URBAN HEAT ISLAND:

INVESTIGGATION OF URBAN HEAT ISLAND EFFECT.

A Case Study of Nairobi.

by

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THE UNIVERSITY OF NAIROBI

A project present to the Department of Meteorology in Partial fulfillment of the requirements for the award of degree in:

Bachelor of science in Meteorology

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DECLARATION

I hereby declare that the work entailed here is my original work. I have not copied from any other students' work or from any other sources, except where due reference or acknowledgement is made explicitly in the text, nor has any part been written for me by another person. The aforementioned work has not been presented to any University or institution therein, to the best of my knowledge.

SILAS OWITI ODONGO

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Signature………………..

SUPERVISORS:

Professor Ng'ng'a **Signature…………………….**

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I would also like to thank my external guide Dr. David Dickerson, The Director at Environmental Pollution Management LTD United Kingdom and all the people who provided me with the facilities being required and conductive conditions for my case study

DEDICATIONS

I dedicate this work to my Grandma, Rosebella Oguma Nyol whose non-stop prayers saw me through the tough times and difficult decisions during the course work. I dedicate the work to my family members for constant reminder that I can do it whenever I doubted myself, to my brother Antonio, you are a true believer in a potential. To Teddy Onyango thank you for being there whenever you were needed. To Meshack Eggrey, your help in extracurricular situation was very important. To Terry Newton, James Dawe, Richard Portsmouth, Noel Onyango, I say thank you, and finally, to Nahjma Mohamed, well you are an inspiration.

ABSTRACT

In this paper the Urban Heat Island effect is investigated and the effect of urbanization on UHI is analyzed as a case study in Nairobi City. The primary aim of this study was to provide a comprehensive quantification of the effect of Urbanization to the UHI effect to the urban planning management. The study consisted of three parts; Analysis of Urbanization using the DMSP/OLS night time light images, investigation of UHI effect using Landsat 8 OLI/TIRS images and correlation analysis between the UHI, NDVI (representing vegetated surfaces) and Urbanization(landuse/Landcover) to establish a relationship between the UHI effect and urbanization. A mono-window algorithm was used to retrieve the land surface temperature(LST) distribution from the Landsat 8 images, using specifically band 10 and band 11 images. The spatial pattern of LST in the study area retrieved to characterized their local effects on the urban heat islands. In addition, the correlation between LST and the NDVI (Normalized difference vegetation index), Urbanization was analyzed to explore the impacts of the vegetation and urbanization on the urban heat island effect. The results indicate that, though not pronounced, there is a distribution of heat islands in Nairobi. The negative correlation between LST and NDVI suggests that vegetation weakens the heat island effect, while the positive correlation between LST and Urbanization indicates that the urbanization elevates the heat island effect. The study concluded that, with the rate of urbanization, the distributed heat island, with time will conglomerate into a large heat island in the region. Although satellite data (e.g., Landsat 8 level one products) can be applied effectively to examine the distribution of urban heat islands, the research still needs to be refined with *in situ* measurements of LST in future studies.

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List of Abbreviations and Acronyms

UHI – Urban Heat Island

UBL – Urban Boundary Layer

UCL – Urban Canopy Layer

LST – Land Surface Temperature

LSE – Land Surface Emissivity

NDVI – Normalized Difference Vegetation Index

TM – Thematic Mapper

ETM+ - Enhanced Thematic Mapper plus

OLI – Operational Land Imager

TIRS – Thermal Infrared Sensor

SNR – Signal to Noise Radiometric

WGS – World Geodetic System

UNESCO – United Nations Educational, Scientific and Cultural Organization

EIA – Environmental Impact Assessments

EPA – Environmental Protection Agency

KMD – Kenya Meteorological Department

CBD – Central Business District

USGS – United States Geological Survey

RGB – Red, Green, Blue Band layers

DMSP/OLS – Defense Meteorological Satellite Program – Operational Linescan System

DN – Digital Number

GIS – Geographic Information System

CHAPTER 1

1.1 INTRODUCTION

1.1.1 Overview

In Nairobi City, infill development and urban sprawl are leading to the loss of vegetation and the ratio of land use have increased over the years, these are majorly composed of impervious surfaces such as buildings and parking areas and tarmac roads as well. This therefore has affected the heat balance provided by the natural ecosystem. As warming associated with urban development and climate change intensifies, vulnerable groups will be at risk of heat-related morbidity and mortality. This warming of the city due to the related urbanization and other factors has led to Urban Heat Island effect. The UHI effect is a critical factor for air quality management and public health in urbanized areas all over the world. This effect is relating to an increase in temperatures in urban areas as compared to the surrounding lower density rural areas.

1.1.2 Preview

In the near future it is expected that the global rate of urbanization will increase by 70% of the present world urban population by 2030. As urban agglomerations emerge and population migration from rural to urban/suburban areas continues, sustainable urban planning faces two major challenges: first the impact of climate change and the necessity for adaptation measures to mitigate the consequences, and second, that of urbanization and the necessity of balancing the various conflicting spatial demands. For to address these issues a comprehensive study on some of the effects related to urbanization is necessary.

Urbanization negatively impacts the environment mainly by the production of pollution, the modification of the physical and chemical properties of the atmosphere, and covering of the land surface. Considered to be a cumulative effect of all these impacts is the UHI effect, defined as the rise in temperature in any man made area, resulting in a well-defined, distinct “warm Island” among “Cool Sea” represented by the lower temperatures of the areas nearby natural landscape. Heat Islands develop when a large fraction of the natural land cover in an area is replaced by built surfaces that trap incoming solar radiation during the day and then re-radiate it at night (Quattro chi et al 200; Oke 1982)) (figure 1.1).

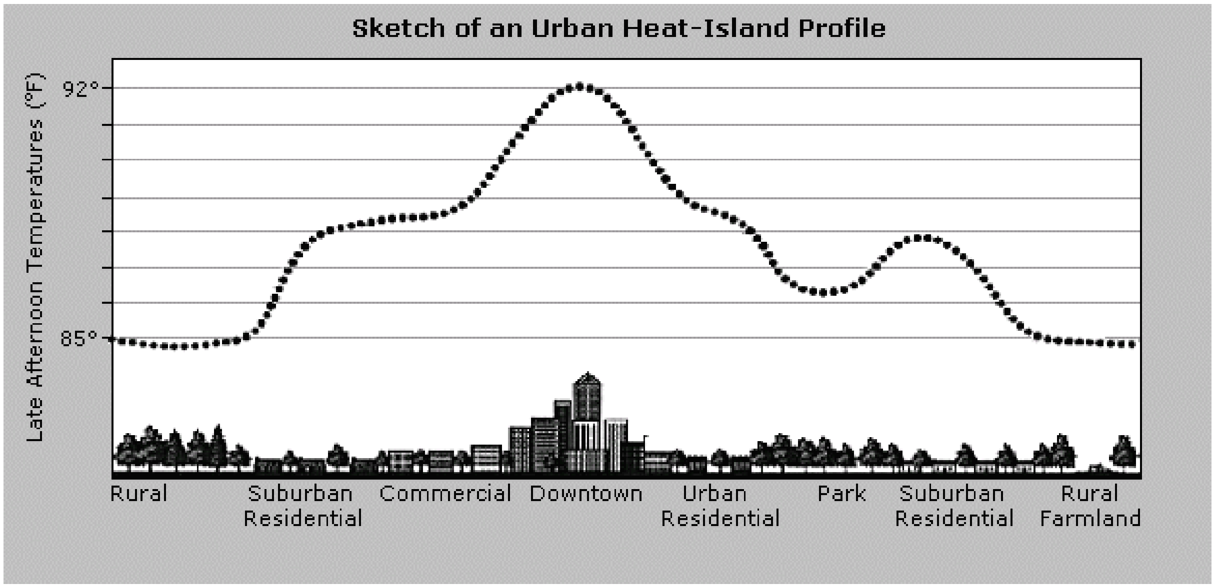

Figure 1.1(source; EPA, 2008): Sketch of an Urban Heat Island Temperature Profile for late afternoon.

The UHI effect is a worldwide concern; in Europe, climate change projections suggest that the summer heat waves will become more frequent and severe during this century, consistent with the observed trend of the past decades [1]. This will also be true for the Northwest Europe, including the Netherlands [2]. While urban areas will generally be exposed to the same change in regional climate as the surrounding areas, the urban setting can exacerbate the impact of this exposure on a local scale, this is influenced by the fact that urbanization will continue in the next decade at a higher rate. These developments may significantly influence future urban climate conditions, thermal comfort of citizens and livability of urban areas.

The presence of many buildings and artificial or impervious surfaces at the expense of the natural environment, creates a unique local climates altering temperature, moisture, wind

patterns and radiation. The UHI effect I pronounced during periods of low wind speeds; it can be as much as 4-5^{0}C higher in the City Centre compared to the surroundings where there is much more vegetation with damp ground to keep the temperatures lower.
Consequently, local climate may vary considerably within large cities. To ensure an effective and coherent development of adaptation strategies aimed at improvement of the urban thermal environment, a better understanding of the spatial and temporal variability in local climate (intra-urban variability), and the influence of urban features is needed.
To date, relatively few long term observational data on the spatial variability of local climate within the cities are available, but most research is now focused in the study of the urban local climatic conditions [6]. The climatology description of a city is often based on one or few fixed meteorological stations, usually located in the city Centre and or at the airport, not well distributed in the local areas, and therefore not representing the whole city.
A distinct feature of urban climates is the UHI. A distinction can be made between surface UHI, the difference in surface temperatures between the urban and rural area, and the atmospheric UHI, the corresponding differences in air temperature. Two types of atmospheric UHI can be distinguished, that of the Urban Boundary Layer (UBL) and that of the Urban Canopy Layer (UCL) [6].
For outdoor thermal comfort, the UCL-UHI is the most important one since people live in the urban canopy layer. Therefore, the UCL-UHI is the most commonly observed of the two atmospheric types and often referred to in discussions of urban heat islands. In contrast to the surface UHI, the atmospheric UHI is mainly a nocturnal phenomenon; it's often weak during the late morning and throughout the date and becomes more pronounced after sunset as a result of slower cooling down of the urban areas as compared to the rural surrounding. This paper focuses on the surface Heat Island.

1.1.3 Background

It is well-known and documented that urbanization can have significant effects on local weather and climate [1]. UHI as an effect of urbanization is the direct representation of environment degradation [3]. The high urbanized areas lead to more distinct urban heat island with huge temperature differences between urban and rural areas. As early as

1833, the concept of UHI was described by Luke Howard [4]. The buildings, concrete, asphalt and industrial activities of urban areas causes the UHI effect.

UHI mainly appeared in the spatial distribution of land surface temperature (LST), which is governed by heat fluxes and affected by urbanization. Consequently, acquiring LST is the primary and key step to the UHI analysis. The LST difference is usually larger at night than during the day. Seasons influence the LST difference as well. Heat Island Cities located in the mid latitude are usually strong in the summer seasons. In the Tropical climates, he day season may affect the large island magnitudes. Thus, there are differences in day, night and seasonal measurements of LST. This implies that if the LST is unavailable in the case studies, the near-surface air temperatures can also be used to validate the UHI effect. Traditionally, UHI analysis is based on the LST data observed at the meteorological points always with in situ measurements [3]. However, the uneven distribution and limited conditions of these isolated meteorological observation locations may result in the observed LST data not fully representing the distribution of LST across the region. Since the 1960s, with the advent of high-resolution earth-monitoring satellites, remote sensing technology has the advantages of high-resolution, wide-coverage and intensive-points which makes large-scale UHI research possible.

The Landsat TM data is one of the most widely used satellite images for LST retrieving because of its high resolution (120m) and free download availability from the USGS, which has one thermal infrared (TIR) band. This makes retrieving LST from a single band more difficult than from multiple thermal bands. In 2001, Qin et al proposed a mono-window algorithm for retrieving LST using Landsat TM TIR band data [17]. The mono-window algorithm provided a simple and highly effective method for retrieving land surface temperatures for the analysis of UHI effect[8].

