphology type relationships

Land surface temperature of UMT calculation was also done using zonal statistics algorithm in Arc GIS 10.3. The urban morphological types of the three different morphologies which are Condominium, Villa and mud house are correlated with the land surface temperature. One way ANOVA statistical test also used to check the difference among the morphology types of mean land surface temperature. The statistical significance was tested at p value <0.05 as a threshold using R software v3.3.2.

4.6 Methodological frame work

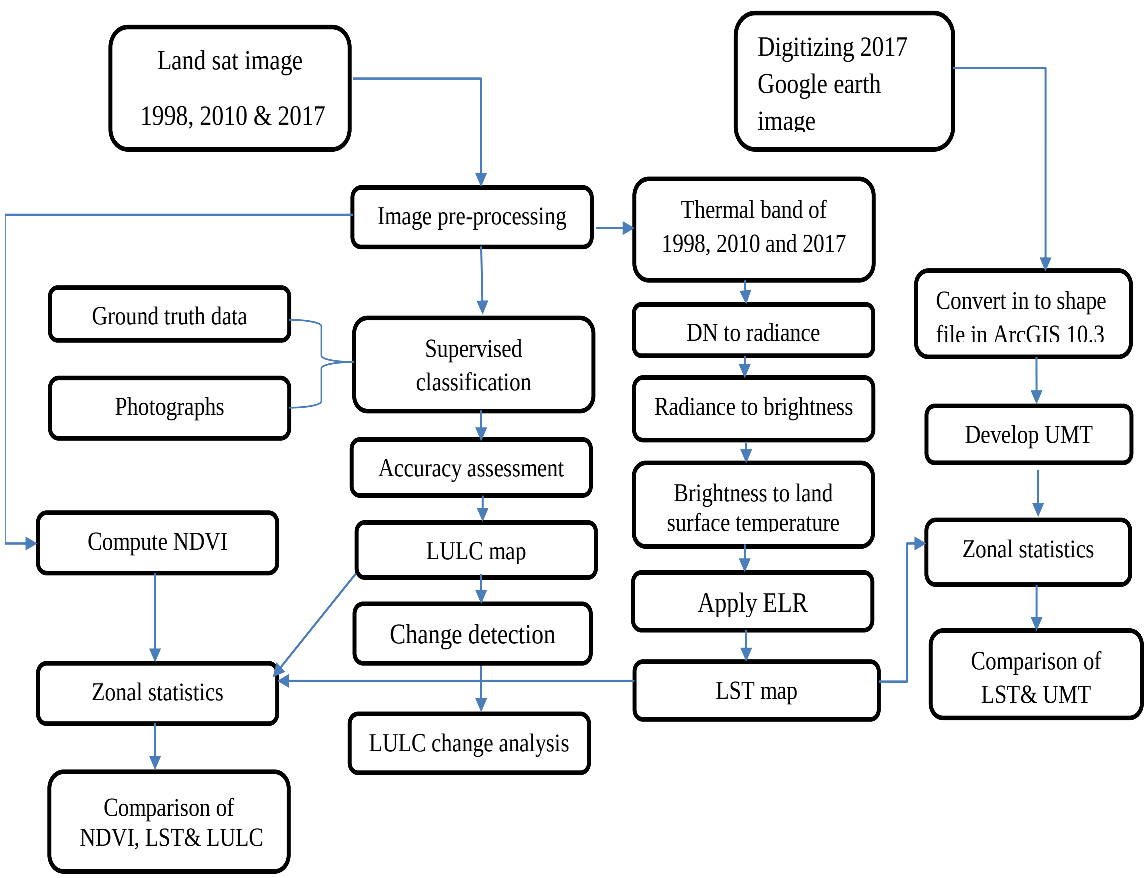


Figure 10: Methodological frame work of the study

5. Results

5.1 Land-use/land-cover change in 1998, 2010 and 2017

Based on the Support Vector Machine (SVM) classification technique result, land use land cover of the study area was classified into three land use types: Farm land/bare land, Vegetation and Built-up and is presented in the (Figures 11, 12 and 13). The largest land cover type was farm land/bare land followed by built-up and vegetation. Farm land/bare land cover in 1998, 2010 & 2017 LULC map were 26655.5 ha 20207.13 ha and 15488.11 ha respectively, and Vegetation cover was 1493.15 ha, 3193.79 ha and 3307.9 ha and the built up covers 4486.28 ha9233.25 ha and 13837.19 ha in 1998, 2010 and 2017 LULC map respectively, (Table 2).

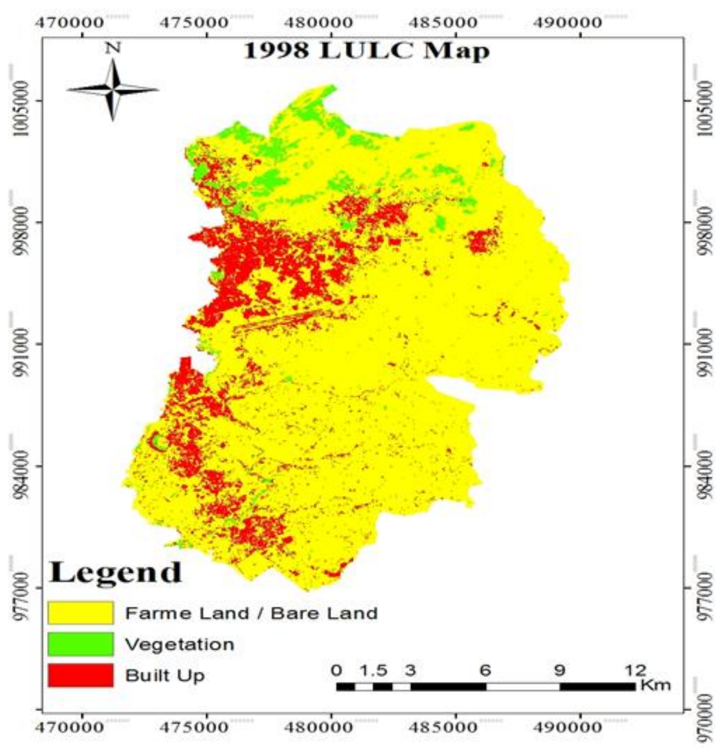


Figure 11: LULC map of 1998

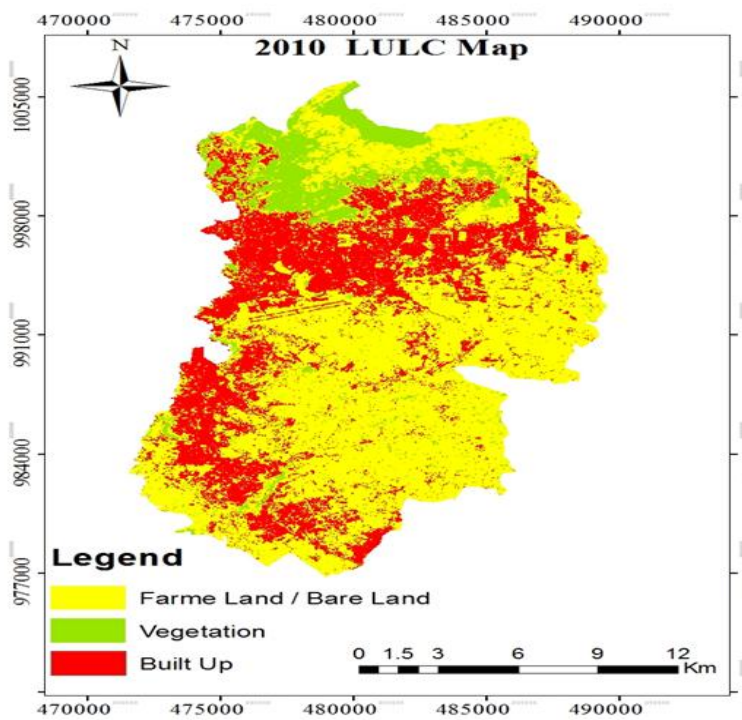


Figure 12: LULC Map of 2010

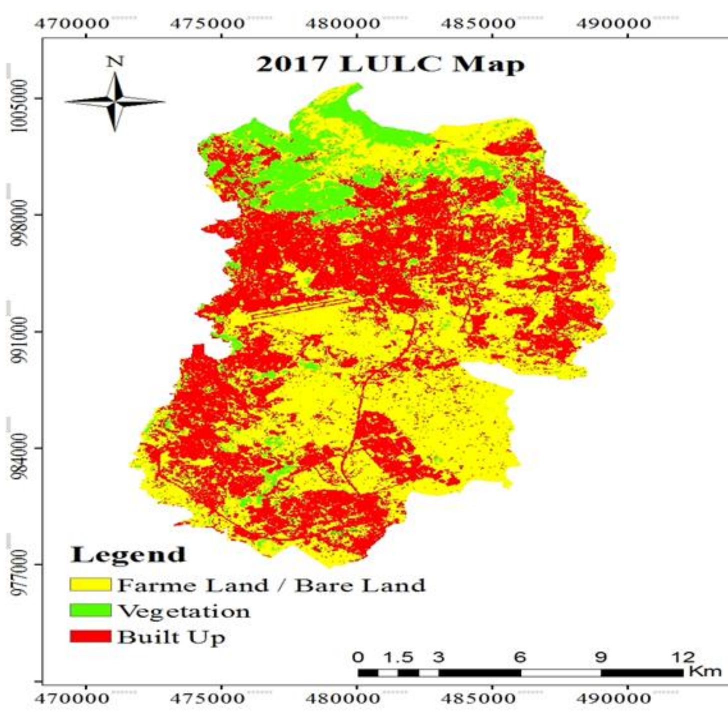


Figure 13: LULC map 2017

Table 2: land use land cover classification

	Area (ha) 1998	Area (%)	Area (ha) 2010	Area (%)	Area (ha) 2017	Area (%)	
Farm land / bare land	26655.5	81.7	20207.1	61.9	15488.1	47.5	
Vegetation	1493.2	4.6	3193.8	9.8	3307.9	10.1	
Built up	4486.3	13.7	9233.3	28.3	13837.2	42.4	
Total (%)							100
Total (ha)							32634.3
Total in (Km^2)							326.3

The graphical representation of trend and percent statistics of land use land cover classes showed that in 1998, 2010 and 2017 for farmland/bare land cover accounted 81.70 %,61.90 %and 47.50 % of the study area respectively which shows a declining trend. vegetation cover was 4.60 %,9.80 %, and 10.10 % and shows a slight increasing trend and similarly, the built cover-up was 13.70 %,28.30 % and 42.40 % respectively which shows an increasing rate from the period of 1998 to 2017 (Figure 14).

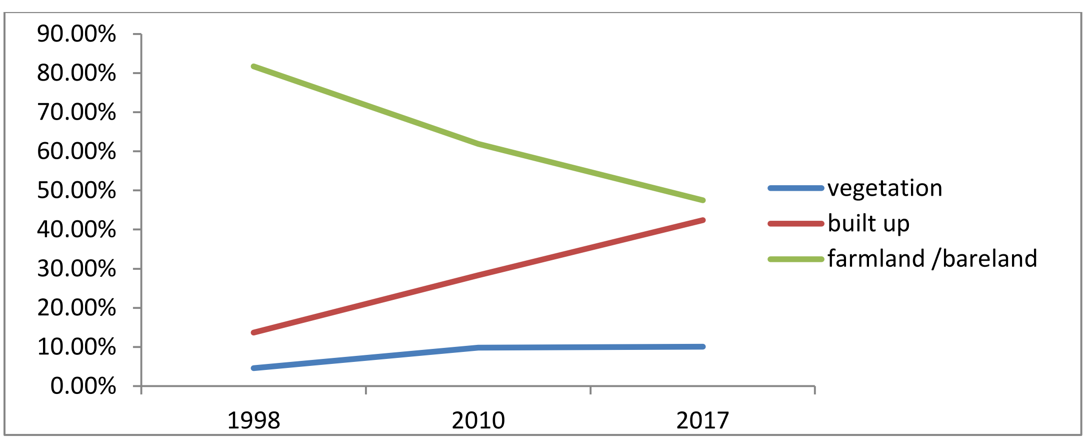


Figure 14: Trend of LULC from 1998 to 2017

5.2 Extent and trend of land use land cover change

The pattern of land use land cover in the study area showed a significant change between 1998 and 2017. Among the three major LULC classes, farm land / bare land decreases from the period of 1998 to 2017.it was 81.70 % in 1998 which decreases to 61.90 % in 2010 and it also decreases in 2017 to 34.20 %. the other major land use type of the study area is Built-up and it shows an increasing rate from the period of 1998to 2017 it was 13.70%in the period 1998 and it increases to 28.30 % in 2010 and 42.10 % in 2017, vegetation also increase by5.5% from the period of 1998 to 2017.it was 4.60% in 1998,increase to 9.80 % in 2010 and 10.10 % in 2010.(Table 3,4,5) summarize the detail statistical data of change from 1998-2010,2010-2017and (Table 6) summarize the rates of LULC changes from the period 1998-2017 per year and (Figure 14) interpret the net change of each land use class from 1998 to 2017 in ha.

