**COLLEGE OF SCIENCE AND TECHNOLOGY**

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**DEPARTMENT OF GEOGRAPHY AND URBAN PLANNING**

**OPTION : URBAN AND REGIONAL PLANNING**


**FINAL RESEARCH PROJECT:**

# Impacts of Land Use and Land Cover Dynamics on Land Surface Temperature in a Rapidly Urbanizing City, Kigali, Rwanda.


**Submitted by:**

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## DECLARATION

We, Eric HABINEZA, Magnifique Thierry IGIRIMPUHWE, Boaz MWUBAHIMANA with Registration numbers: 218008552, 218013133 and 218003920 respectively, year 3 finalist students at University of Rwanda College of Science and Technology, School of Architecture and Built Environment, Department of Geography and Urban Planning, Option of Urban and Regional Planning, do hereby declare that this final research project report attachement is our own original work. It is being submitted to the Department of Geography and Urban Planning and has not been submitted to any other University or Higher Learning Institution for any award or degree. We have acknowledged the outsources as one of the academic regulation at University of Rwanda.

We also confirm that it was done for our academic requirement for the partial fulfillment of our Bachelor's Degree with Honors in Geography, Option of Urban and Regional Planning. We will not allow anyone to copy this work and use it as it is his/her own work without our prior consent.

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Magnifique Thierry IGIRIMPUHWE

Boaz MWUBAHIMANA

## Dedication

We would like to dedicate this dissertation

"To the Father Almighty God"

"To our families"

"To our lecturers and our colleagues"

"To someone special and to everyone who cares for us"

**ACKNOWLEDGEMENT**

Writing this thesis was challenging and fascinating for us. Its completion has required help and support from different people. We would like to express our sincere appreciation to all those helpful people.

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**ABSTRACT**

Over the past three decades, the city of Kigali has experienced rapid developments and land use and land cover (LULC) changes. These developments have numerous short-term and long-term consequences including increase the Land Surface Temperature (LST) of the city. This study assessed the impacts of LULC dynamics on LST in a rapidly urbanizing city of Kigali. By use of satellite imageries, Landsat 8 Operational Land Imager (OLI) as the latest satellite launched in 2013 with instrument of OLI and TIRS, Landsat 5 Thematic Mapper(TM) and Landsat 7 Enhanced Thematic Mapper (ETM+) and their thermal bands, 10 &11 for Landsat 8, and band 6 for Landsat 5 & 7. The study firstly analyzed and detected the LULC dynamics using maximum likelihood classification method and derive the LULC maps for the years of 1999, 2010 and 2020. Using classified images, the study revealed that Kigali has exponential dramatic increase of built up area from 1999 to 2010 was 4402.11 hectares and 5254.21 from 2010 to 2020. This has indicated that urban expansion intensity was more in 2010s compared to 1999s. Urban expansion has led to deep decline in vegetation cover from -9.3% to -10.62% in 2010. Secondary, the analysis of LST from Thermal bands results has shown that there is high increase of Land Surface Temperature in built up area where there is strong positive relationship between NDBI and LST. The relationship of NDBI and NDVI has shown that there is strong negative correlation shown by Pearson's correlation coefficients $R^2$ = 1, 09929 and 1 in 1999, 2010 and 2020. These insights determine and confirm the effect of LULC change on temporal LST. This study is crucial to urban planners, environmentalists and local authorities to help them understand the impacts of LULC on LST for adopting and implementing appropriate urban planning regulations for policy makers and public awareness for a sustainable planning of the city of Kigali and its management in the years to come.

**Keywords**: Land Use and Land Cover Dynamics, Land Surface Temperature, GIS and Remote Sensing, Landsat 5, 7 and 8, City of Kigali

**TABLE OF CONTENT**

**LIST OF FIGURES**

## LIST OF TABLES

## LIST OF ABBREVIATIONS AND ACRONYMS

**CBD**: Central Business District

**CGIS:** center for Geographical Information Systems and Remote Sensing

**DEM:** Digital Elevation Model

**ETM**: Enhanced Thematic Mapper

**GIS**: Geographic Information Systems

**LST**: Land Surface Temperature

**LULC**: Land Use/Land Cover

**MLC**: Maximum Likelihood Classification

**NDBI**: Normalized Difference Built-up Index

**NDVI**: Normalized Difference Vegetation Index

**NDWI**: Normalized Difference Water Index

**UHI**: Urban Heat Island

**OLI**: Operational Land Imager

**TM**: Thematic Mapper

**USGS**: United States of America Geological Survey

# Chapter 1. GENERAL INTRODUCTION

## 1.1.BACKGROUND

Cities are facing high urbanization problem in developing countries than developed countries, and proportion of urban growth is estimated in medium and small-sized cities(Rahman et al., 2017; Grimmond, 2007). The rapidly growing urban population significantly changes the Land Use/Land Cover (LULC) and creates negative impacts on urban Land Surface Temperature (LST) (Argüeso et al., 2014). This rapid growth brings city expansion, transformation of different LULC and affected LST. (Kafy et al., 2019). Thus, the evaluation of urban LULC change and its influence on LST is important to create an environmental friendly city(Kafy & Hasan, 2019). The rapidly population growth and LULC change are closely related(Grimmond, 2007)(M. S. Rahman et al., 2019). The significant growth of population affect severely on ecosystem, social aspect and human health(Trolle et al., 2019).

Land Surface Temperature is one of the key parameter in the physical land surface processes from local through to global scale(Li et al., 2013). It is important parameter in the field of atmospheric sciences as it combines the results of all surface-atmosphere interaction and energy fluxes between the ground and atmosphere and is, therefore, a good indicator of energy balance at earth's surface(Michel, 2003).

Land Use Change is an important driver for Land Surface Temperature (LST) and there is interrelation between them(Aik et al., 2020). The increase in built up areas in the urban center could cause increase in Land Surface Temperature, which could be a concern for geographers, climatologists and urban planners(Nguyen et al., 2019), (Buchecker & Frick, 2020)(Gaffin et al., 2008). High temperature occur in central business district (CBD) and high density residential (HDR) areas(Hart & Milstein, 1999). These kinds of temperature changes may have negative environmental and socio-economic effects on built-up areas, including enlarged consumption of heating and air conditioning thus raising energy prices and pollution related health threat(Cohen, 2004).

Urban development, as a major type of Land Cover Change in human history, has a great impact on the environment. In this process of urbanization, natural vegetation cover is largely replaced by impervious surfaces such as buildings, roads, parking lots, sidewalks and other building surfaces(Fish & Service, 2013). Human migration to cities causes urbanization, which brings rapid changes in the ecosystem, biodiversity and the environment(Anderson et al., 2013). Due to the substitution of impermeable surfaces and buildings as cities expand their coverage and protection is diminished (Use et al., 2020), (Jiang & Tian, 2010).

## 1.2.Study Area

Kigali is capital city of Rwanda and rapidly growing smart city in Africa and it was selected as the study area. The city is built on hilly landscape and it extends from $29^0$43'0'' E and $29^0$44'0''E of longitude and $2^0$35'0''S and $2^0$37'0''S of latitude (Fig. 1). The range elevation of the study area is approximately 1333m and 2069m above sea level.

Overall the city is under a tropical climate and is strictly 2 not of the equatorial rainy type, it has modified humid climate including rainy forest and savannah type. The climate of the country is generally of semi-arid type owing to its position in the rainy shadow of the western highlands. According to Rwanda Meteorological Agency, there is pre-monsoon, monsoon, post-monsoon in (dry and wet season) in Kigali city. Pre-monsoon season (March-June) is hot and dry. Most of heavy showers occur in July to September (Monsoon season) temperature falls at a significant rate in the post monsoon period (October-November). Wet has 2 parts (December-February) is characterized by dry and cool weather. The average annual range of temperature is $21^0$C, $29^0$C and average annual precipitation is 1200mm. the highest recorded temperature in Rwanda was $32.7^0$C. Kigali is among five provinces, which compose the country of Rwanda. it is surrounded by the Northern province on the North,  Eastern province on the East, Southern province on South and Western province on South(Nduwayezu et al., 2017). Kigali city is divided into three districts namely Gasabo, Kicukiro and Nyarugenge district, (Science, 2019). According to data from Kigali city, Kigali is presently inhabited by approximately 1.2 million inhabitants. Kigali is 70% rural with a population which is relatively young. The youth make up about 60% and women make slightly more than 50%.

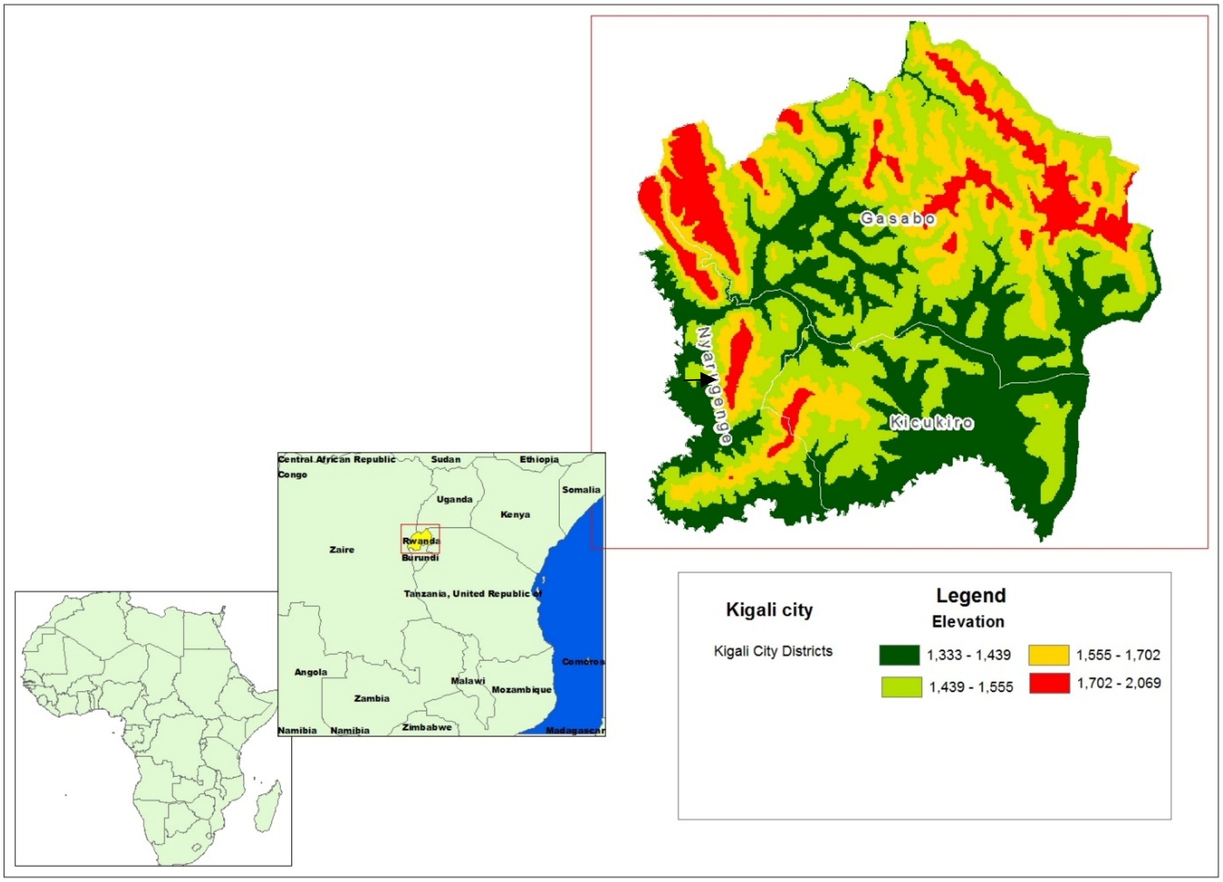


*Figure 1: Location of the city of Kigali, and its elevation map*

## PROBLEM STATEMENT

Urban Heat Island is generally linked to urban development and land cover transformations associated with urban land use. Land cover transformation in urban areas include conversion of natural vegetation and agriculture lands to impervious surfaces(Buyantuyev & Wu, 2010). While studying the linkage between land surface temperature and vegetation, NDVI has commonly been used as a proxy for vegetation abundance(Chu et al., 2020).