The study directly aimed at deriving urban heat islands through Landsat 8, attempting to detect the whereabouts of the UHI as a focus thermal heat which directly affects the city as influential in human life by raising the temperature regions as it was located. It isn’t enough to explain the reason His through satellite images without identifying through GIS, so this study involves converting digital satellite images data of the surfaces temperatures (TIRS) to ISO temperature lines which are able to determine the thermal islands and Thermal Island peaks more effectively.

Landsat 8 has two instruments: The OLI sensor, which includes refine heritage bands, along with three new bands; a deep blue and for coastal/aerosol studies, a short-wave infrared band for cirrus cloud detection and a quality assessment band. The TIRS sensor provides two thermal bands. These sensors both provide improved signal-to-noise (SNR) radiometric performance quantized over 12-bit dynamic range. This translates into 4096 potential gray levels in an image compared with only 256 gray levels in the previous 8-bit instruments. Improved signal to noise performance enables better characterization of land cover state and condition. Products are delivered as 16-bit images (scaled to 55000 gray levels)

In addition, Landsat 8 carries two push-broom instruments: the OLI, and the TIRS sensor. The spectral bands of the OLI sensor, while similar to Landsat 7's ETM+ sensor, provides enhancement from prior Landsat instruments, with the addition of two new spectral bands: a deep blue visible channel (band 1) specifically designed for water resources and coastal zone investigation, and new infrared channel (band 9) for the sensing of cirrus clouds. A new quality assurance band is also included with each data product. It provides information on the presence of features such as clouds, water and snow. The TIRS instrument collects two spectral bands for the wavelength covered by a single ring on the previous TM and ETM+ [6].

1.2 Study Area

The study area is Nairobi, which is the largest city in Kenya and the country's capital with a focus on the densely urbanized and populated areas. The main focus is the Nairobi CBD which is considered fully urbanized with most surfaces covered with tarmac or various construction materials such as buildings and parking lots. There is maximum land use with minimum vegetation cover compared to the surrounding and during the day and various nights the area is highly populated as much of the activities are carried out in the city Centre. This therefore makes it an ideal area of study for the research topic. It lies in between the latitude $1^0$16'59" South; Longitude $36^0$49'00'' East, with an elevation of 1684m above the sea level according to WGS 84 (Latest World Geodetic System) (**figure 1.2)**

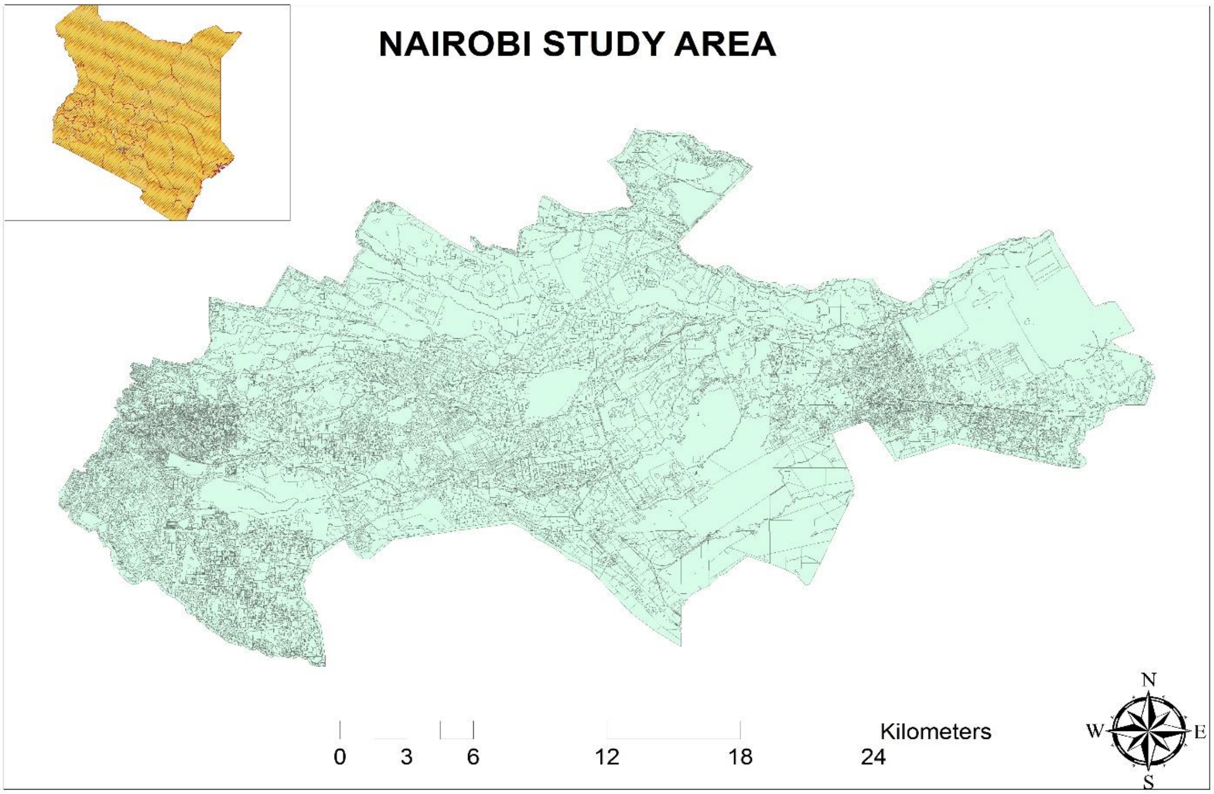

Figure 1.2 (source: drawn with ArcGIS 10.3): the map showing Nairobi region, study area

Figure 1.3 :(source: Google maps): showing the Nairobi CBD, focused study area.

1.3 Problem Statement

Urbanization is slowing down wind speed as buildings and other structures block the flow path, as a result, pollutants are not being properly dispersed putting the health of hundreds of thousands of city residents at risk. Recent studies show that Nairobi is on a risky path of becoming a large heat island as tall skyscrapers block the dispersal of pollutants (June 2015 UNESCO conference “Our Common Future Under Climate Change”). This therefore shows that the situation of urban heat Island has not been established with the recent studies done. This therefore creates a study area leading to this investigation. The UHI effect, together with solar radiation set in motion conditions that that foster biophysical hazards such as heat stress and increased concentration of secondary pollutants.

1.4 Justification

The Kenya economic survey indicate that the effects of climate change continue to be felt in Kenya in the form of high temperatures and droughts. It also reports that total number of environment impact assessment risks increased by 35.6% from 1153 in 2013 to 1563 and, that human settlements and infrastructure sector accounted for the highest number of EIAs reported over the years followed by the transport sector. This therefore shows that urbanization influences the temperatures variations especially in Nairobi. Although UHI effect studies has been done in the major developed countries, in Africa continent there is reported few studies conducted making a need for such studies in order to inform city planners to cope with the challenges of urban climates.

1.5 Objectives

The study hypothesized that the population increase associated with urbanization will lead to modification on the urban local weather hence the effect of UHI. The study aims at evaluating the temporal patterns of urbanization and investigation of urbanization effects on the temperature, which will be vital in enhancing human comfort as well as ensuring environmental sustainability.

The main objectives of this project are:

1. To contribute to the effective environmental management of Nairobi on the effect of UHI and population growth.
2. The analysis of the UHI effect using satellite images
3. Analysis of Urbanization using nighttime Light images from DMSP/OLS

The specific objectives include:

1. Downloading Landsat images from USGS website.
2. Correction of the images
3. Analysis of the UHI using ArcGIS
4. Downloading nighttime light images from DMSP/OLS
5. Analysis of urbanization and classification of the images
6. Establishing a relationship between the UHI effect and Urbanization.

CHAPTER 2

2.1 LITERATURE REVIEW

2.1.1 Overview

Before human development began disturbing natural habitats, urbanization, soils and vegetation constituted part of a balanced ecosystem that managed precipitation and Solar energy effectively (Getter and Rowe 2006). As a result of these feature, the surface has been replaced with impervious areas. In the United States, it is estimated that 10% of residential developments and 71-95% of industrial areas are and shopping Centre are covered with impervious surfaces. Today, two-thirds of all impervious areas are in the form of parking lots, driveways, roads, and highways (Getter and Rowe 2006). These increasing impervious areas consist of cities, towns, and suburbs. It is documented that urbanization can have significant effects on local weather and climate. Of these effects one of the most familiar is the UHI (Streuker 2002). The increase of urbanization has greatly increased over the last century. Though it may seem that the study of the UHI is fairly new, it was actually noticed and documented as far back as 1820.

The UHI is a metropolitan area that is significantly warmer than its rural surroundings (Figure 1.1) and it develops when a large fraction of natural land cover is replaced by built surfaces, concrete and glass buildings as well as tarmacked roads. The thermal characteristics of materials used in the city (asphalt, brick, concrete, glass, etc.) differ greatly from those found in the rural areas (trees, grass, water bodies, bare soil, etc.) in addition, the canyon structure created by tall buildings enhances warming by the sun (figure 2.1)

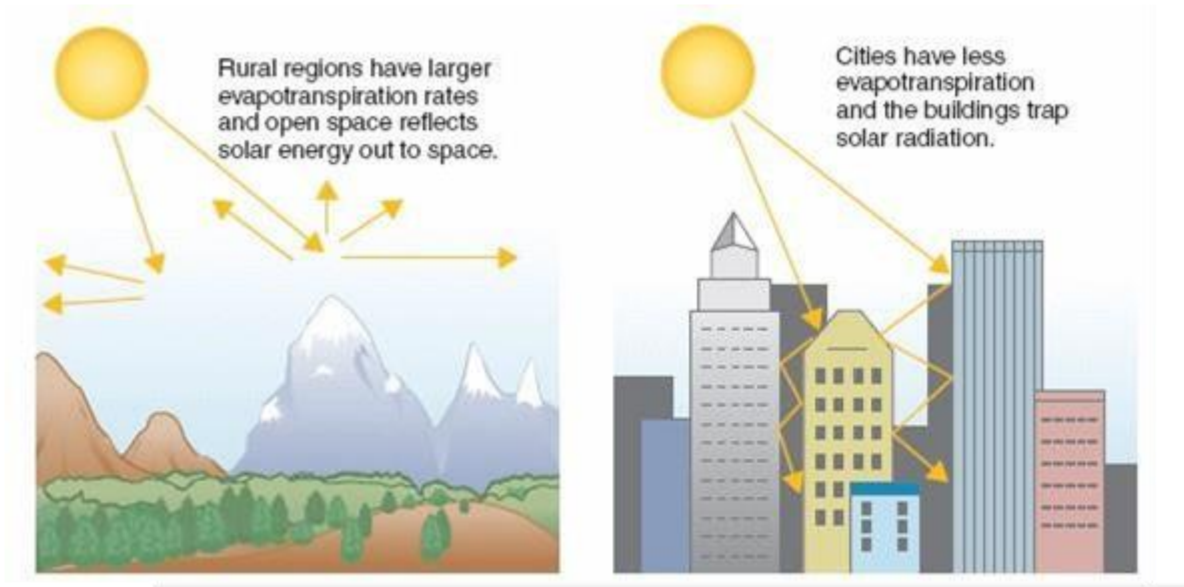

Figure 2.1: (source; EPA) showing the magnitude of the urban heat island as a temperature difference between a city and its surroundings, for clear sky and light wind.