Table 3: Land use land cover change from 1998-2010

	1998		2010		Net change from 1998- 2010	
LULC Classes	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Farm land / bare land	26655.5	81.70	20207.13	61.90	-6448.37	-19.80
Vegetation	1493.15	4.60	3193.79	9.80	1700.64	5.20
Built up	4486.28	13.70	9233.25	28.30	4746.97	14.60

N.B :The -(negative sign) shows the declining traned of the class

Table 4: Land use land cover change from 2010-2017

	2010		2017		Net change from 2010 2017	
LULC Classes	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Farm land / bare land	20207.13	61.90	15488.11	47.50	-4719.02	-14.40
Vegetation	3193.79	9.80	3307.9	10.10	114.11	0.30
Built up	9233.25	28.30	13837.19	42.40	4603.94	14.10

N.B:The –(negative sign) shows the declining traned of the class

Table 5: Land use land cover change from 1998-2017

	1998		2017		Net change from 1998-2017	
LULC Classes	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Farm land and bare land	26655.5	81.70	15488.11	47.50	-11167.39	-34.20
Vegetation	1493.15	4.60	3307.9	10.10	1814.75	5.50
Built up	4486.28	13.70	13837.19	42.40	9350.91	28.70

N.B:The –(negative sign) shows the declining traned of the class

Table 6: The rates of LU/LC changes from the period 1998-2017 per year

	Annual average rate of change ($year^{-1}$ ha^{-1})		
LULC class	1998-2010	2010-2017	1998-2017
Farm land / Bare land	-339.4	-248.4	-587.75
Vegetation	89.5	6	95.51
Built Up	249.84	242.31	492.15

N.B:The –(negative sighn) shows the declining traned of the class

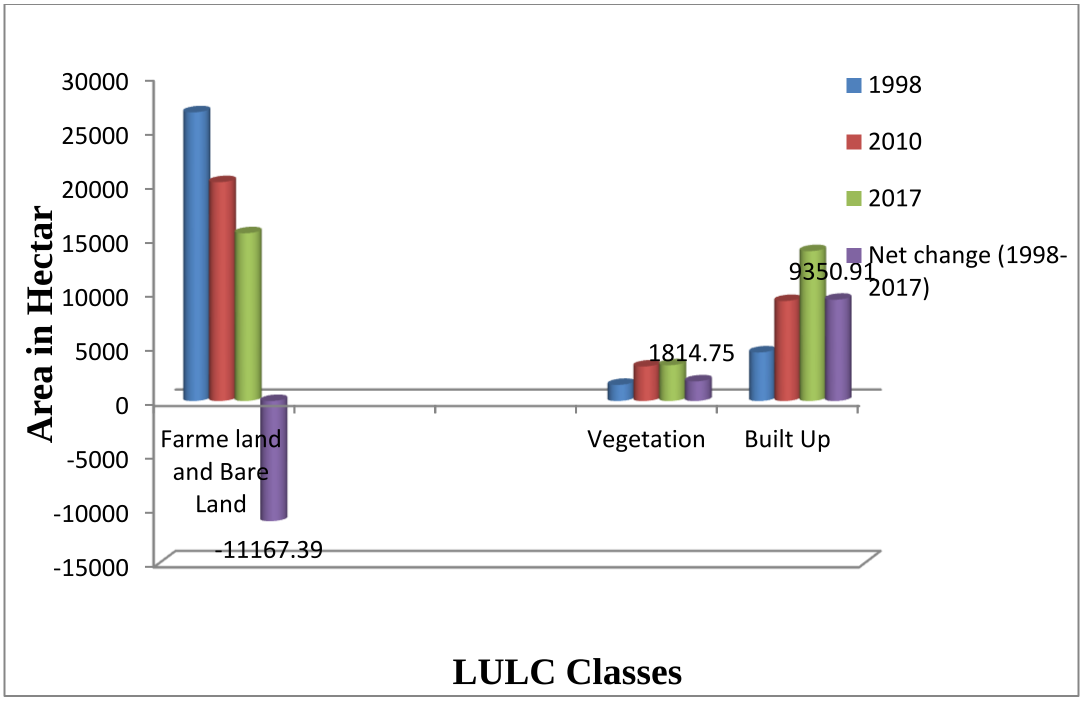


Figure 15: the net change of the LULC classes

5.4 Land surface temperature and land use land cover indices

The land surface temperature of the study area was derived from Landsat TM 5 and land sat 8; the deep orange color showed the highest land surface temperature of the study area whereas the green is the lowest land surface temperature of the study area. The deep orange lies on bare land and built up of different impervious surface; green color represents lower land surface temperature value that was dominated by vegetation. The maximum and minimum LST ranged from 8.22 ^{0}C to 42.17 ^{0}C in 1998, 19.63 ^{0}C to 41.54 ^{0}C in 2010 and 22.07 ^{0}C to 43.98 ^{0}C in 2017, respectively (Figure 16, 17 and 18).

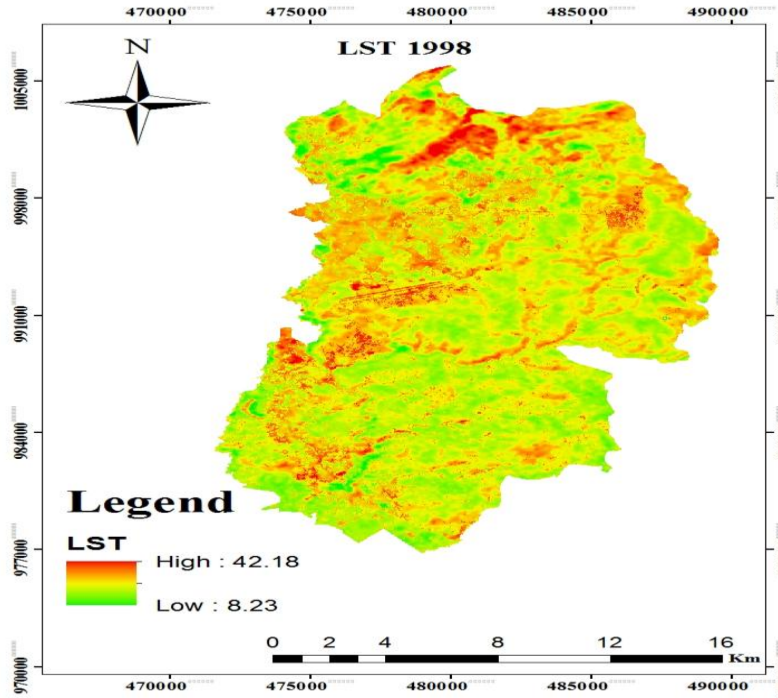


Figure 16: LST map of 1998

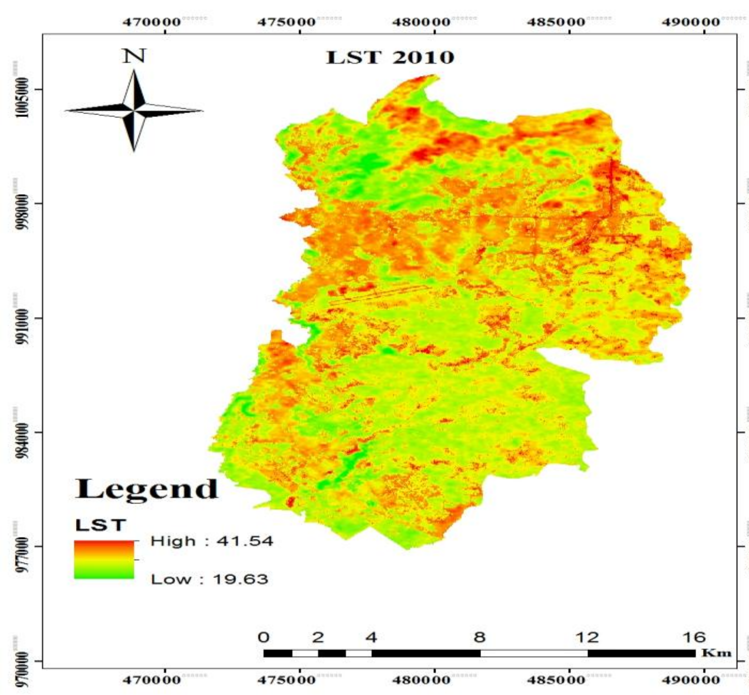


Figure 17: LST map of 2010

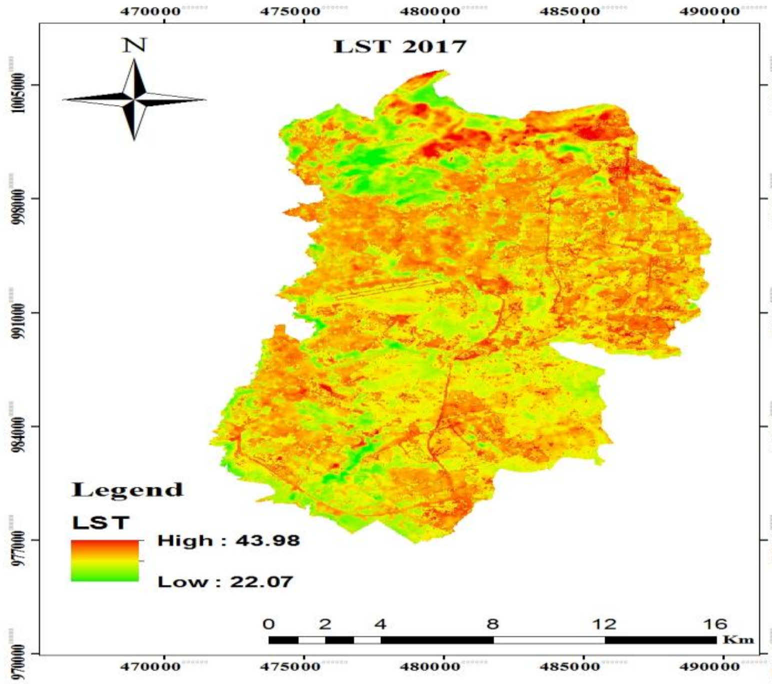


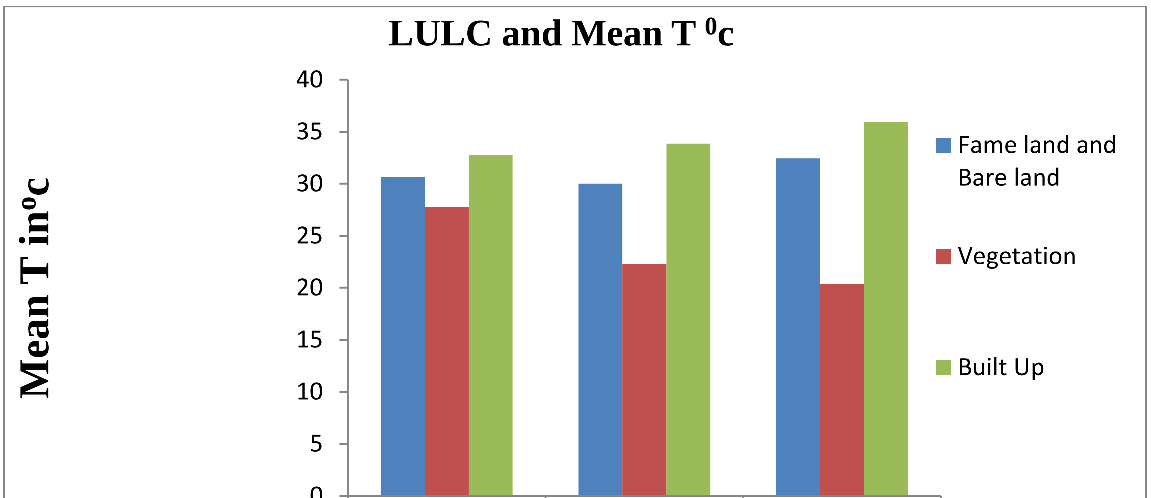
Figure 18: LST map of 2017

The mean land surface temperature of farm land / bare land for the year 1998, 2010 and 2017 were 30.63 ^{0}C, 30 ^{0}C and 32.43 ^{0}C. Land surface temperature of farm land/ bare land class was decreased from 1998 to 2010 by 0.63 ^{0}C and increased from 2010 to 2017 by 2.43 ^{0}C. Similarly, the vegetation cover land surface temperature showed decreasing trend from 1998 to 2010 and increasing trend from 2010 to 2017.