In the city of Kigali, there are different modifications on land, as day's landscape modified by different human activities such construction of houses for living, commercial or other uses, roads and leaving bare surfaces due to the decline in vegetation, and this leads to a significant increase in Land Surface Temperature.

The city of Kigali, the capital city of Rwanda, the country of thousand hills, has experienced dramatic change of temperature where it has received an increase from 21.08 $^{0}$C of August 2000 to 20.02 $^{0}$ C in July of 2013 (Trading, 2013) . Since 2000, Rwanda has experienced significant rapid urbanization especially within Kigali city. This was due to the availability of different job opportunities, which made people, migrate from rural to urban area of Kigali seeking jobs opportunities. This has resulted to the changes of land use and land cover categories, where by people have developed infrastructures such as residential and commercial buildings on formerly vegetated land. On the other hand, government played a part in reduction of vegetation cover in terms of public infrastructures provision such as complete paved roads, civic center with intention of good services to urban dwellers as major pillars of good governance to speed up programs with little attention on urban vegetation sensitivity. Nevertheless, developed infrastructure left some parts of the city exposed direct to the sun and land bared which reduced sunrays absorption phenomena of vegetation cover, hence leading to Urban Heat Island. Understanding the contribution of human modification of Land Surface Temperature and on UHI remains an open research question.

The Land Use and Land Cover Change literature shows that a tremendous number of efforts has been made for mapping, monitoring, and modelling land cover and land use at local, regional, and global scale. However, the comprehensive books and articles have not been published to specifically address the issue of Land Use/Land Cover on Land Surface Temperature.

The recent research was highly emphasizing on the assessment of land use and land cover change using satellite images in city of Kigali looking for the Land Use/ Land Cover change due to the urban sprawl, (Hakorimana et al., 2018). Safari, (2014), in " Trend Analysis of the Mean Annual Temperature in Rwanda during the Last Fifty Two Years" , didn't show the correlation of Land Cover change with Land Surface Temperature, where he only used time series of daily data of near surface mean air temperature collected from Rwanda National Meteorological Service, which is not accurate compared to satellite data source. Too much Modelling urban growth in Rwanda have been made, where urban growth directly include Land Use/Land Cover change at high extent but lacking linkage of spatial modelling of land use land cover changes to land surface temperature especially in Rwanda (Nduwayezu et al., 2017). In their research entitled " Land Surface Temperature Analysis", Bosco & Thomas,( 2019) didn't show deeply how indices such as Normalized Difference Vegetation Index(NDVI) and Normalized Difference Built-up Index(NDBI) are related to each other and to Land Surface Temperature.

Therefore, after reading and consulting different studies made on Land Use and Land Cover changes in Rwanda and Land Surface Temperature, we decided to demonstrate the relationship of this LULC dynamics and their indices on Land Surface Temperature in the city of Kigali using satellite data as unique source of information and as a better way to show the hottest and coolest areas as compared to temperature collected from urban weather station, as a revealed gap.

## 1.3.RESEARCH OBJECTIVES

### 1.3.1. General Objectives

The main aim of this research is to assess the impacts of Land Use and Land Cover dynamics on Land Surface Temperature in a rapidly urbanizing of the city of Kigali, Rwanda as our case study.

### 1.3.2. Specific Objectives and research Questions:

***Table 1: Specific research objectives and research questions***

| **Specific Objectives** | **Research Questions** |
|---|---|
| 1. To analyze spatial pattern of land cover changes with respect to built-up area in the city of Kigali. | How is the status of land cover dynamics in the city of Kigali? |
| 2. To analyze trends of land surface temperature in the city of Kigali within the period of 1999, 2010 and 2020. | At which extent does land surface temperature has increased from 1999 to 2020? |
| 3. To evaluate the effects of land use and land cover dynamics on the land surface temperature in the city of Kigali. | What are the major contributions of land use and land cover on the surface temperature change? |

## Chapter 2. RESEARCH METHODOLOGY

Research methodology is a part that provides and discusses different materials, methods, techniques, tools, and present different scientific approaches that have been used to conduct the research for reliable results (Ruzindana E, 2018). The different methods have been designed to classify satellite images, however, supervised classification methods considered relatively more accuracy to classify remotely sensed data quantitatively. In a supervised classification, the user creates spectral signatures rather than the computer, which are used for assigning pixels to different land covers in classified image (Rwandga and Ndambuka.2017). In a supervised classification methods Thus, geographical information systems (GIS) and Remote Sensing techniques are effective and powerful tools for analysis of LULC change and LST(Scarano & Sobrino, 2015). The study deals with multi-temporal Landsat 8 Operational Land Imager (OLI) and Thematic Infrared Sensor (TIRS) instruments of satellite images obtained from US Geological Survey (USGS) website (https://earthexplorer.usgs.gov) for years of 1999, 2010 and 2020. All the images contain 30m spatial resolution. The Landsat images will be projected to UTM zone (30s) South projection using WGS-84 datum. Images will be captured from cloud-free environment in late dry of July and August for preparation of LULC and LST distribution maps. Image processing, image classification, image change detection, LST distribution and mapping will be processed in ERDAS Imagine 14 and ArcGIS 10.6 software.

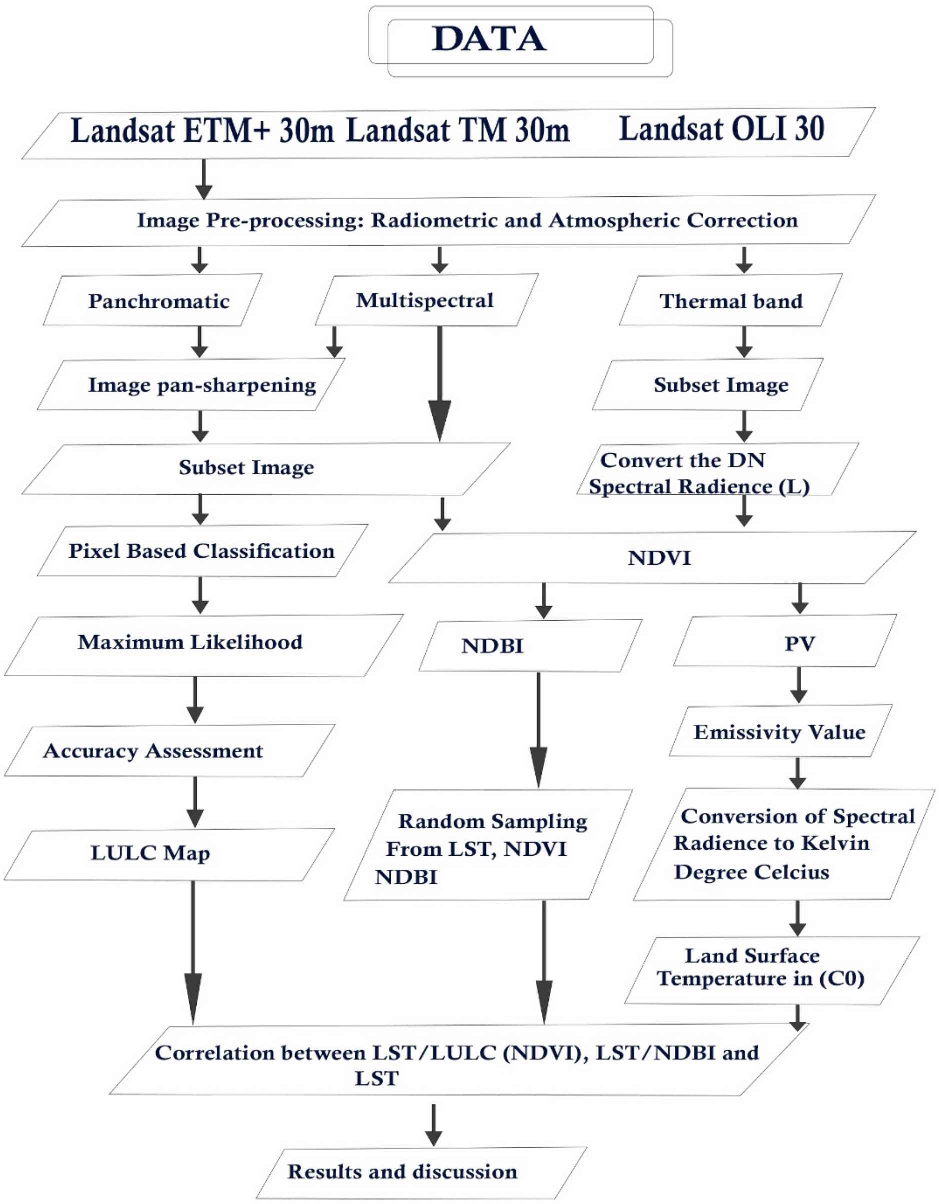


*Figure 2: Data Processing Workflows*

### 2.1. Data collection and Acquisition

The data used in this research came from different sources and institutions as illustrated in Research Matrix Table (2).

Surface reflectance high level data products images include Landsat 7 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper Plus (ETM+), and Landsat 8 Operational Land Imager

(OLI) are the main data source in this study (Table 2). These freely accessible images are processes by NASA which generates radiometric calibration and atmospheric correlation algorithms (level-1 products https://earthexplorer.usgs.gov/). Satellite images were used to derive LULC classification and LST retrieval.

*Table 2: Remote Sensing Data, Research Matrix Table*

| No | **Research Specific Objectives** | **Research Questions** | **Data Requirements** | **Data Sources** | **Methods/Techniques** | **Expected Results** |
|---|---|---|---|---|---|---|
| 1 | To analyze the spatial analysis of land cover dynamics with respect to built-up area in the city of Kigali. | How is the extent of land cover dynamics in the city of Kigali? | Landsat TM+30m<br>Landsat ETM+30m<br>Landsat OLI+30m | USGS Earth Explorer | Pixel image analysis through maximum likelihood classifier approach. | Land cover classes |
| 2 | To analyze the trends of land surface temperature in the city of Kigali form 1999, 2010 and 2020. | At which extent does land surface temperature increased form 1999, 2010 and 2020. | Landsat TM+30m<br>Landsat ETM+30m<br>Landsat OLI +30m | USGS Earth Explorer | Raster image Calculator Equation (UGS formulas) | Spatial temporal maps of LST. |
| 3 | To evaluate the effects of land use, land cover change on the land surface temperature | What a major conditions of the land use, land cover on the land surface temperature change? | Spatial temporal maps of LST and LULC. | USGS Earth Explorer | Correlation analysis of LST using LULC indices. | Effects of LULC on LST. |

*Table 3: Vector Data*

| $N^0$ | Types of data | Time | Source | Ready available | Contacted available | Purpose |
|---|---|---|---|---|---|---|
| 1 | Kigali administrative data and DEM | 2020 | CGIS | yes | yes | Delineation of Study Area |

# Chapter 3: LITERATURE REVIEW

## 3.1.Introduction and meaning of key concepts

The terms “Land Cover” and “Land Use”, sometimes, confuse people.