During the day, the energy is trapped by multiple reflections and absorptions by the buildings (Chapman 2005). This stored energy in urban areas is then radiated as long-wave radiation less efficiently than in rural areas during the night (Solecki and others 2005) keeping the urban areas three times warmer than the surrounding rural areas, while the buildings play a role in reducing wind speed. The combination of reducing wind speed, and cloud cover aid in the UHI magnification. Higher temperatures also accelerate the chemical reaction that produces ground level ozone and smog (EPA 2003). Adding to the global warming effect, heat island magnitudes are largest under calm and clear weather conditions. Increasing winds, mixes the air and reduces the heat islands while increasing clouds reduce radiative cooling at night and also reduce the heat island (Vogt2004). Another component that adds to the creation of UHI is from waste heat or anthropogenic heat in general. Waste heat is emitted from a range of human activities- automobiles, industrial facilities and a variety of other sources, including human metabolism (Sailor and Dietsch 2005). Air temperatures are also reduced through evapotranspiration; this occurs when there is loss of water vapor through pores in the pants' leaves. The water draws heat as it evaporates, thus cooling the surrounding air temperature in the process. In a hot, dry climate, this cooling effect equals that of five air conditioners running for 20 hours per day (Gry and Finster 2008). In contrast to the natural landscape, cities tend to have little vegetation, and due to the large fractional cover of impervious surfaces, there tend to be less surface moisture in Urban areas (Sailor and Dietsch 2005). The Kenya 2014 Economic survey indicates an increase in development of infrastructure and constructions, especially in Nairobi, this therefore shows an increase in Urbanization development which is a 'blessing in disguise'. A research carried out by the KMD in 2007 indicated that if the then current trends of rising population, increased motor vehicle density and enhanced industrialization persist, then the anthropogenic waste heat ejection would be large enough to alter the heat balance of Nairobi. In a paper presented mid 2015 in Paris, France by a team of Kenyan scientists, indicates that Nairobi is on a risky path of becoming an urban heat island as skyscrapers block the dispersal of pollutants (Figure 2.2)

The increase in urban temperatures can affect public health, environment, and the amount of energy that consumers use in the hot days cooling. The Kenya 2014 economic survey reports respiratory diseases as a continuing leading cause of illness, accounting for 58.8% of the total in 2014. A study of air quality in the Nairobi region established that the air we breathe in Nairobi may kill us, this implies that the quality of air in Nairobi is ten times more dangerous, according to the WHO threshold of 20-micrograms per cubic meter for key pollutants.

It has been largely demonstrated that cities with varied landscape can exhibit temperatures several degrees higher than their surrounding rural areas, a phenomenon which if increases in the future may result in a doubling of the urban to rural thermal ratio in the future. Characteristics inclination towards the warming of urban surface is exacerbated during hot days and heat waves, which reinforces the air temperature increase, particularly in ill ventilated outdoor spaces or inner spaces of residential and commercial buildings with poor thermal insulation.

Figure 2.2: (source; Daily Nation (online)) showing trapped pollutants over Nairobi CBD.

2.1.2 Urban Heat Island

Broadly, according to (Oke, 1987), there are three different types of urban heat island defined as follows:

i. Canopy layer or air UHI- this includes urban canopy layer heat island that is found in the air beneath the roof level and the urban boundary layer heat island that is found in the air above the roof level. These are closely coupled but have different magnitudes and are generated by different processes.

ii. Boundary layer (UBL) heat island or surface UHI. This kind can be distinguished based on the temperatures of urban surfaces.

iii. Subsurface urban heat island- is that which is associated with the ground beneath the surface.

2.1.2 Causes

The urban heat island phenomenon varies in time and space. It is mainly influenced by two factors, namely; meteorological conditions and urbanization. Its morphology is strongly controlled by the unique characteristics of each city. It is greatest in large cities. It is majorly cause by progressive replacement of natural surfaces with built surfaces through urbanization. Natural surfaces are often composed of vegetation and moisture-trapping soils, utilizing a relatively large portion of the absorbed radiation in the evapotranspiration process and release water vapor that contributes to cooling of the air I the vicinity. Built surfaces are composed of high percentage of non-reflective and water resistant construction materials. They tend to absorb a significant proportion of the incident radiation which is released as heat. Narrow arrangement of buildings along city's streets form urban canyons that inhibit the escape of the reflected radiation from most of the three-dim urban surface to space. This radiation is ultimately absorbed by the building walls thus enhancing the urban heat released. Urban heat island is highly correlated with meteorological factors such as the cloud, humidity, sunlight, precipitation and wind speed. Current meteorological conditions over cities are associated with increased population experienced in most cities. Over time, urban microclimates are formed and are caused by change in factors such as air temperature, wind speeds, cloud cover and precipitation.

2.1.3 Impacts

UHI reinforces the increase of air temperature, thus increasing the overall energy consumption for refrigeration and air-conditioning. This will lead to the increasing in energy production, which will eventually generate higher emissions of heat trapping greenhouse gases and pollutants, such as sulfur dioxide, nitrogen oxide, carbon dioxide. The whole process is an inevitable cycle.

Excessive heat events due to ill-ventilated outdoor spaces or internal spaces of residential and commercial buildings with poor thermal insulation, creates dramatic temperature increases, and can result in high rates of mortality. It has been estimated that the heat exposure leads to more than 8000 deaths in the US.

Although some developers claimed that UHI creates waves that can be transferred into the interior of homes and buildings through roofs (EPA website), causing the internal air temperature of buildings rise significantly; there is no specific case study to be carried out yet to prove the claims.

2.1.4 Past Urban Heat Island Studies

The Maasai Mara ecosystem.

The study was done to investigate the urban heat island effect to changes in land use/land cover of an ecosystem over time. The area of study was in a rich diverse ecosystem located in South Western Kenya. This study used the remote sensing approach to investigate the land cover changes and in particular vegetation change and LST changes as indicator of land surface change. Further the study evaluated the relationship between LST human related influence factor to landuse/Landcover around the Maasai Mara National reserve. It incorporated the use of thermal band in Landsat Satellite images for epochs 1985,1995,2003 and 2010. The Land surface retrieval algorithm used was that based on vegetation abundance (Nduati et al 2013). The results from the study indicated that there was a negative and strong correlation existence between LST and NDVI thus indicating that with decrease in Landcover, there is increase in LST in the region. The highest NDVI values were in the areas under forest of dense vegetation cover while the least NDVI values occurred in areas under the water class. The variability between the retrieved satellite LST and the meteorological measurements of land surface air temperature at the Narok weather station was similar to the trends of the ground. There was a progressive and significant increase in minimum temperature, however, the ground measurements indicated a decrease in the maximum temperature which was contrary to the satellite derived LST which indicated an almost commensurate increase in maximum LST. The contrast was attributed to changes in landuse/Landcover. The Wildebeests are the flagship species for Maasai Mara National Reserve (MMNR) and grazers hence reliant on vegetation. Other wildlife species that are negatively impacted by vegetation loss, are also affected by habitat fragmentation such as that occasioned by roads and human settlements. Landuse/Landcover change has been shown to have an impact on LST and NDVI in this study and also the contribution that wildlife and livestock have on land surface changes and by extension, LST (Nduati et al 2013).

CHAPTER 3

3.1 DATA AND METHODOLOGY

3.1.1 Data

Landsat 8 OLIS/TIRS was used in the retrieval of land surface temperature due to the presence of thermal infrared bands. The Nighttime light images were used in analysis and classification of urbanization, these products are widely used in urban studies and energy or population research (Table 3.1)

Table 3.1 Landsat OLI/TIRS and Nighttime Light images

Data	Resolution (m)	Time	Date
Landsat 8 OLI/TIRS	30 X 30	Day and night	2013-2014
Nighttime Light images	120 X 120	Night time	2013-2014

3.1.1.1 Other Auxiliary Data

In addition, the GIS boundary data for Kenyan Districts, the Landuse/Landcover TIFF format data were downloaded from the ILRI website to help in the analysis as well.

3.1.2 Methodology

3.1.2.1 Urbanization investigation

DMSP/OLS products are widely used in urban studies. One of the most frequently used data from DMSP/OLS is the version 4 of global nighttime light series, which provide annual global composite imagery. The most notable advantage of DMSP/OLS nighttime light imagery is that the night light brightness has been utilized in several studies for quantitatively estimating and mapping socio-economic activities related to the urbanization process at regional to global scales. The analysis was carried out step by step (figure 3.1)

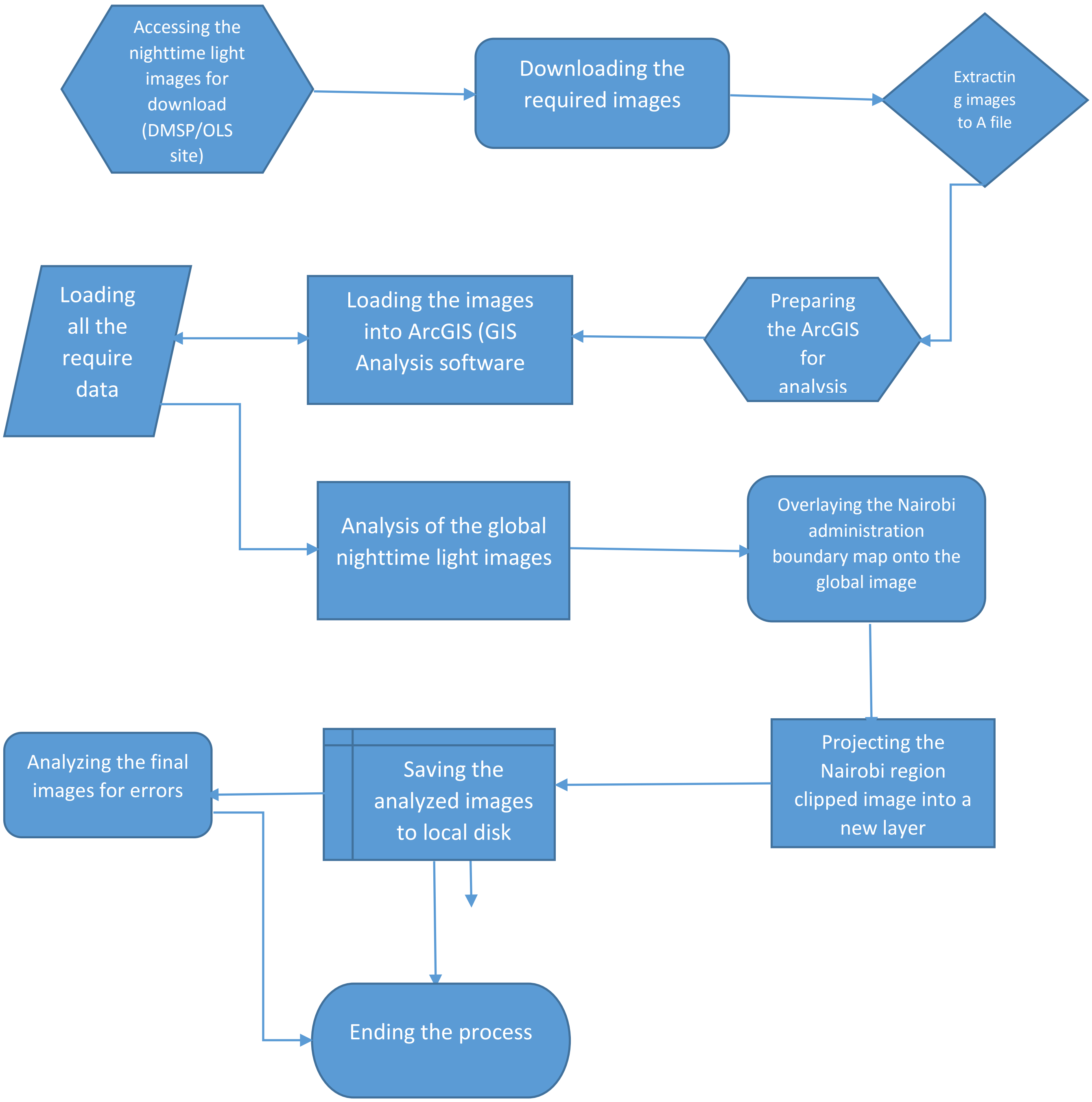

Figure 3.1: flow chart showing the process of Urbanization analysis.