The mean land surface temperature of the vegetation for the year 1998 is 27.45^{0}C and for the year 2010 and 2017 were 22.29^{0}C and 20.39^{0}C respectively. Built-up mean land surface temperature shows increment between 1998 to 2010 and 2017. The mean land surface temperature of built up for the year 1998, 2010 and 2017 are 32.76^{0}C, 33.840C and 35.46^{0}C (table 8) and (Figure18).

Table 7: Zonal Statstic Report of LULC and LST

	1998			2010			2017		
LULC Classes	min T ^{0}C	Max T ^{0}C	Mean T ^{0}C	Min T ^{0}C	Max T ^{0}C	Mean T ^{0}C	Min T ^{0}C	Max T ^{0}C	Mean T ^{0}C
Farm land / bare land	8.22	42.17	30.63	20.55	40.88	30.00	23.75	42.93	32.43
Vegetation	20.62	40.02	27.76	14.23	34.46	22.29	15.98	35.48	20.39
Built Up	17.79	42.11	32.76	23.32	41.54	33.84	24.02	43.98	35.46



	1998	2010	2017
Fame land and Bare land	30.63	30	32.43
Vegetation	27.76	22.29	20.39
Built Up	32.76	33.84	35.94

Figure 19: Thermal variation among different LULC types

5.5 Relationship between land use/land cover types, vegetation intensity and land surface temperature

The estimated intensity and distribution pattern of surface vegetation using normalized vegetation index show that brighter blue color has relatively high NDVI value and the yellow color shows low NDVI value of the study area. the NDVI value of each study year was different. Mean NDVI value of 1998 LULC was higher than 2010 and 2017 LULC. The max NDVI vlaue for the study year 2010 is higher than 1998 and 2017which showed that vegetation cover was increasing. the max NDVI vaule is showed in the uper part or the edge of the study area which has high vegetation cover than the other part of study area, low NDVI value was concenterated in the centeral and north weastern part of the study due to built-up concentration. and the maximum and minimum NDVI value of the study years are 0.75to -0.46,1 to -0.87 and 0.75 to 0.81 for the year 1998,2010 and 2017 respectively (Figure,20,21,22&23) (Apendix 15).

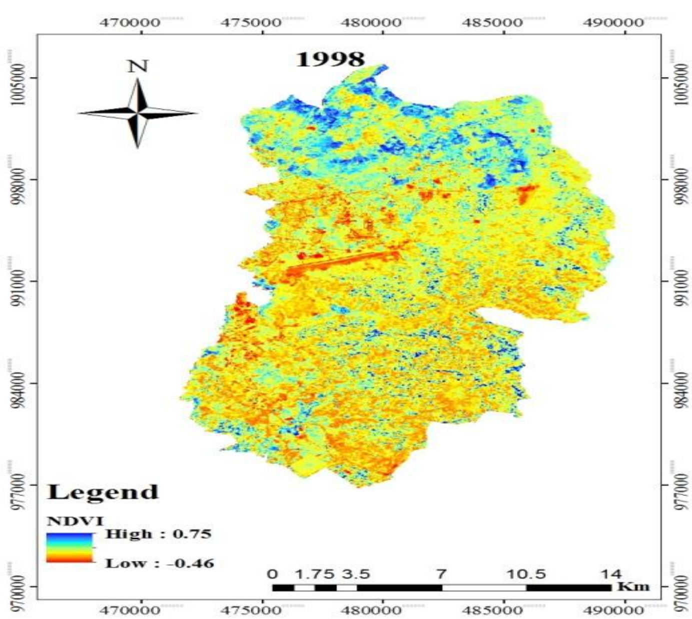


Figure 20 : NDVI map of 1998

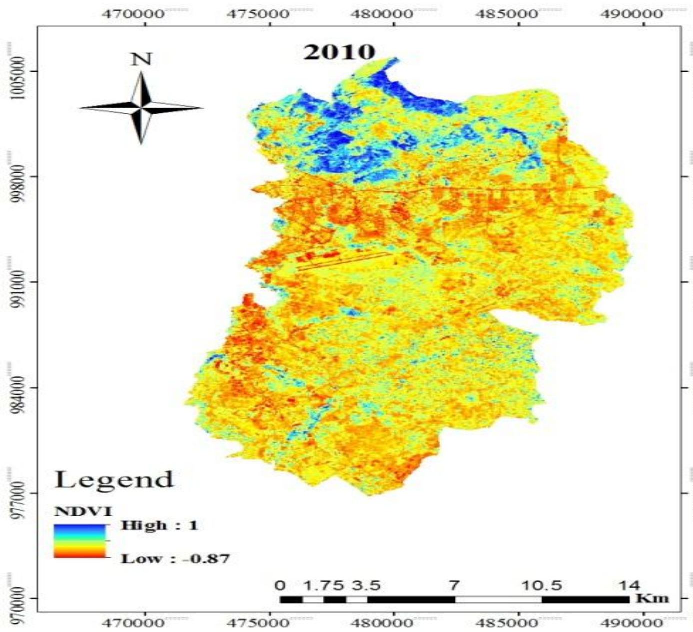


Figure 21: NDVI map of 2010

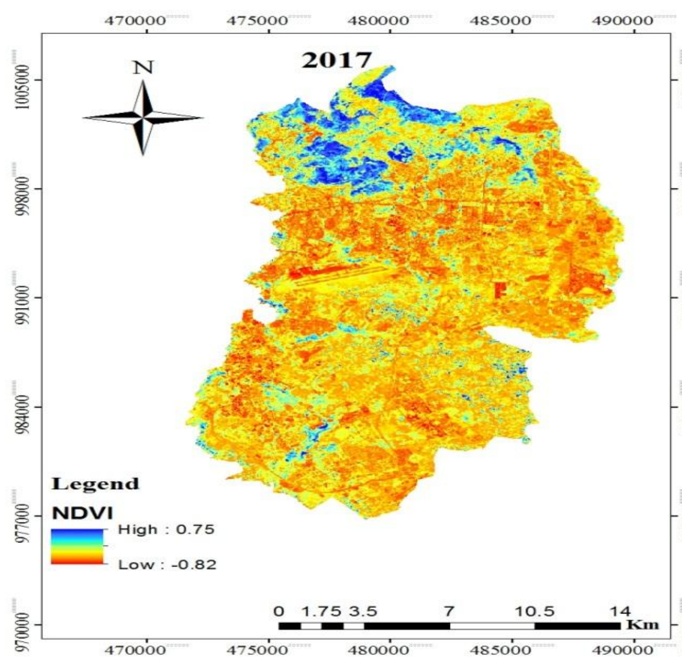


Figure 22: NDVI map of 2017

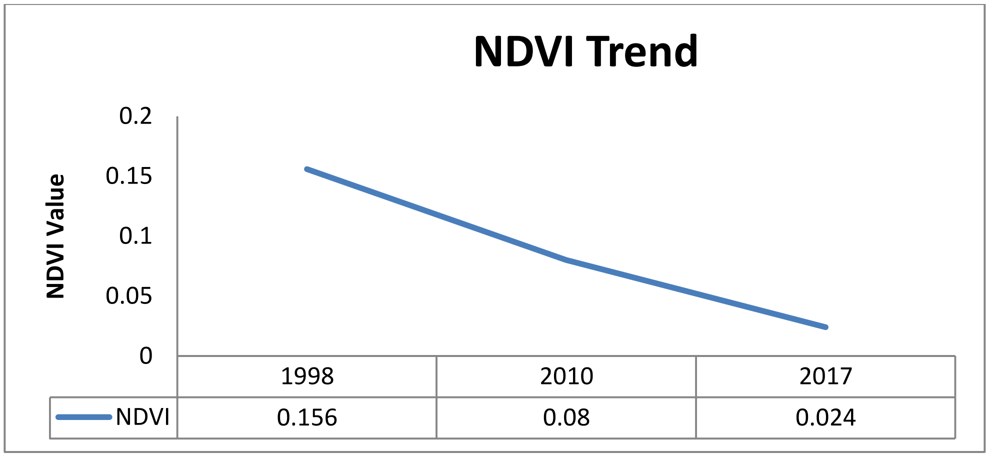


Figure23: the over all NDVI traned of the study area for the year 1998.2010and 2017.

5.5.1 Relationship between land use land cover classes and normalize difference vegetation index

Normalize difference vegetation index the value differ from one area to the other based on the vegetation intensity of the specific land use type. The over all NDVI trend of each land use land cover types showed that farmeland/bare land shows a decline range from the year 1998 to 2017. similarly due to an increanment of built up from the period of 1998 to 2017 it shows decline trend. but the NDVI traned of vegetation shows an increasing rate because of an increament of vegetation cover in the study area(Figure 24,25,26).