According to ESRI GIS Dictionary, land cover is the classification of land according to the vegetation or materials that cover most of its surface; for example, pine, forest, ice, water, or sand. Whereas, land use classifies the land according to what activities take place on it or how human occupy it; for example, agriculture, industrial, residential, urban, rural, or commercial.

Land Surface Temperature is defined by NASA earth observatory as how hot the “surface” of the Earth would feel to the touch in a particular location. From a satellite’s point of view, the “surface” is whatever it sees when it looks through the atmosphere to the ground. It could be snow and ice, the grass on a lawn, the roof of a building, or the leaves in the canopy of a forest. Thus, Land Surface Temperature is not the same as the air temperature that is included in the daily weather report.

According to NASA earth observatory, the scientists put much attention to check on Land Surface Temperature because the warmth rising off Earth’s landscapes influences (and is influenced by) our world’s weather and climate patterns. Scientists want to monitor how increasing atmospheric greenhouse gases affect land surface temperature, and how rising land surface temperatures affect glaciers, ice sheets, permafrost, and vegetation in Earth’s ecosystems.

### 3.2. Drivers behind land surface temperature variation: (or factors affecting land cover change)

- **Lack of proper planning policies**: lack of consistency and well-experimented planning policies may led to variation in temperature. A city may be planned with excluding zoning policies for green vegetation. These means lacking of green vegetation will lead to increase in temperature especially for the increase in buildup area of green and pavement. Increase of Bare land and build up pavement area has a high temperature while in the denser vegetated area has low temperature compared to build up and pavement area.
- **Increase of population growth**: high population growth cause alteration of land cover and land use. This alteration cause temperature variation in national, regional and global scale.
- **Breasting industrialization**: development of industrial concentration contributes to increase of land surface temperature due to high emission of greenhouse gases. Which will lead to increase of land surface temperature.
- **Human activities**: land cover transformation in urban areas include the conversion of natural vegetation and agriculture to impervious surface. While studying the link between land surface temperature and vegetation, the NDVI, has commonly been used as a proxy for vegetation abundance. Understanding the contribution of human modification on changes of land surface temperature and on UHI remains an open research question.

### 3.3. Effects of land use/cover dynamics on LST

The study entitled “Impacts of LULC changes on land surface temperature in Rajshahi District of Bangladesh: Remote Sensing approach “, shows that “the analysis of land use land cover change exposes remarkable increase in the built-up areas and a significant decrease in the vegetation and agricultural land. The built-up areas were increased almost double in last twenty years in their study area. The distribution of changes in land surface temperature shows that built-up area recorded highest temperature followed by bare land, vegetation and agricultural land and water bodies. The LULC-LST profiles also revealed the high temperature in built-up area and the lowest temperature in water bodies(Kafy & Hasan, 2019).

Pal & Ziaul, (2017), have conducted a research entitled “Detection of Land Use and Land Cover Change and Land Surface Temperature in English Bazar Urban Centre”, and the results show that LST increases 0.070 $^{0}$C/year and 0.0114 $^{0}$C/year during winter and summer periods respectively and significant LST difference exist of different LULC units. Built- up area has maximum LST in all selected phases. The correlation coefficient among different deriving factors of LST with LST reveals that impervious surface (land) maximally control LST, followed by water bodies and vegetation cover. LST is almost co linear with aerial temperature as indicated by significant correlation value (0.44604 for January and 0.658 for April 20140. The estimated temperature gap is also strongly controlled by LULC. As the LULC pattern changed, its imprint is reflected on LST and air temperature. They concluded saying that, immediate thinking about new urbanism should be adopted, started and implement to arrest the rising temperature and effect of urban heat island.

According to Tan et al., (2020), in recent decades, rapid social and economic development has led to increased land use/land cover (LULC) changes in the Dongting Lake area, which affect the surface energy balance and hydrological processes. Its contemporary variability under climate change remains highly uncertain. They explored the relationship between LST with the LULC types using Landsat 7 image. The results showed that LST significantly affected by surface type. LST varied significantly across LULC types, with higher LSTs in built-up land, reed beach land, forest land, and paddy fields than in water bodies, mud beaches, marshlands, and riparian forests. Water bodies play an important regulatory role in reducing LST and mitigating thermal effects on the ground. Compared with the relationship between the NDVI, DEM and distance from the water body, the negative correlation between the NDMI and LST was stronger and more stable and had the greatest effect on LST. Their insights and findings improve the understanding of the land cover change effects on the LST dynamics.

Also Jiang & Tian, (2010) in their study entitled “Analysis of the Impact of Land Use/Land Cover Change on Land Surface Temperature with Remote sensing, have proven that the rapid urbanization process brought about many Eco-environmental problems, such as the drastic change of land use and development of urban heat island. The results showed that the land use changes were an important driver for LST increase, with high temperature in sparse-vegetation area and low temperature in dense-vegetation area.

### 3.4.Rwanda context overview on land surface temperature and land cover

Bosco & Thomas, (2019) in the study entitled “Land Surface Temperature Analysis in Kigali city”, have analyzed the change in temperature due to the land cover in place and inform everyone to take care of land cover. The modification and transformation of land cover in a city, affect an evapotranspiration process, storage, and emission of the heat in the urban environment. The land cover classification results showed that, the area is dominated 48% vegetation, 38% bare soil, 13% built-up and 1% water. The maximum temperature was $30^0$C and lowest is $16^0$C. There is positive correlation between NDBI and LST and negative correlation between NDVI and LST.

The rapid Urbanization of Kigali City, caused the migration of population to Runda satellite city which is the key drivers of the detected changes on Land Cover Land Use Patterns(Hakorimana et al., 2018).

## Chapter 4: RESULTS AND DISCUSSION

### 4.1. General Introduction

From problem identification, proofreading from research general tendency, data collection analysis made with intention of overall research objectives and their respective research questions. This chapter will in details and deeply describe, model and demonstrate the answer of the research questions to achieve the purpose of our research objectives. Spatial patterns of land use and land cover dynamics and land surface temperature distribution in the city of Kigali were modelled and quantified.

#### 4.1.1. Data acquisition and processing

The use of remote sensing will support to have access in remote area of the city of Kigali. In classification of Landsat images of 1999, 2010 and 2020, five classes have been considered such as Open land, built up, forests, wetlands and water bodies. Extraction of these LULC class more categories were defined into five groups.  The maximum likelihood classification scheme (Level1) was used for LULC classification which is commonly used classification system for Landsat data. The acquired Landsat images were classified for the year 1999, 2010 and 2020 using Maximum Likelihood method (Figure 3). To generate the following Land Cover target classes more plot of square training samples was taken in each feature spaces. The considered classes are: (i) Open land (consist of agricultural land, vacant land, fallow land, firms and bare land (ii) Water bodies (comprises of artificial pond of Nyarutarama inside hinterland, Masaka near Inyange industry and Muhazi natural lake in North part of Kigali, coast water, and streams. (iii) Forest (iv) Built-up (consist of residential, industrial, commercial infrastructure and transportation network such as roads, Kanombe international airport) and (v) wetlands. In order to evaluate and validate the classification accuracy, ground truth data was obtained from the 40-land cover reference point for validation and these were overlaid on high-resolution satellite images of Google Earth. For better accuracy, both spectral and spatial profiles and ancillary information such as Google Earth images were used for training site development.

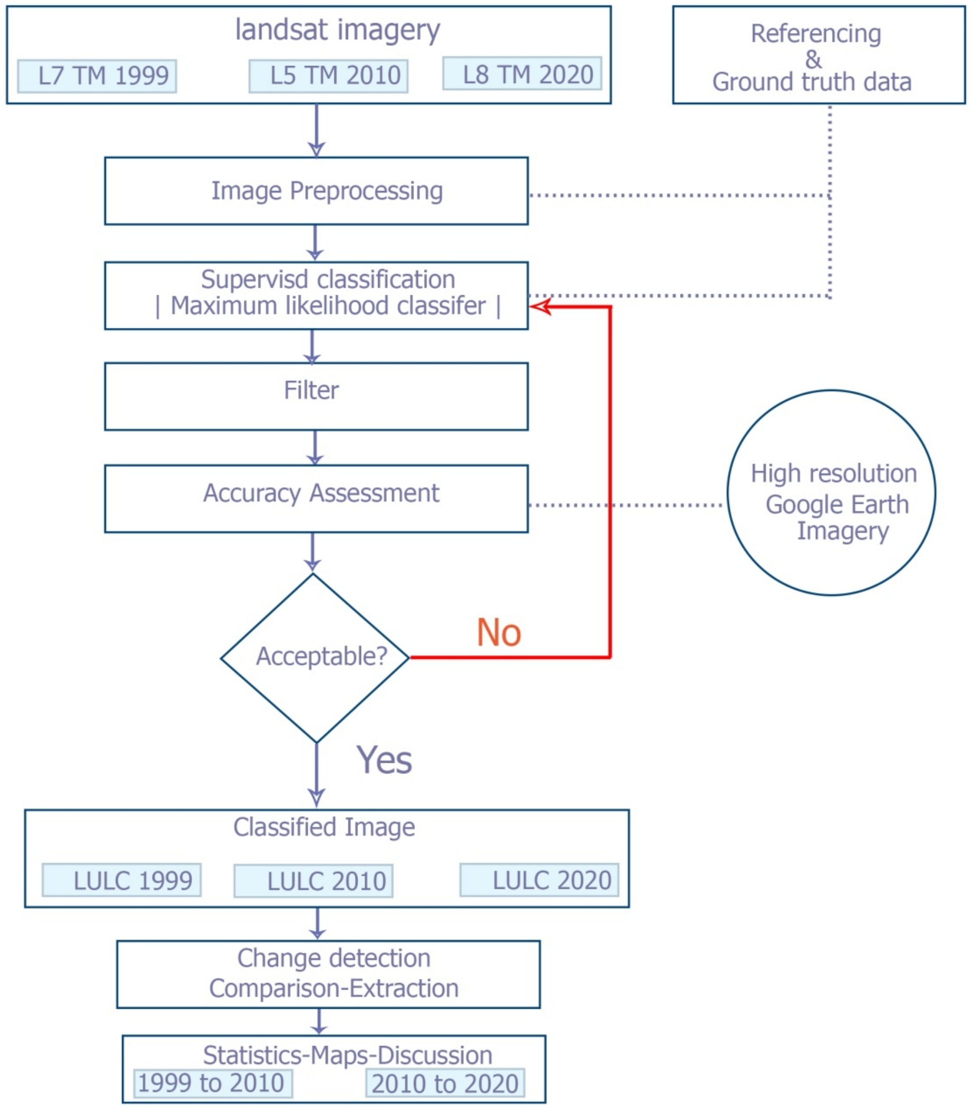


***Figure 4: The city of Kigali, Land Use and Land cover dynamics analysis workflows***

Table (4) below, represents all the parameters introduced in this section. The thermal infrared bands of different types of Landsat images (band 6 of Landsat 7 TM and band 10 for Landsat 8) were used to estimate the LST of Kigali city.