From the DMSP/OLS website, the data were selected according to availability and the years needed were predetermined making the selection easier. The version 4 of the nighttime light images were then downloaded from the sight which is freely available for public use. because of the size of the nighttime images, the downloaded compressed files were then decompressed using the available software for file extraction into suitable directory. The downloaded Nairobi administration boundary GIS data were then put into the same directory with the nighttime light images to for the analysis.

ArcGIS 10.3 student version was used in analysis as this software had all the capabilities of spatial analysis. The images were then uploaded to the software and the calculation of the Average DN values were calculated using the following formulae (Standard DMSP/OLS formula for calculating average DN values):

Average DN= $(\sum_{i=0}^{63} DNi * Ni)/Ntotal$

where:

1. N_I is the number of the pixels whose digital number value equals $DN_{i;}$
2. N_{Total} is the total number of pixels within the boundary of the study are.

The Average DN values were calculated for each image then the images were then put into a composite and average of the composite image was then done. The images were analyzed first before overlaying it on the Nairobi administration map to minimize the loss of data during the overlaying. For Nairobi, all pixels spatially contained within the administrative boundary were collected by overlaying the administrative unit map onto DMSP/OLS images based upon a uniform georeferenced system.

The area was then divided into five types of landuse classes, using indices of urban compactness, the classification criteria used was as shown below:

1. 0≤DN<5 no-development area;
2. 5≤DN<20 scattered development area
3. 20≤DN<52 sub-urban development area;
4. 52≤DN<60 compact development area;
5. 60<DN<63 central core area.

In addition to the classification of the different types, the part with DN values greater than 20 was considered as the urban area, otherwise was treated as rural are.

The Landuse/Landcover of Nairobi was then plotted using the data from ILRI website to determine the correlation of the Urbanization classification using nighttime light images to the Landuse/Landcover for the year 2010 and 2012, the selection was solely based on the availability of the data.

3.1.2.2 Urban heat island investigation

3.1.2.2.1 Acquiring Landsat data

Landsat 8 OLI/TIRS is available for the public from USGS website. The require images were selected from the mono-log window of the web based application Earth explorer that enables one to select the images needed based on the location by providing either the name or geolocation of the study area. Window therefore allows the selection of different types of Landsat images with clear definition of the date. The monthly images were selected for the year 2013 to 2015, the images were then submitted to the USGS servers for correction and it was later on downloaded through the services known as Bulk Download that is made available by the USGS website. It enables one to choose the images required for the study, submit for correction and then download the images once you are notified that they are ready. It takes about two days for the images to be ready depending with the USGS servers.

3.1.2.2.2 Building Geodatabase

The images used were using Universal Transverse Mercator Projection (UTM) and coordinate system (WGS 84). The grooming of the images passed many important forms in order to be valid for producing thermal composition maps for Nairobi City, briefed as follows and shown in the (Figure 3.2)

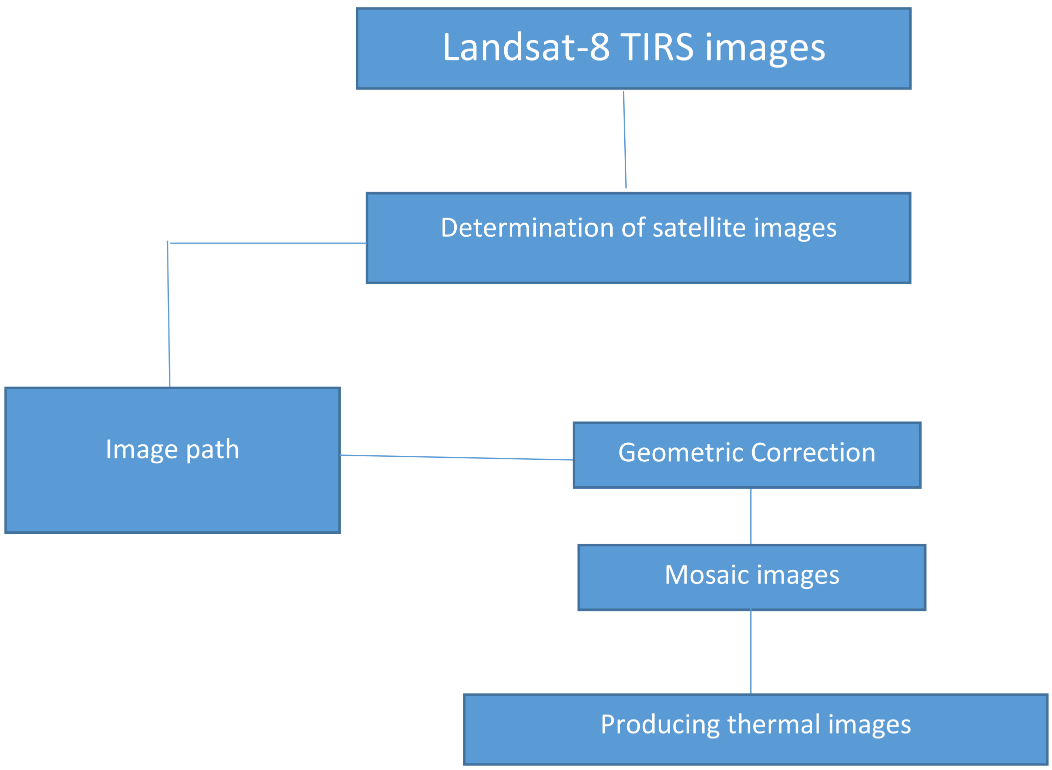

Figure 3.2: showing the process of producing thermal images.

1. Geometric correction of satellite images
   Evaluation of the results of the geometric correction used a set of checkpoints different from the ground control points(GCPs). Used in the least squares transformation, and using the same polynomial equations as for the GCPs set to

determine residuals, and RMS errors for the checkpoint, image to image rectification was used for Landsat images and the goal process correct distortions random by comparison to GCPs.

2. Mosaic images

   Mosaic streamlines is an editing process with various capabilities, allowing the user to select images directly, control the input images which are then rendered and turns image footprints and other graphics on and off. The user interface of ArcGIS also simplifies the workflow by providing tools in a single window.

3.1.2.2.3 Data pre-processing

The data pre-processing was performed in ArcGIS 10.3 student version. Each OLI/TIRS file is composed of the independent single-band images. The images therefore are used to combine the single-band images to a multiband image into a RGB composite layer. This was done by using a layer stacking tool. The geometric correction was done on the composite layers by which each point on the image would have only latitude or longitude geographical coordinates. This is the most important step in pre-processing. After geometric correction, the image subset tool was used to clip the study area. Figure 3.3 shows the basic procedure of the satellite data pre-processing.

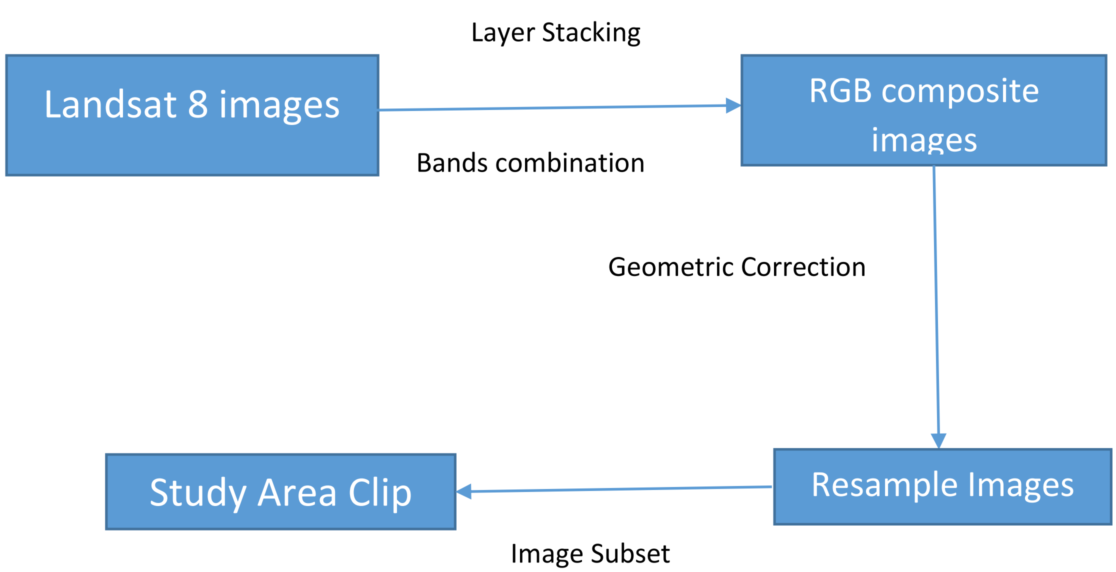

Figure 3.3: the data pre-processing procedures.

3.1.2.2.4 LST Retrieval Methodology

Different LST retrieval methods have been developed according to different data sources, such as the split-window method, temperature/emissivity separation method, mono-window method and single channel method. As the thermal infrared (TIR) channel, band 10 record the radiation with spectral range in 10.4-12.5 µm from the earth surface. Three LST retrieval methods: radiative transfer equation, mono-window algorithm and single channel algorithm can be applied to Landsat 8 data. Although these methods all provide good results, the radiative transfer equation is not available without *in situ* parameters of the atmospheric profiles simultaneously when the satellite passes. The mono-window algorithm with radio sounding data can give a better result than the single-channel algorithm with root mean square deviation of 0.9 K. thus, the mono-window algorithm is applied in this study to retrieve the LST. The mono-window only requires three parameters- emissivity, transmittance and effective mean atmospheric

The procedure for retrieval was as outline below:

3.1.2.2.5 conversion to TOA radiance.

OLI and TIRS band data was converted to TOA spectral radiance using the radiance rescaling factors provided in the metadata file:

$$L_{\lambda} = M_L Q_{cal} + A_L$$

Where:

L_{λ} = TOA spectral radiance (watts/(m^2*srad*µm)

M_L = Band specific multiplicative rescaling factor from the metadata

A_L = Band specific additive rescaling factor from the metadata

Q_{cal} = quantized and calibrated standard product pixel values (DN)

3.1.2.2.6 Conversion to At-satellite Brightness Temperature

The data was then converted from spectral radiance to brightness temperature using the thermal constants provided in the metadata as follows:

$$T = \frac{K2}{\ln(\frac{K1}{L\lambda}+1)} + 273.15$$

Where:

T = At-satellite brightness temperature (K)

L_λ = TOA spectral radiance (watts/(m^2*srad*µm)

K_1 = Band specific thermal conversion constant from the metadata

K_2 = Band-specific thermal conversion constant from the metadata

3.1.2.2.7 Deriving Land surface emissivity

The LSE was then calculated using the following formula:

$$Pv = \left(\frac{NDVI - NDVImin}{NDVImax - NDVImin}\right)^2$$

Where: P_v = proportion of vegetation.

The NDVI was calculated using the automated window provided in the ArcGIS for image analysis. The land surface emissivity was then arrived at by using the standard formula

$$e = 0.004Pv + 0.986$$

Where e is the emissivity.