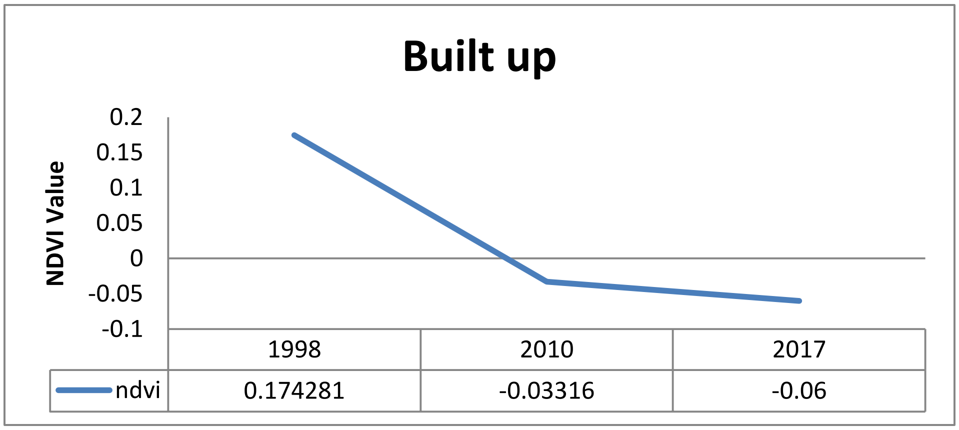


Figure 24: NDVI trend of Built Up

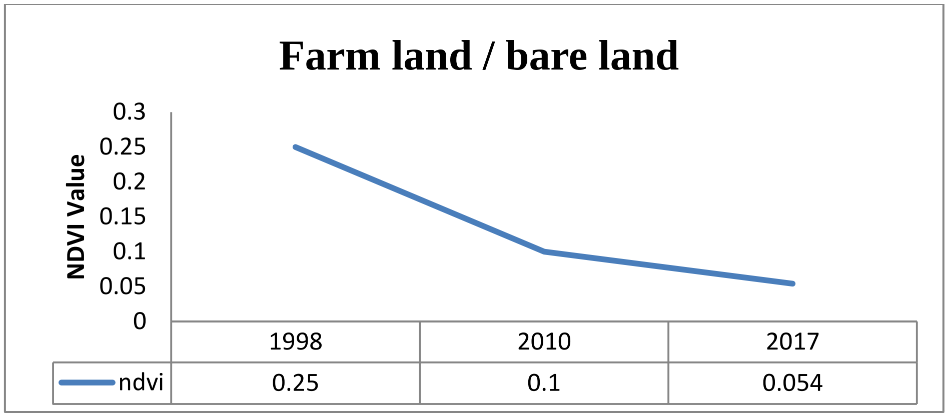


Figure 25: NDVI trend of Farm land /bare land

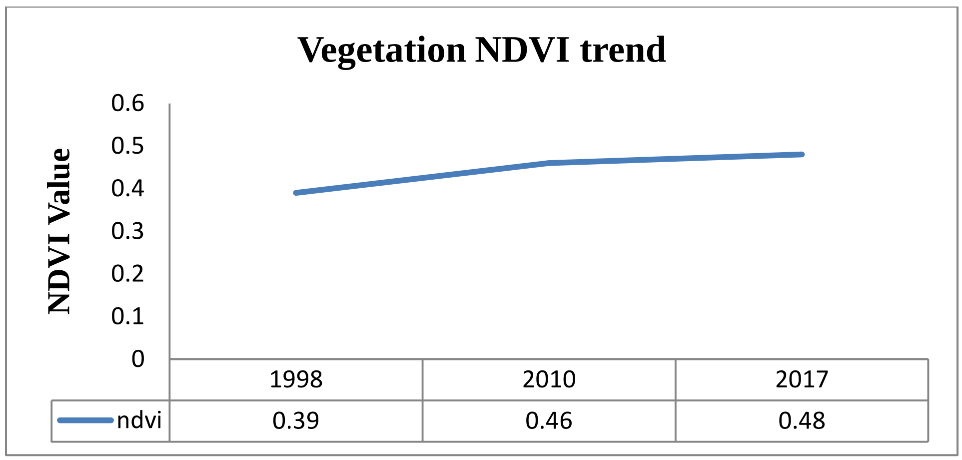


Figure 26: NDVI trend of vegetation

5.5.2 Corelation between normalized difference vegetation index and land surface temperature

The NDVI and LST value of the study period of 1998, 2010 and 2017 showed an indirect relationship. A high LST has low NDVI value and a low NDVI value has a high LST. The R^2 values of the study period 1998, 2010 and 2017 between NDVI and LST correlations indicated 95.32 %, 98.67 % and 98.76 %, respectively. And it shows negative correlation between NDVI and LST (Figure 27, 28&29)

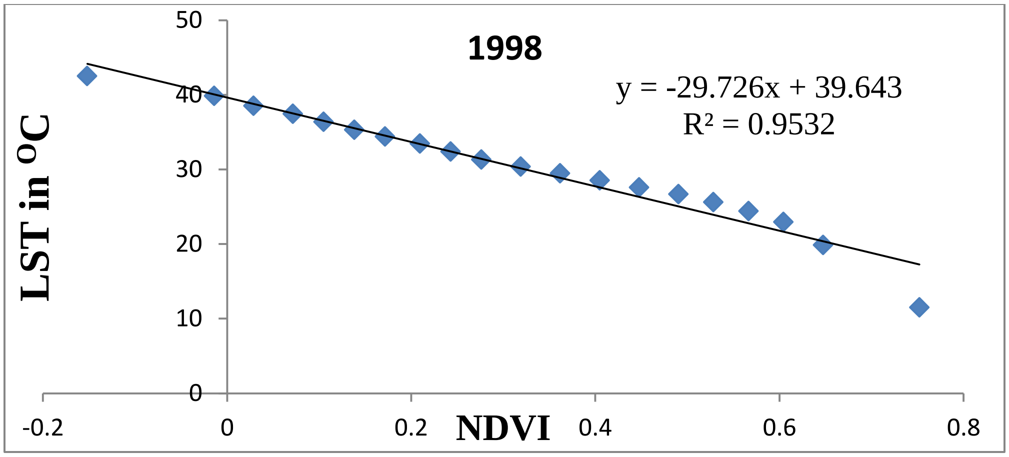


Figure 27: NDVI and LST correlation for the year 1998

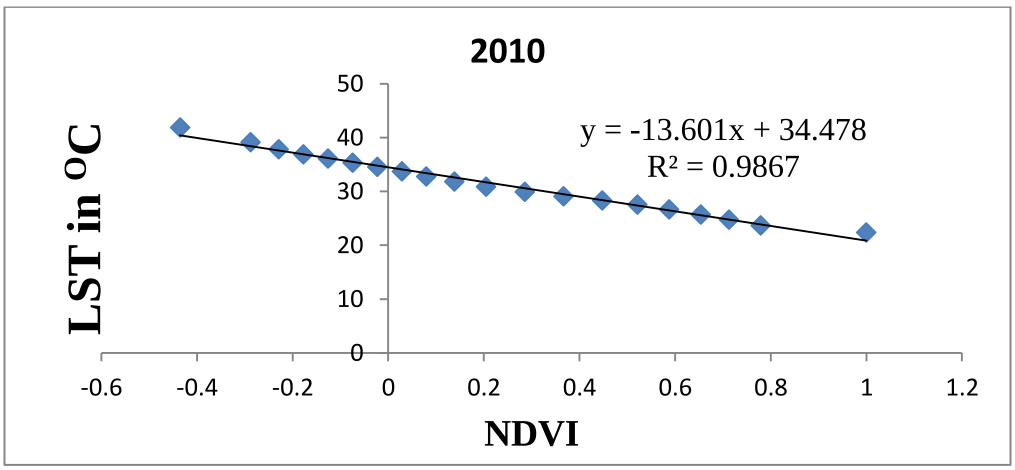


Figure 28: NDVI and LST correlation for the year 2010

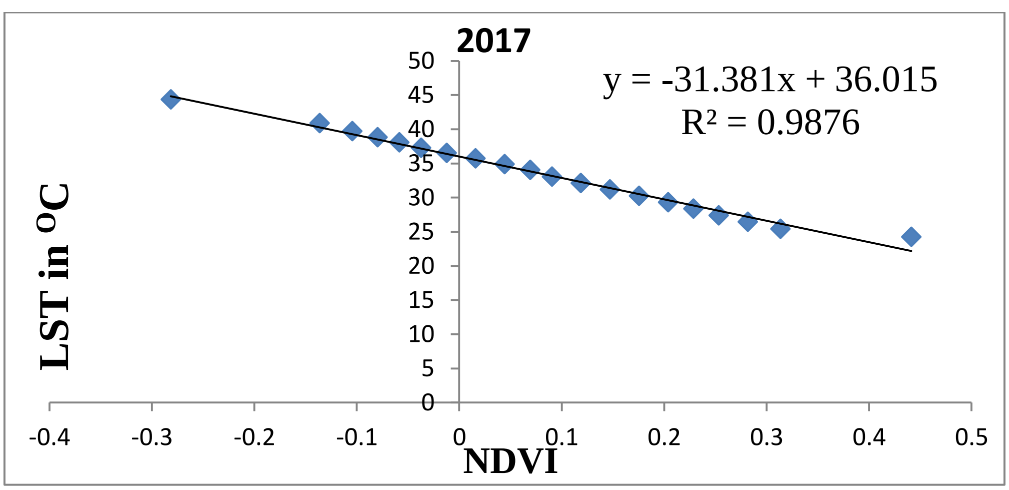


Figure 29: NDVI and LST correlation for the year 201

5.6 Urban morphology type and land surface temperature corelation

From the zonal statistics report each urban morphology types has come out with the mean land surface temperature value it showed in the appendix (18,19&20) and The relationship among the mean land surface temperature of UMT has been evaluated by using ANOVA test of R software and the result showed that the overall P-value (0.00297) is less than 0.05 at 95% confidence interval. This indicated that there is significance difference among the mean land surface temperature of the urban morphology types.

5.6.1 Mean average land surface temperature value of the urban morphology types

The average mean land surface temperature of each UMT are 35.3 ^{0}C,34.14 ^{0}C and 35.08 ^{0}C for condominium, villa and mud house respectively from this the study find that condominium has the highest mean land surface temperature than the other and villa is the lowest mean land surface temperature .

5.6.2 Urban morphology type normalized difference vegetation index value

Normalize difference vegetation index has a capacity to detrmine the vegetation abundance and intensity of a specific area this study NDVI value of different morphology type also showed that a variation on NDVI due to in abundance of vegetation in each morphology type . The over all NDVI value of of each UMT showes in the (Figure 30) and from the figure the value of mean NDVI value of Vill is higher than the other UMT.(Appendix 12) showed the statstical value of NDVI for each UMT.

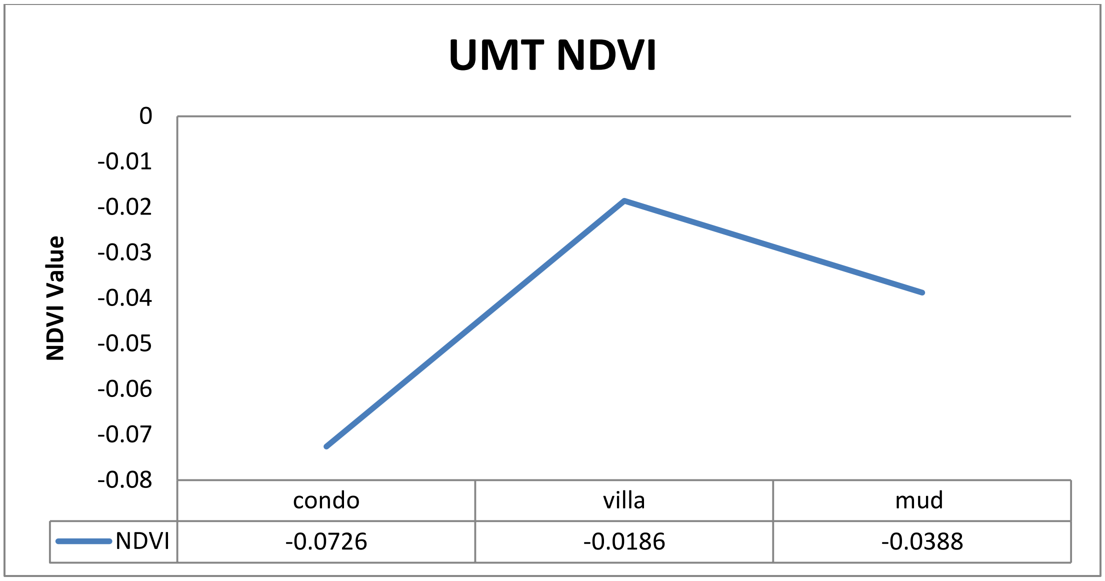


Figure 30: NDVI trend of each UMT.

5.6.3 Percent of land cover type for each urban morphology type

The percentage surface cover of each urban morphology type is categorized and the study reveals that in each UMT the highest proportion is roof and graveled road and the lowest is asphalt and vegetation from the UMT Villa has high vegetation proportion than the other UMT, Which has 28% from the total of other land cover type in the category .and the detail land cover type of each polygon of UMT has in the (Appendix 11)

6. Discussion

6.1 Land use land cover change

The study integrated remote sensing and GIS to examine urban land use land cover change impact on land surface temperature and the result reveals that there is declines of farm land/bare land and an increment of built-up in the study period of 1998, 2010 and 2017.The extent of Farmland /bare land in the past 20 years was decreased by 11,167.4 ha (587.75 ha/year).