Normalized difference vegetation index (NDVI) (Tucker 1979) is the most frequently used index for extracting vegetation. It is also applied in deriving LST and normally shows a negative correlation with LST. Normalized difference build up area index (NDBI) was applied in this study to detect the built-up area

*Table 4: Parameters in LST retrieval*

| Parameters | Definition |
|---|---|
| $L_{\lambda}/L_{TOA}$ | The spectral at-sensor radiance (top of the atmosphere) |
| $G_{re\_scale}$ | The rescaled gain ( the data product " gain" contained in the level 1 product header or ancillary data recorded |
| $B_{re\_scaled}$ | The scaled bias ( the data product "offset" contained in the level 1 product header or ancillary data record |
| $Q_{cal}$ | The quantized calibrated pixel value |
| $L_{Min,\lambda}$ | The spectral radiance scaled to QCALMIN |
| $L_{Max,\lambda}$ | The spectral radiance scaled to QCALMAX |
| $Q_{Cal,Min}$ | The minimum quantized calibrated pixel value ( corresponding to $L_{Min},\lambda$ ) |
| $Q_{Cal,Max}$ | The maximum quantized calibrated pixel value ( corresponding to $L_{Max},\lambda$ ) |
| $M_L$ | The radiance multiplicative scaling factor for the band ( RADIANCE_MULT_BAND_n from the metadata) |
| $\Delta_L$ | The radiance additive scaling factor for the band (RADIANCE_ADD_BAND_n from the metadata |
| $\tau$ | The atmospheric transformation |
| $\varepsilon$ | The emissivity of the surface |
| $L_U$ | The upwelling or atmospheric path radiance |
| $L_d$ | The apparent surface temperature in kelvin |
| $K_1$ $K_2$ | The calibration constants |

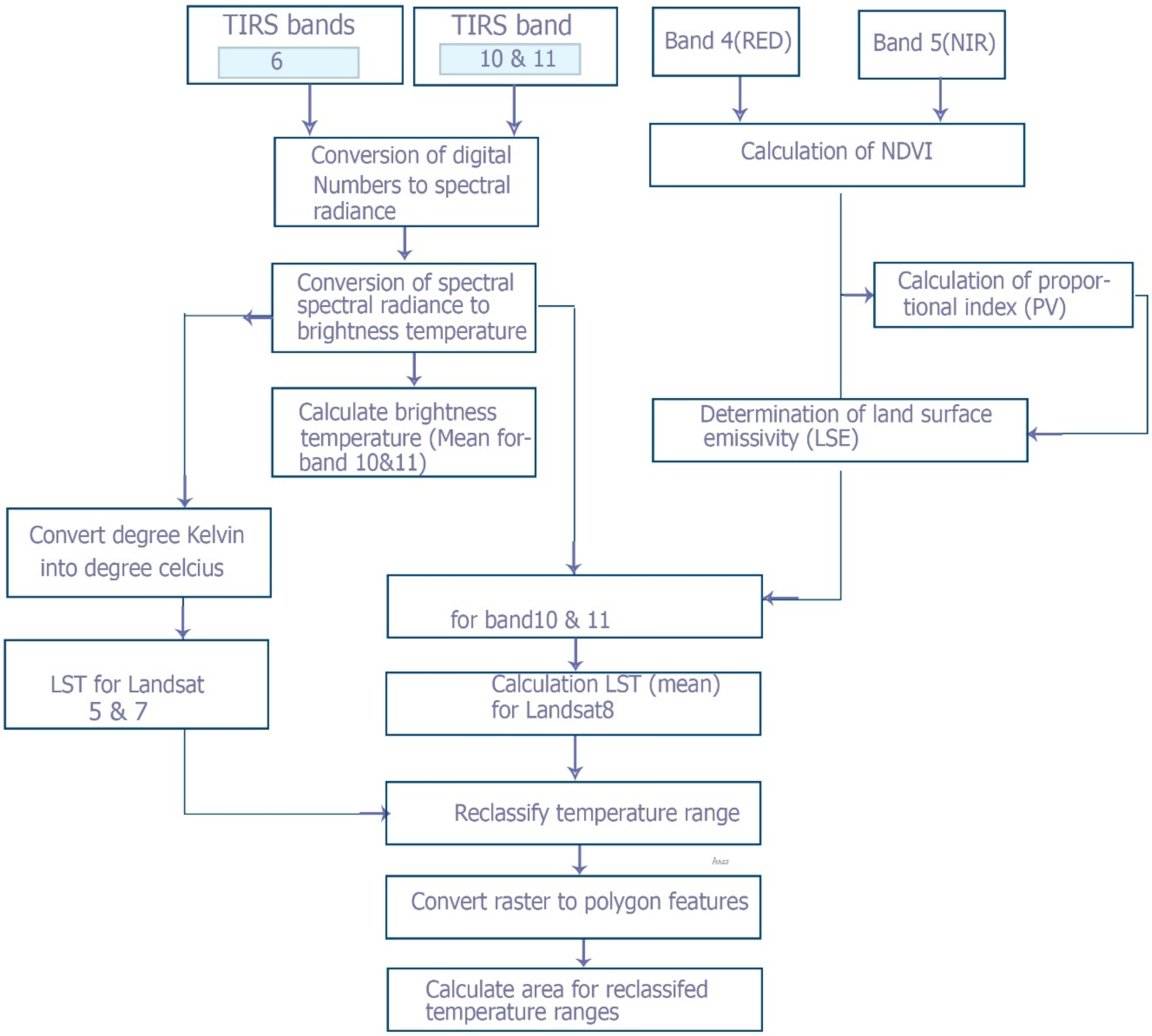


***Figure 5: The City of Kigali Land Surface temperature analysis workflows***

*Table 5: USGS formulas for NDVI and NDBI calculations*

| Acronym | Description | Formula | Purpose | Reference |
| --- | --- | --- | --- | --- |
| NDVI | Normalized difference vegetation index | $\frac{NIR - Red}{NIR + Red}$ | This will support in finding greenness | Tucker 1979 |
| NDBI | Normalized difference built-up index | $\frac{SWIR1 - NIR}{SWIR1 + NIR}$ | To characterize conditions of land surface vegetation and key variable of models for simulating cycle of water, carbon and energy on land surface | Zha, Gao, and Ni at al.2003 |

**Formulas for the estimation of LST**

The column of atmospheric gases such as water vapor, ozone, oxygen, atmospheric molecules, dispersed aerosols particles, and thin clouds exist between land surface objects and satellite sensors. The scattering and absorption of these molecules and aerosols cause a distortion effect on the original reflectance produced by target objects. Therefore, land surface information received by satellite sensors needs conversion from to-of-atmosphere (TOA) radiance to surface reflectance (Ling et al.2002, Zaidi et all.2017). Proper atmospheric correction is critical when satellite data is used for change detection because the spatial heterogeneous aerosol distribution over the study area can cause a false indication of change or mask real pixels of change (De-Keukelaere et al.2018). Therefore, to avoid errors we selected Landsat images from TM, ETM+, and OLI sensors with cloud coverage less than 10%.

The LST was derived from geometrically corrected Landsat satellite images for the year of 2000, 2010 and 2020. The following set equations was used to calculate LST

6.2.3 Convert the DN Spectral Radiance (L)

First, the pixel value was converted from digital number units to radiation values by using thermal band for (Landsat 4 TM and Landsat 7 ETM+),

$$L_{\lambda} = \frac{Lmax\lambda - Lmin\lambda}{Qcal,Max - Qcal,Min} * (Q_{cal} - Q_{cal,Min}) + L_{Min,\lambda}$$

Where $L_{max,\lambda}$ and $L_{min,\lambda}$ are the maximum and minimum radiance values, respectively; and their values were available from the metadata of Landsat images. Secondary, the L value were converted into brightness temperature ($T_B$) as follows:

$$T_B = \frac{K2}{Ln(\frac{K1}{Lx}+1)} - 273.15$$

Where $K_1$ and $K_2$ are constant available form United States Geological Survey. Thirdly, the $T_B$ value were translated into LST as follows:

$$LST = \frac{TB}{[1+[\frac{\lambda\, TB\sigma}{h\, c} Ln\varepsilon]]}$$

Where λ is the center of wavelength, σ is Boltzmann constant (= $1.380649 \times 10^{-23}$ J/K), h is the Planck's constant (= $6.626 \times 10^{-34}$J/s), c is the velocity of light (= $2.998 \times 10^{8}$ms/s), and ε is the emissivity that is being derived as follows:

$$\varepsilon = 0.004\ PV + 0.986$$

Where PV is the proportion of vegetation and calculated as a function of NDVI values as follows:

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

Where $NDVI_{max}$ and NDVImin is are the image-specific maximum and minimum of the NDVI values, respectively. In addition, the calculation of NDVI is found in Table (5).

Note that Landsat 8 has two thermal bands centered at 10.9 μm and 12 μm. Therefore, LSt for Landsat 8 was calculated by averaging LST values from both of the bands. Normalized Difference Built-up Index (NDBI). Land Surface Emissivity (LSE) is the average emissivity of an element of the surface of the Earth calculated from NDVI values: Land Surface Temperature (LST): and this radiative temperature is calculated using Top of Atmosphere Brightness Temperature, Wavelength of emitted radiance, Land Surface Emissivity.

The values of λ for Landsat bands are listed in the following table:

***Table 6: Center wavelength of Landsat bands***

| satellite | Band | λ( μm ) |
|---|---|---|
| Landsat 4, 5, and 7 | 6 | 11.45 |
| Landsat 8 | 10 | 10.8 |
| Landsat 8 | 11 | 12 |

### 4.2. The city of Kigali Land Use and Land Cover dynamics within the periods of 1999, 2010 and 2020.

This study indicates the capability of using medium resolution Landsat images to assess the dynamics of land use and land cover impacts on land surface temperature. The maximum likelihood supervised classification come into existence. The spatial resolution of images could affect the final classified images however understanding the satellite scenes, Landsat time of acquisition and Landsat color compositions based on spatial feature's reflectance brings attention of reducing percentage of cloud cover during data acquisition which is in part of image enhancement to reduce image classification biases.

The variability of LULC in this research was clearly demonstrated using remote sensing techniques and GIS software where classified images of all three-time frame of years were converted into polygons and merge all the same grid codes of grid cell classes and determine area coverage of fields in hectare distance measurement unit.