3.1.2.2.7 Retrieving LST

LST was derived using the formula below having calculated the required parameters above:

$$LST = \frac{BT}{1+w} * \left(\frac{BT}{p}\right) * \ln(e)$$

Where:

LST = Lands Surface temperature

BT = At satellite temperature

W = wavelength of emitted radiance (11.5µm)

P = $h * c/s(1.438 * 10^{-2} mK)$

h = Planck's constant (6.626*10^-34 Js)

s = Boltzmann constant (1.38*10^-23 J/K)

c= velocity of light (2.998*10^8 m/s)

this therefore implies that p= 14380 m K

The LST was calculated for each band, band 10 and 11 then average was calculated using cell statistics that calculated the average per cell. All other formulas were implemented using Raster Calculator that did the arithmetic by creating raster's in the given study area

CHAPTER 4

4.1 RESULTS AND DISCUSSION

4.1.1 Urbanization results

The analysis of the urbanization was as shown in the (figure 4.1):

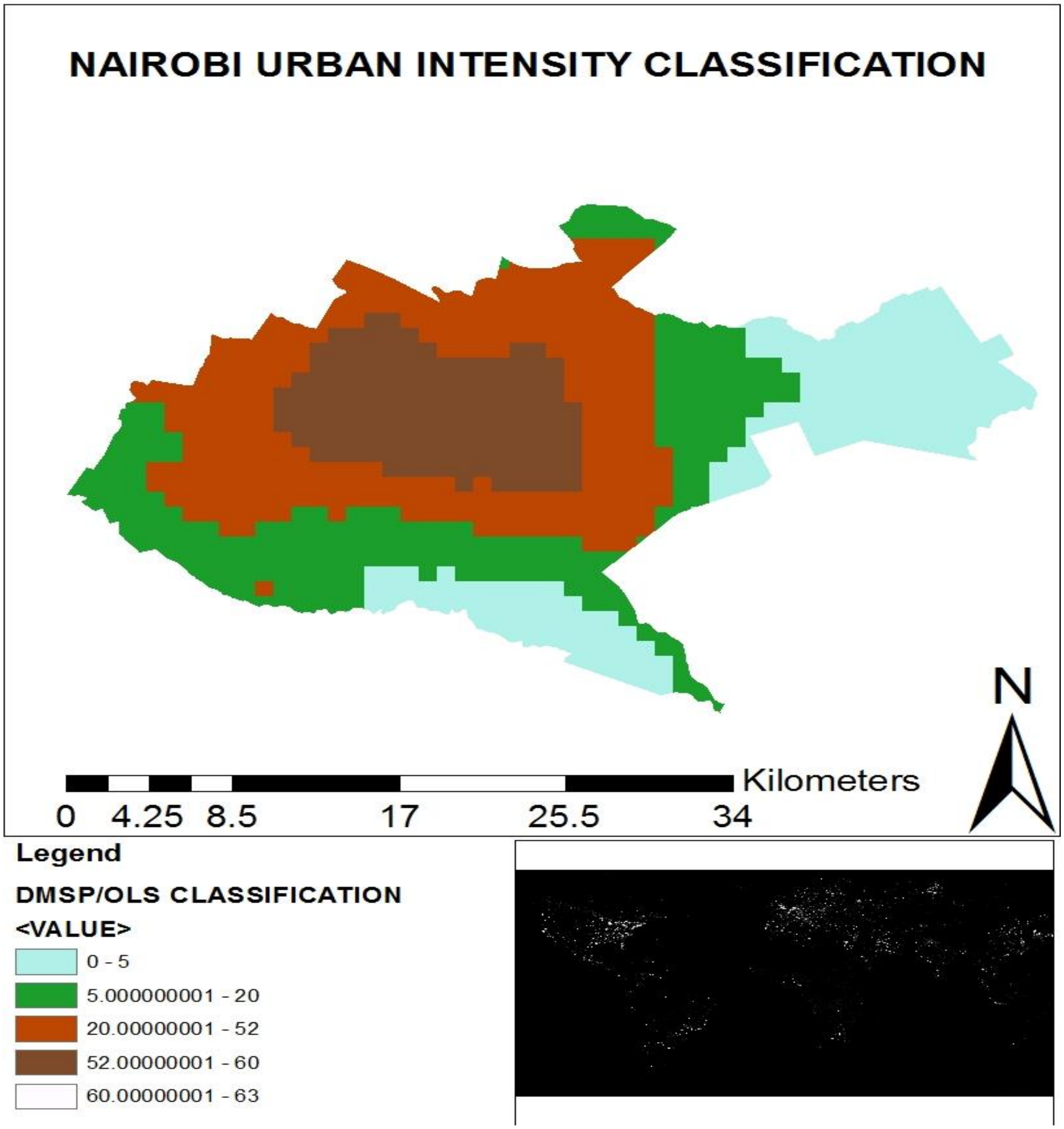

Figure 4.1: false color mapping of urbanization classification from Nighttime light images

The map shows the false color representation of the urban areas, from the map, it can be noticed than the central but of Nairobi is considered to be highly urbanized as it depicts the point with high average DN values. The nighttime light images work in the aspect of reflected light during the night therefore signifying human activities in the given location hence are used in classification of urbanization. The inset map shows the true color global nighttime light image from which the Nairobi map was projected. The classification was then correlated by the landuse/Landcover mapping shown in the (figure 4.2)

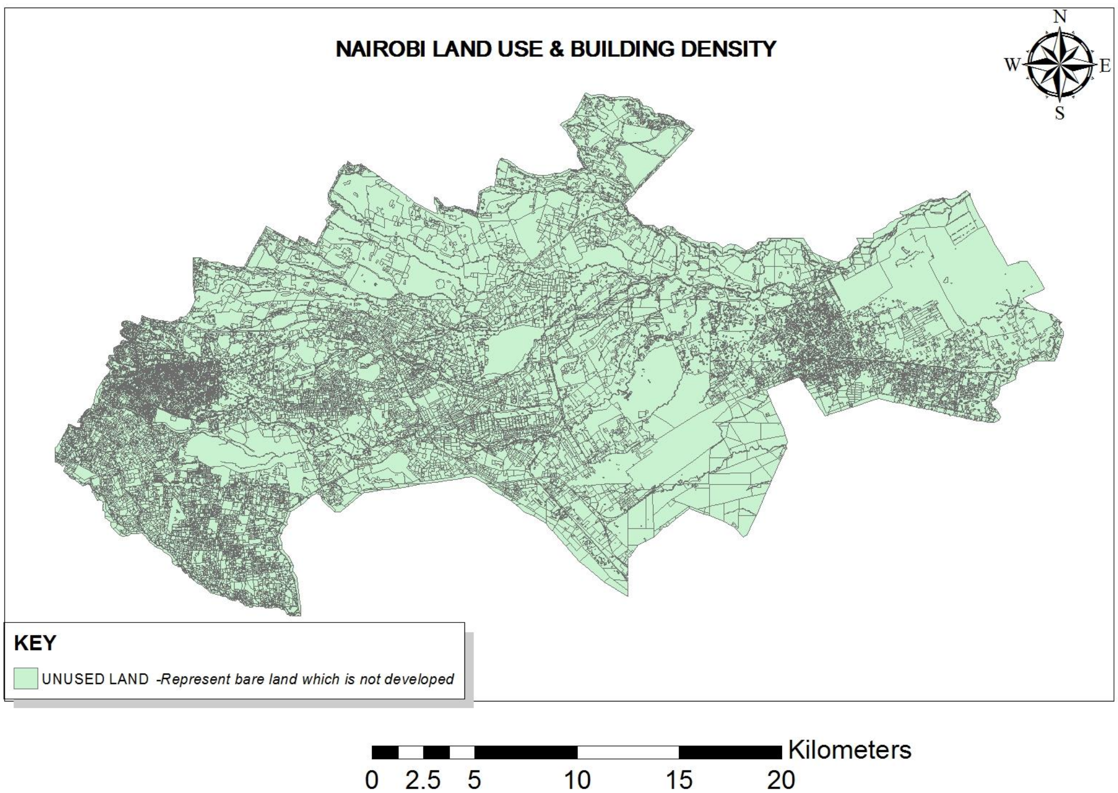

Figure 4.2: 2010 Nairobi Landcover/Landuse and building density

The nighttime light images were therefore found to be highly correlated making the nighttime light images to be sufficient in the classification of the urban areas. The mapping of Urban areas was then mapped after the correlation analysis to give a final representation of urban areas in Nairobi region (figure 4.3)

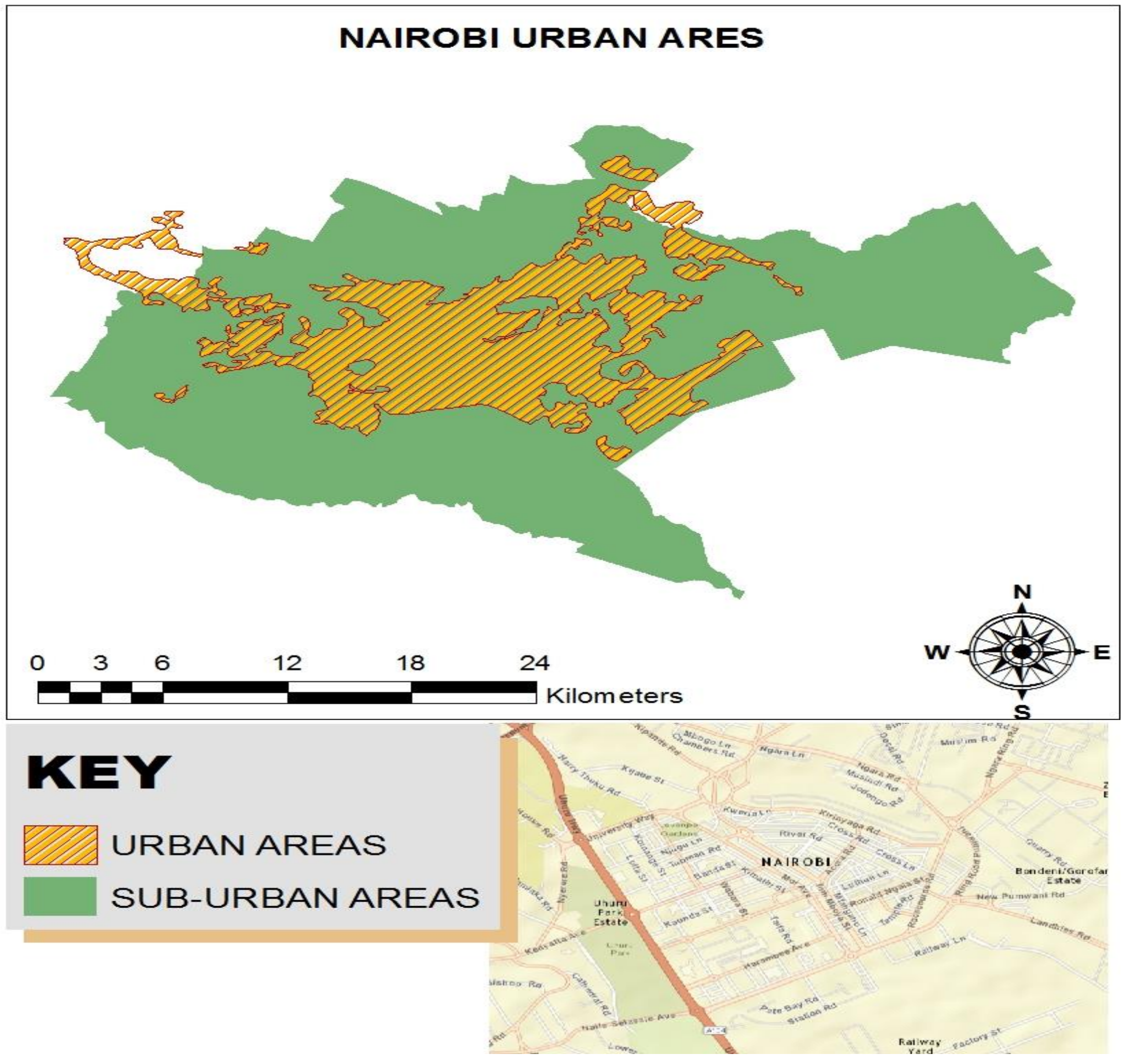

Figure 4.3: false color representation of Nairobi urban and suburban areas.