Due to the reduction of the farm land /bare land, there has been dramatically increasing of built-up areas. The probable reason for these changes could be high demand of land for urban development. For instance, built up was increased with a value of 14.70 % from the period of 1998 to 2010, 14.10 % from the period of 2010 to 2017. Arsiso et al., (2018) had reported that built up area expansion in the expense of forest and Agricultural land in Addis Ababa city was observed. Similarly Mulugeta et al.,(2017) also revealed that there is a high rate of urban expansion in peri-urban area of Addis Ababa and this urban expansion is the major factor for land use land cover change of the area and the case for declining of farmland and vegetation. Leulsegged et al.,(2011) also noticed that Addis Ababa urban expansion was due to high demand of house in the city and massive housing program construction activities are listed as the cause for the decline for agricultural land in the city.

Even if vegetation is occupied the smaller portion in the study area which was 4.60 % in 1998, there was slight increasing rate by 9.8 % in 2010 and 10.10 % in 2017. This is due to plantation campaign that has been taken place every year in the upper part of the study area mainly in the Yeka sub-city with supported of Addis Ababa environmental protection authority (AAEPA) of natural resource development and protection case team and. According to Leulsegged et al.,(2011) the rate of declining forest is reduced due to improved tree plantation activities accompanied in the whole Addis Ababa city.

6.2 Land surface temperature, normalized vegetation index and land use land cover types nexuses

6.2.1 Land use land cover change and land surface temperature relationship

Land use land cover change has a capacity to modify the land surface temperature of a specific area because land surface temperature influenced by climatic condition and physical characteristics of the land surface (Fathizad et al., 2017). Because LULCC can affect the thermal environment and each land use type has its own thermal, moisture, and optical spectral properties (Chen and Zhang, 2017). Among the land use land cover classification classes, built up has high land surface temperature than the others land use classes. The reason may be due to an increment of building in the study area and decline of NDVI value of the class.

According to Teferi and Abraha, (2017) in Addis Ababa the LST average value of Built-up was increased from the period of 1986 to 2011 than other type of land use land cover signatures. The average LST for the urban/built-up area was 303.4 ^{0}k and 304.42 ^{0}K in 1986 and 2011, respectively. Similarly according to Hokao and Phonekeo, (2012) urban areas has low NDVI value than the surrounding rural area and their finding showed that the mean NDVI and LST values are negatively correlated . Next to built-up Farm land / bare land has showed significant LST value because the image was taken in the dry season and harvesting time it make the land more dry and barren this has the probability to increase the land surface temperature of the area (Sannigrahi et al., 2017) .Even if these researchers revealed that there is an increment of land surface temperature but they did not recognize the effect of altitude that affects temperature variations.

Vegetation categories LST showed a declining trend from the period of 1998 to 2017. This is due to the slight increment of vegetation in the study area. The study conducted by Fathizad et al., (2017) indicate that, vegetation has high thermal impact the study indicated that vegetation density increment shows a decrease in land surface temperature. Similarly, Shiflett et al.,(2017) also indicated that different land use land cover types that has a vegetation cover has lower land surface temperature of the area.

6.2.2 Land surface temperature and normalized difference vegetation index relationship

NDVI index is a measure of vegetation condition and also used to determine LST. NDVI is an indicator of Land surface temperature (Amiri et al., 2009). The overall ndvi value indicated that there is a declining range in the study area this increase the probability of the increment of land surface temperature in the study area. Based on regression analysis the relationship between LST and NDVI of this study showed that inversely related. The coefficient of determination (R^2) also showed that with a value of 0.95, 0.98 and 0.98 of the year 1998, 2010 and 2017, respectively. These values clearly indicated that per unit change of the independent variable (NDVI) has created change on a dependent variable (LST), indicating that vegetation abundance highly determines the land surface temperature of a specific area. Different researches that conducted in different area reported a negative correlation between NDVI and LST (Akher and Chattopadhyay, 2017).

6.3 Urban morphology type correlation with land surface temperature and normalized difference vegetation index

To investigate and understand the relationship between the land surface temperature and the urban morphology type this study used three residential urban morphology that are found in the study area, those are condominium, villa and mud house, in order to distinguish the relation between the UMT and mean land surface temperature the study computed zonal statistics. The result showed that the mean average land surface temperatures of each UMT are 35.31 ^{0}C, 34.14 ^{0}C and 35.08 ^{0}C of condominium, villa and mud house respectively (Appendix 18, 19 &20). In the present report, there is mean land surface temperature difference between the urban morphology types, and condominium has high mean LST value than the other. Based on this finding, different UMT has different temperature pattern because the surface cover types of the UMT differ from one another.

The research that conducted in East Africa shows that condominium has higher land surface temperature than other type of residential morphology types and the projected land surface temperature is greater than 40 ^{0}c (Cavan et al.,2014) and it does not exclude the effect of elevation, in our finding case the average land surface temperature of condominium UMT is 35.31 ^{0}C. This value is considering only the land cover type and excludes the effect of elevation. Maniur ,(2017) also agreed that built up type of different residential area will have a different land surface temperature but the absence vegetation will have the probability to increase the land surface temperature.

From one way ANOVA test the mean land surface temperature of each UMT has a significance difference since the P-value is 0.00297 which is less than the threshold value

0.05. The mean NDVI value of UMT as showed in the (Figure 30) from those UMT villa residential area has relatively high NDVI value than other because according to field observation and percent land cover analysis most villa houses in the study area has gardening and has trees than the other UMT. According to Rani et al., (2018) the higher the NDVI value indicates the healthy vegetation and this is important for the provision of surface temperature regulation.

The result of this research finding in the relation among LST with LULC and UMT only consider the physical structure and the land use cover types by eliminating the altitude effect because elevation and land surface temperature have a strong linear relationship (Khandelwal et al., 2017).

7. Conclusion and Recommendations

This study reveals temporal and spatial changes of LULC in the study area using Landsat images taken in 1998, 2010 and 2017 and associated changes in vegetation and surface temperature. The study found that the land use in the study area is continually changing with the expansion of built up in the last 20 years. These land use land cover changes were mainly attributed to urbanization. The change of LULC, accompanied by the change in land surface temperature and vegetation cover, exhibited high variation within and among classes. Built surface temperature has increased and continued to climb between the periods of 1998 to 2017.

This study also demonstrates changes in NDVI to estimate the vegetation cover, and the NDVI value shows that the built-up classes of the study area lower than the other land use land cover classes. The correlation between LST and overall NDVI of study area are negatively related and with strong coefficient of determination (R^2), which measures the strength of the linear regression as the vegetation intensity decrease, the land surface temperature increases, so we found that NDVI is a good indicator of land surface temperature. The urban morphological type of different residential area characteristics on land surface temperature is assessed in this paper and the study revealed that there is a significant land surface temperature difference among the urban morphology types. Based on the field observation and percent land cover analysis, villa has the lowest surface temperature, which can partly be explained by the existence of green structure in the area than the other UMT.

The findings of this study signify that green structure play important role in providing temperature regulation services. Urban planning should consider the importance of vegetation and green area in order to mitigate the development and increments of land surface temperature because introduction of more urban vegetation seems manageable and actual long-term strategy to provoke land surface temperature. Protecting green areas and especially urban parks and other types of green infrastructures should be strengthened and further studies in urban green space structures and composition that have effectively reduced the LST in the study area should receive more attention.

For future study in the study area, we recommend using high resolution images to detect the LULC change and in order to generate accurate results for LST, LULC relationship, it would be better to take both daytime and night time temperature data of more, and considering the detail investigation of all UMT morphologies structure (e.g. characterizing structures of building, roof type, shape and color) and their thermal variation by considering detail data on built-up structures, and built up material and analyzed the impact on urban climate. The negative consequence of land surface temperature on socio-economic, health of the people that lives in the study area could also be the future research direction in the study area.

References

Ahlqvist, O. (2008). Extending post-classification change detection using semantic similarity metrics to overcome class heterogeneity: A study of 1992 and 2001 US National Land Cover Database changes. *Remote Sensing of Environment* **112**, 1226-1241.

Akher, S., and Chattopadhyay, S. (2017). Impact of Urbanization on Land Surface Temperature-A Case Study of Kolkata New Town. *The International Journal Of Engineering And Science (IJES)* **6**, 71-81.

Amiri, R., Weng, Q., Alimohammadi, A., and Alavipanah, S. K. (2009). Spatial–temporal dynamics of land surface temperature in relation to fractional vegetation cover and land use/cover in the Tabriz urban area, Iran. *Remote sensing of environment* **113**, 2606-2617.

Areas, E. (1997). Ecosystem appropriation by cities. *Ambio* **26**, 167-172.

Arsiso, B. K., Tsidu, G. M., Stoffberg, G. H., and Tadesse, T. (2018). Influence of urbanization-driven land use/cover change on climate: The case of Addis Ababa, Ethiopia. *Physics and Chemistry of the Earth, Parts A/B/C*.

Artis, D. A., and Carnahan, W. H. (1982). Survey of emissivity variability in thermography of urban areas. *Remote Sensing of Environment* **12**, 313-329.

Babalola, O., and Akinsanola, A. (2016). Change Detection in Land Surface Temperature and Land Use Land Cover over Lagos Metropolis, Nigeria. *J Remote Sensing & GIS* **5**, 2.

Beck, P. S., Atzberger, C., Høgda, K. A., Johansen, B., and Skidmore, A. K. (2006). Improved monitoring of vegetation dynamics at very high latitudes: A new method using MODIS NDVI. *Remote sensing of Environment* **100**, 321-334.

Becker, F., and Li, Z.-L. (1990). Temperature-independent spectral indices in thermal infrared bands. *Remote sensing of environment* **32**, 17-33.

Bobrinskaya, M. (2012). Remote Sensing for Analysis of Relationships between Land cover and Land Surface Temperature in Ten Megacities.

Campbell, J. B., and Wynne, R. H. (2011). "Introduction to remote sensing," Guilford Press.

Cavan, G., Lindley, S., Jalayer, F., Yeshitela, K., Pauleit, S., Renner, F., Gill, S., Capuano, P., Nebebe, A., and Woldegerima, T. (2014). Urban morphological determinants of temperature regulating ecosystem services in two African cities. *Ecological indicators* **42**, 43-57.

Chen, X.-L., Zhao, H.-M., Li, P.-X., and Yin, Z.-Y. (2006). Remote sensing image-based analysis of the relationship between urban heat island and land use/cover changes. *Remote sensing of environment* **104**, 133-146.

Chen, X., and Zhang, Y. (2017). Impacts of urban surface characteristics on spatiotemporal pattern of land surface temperature in Kunming of China. *Sustainable cities and society* **32**, 87-99.

Chipman, J. W., Lillesand, T. M., Schmaltz, J. E., Leale, J. E., and Nordheim, M. J. (2004). Mapping lake water clarity with Landsat images in Wisconsin, USA. *Canadian journal of remote sensing* **30**, 1-7.

Choudhary, K., Boori, M. S., and Kupriyanov, A. (2017). Spatial modelling for natural and environmental vulnerability through remote sensing and GIS in Astrakhan, Russia. *The Egyptian Journal of Remote Sensing and Space Science*.

Cohen, B. (2006). Urbanization in developing countries: Current trends, future projections, and key challenges for sustainability. *Technology in Society* **28**, 63-80.

Conway, D., Mould, C., and Bewket, W. (2004). Over one century of rainfall and temperature observations in Addis Ababa, Ethiopia. *International Journal of Climatology* **24**, 77-91.

CSA, E. (2013). Population projection of Ethiopia for all regions at wereda level from 2014–2017. *Central Statistical Agency of Ethiopia*.

Di Gregorio, A. (2005). "Land cover classification system: classification concepts and user manual: LCCS," Food & Agriculture Org.

Fathizad, H., Tazeh, M., Kalantari, S., and Shojaei, S. (2017). The investigation of spatiotemporal variations of land surface temperature based on land use changes using NDVI in southwest of Iran. *Journal of African Earth Sciences* **134**, 249-256.