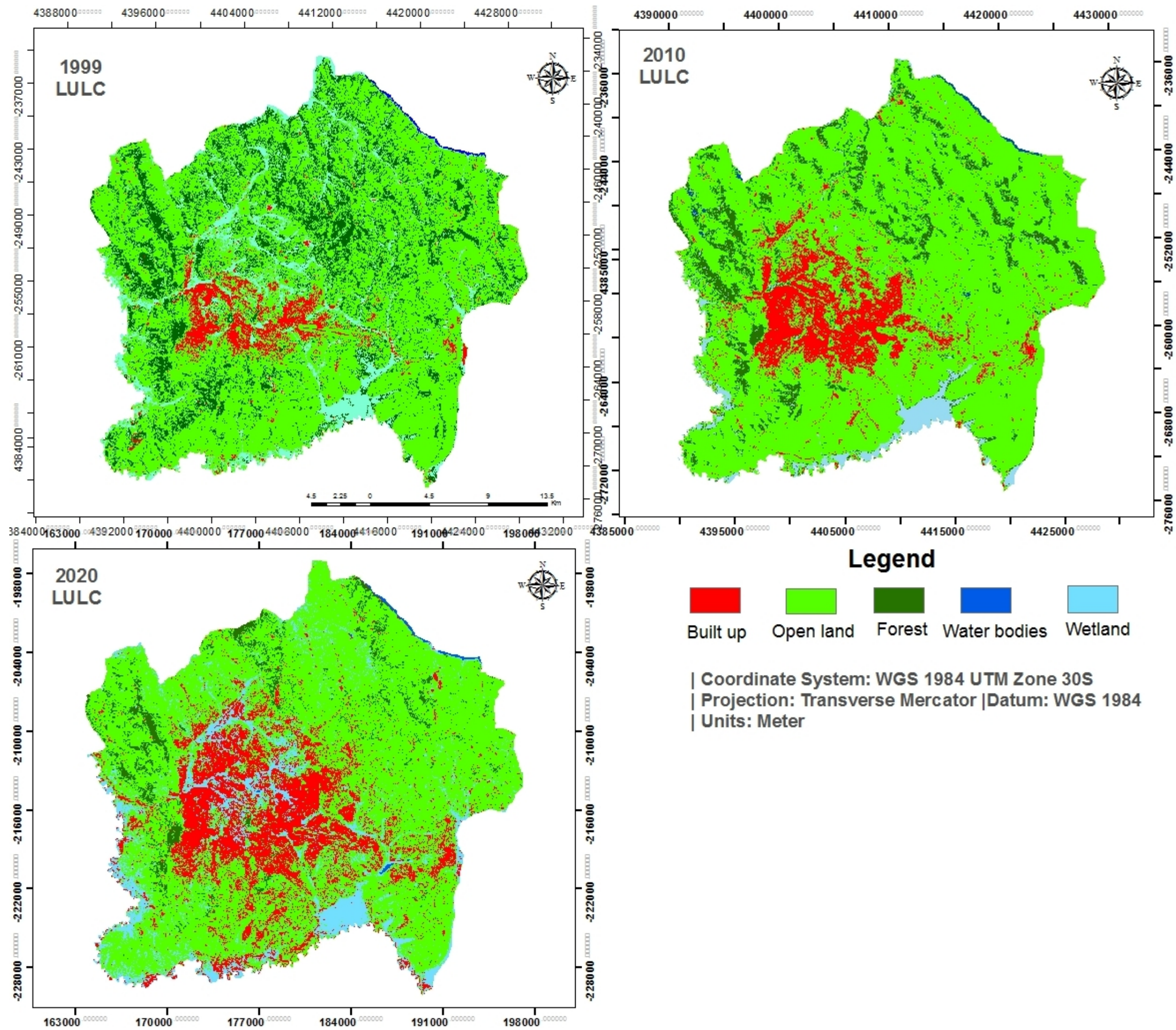


***Figure 6: The city of Kigali Land Use and Land Cover Dynamics from 1999, 2010 and 2020***

*Table 7: The city of Kigali Quantified 1999 LULC area coverage in both Percentage % and Hectare (ha) unit*

| Nº LULC | LULC classes | Area coverage in hectare | Percentage (%) |
|---|---|---|---|
| 1 | Built up | 3,629.34 | 5.054% |
| 2 | Wetlands | 7,291.61 | 10.15 |
| 3 | Open land | 47,271.75 | 65.77 |
| 4 | Forest | 13,500 | 18.8 |
| 5 | Water bodies | 155.47 | 0.21 |

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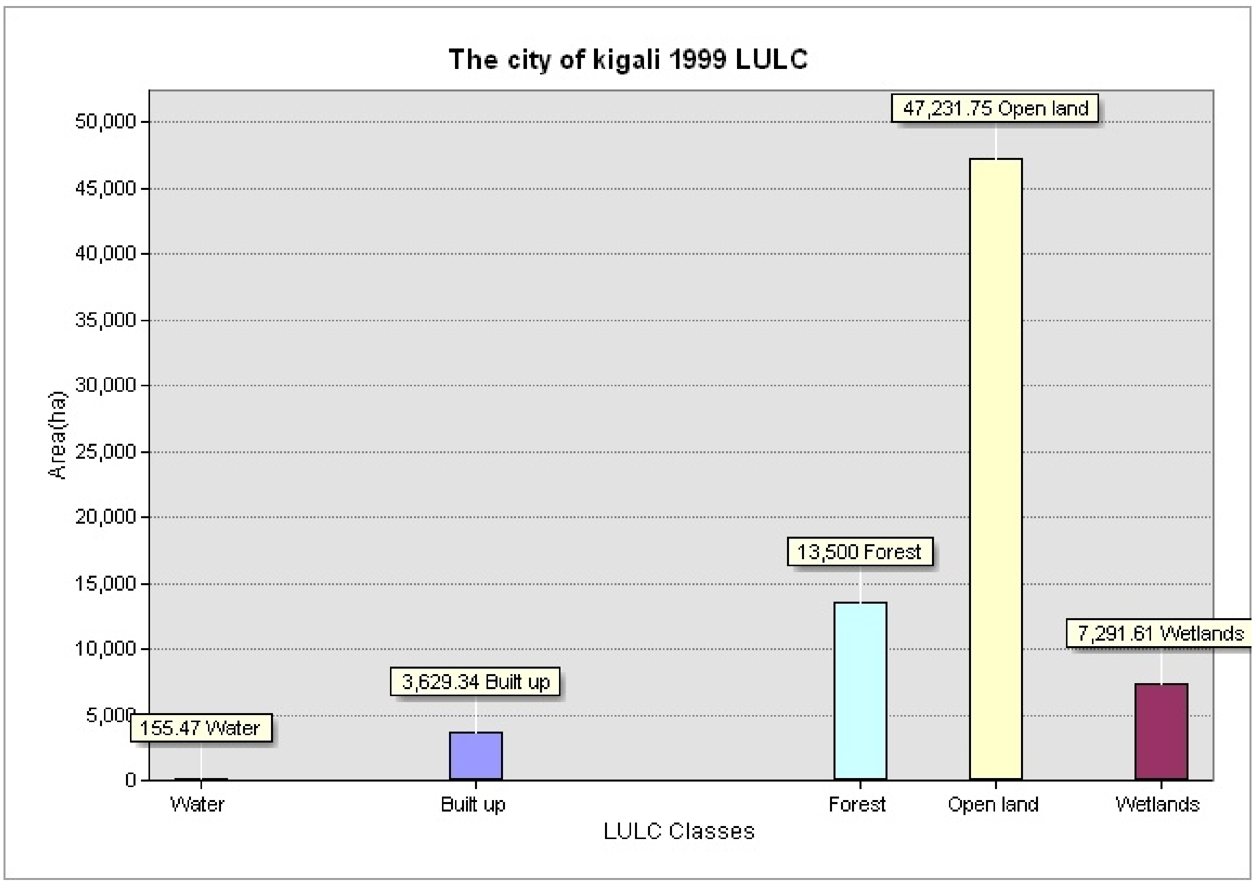



*Figure 7: The city of Kigali 1999 LULC Trends*

*Table 8: The city of Kigali Quantified 2010 LULC area coverage in both Percentage (%) and Hectare (ha) unit*

| $N^0$ of LULC | LULC Classes | Area coverage in hectare | Percentage (%) |
|---|---|---|---|
| 1 | Built up | 8,031.45 | 11.18 |
| 2 | wetlands | 2,386.06 | 3.32 |
| 3 | Open land | 54,881.6 | 76.39 |
| 4 | Forest | 6,303.2 | 7.77 |
| 5 | Water bodies | 238.27 | 0.33 |

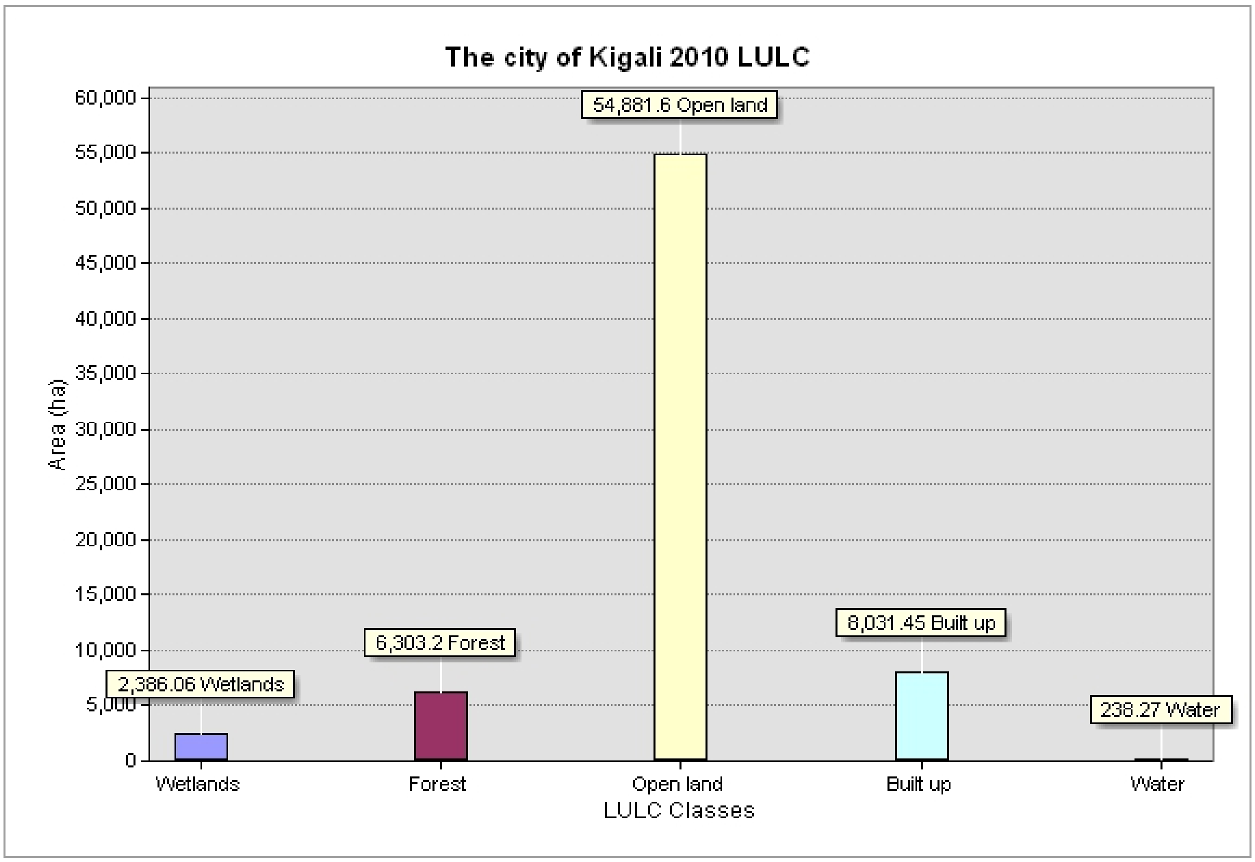



*Figure 8: The city of Kigali 2010 LULC Trends*

*Table 9: The city of Kigali Quantified 2020 LULC area coverage in both Percentage (%) and Hectare (Ha) unit*

| $N^0$ of LULC | LULC Classes | Area coverage in hectare | Percentage (%) |
|---|---|---|---|
| 1 | Built up | 13,285.66 | 18.17 |
| 2 | Wetlands | 8,105.66 | 11.9 |
| 3 | Open land | 48,599.53 | 66.47 |
| 4 | Forest | 2,935.62 | 4.015 |
| 5 | Water bodies | 189.29 | 0.26 |