4.1.2 UHI results and discussion

All band 10 monthly images and band 11 were combine together respectively for every year to give a RGB layer to be used in the further analysis of the UHI and to calculate the parameters required for LST retrieval. (figure 4.4

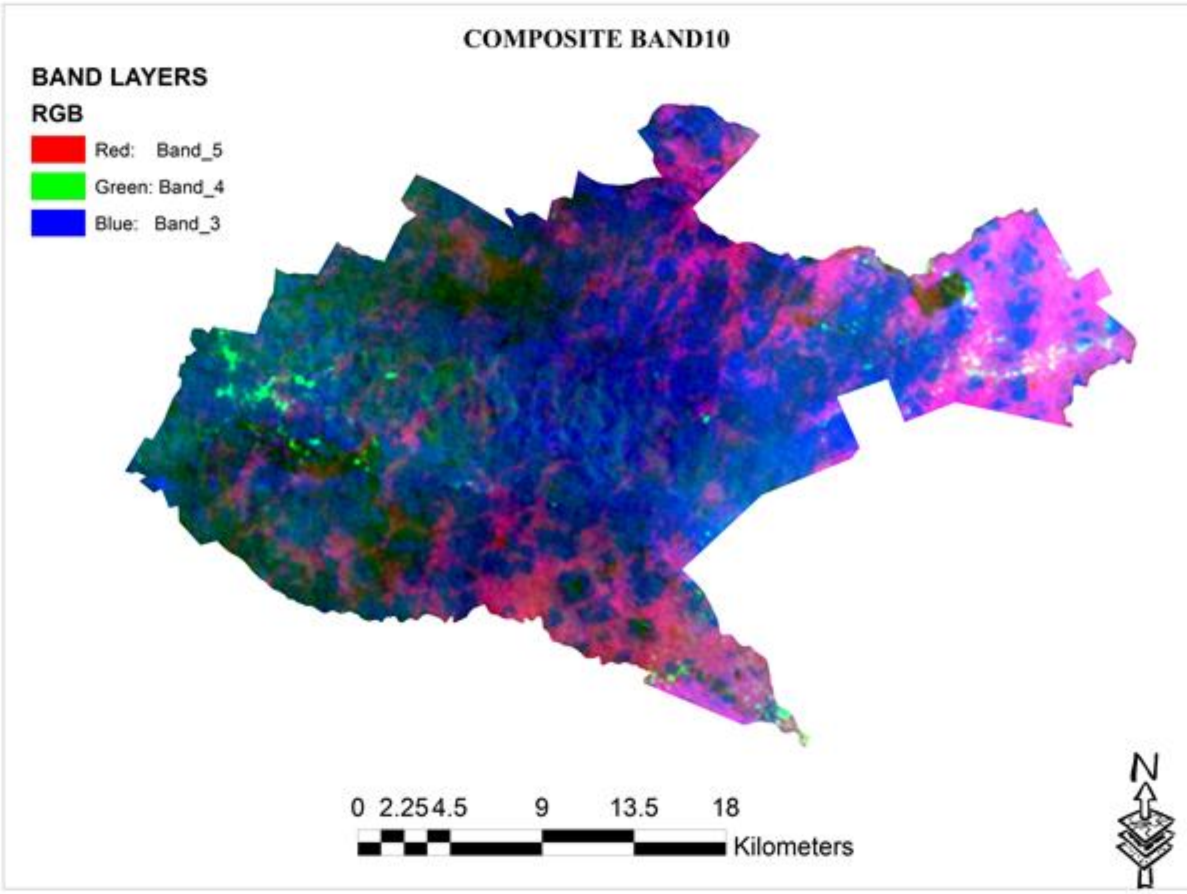

Figure 4.3: RGB layer composite band10

The NDVI was calculated using the Average of band 10 band 11 RGB composite using the automated algorithm which works with the formula:

$$NDVI = \frac{Band4 - Band3}{Band\ 4 + Band3}$$

The obtained map was then classified into two layers to distinguish the build surfaces and the vegetated areas (figure 4.4)

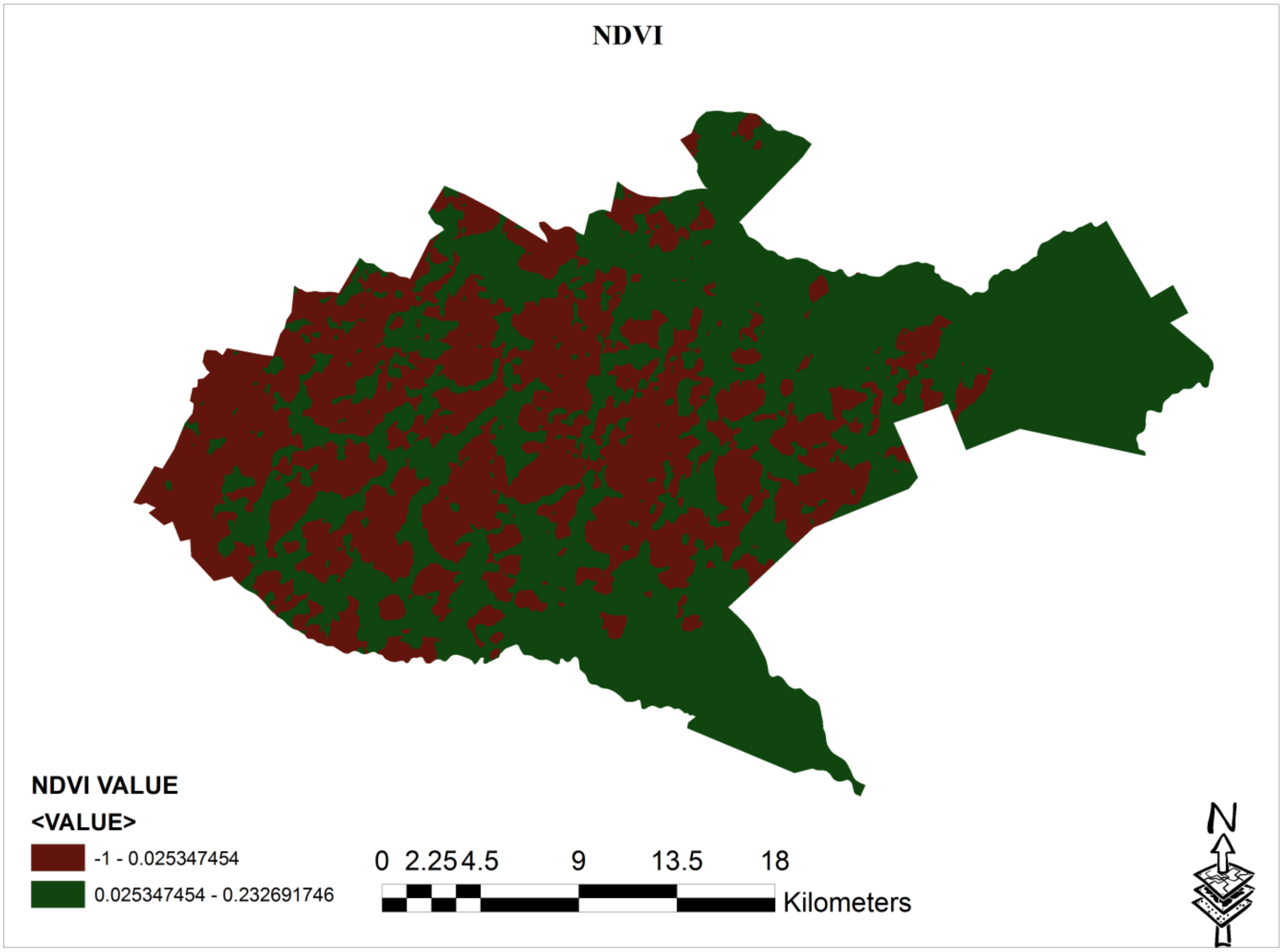

Figure 4.4: false color image for the classified built up surfaces using the NDVI

The original calculated NDVI had 5 classification value which were then reduced to two values classification to classify the built up surfaces and vegetated areas. The NDVI ranges from -1 to 1, with the lower values representing the built up surfaces and the higher values the vegetated areas. The NDVI was also used in calculating the Pv, a parameter that was used in retrieval of LST.

Another parameter that was determined was the AT-satellite temperature, this was obtained from band10 and band11 respectively to be used in the calculation of the LST. (figure 4.5)

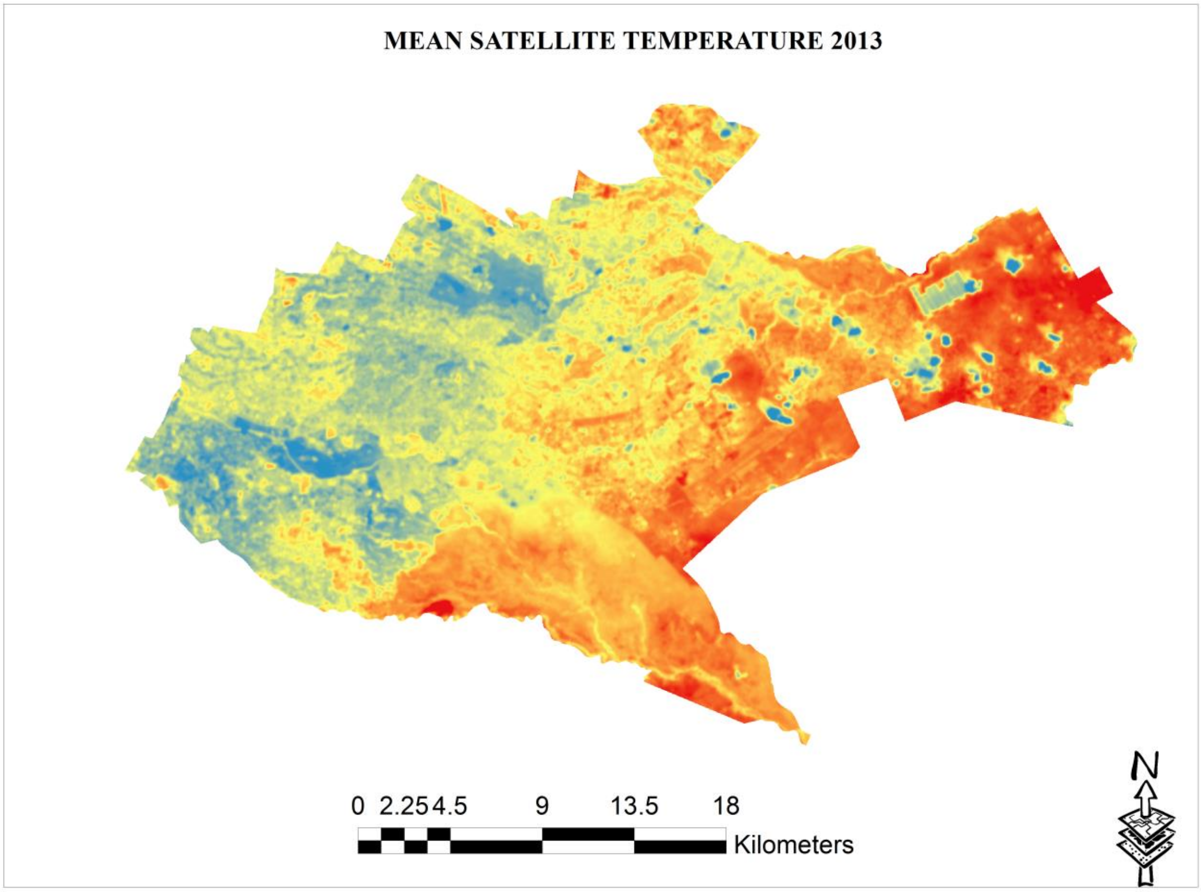

Figure 4.5: mapping of 2013 mean satellite temperature.