Feyisa, G. L. (2013). Urbanization, urban climate and influence of vegetation: the case of cities in Ethiopia, Department of Food and Resource Economics, University of Copenhagen.

Feyisa, G. L., Dons, K., and Meilby, H. (2014). Efficiency of parks in mitigating urban heat island effect: An example from Addis Ababa. *Landscape and Urban Planning* **123**, 87-95.

Foody, G. M. (2002). Status of land cover classification accuracy assessment. *Remote sensing of environment* **80**, 185-201.

Forman, R. T. (2016). Urban ecology principles: are urban ecology and natural area ecology really different? *Landscape ecology* **31**, 1653-1662.

Fu, C. (2003). Potential impacts of human-induced land cover change on East Asia monsoon. *Global and Planetary Change* **37**, 219-229.

Fu, P., and Weng, Q. (2016). A time series analysis of urbanization induced land use and land cover change and its impact on land surface temperature with Landsat imagery. *Remote Sensing of Environment* **175**, 205-214.

Guo, G., Zhou, X., Wu, Z., Xiao, R., and Chen, Y. (2016). Characterizing the impact of urban morphology heterogeneity on land surface temperature in Guangzhou, China. *Environmental Modelling & Software* **84**, 427-439.

Hadjimitsis, D. G., Papadavid, G., Agapiou, A., Themistocleous, K., Hadjimitsis, M., Retalis, A., Michaelides, S., Chrysoulakis, N., Toulios, L., and Clayton, C. (2010). Atmospheric correction for satellite remotely sensed data intended for agricultural applications: impact on vegetation indices. *Natural Hazards and Earth System Sciences* **10**, 89-95.

Hegazy, I. R., and Kaloop, M. R. (2015). Monitoring urban growth and land use change detection with GIS and remote sensing techniques in Daqahlia governorate Egypt. *International Journal of Sustainable Built Environment* **4**, 117-124.

Henderson, J. V., Storeygard, A., and Deichmann, U. (2017). Has climate change driven urbanization in Africa? *Journal of development economics* **124**, 60-82.

Hokao, K., and Phonekeo, V. (2012). Assessing the impact of urbanization on urban thermal environment: A case study of Bangkok Metropolitan. *International Journal of Applied* **2**.

Houghton, R. A. (1994). The worldwide extent of land-use change. *BioScience* **44**, 305-313.

Huisman, O., and De By, R. (2009). Principles of geographic information systems. *ITC Educational Textbook Series* **1**, 17.

Hussain, M., Chen, D., Cheng, A., Wei, H., and Stanley, D. (2013). Change detection from remotely sensed images: From pixel-based to object-based approaches. *ISPRS Journal of Photogrammetry and Remote Sensing* **80**, 91-106.

Ibrahim, F., and Rasul, G. (2017). Urban Land Use Land Cover Changes and Their Effect on Land Surface Temperature: Case Study Using Dohuk City in the Kurdistan Region of Iraq. *Climate* **5**, 13.

Jain, S. K., Goswami, A., and Saraf, A. (2008). Determination of land surface temperature and its lapse rate in the Satluj River basin using NOAA data. *International Journal of Remote Sensing* **29**, 3091-3103.

Kasperson, R. E., Kasperson, J. X., Turner, B., Dow, K., and Meyer, W. B. (1995). Critical environmental regions: concepts distinctions and issues.

Kebede, A., Ayalew, S., Mesfin, A., and Mulualem, G. (2017). Assessment on the Use, Knowledge and Conservation of Medicinal Plants in Selected Kebeles of Dire Dawa Administration, Eastern Ethiopia. *Journal of Plant Sciences* **5**, 56-64.

Khandelwal, S., Goyal, R., Kaul, N., and Mathew, A. (2017). Assessment of land surface temperature variation due to change in elevation of area surrounding Jaipur, India. *The Egyptian Journal of Remote Sensing and Space Science*.

Lambin, E. F., Geist, H. J., and Lepers, E. (2003). Dynamics of land-use and land-cover change in tropical regions. *Annual review of environment and resources* **28**, 205-241.

Lambin, E. F., Turner, B. L., Geist, H. J., Agbola, S. B., Angelsen, A., Bruce, J. W., Coomes, O. T., Dirzo, R., Fischer, G., and Folke, C. (2001). The causes of land-use and land-cover change: moving beyond the myths. *Global environmental change* **11**, 261-269.

Latif, M. S. (2014). Land Surface Temperature Retrival of Landsat-8 Data Using Split Window Algorithm-A Case Study of Ranchi District. *International Journal of Engineering Development and Research* **2**, 2840-3849.

Leulsegged, K., Gete, Z., Dawit, A., Fitsum, H., and Andreas, H. (2011). Impact of urbanization of Addis Ababa city on peri-urban environment and livelihoods. *In* "A paper presented for the 10th international conference on Ethiopian economy".

Li, J., Liu, Y., Cao, M., and Xue, B. (2015). Space-time characteristics of vegetation cover and distribution: case of the Henan province in China. *Sustainability* **7**, 11967-11979.

Li, J., Song, C., Cao, L., Zhu, F., Meng, X., and Wu, J. (2011). Impacts of landscape structure on surface urban heat islands: A case study of Shanghai, China. *Remote Sensing of Environment* **115**, 3249-3263.

Li, Z.-L., Wu, H., Wang, N., Qiu, S., Sobrino, J. A., Wan, Z., Tang, B.-H., and Yan, G. (2013). Land surface emissivity retrieval from satellite data. *International Journal of Remote Sensing* **34**, 3084-3127.

López, E., Bocco, G., Mendoza, M., and Duhau, E. (2001). Predicting land-cover and land-use change in the urban fringe: a case in Morelia city, Mexico. *Landscape and urban planning* **55**, 271-285.

Madanian, M., Soffianian, A. R., Koupai, S. S., Pourmanafi, S., and Momeni, M. (2018). The study of thermal pattern changes using Landsat-derived land surface temperature in the central part of Isfahan province. *Sustainable Cities and Society* **39**, 650-661.

Maini, R., and Aggarwal, H. (2010). A comprehensive review of image enhancement techniques. *arXiv preprint arXiv:1003.4053*.

Mallick, J., Kant, Y., and Bharath, B. (2008). Estimation of land surface temperature over Delhi using Landsat-7 ETM+. *J. Ind. Geophys. Union* **12**, 131-140.

Maniur, R. (2017). Analyzing the relationship between land surface temperature and urban structure types in Bandung,Indonsia, University of Twente, Netherland

McCarthy, M. P., Best, M. J., and Betts, R. A. (2010). Climate change in cities due to global warming and urban effects. *Geophysical Research Letters* **37**.

Meyer, W. B., and Turner, B. L. (1992). Human population growth and global land-use/cover change. *Annual review of ecology and systematics* **23**, 39-61.

Mountrakis, G., Im, J., and Ogole, C. (2011). Support vector machines in remote sensing: A review. *ISPRS Journal of Photogrammetry and Remote Sensing* **66**, 247-259.

Mulugeta, M., Tesfaye, B., and Ayano, A. (2017). Data on spatiotemporal land use land cover changes in peri-urban Addis Ababa, Ethiopia: Empirical evidences from Koye-Feche and Qilinto peri-urban areas. *Data in brief* **12**, 380.

Muttitanon, W., Kongthong, P., Kongkanon, C., Yoksan, S., Nitatpattana, N., Gonzalez, J. P., and Barbazan, P. (2004). Spatial and temporal dynamics of dengue haemorrhagic fever epidemics, Nakhon Pathom Province, Thailand, 1997-2001.

Nations, U. (2014). World urbanization prospects: The 2014 revision, highlights. department of economic and social affairs. *Population Division, United Nations*.

Oke, T. R. (1982). The energetic basis of the urban heat island. *Quarterly Journal of the Royal Meteorological Society* **108**, 1-24.

Pongracz, R., Bartholy, J., and Dezso, Z. (2006). Remotely sensed thermal information applied to urban climate analysis. *Advances in Space Research* **37**, 2191-2196.

Quattrochi, D. A., and Luvall, J. C. (1999). Thermal infrared remote sensing for analysis of landscape ecological processes: methods and applications. *Landscape ecology* **14**, 577-598.

Ramankutty, N., and Foley, J. A. (1999). Estimating historical changes in global land cover: Croplands from 1700 to 1992. *Global biogeochemical cycles* **13**, 997-1027.

Rani, M., Kumar, P., Pandey, P. C., Srivastava, P. K., Chaudhary, B., Tomar, V., and Mandal, V. P. (2018). Multi-temporal NDVI and surface temperature analysis for Urban Heat Island inbuilt surrounding of sub-humid region: A case study of two geographical regions. *Remote Sensing Applications: Society and Environment* **10**, 163-172.

Reddy, S. N., and Manikiam, B. (2017). Land Surface Temperature Retrieval from LANDSAT data using Emissivity Estimation. *International Journal of Applied Engineering Research* **12**, 9679-9687.

Salisbury, J. W., and D'Aria, D. M. (1992). Emissivity of terrestrial materials in the 8–14 μm atmospheric window. *Remote sensing of Environment* **42**, 83-106.

Salla, R., Wilhelmiina, H., Sari, K., Mikaela, M., Pekka, M., and Jaakko, M. (2018). Evaluation of the confusion matrix method in the validation of an automated system for measuring feeding behaviour of cattle. *Behavioural processes*.

Sannigrahi, S., Bhatt, S., Rahmat, S., Uniyal, B., Banerjee, S., Chakraborti, S., Jha, S., Lahiri, S., Santra, K., and Bhatt, A. (2017). Analyzing the role of biophysical compositions in minimizing urban land surface temperature and urban heating. *Urban Climate*.

Shahmohamadi, P., Che-Ani, A., Maulud, K., Tawil, N., and Abdullah, N. (2011). The impact of anthropogenic heat on formation of urban heat island and energy consumption balance. *Urban Studies Research* **2011**.

Shi, T., Huang, Y., Wang, H., Shi, C.-E., and Yang, Y.-J. (2015). Influence of urbanization on the thermal environment of meteorological station: Satellite-observed evidence. *Advances in Climate Change Research* **6**, 7-15.

Shiflett, S. A., Liang, L. L., Crum, S. M., Feyisa, G. L., Wang, J., and Jenerette, G. D. (2017). Variation in the urban vegetation, surface temperature, air temperature nexus. *Science of the Total Environment* **579**, 495-505.

Stathopoulou, M., Cartalis, C., and Petrakis, M. (2007). Integrating Corine Land Cover data and Landsat TM for surface emissivity definition: application to the urban area of Athens, Greece. *International Journal of Remote Sensing* **28**, 3291-3304.

Tafesse, B. (2017). impact of land-use/land-cover changes on land surface temperature in adama zuria woreda, ethiopia, using geospatial tools, Addis Ababa University, Ethiopia

Takeuchi, W., Hashim, N., and Thet, K. M. (2010). Application of remote sensing and GIS for monitoring urban heat island in Kuala Lumpur Metropolitan area. *In* "Map Asia 2010 and the International Symposium and Exhibition on Geoinformation, Kuala Lumpur".

Tarawally, M., Xu, W., Hou, W., and Mushore, T. D. (2018). Comparative Analysis of Responses of Land Surface Temperature to Long-Term Land Use/Cover Changes between a Coastal and Inland City: A Case of Freetown and Bo Town in Sierra Leone. *Remote Sensing* **10**, 112.

Tayyebi, A., Shafizadeh-Moghadam, H., and Tayyebi, A. H. (2018). Analyzing long-term spatio-temporal patterns of land surface temperature in response to rapid urbanization in the mega-city of Tehran. *Land Use Policy* **71**, 459-469.

Teferi, E., and Abraha, H. (2017). Urban Heat Island Effect of Addis Ababa City: Implications of Urban Green Spaces for Climate Change Adaptation. *In* "Climate Change Adaptation in Africa", pp. 539-552. Springer.