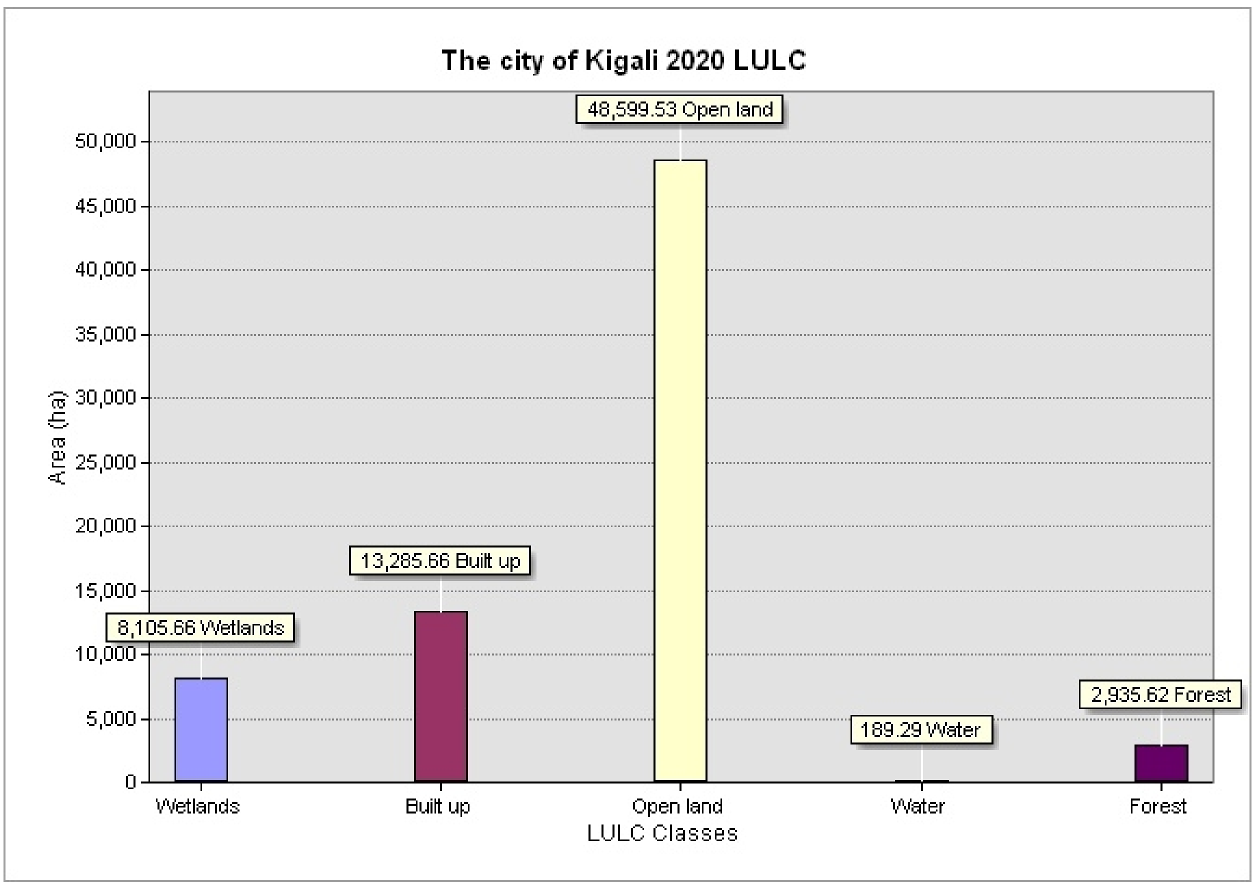



*Figure 9: The city of Kigali 2020 LULC trends*

Our first objective was to analyze the land cover changes with respect to built-up area by determining the status of land cover dynamics in the city of Kigali.

We first downloaded the Landsat images from USG. The entire Landsat scene cloud cover for the years of 1999, 2010 and 2020 was about 1%-13% but it was less than 10% in the study area. Imagery was classified into five separate LULC classes based on Level 1 of Anderson classification scheme. It is preferred classification system for classifying Landsat data (Anderson 1976). Table (8, 9 and 10) highlights the LULC features included for each class. To classify the LULC from the pre-processed Landsat images, MLC techniques was used with more 140-point sample of signatures collected among five classes identified through field surveys, GeoEye image, and Google Earth imagery.

Land use and land cover (LULC) maps for Kigali (figure 5) were extracted for 3 years (1999, 2010 and 2020) using downloaded satellite data. The results cleared at (Table 8, 9 and 10) and histogram (figure6, 7 and 8) shown that an increase has occurred in the area of impervious surfaces, annual urban area expansion (AEA), and annual urban percentage rate (figure6, 7 and 8). For the past 3 decades, urban areas in 3 districts Nyarugenge, Gasabo and Kicukiro have expanded dramatically from 3,629.43 hectares, (5.054%) to 13, 285.66 hectares, (18.17%) (Table8, 9 and 10), where the increase occurred in urban expansion area is 18.17%. The extent of urban sprawl between 1999 to 2010 was 4402.11 hectares (6.13%) and between 2010 to 2020 was 5254.21 hectares (7.00%). This indicates that urban expansion was more intense after 2010 as compared to 1999. This is also significant evidence from fig8, which shows a slow rate of urbanization before 1999 and high rate of urbanization from 2010 to 2020. There was huge urban expansion in Kicukiro and Nyarugenge district as shown by the significant increase in built-up areas of tjose districts.

As urban expansion got exponentially increasing specifically built up area, the Table8, 9 and 10 shown that open land in which vegetation, grassland is among declined significantly by 7,648.85 hectares, -10.62% from 1999 to 2010 and by 6282.07hectares, -9.3% from 2010 to 2020.

### 4.3. Land surface temperature estimation

The second research objective of this study was to analyze the Trends of Land Surface Temperature of the city of Kigali within the period of 1999, 2010 and 2020. The Landsat thermal bands were selected to extract Land Surface Temperature of Kigali. From Landsat 8, the average mean of 10 and 11 thermal bands have been used in LST extraction and Land Surface Emissivity (LSE) was extracted from the condition of vegetation cover indices (NDVI) and transformed into Proportional Vegetation (PV) with Near Infrared band 5 (NIR) and Red band4. For Landsat 5 and 7, thermal band 6 for LST estimation was used together with Near Infrared Band 4 and Red band 3.

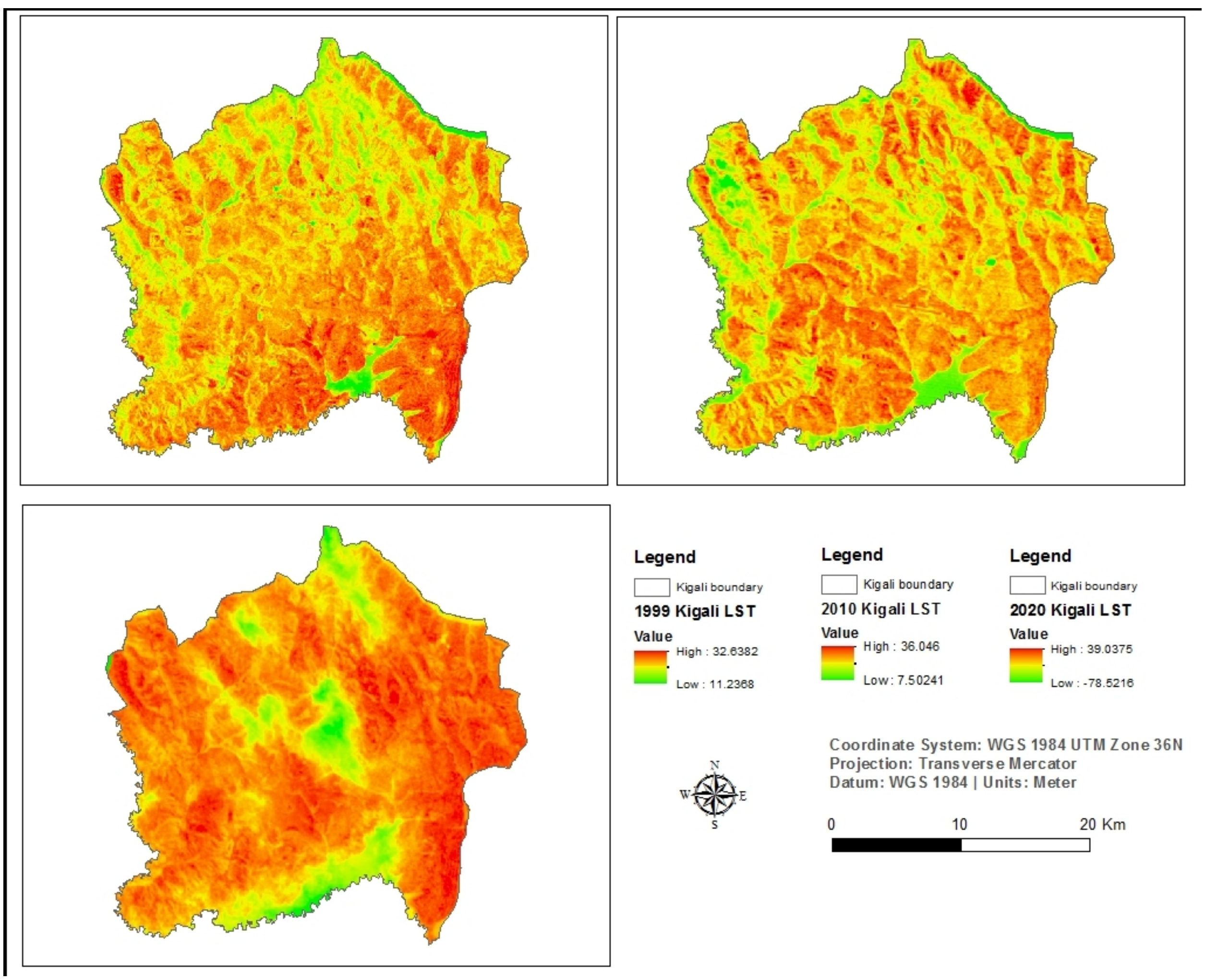


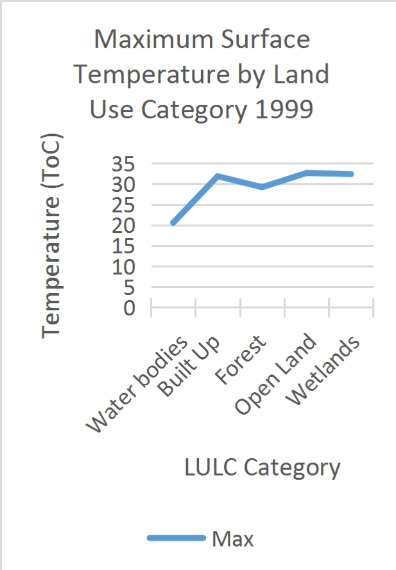
***Figure 10: The city of Kigali Land Surface Temperature Spatial Pattern in time series from 1999, 2010 and 2020***