The mean satellite temperature, the NDVI, LSE (Land surface emissivity) was used to calculate the LST for the composite Band10 and Band11 respectively for the 2 years, and the cell statistic was used to get the average LST of the given years respectively. (Figure 4.5(a) and Figure 4.5(b):

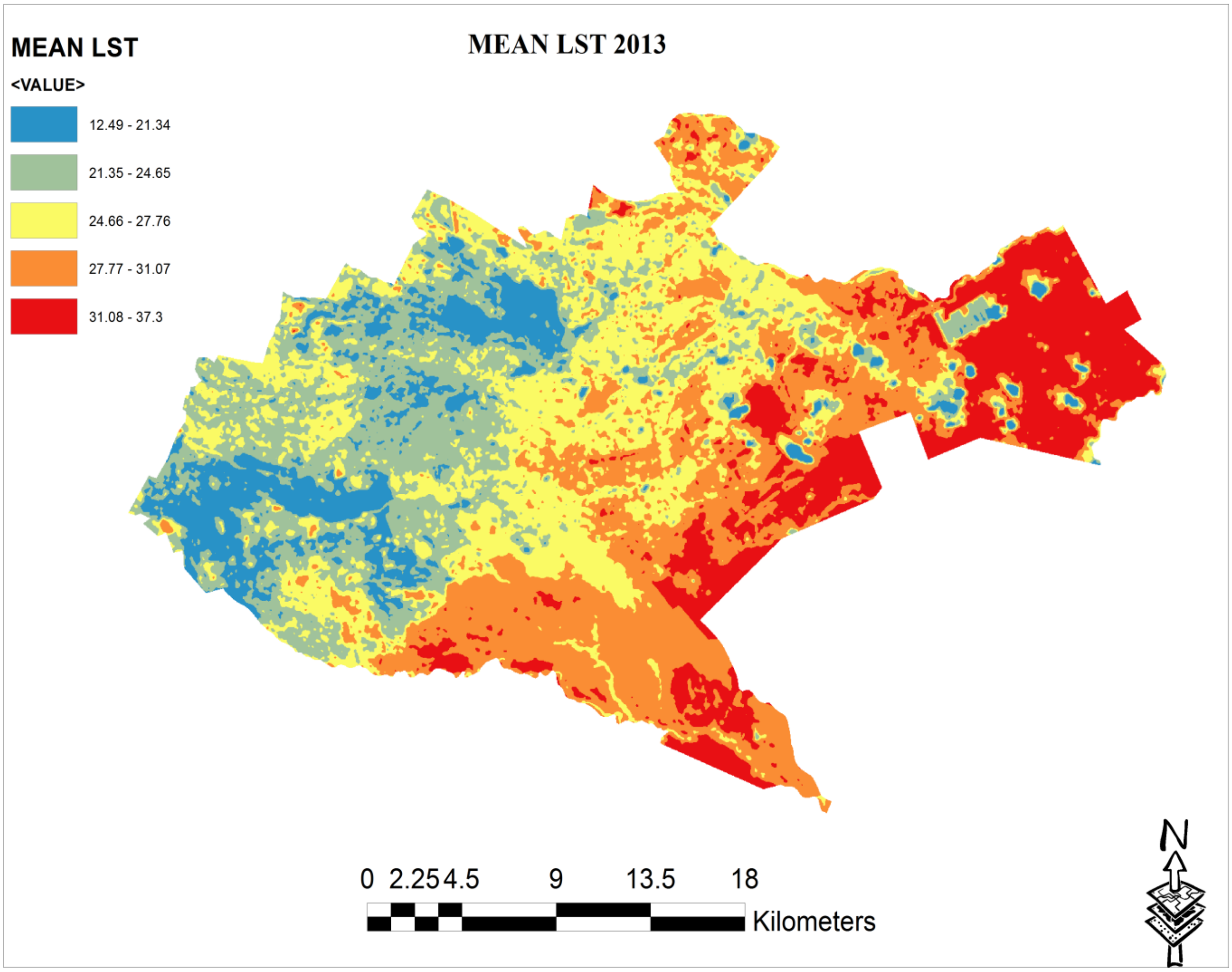

Figure 4.5(a): distribution of Land Surface Temperature for year 2013

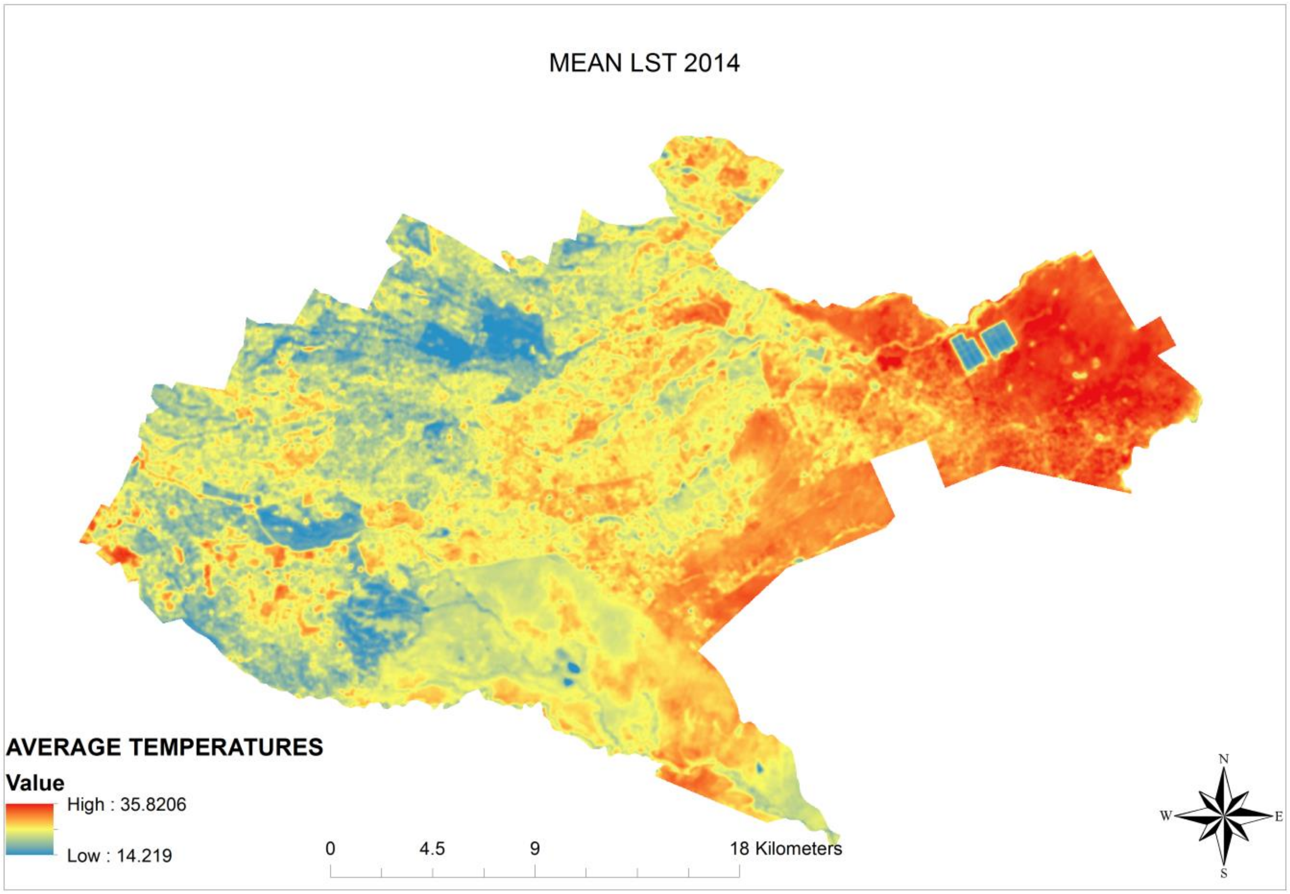

Figure 4.5(b): Distribution of Land surface temperature for the year 2014

It can be noted that there was an increase in the average minimum land surface temperatures and a decrease of the average Maximum temperatures from 2013 to 2014, this indicated the temperature variations and that the year 2014 experienced lower temperatures.

The distribution temperatures were used, with a spatial analysis tool, Point analysis, to calculate the temperature variation using the point temperature and getting the difference in reference to the points and their surrounding respectively. This therefore enabled the mapping of Urban Heat Island distribution for the year 2013 and 2014 respectively (Figure 4.6 (a),4.6(b))

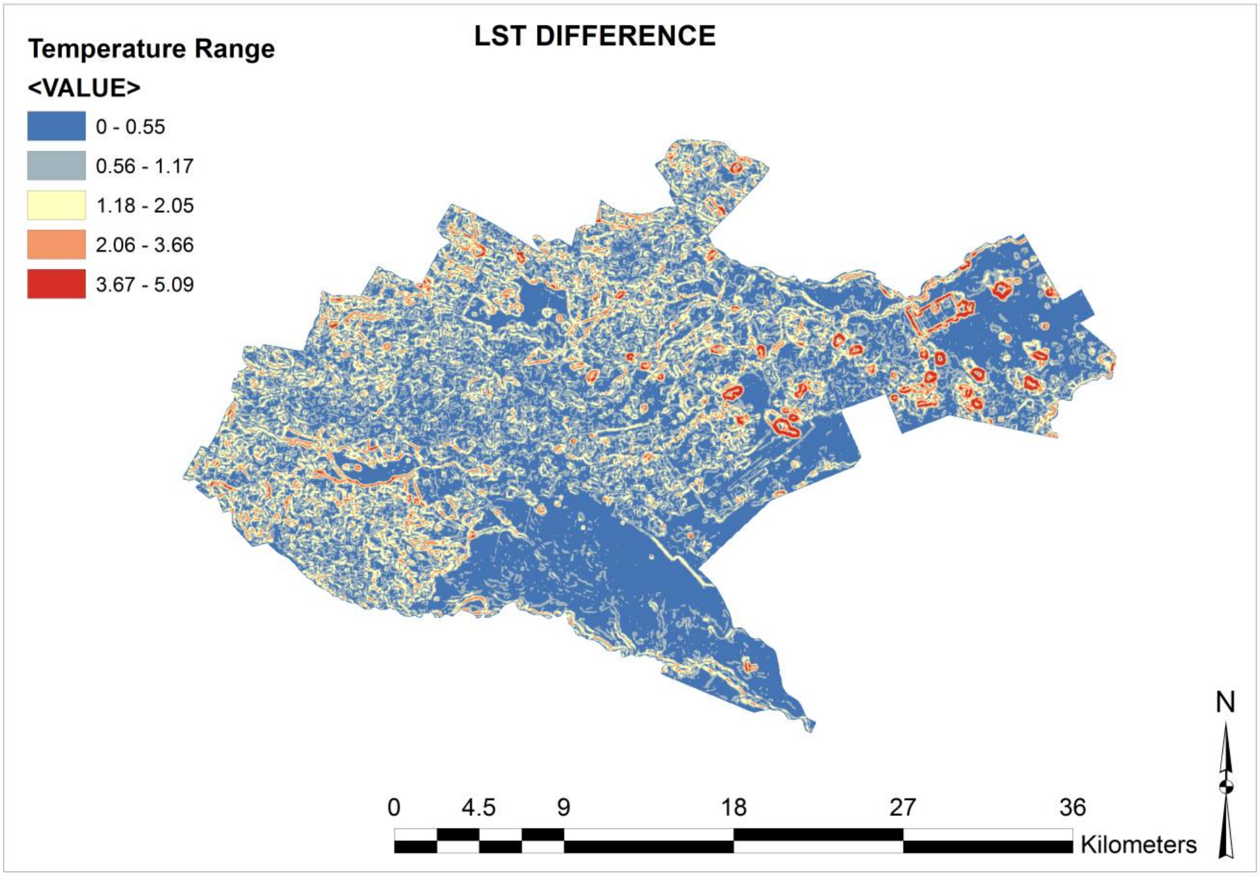

Figure 4.6(a): mapping of point LST difference, showing the distribution of heat Islands.2013

Though not very pronounced, the LST indicated lamps of Heat Island distributed in the region. The parameters used in calculation of the LST is listed on the table below:

	Band 10	**Band 11**
Radiance Multiplier	0.0003342	0.0003342
Radiance Add	0.1	0.1
K1	774.89	480.89
K2	1321.08	1201.14

Table 4.1: showing the constants used in the mono-window algorithm in calculation of LST

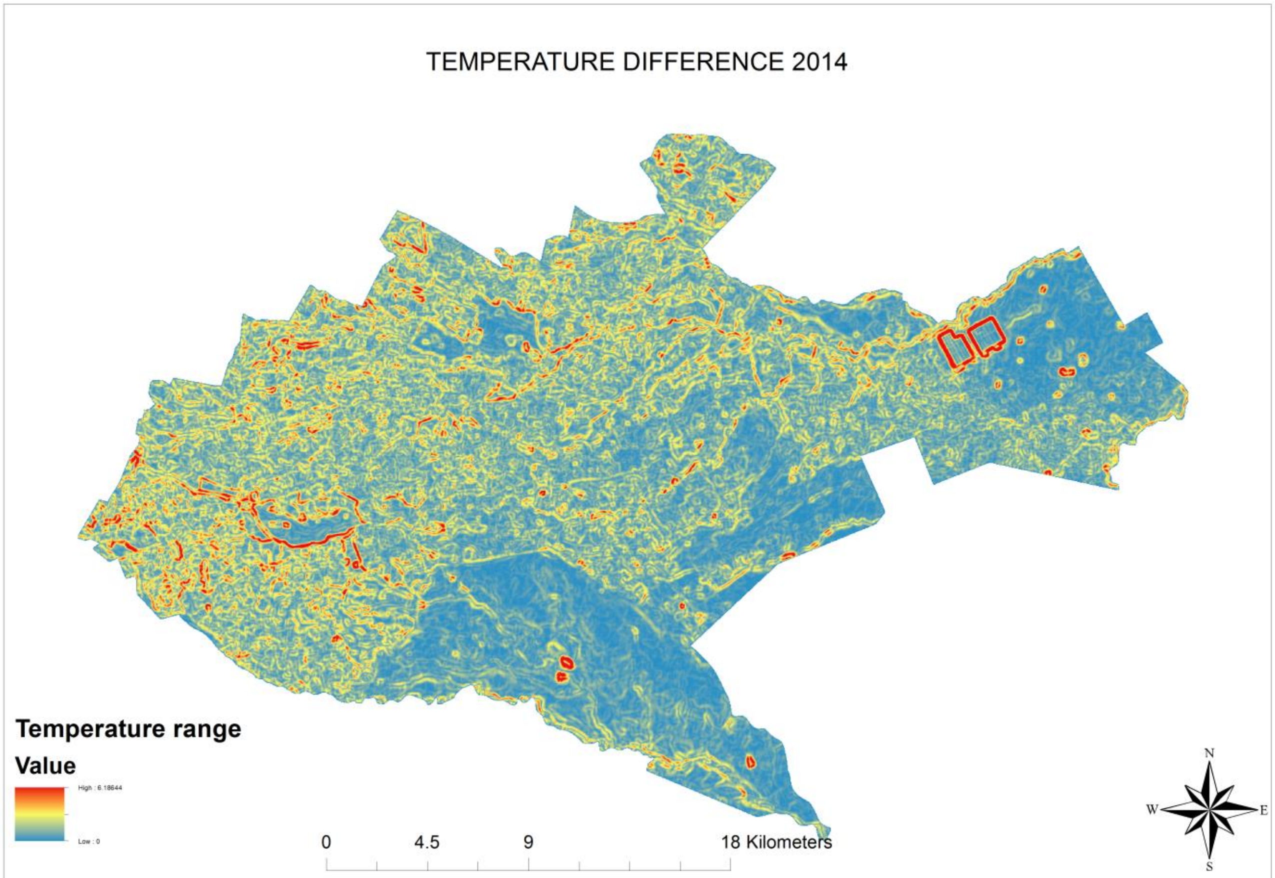

Figure 4.6 (b): mapping of point LST difference, showing the distribution of heat Islands 2014.

4.1.2 Sensitivity Analysis for the LST retrieval Algorithm

Figure 4.7(a) shows the LST error in corresponding to transmittance error at different transmittance levels i.e. (50%, 60%,70%,80% and 90%). Data revealed that at high transmittance levels (90%) LST error is about 0.2˚C and as transmittance decreases LST estimation error increases till 50% transmittance and reaches 2˚C. when testing the proper LST estimation error against different brightness temperature for different transmittance values as indicated in Figure 4.7(b), it reflects that; as brightness temperature increases from 0˚C to 20˚C, the LST error decreases but after 20˚C it becomes a linear relationship with different slope, which depends on the transmittance value. It is clear that for small transmittance error (0.005%) the LST error is less than 1˚ on contrast to high transmittance error (0.06) it reaches 3˚C.

The model transmittance to errors due to emissivity estimation errors is presented in Figure 4.7(c) and Figure 4.7(d). Figure 4.7(c) shows that LST estimation error is in linear relationship with the emissivity value i.e. (emissivity =90%, 92%, 94%, 96%, $ 98%) for high emissivity values (>98%) the expected LST error is 1.2˚C when the emissivity error is 0.025% and as emissivity decreases to 90% the estimated error would be 1.4˚C. Figure 4.7(d) illustrates the linear relationship between the LST calculation error and the brightness temperature for different emissivity errors. It is clearly shown that as emissivity error increases, LST error increases rapidly.

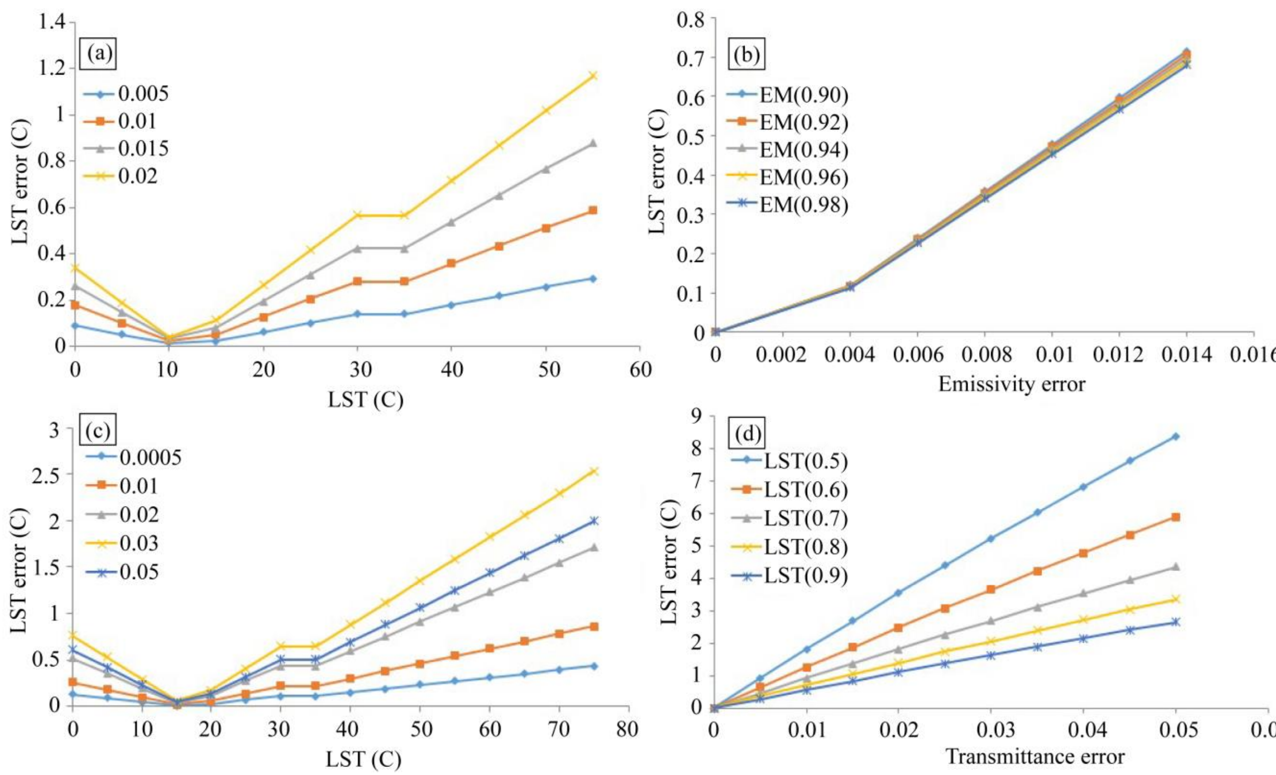

Figure 4.7: Probable LST estimation error due to the possible transmittance and emissivity error. (a) Average LST error against transmittance error, (b) LST error against brightness temperature, and (c) Average LST error against emissivity error.

4.1.3 The Correlation Analysis between Urban Heat Island, NDVI and Urbanization

In order to compare the green land and the built-up (urbanization) to UHI effect which provides useful information for the urban development and environment protection, the correlation between LST, NDVI and Urbanization was analyzed. Table 4.2 show the calculated correlation coefficients. The correlation coefficient of LST and NDVI is -0.41, while the coefficient of LST and Urbanization is 0.71. the negative coefficient between LST and NDVI indicates that the impact of vegetation on heat island is negative, which means that the vegetation can weaken the urban heat island effect. In comparison, the positive correlation between LST and Urbanization suggests that the urbanization strengthen heat islands effect in this case study.

Table 4.2 the correlation coefficient

	LST	**NDVI**	**URBANIZATION**
LST	**1**		
NDVI	**−0.41**	**1**	
URBANIZATION	**0.71**	**−0.56**	**1**

CHAPTER 5

5.1 CONCLSION AND RECOMMENDATION

5.1.1 CONCLUSION

In this study, the mono-window algorithm was applied to retrieve the LST in Nairobi using the Landsat 8 OLI/TIRS level one product data. Through the retrieved temperature data, it I found that the distribution of UHI in Nairobi is mainly located in residential areas and maximum at the city Centre. It is noticed that with the urbanization growth rate, in the near future, the distributed heat islands will conglomerate into one large-scale regional heat Island. In comparison, the scattered urbanized areas have dispersed distribution of urban heat island effects, it is therefore reasonable to envisage the establishment of satellite-urban areas in the city layout separate from the business center in order to prevent the formation of a large-scale regional urban heat island.

In the absence of non-uniform distribution of ground weather stations, remotely sensed data have a great importance to monitor impacts of different environmental issue such as heat islands. The thermal band in the Landsat satellites, have been proven to have a crucial role in estimating surface temperatures. The availability of different algorithms developed by different authors to overcome the shortage of data required for calibrating the satellite estimated surface temperature to field of study made the study be conclusive with minimal errors per see. The mono-window algorithm developed by Qin Z and Berliner is one of these algorithms that have a great importance in case of missing in situ data of ground emissivity; atmospheric transmittance and mean atmospheric air temperature.

The obtained results from this study are concluded as follows;

- UHI exists throughout the year, regardless of the season i.e. warm or cold seasons in the two investigated dates.
- The two types of heat islands, the surface and the urban, exists in the study area though not very pronounced compared to other cities of the developed nations.

- The value of Urban heat island over the urban area is ranging from 0.5 to 3.5˚C above the mean temperatures of the urban areas and it is much related to the existing land use/Landcover.
- UHI which was the main concern in this study is much related to the urbanization

5.1.2 Recommendations

a recommendation to the urban planners is to consider the scattered plan of urban areas, so as to distribute the heat Island to minimize the UH becoming one large heat island in the region, they are also to consider the material used in the building structures to enable mitigate the UHI effect or its further generation**.**

A detailed research that takes into account the parameters such as humidity, wind speed, analysis of the production of anthropogenic heat, analysis of materials used in the building structures, in situ meteorological data of the time that the satellite passed the study area. To be able to quantify the UHI effect is recommended. This is so because the analysis in this report only focused on the distribution and the difference of the LST.

5.1.3 References

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