Tomar, V., Kumar, P., Rani, M., Gupta, G., and Singh, J. (2013). A satellite-based biodiversity dynamics capability in tropical forest. *Electron J Geotech Eng* **18**, 1171-1180.

USGS (2016). Landsat 8 (L8) data users handbook. *USGS* **1**.

USGS, D. (2014). LANDSAT surface reflectance-derived spectral indices.

Valiente, J. A., Niclòs, R., Barberá, M. J., and Estrela, M. J. (2010). Analysis of differences between air–land surface temperatures to estimate land surface air temperature from MSG data. *Spanish Ministerio De Ciencia E Innovación (CONSOLIDER-INGENIO 2010 CSD2007-00067).*

Valor, E., and Caselles, V. (1996). Mapping land surface emissivity from NDVI: Application to European, African, and South American areas. *Remote sensing of Environment* **57**, 167-184.

Wang, S., Ma, Q., Ding, H., and Liang, H. (2018). Detection of urban expansion and land surface temperature change using multi-temporal landsat images. *Resources, Conservation and Recycling* **128**, 526-534.

Weng, Q., Liu, H., and Lu, D. (2007). Assessing the effects of land use and land cover patterns on thermal conditions using landscape metrics in city of Indianapolis, United States. *Urban ecosystems* **10**, 203-219.

Xiao, H., and Weng, Q. (2007). The impact of land use and land cover changes on land surface temperature in a karst area of China. *Journal of environmental management* **85**, 245-257.

Xu, Y., Ren, C., Ma, P., Ho, J., Wang, W., Lau, K. K.-L., Lin, H., and Ng, E. (2017). Urban morphology detection and computation for urban climate research. *Landscape and Urban Planning* **167**, 212-224.

Yang, L., Xian, G., Klaver, J. M., and Deal, B. (2003). Urban land-cover change detection through sub-pixel imperviousness mapping using remotely sensed data. *Photogrammetric Engineering & Remote Sensing* **69**, 1003-1010.

Yang, X., and Li, Y. (2015). The impact of building density and building height heterogeneity on average urban albedo and street surface temperature. *Building and Environment* **90**, 146-156.

Yu, B., Liu, H., Wu, J., Hu, Y., and Zhang, L. (2010). Automated derivation of urban building density information using airborne LiDAR data and object-based method. *Landscape and Urban Planning* **98**, 210-219.

Yu, X., Guo, X., and Wu, Z. (2014). Land surface temperature retrieval from Landsat 8 TIRS—Comparison between radiative transfer equation-based method, split window algorithm and single channel method. *Remote Sensing* **6**, 9829-9852.

Yu, Z., Guo, X., Zeng, Y., Koga, M., and Vejre, H. (2018). Variations in land surface temperature and cooling efficiency of green space in rapid urbanization: The case of Fuzhou city, China. *Urban Forestry & Urban Greening* **29**, 113-121.

Yuan, F., and Bauer, M. E. (2007). Comparison of impervious surface area and normalized difference vegetation index as indicators of surface urban heat island effects in Landsat imagery. *Remote sensing of Environment* **106**, 375-386.

Appendices

Appendix 1: Mean monthly and annual rainfall at Bole station

Year	Months													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Average**	**Annual**
1998	67	40	43.8	99.8	197.7	115	270.7	236.8	173	139	0	0	115.3	1383
1999	4	0	35	17.8	30.5	105	294	270.5	62.8	127	0	0	78.89	946.7
2000	0	0	17.6	87.8	95.2	104	192.9	221.9	161	20	7.5	0	75.64	907.7
2001	0	10.3	174.3	14.8	116.7	179	289.4	207.3	119	11	0	0	93.43	1121
2002	31	25.9	79.4	36.6	49.6	116	213.9	233.6	72.6	0.5	0	33	74.25	891
2003	5	34.1	48.9	111.5	18	122	204.3	238.4	132	4.6	0	33	79.36	952.3
2004	26	11.7	32.4	0	7	124	240.6	230.1	122	50	0.6	0	70.38	844.5
2005	55	14.1	41.8	116.2	164.6	159	174.3	248	77.6	26	7.2	0	90.34	1084
2006	2	36.6	107.8	93.9	37.8	122	313.2	313.1	133	36	0	0	99.56	1195
2007	10	21.3	61.1	86.8	134	165	191.3	305.4	135	37	0.1	0	95.61	1147
2008	0	0	0	34.175	75.3	73.1	295.1	259.1	195	22	53.1	0	83.96	1007
2009	41	0	12.4	46.1	52	84.1	238.2	269.5	86.1	42	2	80	79.47	953.6
2010	0	123	75.6	160.84	94.7	114	320.2	138.8	108	0	13.8	16	97.1	1165
2011	3	13.6	27.9	86	155.6	183	296.5	141.3	0	12	0	0	76.61	919.3
2012	0	0	34.5	75.73	58.5	76	228.8	281.6	177	1.2	0	0	77.77	933.2
2013	0	0	63.5	116.29	78.5	105	157.6	270.2	130	45	3.2	0	80.74	968.9
2014	0	41.7	29.7	33.7	62.1	45.3	179.7	253.6	95.1	35	0	0	64.64	775.7
2015	0	0	21.3	0	169.1	157	163	203	95.1	0	1.3	1.8	67.66	811.9
2016	0	0	0	137.5	124.1	110	162.9	226.6	139	18	3.4	0	76.69	920.3
2017	0	0	66.1	33.1	174.3	44.1	217	241.7	261	0	0	0	86.4	1036.8
Average	**12.2**	**18.6**	**48.66**	**69.43**	**94.77**	**115**	**232.2**	**239.4**	**116**	**31.3**	**4.61**	**8.19**		

Appendix 2: Mean monthly and annual rainfall at Akaki station

Year	Months												**Average**	**Annual**
	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oc	Nov	Dec		
1998	33	30.2	19.6	69.3	159.9	120.8	207.8	280	119	37	0	0	89.64	1075.7
1999	1	1.8	91.8	12.1	45.4	92.8	282.6	300.7	61.7	65	0	0	79.6	955.2
2000	0	0	29.1	113.85	64.9	102.6	188.9	210	124	17	23.4	3.8	73.15	877.85
2001	0	20.7	121.2	24.842	118	149.1	257.5	145	68	2.2	0	0	75.54	906.49
2002	31	10.5	87.8	53.9	76.6	116.05	167.1	166.3	52.3	0	0	18	64.95	779.35
2003	20	28.3	23.9	114	1.4	131.99	325.1	307.4	116	0	0	41	92.37	1108.4
2004	16	15.8	61.4	154.5	15.4	98	150.3	189.1	80.9	4.8	3.4	0.7	65.83	789.9
2005	29	7.3	47.9	119	140.7	151.2	218.7	231.4	231	153	0	2.6	111	1331.7
2006	3	44.2	56.3	79.7	22	88.4	276.4	262.6	153	38	0	3.2	85.57	1026.9
2007	34	24.7	25.6	96.8	64.6	136.45	254.2	221.8	152	14	1.3	0	85.46	1025.5
2008	0	0	0.6	34.2	62.4	140.2	253.5	252.3	191	7.2	64.8	0	83.88	1006.6
2009	60	0	10	118.7	47.7	63.5	235.3	322.4	71.3	33	4.7	17	81.95	983.4
2010	0	66.1	126.2	170	95.2	168.9	334.4	169.8	154	5.2	14.8	7.8	109.4	1312.5
2011	0	2.5	45.2	23.55	128.7	64.275	204.3	304	195	0	4.7	0	80.98	971.73
2012	0	0	29	61	26.1	84.7	228	243.9	127	0	0	0	66.61	799.32
2013	0	0	77	89.1	73.4	113.95	179.6	242.4	143	21	0	0.2	78.23	938.75
2014	0	39.4	76	13.9	0	53.3	176.8	281.9	115	52	0	0	67.41	808.9
2015	0	0	13.7	2.3	96.5	159.6	187.8	247.5	70	0	14.5	0	65.99	791.9
2016	0	46	39.3	193	134.2	111.95	0	0	121	0	9.3	0	54.58	655
2017	0	42.3	0	31.2	0	42.3	0	245	123.4	0	7.4	0		
Average	**11.35**	**18.9**	**49.08**	**79**	**69**	**110**	**206**	**231.2**	**123**	**22.5**	**7.4**	**5**		

Appendix 3: Mean monthly and a rainfall at Kotebe station

Year	**Months**													
	Jan	Feb	Mar	Apr	May	June	Jul	Au	Sep	Oct	Nov	Dec	Average.	Annual.
1998	0	81	40.5	63.2	210.4	120.3	229.4	427.2	167.9	70.6	0	0	117.542	1410.5
2001	0	0	0	0	0	0	0	0	0	11.5	0	25.6	80.463	965.6
2002	111.6	80.8	93.3	26.7	50.1	142.5	312.1	404.8	114.8	0	0	39.7	94.2	1130
2003	5.2	27.2	41.7	172.6	0.3	265.6	373.6			0	0	42.8	101.95	1223
2004	21.3		33.1	183.8	6.3		301.3	434.7	191.4	41.6	0	0.3	91.808	1102
2010	5	162	58.9	131.6	90.5	147.15	291.9	210.6	56.3	0	37.7	20	100.97	1212
2011	3	9.3	65.8	47.85	84.1	377.6	555.8	352.6	182	170	0	0	153.94	1847
2012	0	0	0	280.25	0	67.5	0	0	0	0	0	0	28.979	347.8
2013	0	0	151.3	271.75	91.3	78.8	161.2	193.2	38.6	3.7	0	0	82.483	989.8
2014	0	7.7	34.4	6.2	41.4	0	141.1	137.7	14.8	0	0	0	31.942	383.3
2015	0	0	10.7	12.7	115.8	144.4	327.1	0	120	1	5.7	0	61.467	737.6
2016	0	0	0	127.3	87.9	100.35	209.5	0	127	0	8.1	0	55.021	660.3
2017	0	0	44.1	110.33	0	131.13	0	196.5	0	0	0	0	40.1698	482.037
Average	**11.23**	**31**	**44**	**110**	**60**	**132**	**223**	**196**	**85**	**23**	**4**	**2**		

Appendix 4: Mean monthly minimum temperature (°C) at Bole station

Year	Months												Average
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	
1998	9.8	12	12	12.1	12.6	11	11.7	12.3	11	9	5.4	3.4	10.1755
1999	6.7	7	10	10.4	10.5	10	10.5	10.4	9.9	9.2	6.7	5.6	8.9925
2000	6.8	6	10	12.2	11.1	10	11	10.8	11	8.8	5.9	8.9	9.36083
2001	7.7	8	11	10.9	11.3	10	11.1	11.6	9.8	8.6	6.6	6.4	9.43417
2002	8.5	9	11	11.5	11.8	11	11.2	10.9	11	8.9	7.2	9.6	10.0417
2003	9.9	10	10	11.8	11.4	11	11.5	11.9	11	8.2	6.96	6.01	10.0175
2004	8.5	9	10	11.9	11.1	11	11.4	11.5	11	8.3	7.3	7.8	9.90833
2005	9.1	9	11	11.4	12.1	11	11.5	11.8	12	8.7	8.6	5.8	10.1425
2006	9.4	11	11	12.2	11.9	12	11.9	11.9	11	10.3	7.6	8.7	10.7392
2007	8	10	11	12	12.4	12	12.1	11.8	12	9.3	7.7	5.6	10.325
2008	9	8	8.1	12	12.4	12	11.4	11.5	11	9.8	7.8	6.8	9.98
2009	8.9	10	11	11.8	12.4	12	11	12	11	9.8	8.3	10.11	10.755
2010	9.3	12	12	12.6	13.2	12	11	12.5	12	10	10.6	8	11.1783
2011	8	9	11	12	12.8	12	11	12.3	12	9.3	9.5	7.3	10.5175
2012	9.3	9	11	13.2	12.7	12	11	11.9	12	9.9	9.7	7.9	10.7417
2013	9.5	11	13	13	12.8	12	11	12	11	10.5	9.14	8.4	11.11
2014	8.3	12	12	13.8	13	13	11	11.8	12	10.5	10.9	9.16	11.4325
2015		10	12		24.6	13	11	16.3	12	11.6	9.6	7.5	12.769
2016					13	12	11	12.2	12	10.5	8	0	11.8333
2017	6.4	0	12.4	12.4	13.1	12.3	12.4	12.5	12	9.5	8.1	7.3	9.86667
Average	**8.5**	**9.5**	**11**	**12**	**13**	**12**	**11**	**12**	**11**	**9.4**	**8**	**7**	

Appendix 5: Mean monthly minimum temperature (°C) at Akaki station.