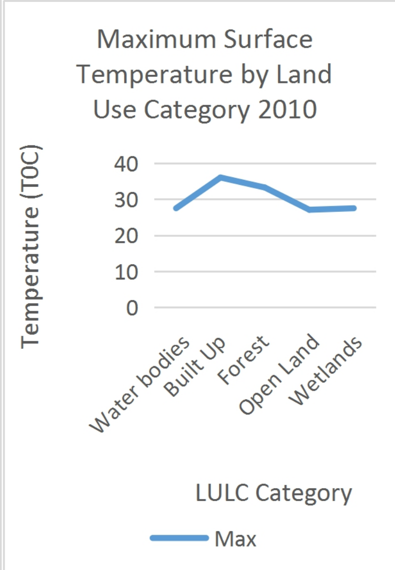
Figure 10 shows a spatial pattern of LST in three periods, from 1999, 2010 to 2020. The analysis has been carried in hot seasons of Rwanda. The first image was taken on July $8^{th}$, 1999; the second was on August $15^{th}$, 2010 and the third was on August $10^{th}$, 2020. The LST maps were prepared USG formulas and algorithms in ArcGIS 10.6. In all the maps, dark redish color highlights high temperature and greenish shows low temperature. The spatial patterns of LST concentration and temporal shift of LST pattern shows the rapid change in LULC. The maximum temperature recorded during the study periods found to be $32^0$C, $36^0$C and $39^0$C with minimum of $11^0$C, $7^0$C and -$78^0$C in 1999, 2010,and 2020 respectively. Using point-based sample location of CBD and its hinterlands the study found the gradual increase in Land Surface Temperature especially in Nyarugenge district where the city of Kigali CBD is Located. The temperature of this point-based sample analysis has founf that CBD in 1999 LST was $26^0$C, in 2010 was $32^0$C and in 2020 was $33^0$C. The reason behind this rise of LST in CBD was due to increase and high development of building and impervious surfaces which led to high temperature within the city centre than its hinterlands and as a result there is UHI phenomena.

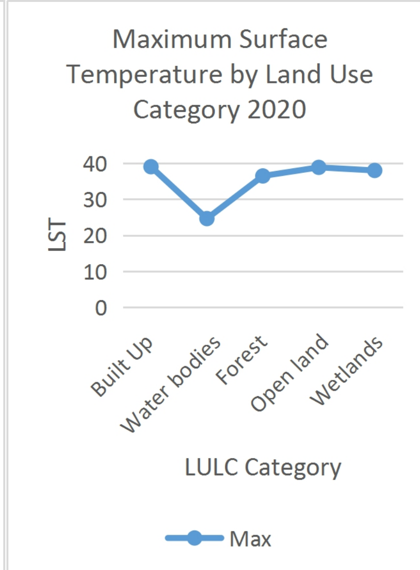
## 4.4.Correlation between LST and LULC

Our last objectives and the main object was to link the LULC and LST in the city of Kigali.

In terms of correlation of LULC and mean LST, the LULC change had the greatest effect on LST change in the periods of 1999, 2010, and 2020. The effect of LULC change was significant and positively correlated in built-up and bare land categories with the mean LST. From our observations, high surface temperature was observed in built-up of CBD and its neighboring areas and bare land (part of open land in our land use land cover classification categories) where as low surface temperature in green vegetative areas. With an increase in built-up and bare land, the mean LST increased significantly. There is also the negative correlation between LULC categories of vegetative areas of forest, agriculture with LST. With an increase in vegetative areas, there is decrease in Land Surface Temperature.




To clearly demonstrate and model the impacts of land use and land cover dynamics on land surface temperature, the land surface temperature and land use indices specifically the spatial condition of Built up and vegetation-based pixel were extracted as follow:

**Land Use Indices**

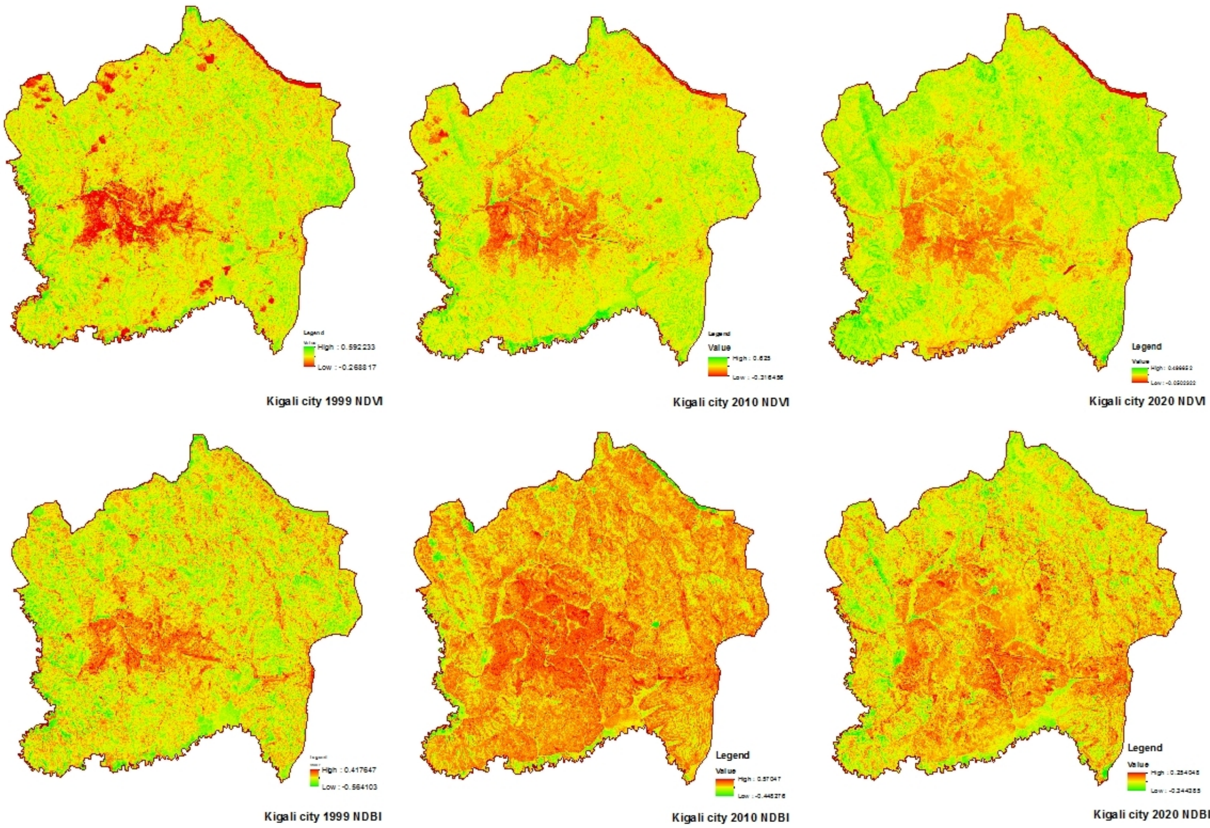
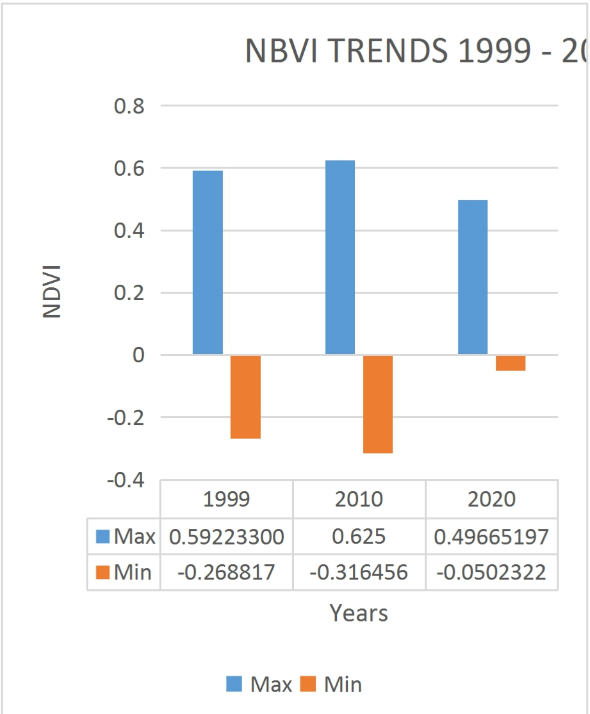
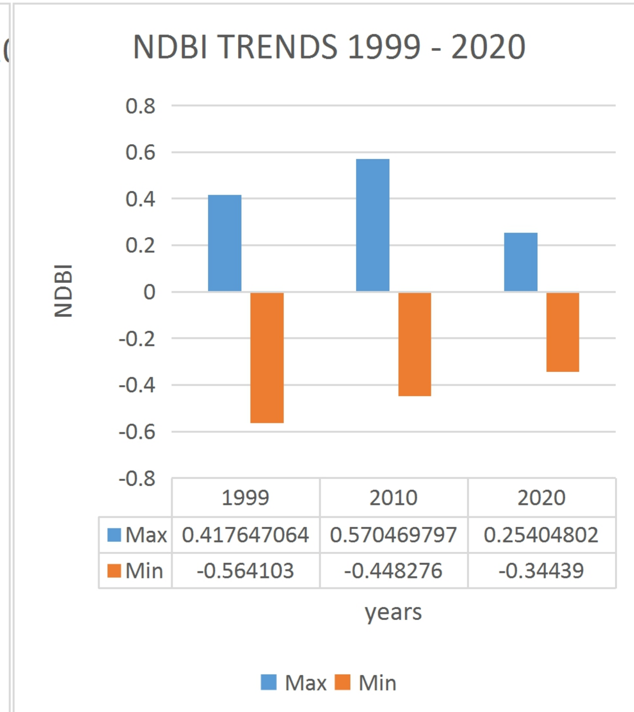



*Figure 11: The city of Kigali LULC indices*

**Trends of LULC indices from 2000, 2010, and 2020.**




### 4.4.1. Correlation between LST, NDVI and NDBI

Land surface temperature acquired from satellite data( Landsat images) represents the surface temperatures of each object within a pixel, which may be composed of several land cover types(Malik et al., 2019). Using the equations described for the processing of Landsat 8, Landsat 5 and Landsat 7 thermal bands 10, 6 and 6 respectively, was computed in ArcGIS to produce LST maps of the city of Kigali. The difference seen in LST in the period of 2000, 2010 and 2020 is due to different land cover types within the city of Kigali having different physical properties. Based on the three Landsat images covering the city of Kigali for the period of 1999, 2010 and 2010 retrieved from USGS, Normalized Difference Vegetation index (NDVI) and Normalized Difference Built-up Index (NDBI) in the above mentioned periods was estimated using radiative transfer model. The spatial and temporal pattern and characteristics of LST, NDVI and NDBI and their relationship are described in details below.

**Land surface emissivity**

Land surface emissivity is a proportionality factor that scales black-body radiance to predict emitted radiance(Malik et al., 2019). The emissivity has been derived from satellite data Landsat 5,7 and 8 images by calculated the proportion of vegetation with the help of ArcGIS software algorithms. Its values are shown in the table bellow

***Table 10: Emissivity in the period of 1999, 2010 and 2020***

| Emissivity | Maximum | Minimum |
|---|---|---|
| 1999 | 0.988535 | 0.986535 |
| 2010 | 0.988641 | 0.986467 |
| 2020 | 0.98824 | 0.986902 |

### 4.4.1.1.NDVI and LST Relationships

The relationship between LST and NDVI in each period has been developed as shown in the figure below. Higher NDVI values were mainly distributed in the regions surrounding the built up area of the city of Kigali in each period. The correlation analysis of LST and NDVI has shown that there has been existed a strong negative correlation in all the years. The Pearson's correlation coefficient in three years (1999, 2010 and 2020) was $R^2 = 0.9688$, 0.9984 and 0.4538 respectively.

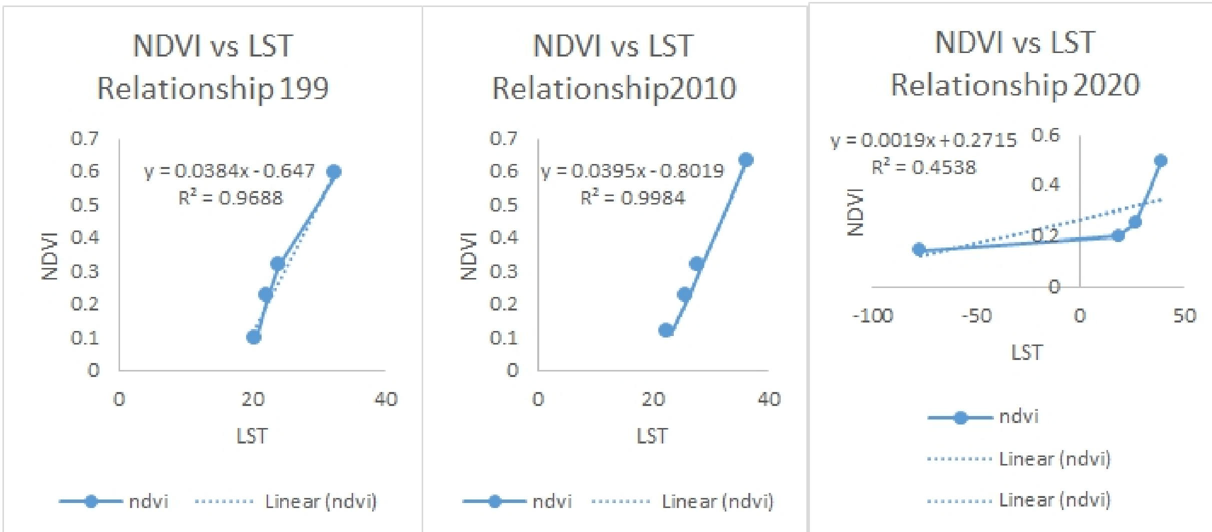



***Figure 12: LST and NDVI Relationship***

**4.4.4.2. NDBI and LST relationships**

The relationship between NDBI and LST were computed in all the years (1999, 2010, 2020). Results of NDBI has shown high values in the built-up area and inducing high temperature variations. There existed a strong positive relationship in each year as signified by the Pearson's correlation coefficient $R^2$ = 0.9995 in 1999, $R^2$= 0.997in 2010 and $R^2$= 0.4529 in 2020 as shown in the figure below.

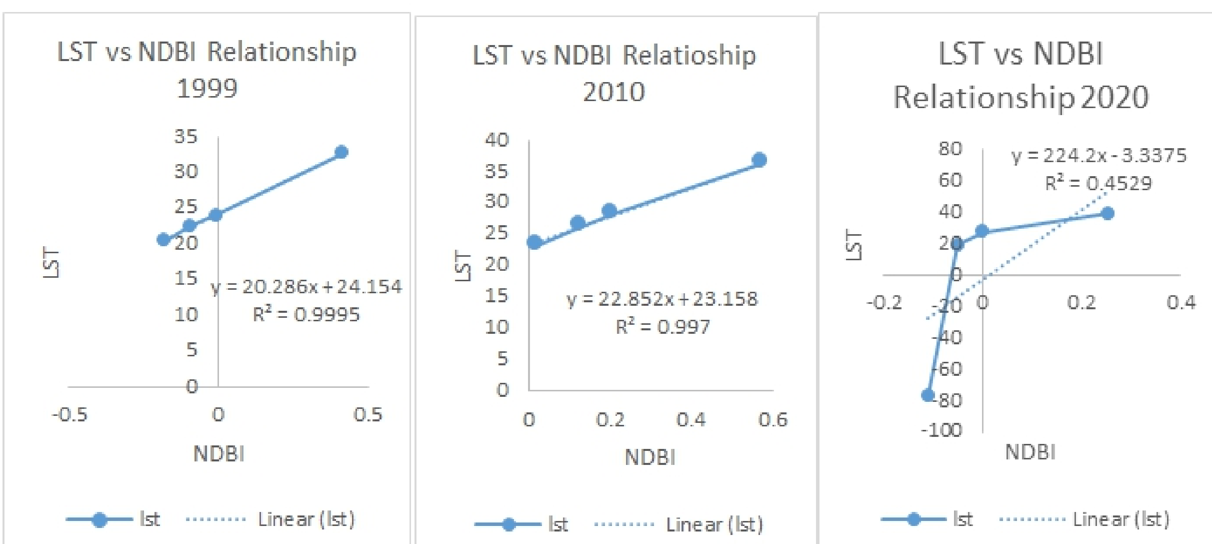



***Figure 13: LST and NDBI Relationship***

This positive relationship between NDBI and LST shows that built-up area is generating much surface temperature variations and is a key contributor in urban heat island (Malik et al., 2019). The statics of NDBI is shown in the fig. 13.

### 4.4.1.2.NDVI and NDBI Relationship

In our study, we have also developed the relationship between NDVI and NDBI. The minimum and maximum values of NDBI are -0.4022, 0.5131, -0.4545, 0.5704 and -0.3443, 0.2540 respectively. The correlation analysis of NDVI and NDBI have shown the strong negative relationship between them as the Pearson correlation coefficients show i.e. $R^2$= 0.9699, 0.9993, and 1

in 1999, 2010, and 2020 respectively. Figure below is the scatter plot showing the correlation between NDVI and NDBI.

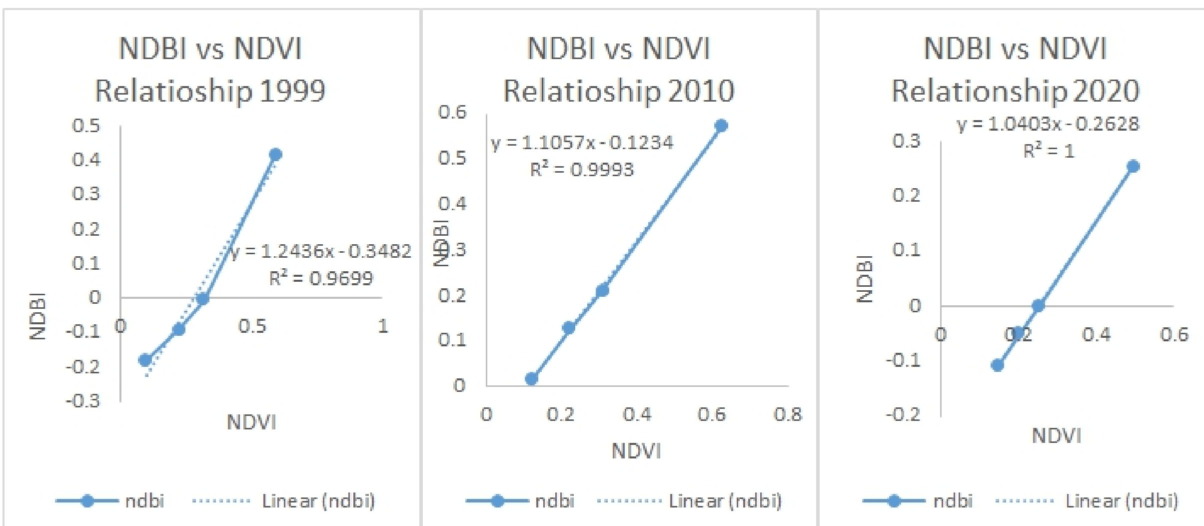



*Figure 14: NDVI Vs NDBI Relationship*

## Chapter 5: CONCLUSION AND RECOMMENDATION

In this research, quantitative and qualitative Landsat images analysis were performed to assess the impact of LULC indices dynamics on LST and their relationships. The analysis focused on three Districts City of Kigali(Gasabo, Kicukiro and Nyarugenge) for the period of 1999, 2010 and 2020. The LULC maps for those periods were prepared using satellite data (Landsat imageries) from USGS. The results showed that LULC dynamics has significantly changed. Forest and open land were reduced by built-up area development. The buit-up area has increased from 3,629.34ha in 1999 to 8,031.45ha in 2010 and 13,285.66ha in 2020. This change was the result of rapid urbanization of the city of Kigali within those periods. After, the LST maps were also prepared using the Landsat images thermal bands. From our observations and analysis, we have seen the higher temperature in built-up area of the CBD and its surrounding neighborhoods and in bare surfaces, while lower temperature in vegetated areas and in hinterlands. The minimum temperature was $11^0$C, $7^0$C, and $-787^0$C and the maximum temperature was $32^0$C, $36^0$C and $39^0$C in 1999, 2010 and 2020 respectively. There is a strong positive correlation between NDBI and LST for all the periods as shown by $R^2$=0.9995 in 1999, $R^2$=0.997 in 2010 and $R^2$=0.4529 in 2020. The correlation between NDVI and NBI i.e. $R^2$=0.9699, $R^2$= 0.9993 and $R^2$=1 in 1999 , 2010 and 2020 respectively indicated the negative relationship for those periods. We have also calculated the Land Surface Emissivity. The correlation between NDVI and LST was negative i.e. $R^2$=0.9688, $R^2$=0.9984and $R^2$= 0.4538in 1999, 2010 and 2020 respectively. This indicates that the more vegetated an area is the less temperature it has.

From our observations, we recommend urban planners, environmentalists and local authorities in the city of Kigali and in Rwanda in general to use LULC data indices i.e. NDVI and NDVI for estimating LST using satellite because it is the best and most accurate better way to show the hottest and coolest areas as compared to temperature collected from urban weather station. This will help to pull out the UHI effect and eventually better urban planning and implementation of better policy measures for sustainable development of the city. Further analysis with the use of high resolution image sensors with capacity of capturing high image resolution (sentinel and planescope ) could be considered. Using these image sensors, details can be extracted for an LULC classification, which would yield more classes and provide a more accurate description of the study site. To avoid Erratic LST values as a result of cloud coverage, calibration of LST data be undertaken in future project is recommended. Population density also plays a role in the acquired LST values, in which high concentrated neighborhoods of the study area displayed high temperature than low concentrated . Furthermore, thermal infrared remote sensing applications could be adapted for future studies to allow for better measurement of heat radiation in concentrated urban areas to provide a full understanding of the drivers of increased LST, which is mainly due to increased demand for urbanization and, in turn, is linked to the expansion of deforestation. However, it is a challenge to prevent urbanization without a change in the decision making of upper management. Thus, it is suggested that the state government authority considers enacting policies and strategies that support the control of deforestation in the highlands. This will address ecological and environmental concerns and help ensure that development takes place sustainably.

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