Year	Months												**Average**
	Jan	Feb	March	April	May	June	July	Au	Sep	Oct	Nov	Dec	
1998	14	14	16	16.1	15.8	15	14.9	14.5	15	14.3	11.3	9.4	14.16
1999	11	11	14	14.5	15	14	13.7	13.3	14	13.3	10.8	9.4	12.78
2000	9.3	10	13	15	15.7	14	14	14.2	14	13.4	11.8	10.4	12.86
2001	10	12	13	15.3	15.5	14	13.9	14.7	14	13	14.4	15.2	13.70
2002	15	16	14	14.6	15.8	15	14.5	14.2	14	13.8	12.7	13.9	14.50
2003	12	13	14	15.1	15	15	14.2	14.1	15	14.9	14.9	12.8	14.16
2004	15	14	15	15.9	16.2	16	14.7	14.6	15	14.6	14.2	14.5	14.875
2005	14	15	17	16.2	16	15	15.8	15.5	15	16	14.5	13.6	15.27
2006	15	15	16	16	16.3	15	15	15.3	15	15.6	15	14.8	15.41
2007	15	15	16	16.3	16.5	15	16.6	16.7	17	17.4	17	16.5	16.26
2008	18	18	17	19	17.7	17	14.4	14.3	16	16	14.2	13.97	16.19
2009	14	16	15	17.2	17.9	18	15.3	15.7	16	15.8	7.8	7.4	14.77
2010	14	15	9.9	16.3	16.5	12	13.2	13.2	13	9.4	17.9	12.7	13.5
2011	9.3	8	8.5	12.3	8.3	8.1	12.6	13	13	8.2	7.4	3.4	9.34
2012	4.1	5	12	8.7	12.2	13	12.5	12.3	12	8.8	8.7	6.7	9.64
2013	8.7	11	11	13	12.5	12	8.8	8.4	7.1	7.7	7	6.9	9.58
2014	6.9	9	13	10.9	13.2	12	12.4	12.1	9.9	7.8	9.5		10.56
2015	11	10		14.2			13	13.1	12	10.4	7.7		11.50
2016				15					12				11.7
2017	12	17		14.5		11.4			14				14
average	**12**	**13**	**14**	**15**	**15**	**14**	**14**	**14**	**14**	**13**	**12**	**11.5**	

Appendix 6: Mean monthly maximum temperature (°C) at Bole station.

Year	**Months**												**Average**
	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec	
1998	24.3	25.1	25.4	26.6	25.2	24.6	22.3	21.9	22	22.5	22.8	23.2	23.8
1999	24.7	26.73	25.44	27.5	26.8	24.6	20.5	20.63	22.1	21.9	22.7	22.7	23.9
2000		25.44	27.3	25.6	25.4	23	21.5	20.55	21	22.5	22.3	23.8	23.5
2001	23.5	25.3	23.98	25.5	24.3	22.5	21.5	20.98	23	24.7	24.3	24.2	23.6
2002	24.2	26.3	25.7	26.8	27	24.8	23	21.8	22.4	24.3	24.8	23.8	24.6
2003	24.4	26.1	26.33	25	26.8	24.4	21.2	20.8	21.8	23.7	23.6	23.4	24
2004	25	25.11	25.4	23.9	26.8	24.6	21.6	21.6	22.2	223	23.6	24.1	40.6
2005	24.1	26.2	26.4	25.9	24.1	23.3	21.1	22.15	22.4	23.6	22.9	23	23.8
2006	23.8	24.9	24.5	24.3	25.1	23.1	20.8	20.1	21.7	24.2	23.5	22.8	23.2
2007	23.6	23.5	25.9	24.5	25	22.4	20.7	20.2	20.9	22.4	22.9	22.6	22.9
2008	24.1	24.3	26.35	25.9	25.5	22.9	21.2	20.72	21.9	23.4	22.2	22.9	23.5
2009	23.2	25.33	26.9	26	26.4	25.8	20.9	20.81	22.6	22.6	23.1	22	23.8
2010	23.4	23.4	23.65	24.7	24.1	23.2	20.9	20.93	21.9	24.1	22.8	22.8	23
2011	23.7	25.5	24.7	24.4	24.9	23.6	21.8	20.7	21.6	24.2	23.4	22.8	23.4
2012	24.5	25.6	26.7	24.7	26.5	23.9	21.2	20.7	22	23.9	24.4		24
2013	24.5	26.33	26.3	26	25.1	23.2	21.3	20.84	22.8	23.2	23.9	23.4	23.9
2014	24.3	25.2	25.8	26.4	25.9	25	22	21.5	21.8	23.2	23.7	22.9	24
2015	23.8	26.2	26.4		25.2	23.9	22.9	22.12	23.2	24.9	24.4	24.2	24.3
2016	24			24.3	24.1	22.9	21.5	21.7	22.7	24	23.3	23.2	23.1
2017	24.7		26.6	26.5	24.8	25.4	21.9	21.4	22			23.2	
Average	**24**	**25**	**26**	**25**	**25**	**24**	**21**	**21**	**22**	**25**	**23**	**23**	

Appendix 7: Mean monthly maximum temperature (°C) at Akaki station.

						Months							**Aver**
Year	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec	
1998	25.8	27.4	27.44	29	27.6	26.6	24.1	23	24.4	25	25.3	24.9	25.9
1999	25.9	27.3	26.5	28	27.98	26.3	23.4	23.6	25.1	24.6	25.1	25.3	25.8
2000	26.2	27.1	28.5	27	27.1	26	24.6	23.8	24.7	25.2	25.7	25.8	26
2001	26.3	27.3	26.2	28	26.9	25.7	24.6	24.7	25.9	26.9	26.5	26.4	26.3
2002	26	27.7	27.5	28	28.5	26.9	25.8	24.7	26.2	26.99	26.5	26.2	26.7
2003	26.7	28.1	27.97	27	28.9	27	23.7	23.6	24.8	26.6	26.6	25.6	26.4
2004	27.4	27.5	27.84	27	28.65	26.3	24.7	24.3	25.7	25.9	26.5	26.7	26.5
2005	27.1	29.2	28.2	27	26.84	26.1	23.7	24.5	24.5	26.21	25.6	26.1	26.3
2006	26.5	27.8	27.9	27	28.6	26	24.3	23.8	24.3	26.4	25.8	25.6	26.2
2007	26.3	27.5	28.82	28	28.23	25.5	23.9	23.4	24.7	25.95	25.8	25.8	26.1
2008	27.2	27	29.3	29	29.03	25.7	24	23.3	25	26.42	25.3	26.2	26.5
2009	26.5	28.1		29	30	29.2	24.5	24.4	26	25.9			27
2010	27	27.2	26.9	28	27.23	26.8	23.4	23.7	24.8	26.7	26	26.2	26.1
2011	26.6	28.2	27.6	30	28.5		25.3		25.2	26.6	26.2	25.8	27
2012	26.7	26.9		28	29.8	27.3	24.1	24	25.1	26.7	26.2	26.5	26.5
2013	27	28.8	29.15	29	28.22	26.8	24.5	23.6	25.9	26	26	25.1	26.7
2014	26.4	27.3	27.8	28		27.5	23.9	23.1	24.2	24.7	25.9	26.3	25.9
2015	26.2	28.7	28.95	30	27.9	26.6	25.8	24.5	25.8	27.4	26.9		27.1
2016	27	28.3	30	27	26.7	26.3			25.6		25.7		27
2017	26.5	27.4		28		26.2		25	25.1		24.6		26
Average	**26.5**	**28**	**28**	**28**	**28**	**27**	**24**	**24**	**25**	**26.1**	**26**	**26**	

Appendix 8: Accuracy assessment for the year 1998, 2010 and 2017

	1998		2010		2017	
Class name	user accuracy	producer accuracy	User accuracy	producer accuracy	user accuracy	producer accuracy
Farm land/bare land	87.94%	88.38%	75%	85.43%	85.25%	92.04%
Vegetation	93.6%	94.71%	86.25%	92%	97.28%	87.75%
Built up	93.41%	91.89%	98.5%	85.17%	94.2%	96.06%
Over all accuracy	91.50%		87.25%		91.90%	
Kappa coefficient	0.8723		0.808		0.879	

Appendix 9: NDVI report

Year	Min	Max	Mean	Std
1998	-0.46121	0.752188	0.15626	0.149
2010	-0.87683	1.00	0.080187	0.149
2017	-0.815	0.752	0.024	0.132

Appendix 10: NDVI of UMT

UMT	min	max	mean	std
Condominium	-0.391	0.389	-0.0756	0.081
Villa	-0.221	0.513	-0.0186	0.086
Mud house	-0.226	0.365	-0.0388	0.089

Appendix 11: UMT percent land cover

UMT	Asphalt	G.R	Vegetation	Roof	Bare Land
Condominium	8	16	2	39	35
Villa	0	14	28	48	7
Mud House	0	14	6	75	5

Appendix 12: Zonal statistics report on LST and urban morphology type of condominium

polygon no	Name	min	max	Mean T in ^{O}C
1	condo 1	31.67	41.38	37.86
2	condo 2	31.81	40.81	37.28
3	condo 3	30.59	36.3	34.37
4	condo 4	29.9	38.45	34.59
5	condo 5	26.3	38.96	34.63
6	condo 6	32.04	36.73	34.95
7	condo 7	30.7	36.47	34.93
8	condo 8	30.31	37.46	34.67
9	condo 9	29.89	38.11	34.65
10	condo 10	31.56	37.84	35.71
11	condo 11	30.42	37.98	35.1
12	condo 12	30.04	38.45	35.21
13	condo 13	29.45	38.45	34.66
14	condo 14	24.82	39.59	35.24
15	condo 15	31.11	38	35.91

Appendix 13: Zonal statistics report on LST and urban morphology type of Villa

Polygon no	name	min	max	Mean T in ^{0}C
1	villa1	31.38	37.94	33.65
2	villa 2	31.78	39.07	36.58
3	villa 3	30.22	36.43	35.24
4	villa 4	30.3	38.57	32.89
5	villa 5	30.36	37.33	34.73
6	villa 6	30.47	35.8	34.42
7	villa 7	32.86	38.5	37.52
8	villa 8	30.44	36.1	33.99
9	villa 9	32.53	37.39	36.28
10	villa10	31.36	37.21	34.96
11	villa 11	28.83	37.45	32.67
12	villa 12	31.9	36.62	35.89
13	villa13	30.57	35.98	34.64
14	villa 14	29.74	36.53	33.8
15	villa 15	28.34	35.34	30.9

Appendix 14: Zonal statistics report on LST and urban morphology type of Mud House

Polygon no	name	min	max	Mean T in ^{0}C
1	mud 1	30.59	35.47	34.48
2	mud 2	30.06	37.23	34.58
3	mud 3	35.5	36.1	35.83
4	mud 4	31.98	33.53	32.98
5	mud 5	33.85	35.38	34.74
6	mud 6	35.27	36.57	36.01
7	mud 7	31.9	33.71	32.45
8	mud 8	35.77	36.38	36.03
9	mud 9	34.57	36.78	35.93
10	mud 10	32.4	36.57	35.92
11	mud 11	33.03	36.94	36.12
12	mud 12	34.12	35.68	35.05
13	mud 13	34.32	35.62	35.05
14	mud 14	33.83	37.14	35.9
15	mud 15	34.13	35.89	35.13