UNIVERSITY of RWANDA

COLLEGE OF SCIENCE AND TECHNOLOGY

Master's Program in Water Resources and Environmental Management

Assessment and possible adaptation on urban heat island. Case study: Rwanda.

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Declaration and Approval

This is to declare that this master's research entitled "**Assessment and possible adaptation to Urban Heat Island**," is submitted in respect of all requirements of University of Rwanda, College of Science and Technology (CST), the School of Engineering.

The thesis is submitted in full originality and high quality for obtaining a Master's of science in Water Resources and Environmental Management.

This dissertation contains the author's own work except where specifically acknowledged.

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Abstract

Urban heat island take place when a town experiences temperatures much warmer than its peri urban regions or rural areas. The difference between developed areas and rural areas belongs on how the land surface areas for each environment absorb and keep the heat due to land modification caused by anthropogenic activities on natural ground soil.

Natural plants undergo a process called transpiration whereby they get water from soil through their roots and store it into their stems and their leaves. Then, water is lost by small holes underside of the leaves. From there, water is converted into water vapor and lost into the atmosphere. This cycle repeats itself and is seen as natural air conditioner or cooling process of the land surface.

Firstly, this research work assessed if there were climate changes caused by UHI in City of Kigali precisely in Gitega Sector (Urban) in comparison to City of Rwamagana (rural) in The Eastern Province of Rwanda during the last 36 years period. With the help of on-site data or meteorologic data from Rwanda Meteorological Agency, we calculated the average mean temperatures for the two locations namely Gitega Sector and City of Rwamagana. Expectedly, we found that Gitega had (28.3°/16.3°C) whereas Rwamagana had (**27.7°**/16.1°C) for 36 years' period respectively. It was found the maximum temperature for Gitega sector was high of a half degree Celsius over Rwamagana area and on minimum temperature Gitega was still high of 0.2 degree Celsius than Rwamagana.

Generally, the main feature characterizing UHI are the structures for example complex buildings, roads, bridges and other infrastructures because they absorb and reflect solar radiations more than natural spaces for instance forests and water courses. In metropolitan zones, these buildings tend to be compacted into a small area and green space is limited. Thus, creating UHI with high temperatures than its peri urban regions.

In Rwanda, the urbanization rate has been increasing from 2011 to 2022, Urbanization rate refer to the share of total population living in an urban setting. It has increased from 16.94% to 17.57%. The urbanization often results in deforestation, habitat loss, and the extraction of fresh water from the environment which can destroy the biodiversity, alter species ranges and interaction.

Key Words: Urban Heat Island, City development, Suburban Areas, Environment, wavelength, absorbed, reflected and transpiration.

Acknowledgement

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Acronyms

Arc GIS: Aeronautical Reconnaissance Coverage Geographic Information System

GIOVANNI: Goddard Interactive Online Visualization and Analysis Infrastructure

MERRA: Modern-Era Retrospective analysis for Research and Applications

NASA: National Aeronautics and Space Administration

RMA: Rwanda Meteorological Agency

UHI: Urban Heat Island

SUHI: Surface Urban Heat Island

AUHI: Atmosphere Urban Heat Island

LULC: Land Use and Land Cover

Chapter 1 Introduction

What is the Urban Heat Land (UHL)?

UHI effect is the difference in magnitude between the ambient temperature in cities and its peri-urban regions (WENG Q & YANG S, 2003). The magnitudes of the differences can be quite large at times depending on weather conditions, urban thermophysical and geometrical features, heat sources present in the area and anthropogenic moisture. The UHI is generated mainly by dense agglomerations of heat absorbing, impervious building materials that trap more heat during the day and release it more slowly at night than natural ground cover, such as soil and vegetation (Sharon L, 2006). At the regional scale, land-use patterns and land cover are the strongest drivers of urban temperatures. Urbanization replaces vegetated surfaces which provide shading, evaporative cooling and rainwater interception, storage and infiltration functions – with impervious built surfaces (V. Whiteford, 2001). The world is undergoing the largest wave of urban growth in history. More than half of the world's population now lives in towns and cities, and by 2030 this number will swell to about 5 billion. Much of this urbanization will unfold in Africa and Asia, bringing huge social, economic and environmental transformations. Urbanization has the potential to usher in a new era of well-being, resource efficiency and economic growth. But cities are also home to high concentrations of poverty. Nowhere is the rise of inequality clearer than in urban areas, where wealthy communities coexist alongside, and separate from, slums and informal settlements, it is important to understand the potential for UHI effects to manifest themselves, and how urban populations can adapt to these effects to minimize the risks to their lives (Programme, 2018).

Quantitative analysis in Bandung in Indonesia, between 1994 and 2002, show that regions with high temperatures between 30 and 35 degrees Celsius are expanding to the residential areas and industrial zones at the rate of 4.47 % by estimation of 12.606 ha. (Syaukat, 2015). As the world braces for more extreme weather and overall higher temperatures, the Rwandan Government is once again determined to set the trend, preparing to be among the first to help fulfill the pledge made two years ago in Kigali, where 197 countries adopted the Kigali Amendment to the Montreal Protocol (Sharon L, 2006). There are a number of existing city-level studies of UHI effects and their relation to land cover and other causes. Same results were found in other big cities in Indonesia such as Semarang with rate of 8.4 per cent (12,174 ha) and Surabaya with the rate 4.8 per cent (1,512 ha) (Syaukat, 2015). Wenga Qihao examined land surface temperature patterns and their relationship with land cover in Guangzhou and in urban clusters in the Zhujiang Delta, China and concluded from a remote sensing investigation that vegetation abundance is one of the most influential factors in controlling land surface temperatures (Qihao Weng, 2003). In the United Kingdom, the largest UHI is located in London with night temperatures of 7 degree Celsius more than temperatures in rural areas at 20 km. In particular, the largest intensity of UHI in London is felt during the night, the slow increase of urban temperature is in the first hour in the afternoon. (Richard Watkins, 2007). The monthly mean maximum UHI intensity in Chiang Mai and Songkhla in Thailand were the greatest in April (2.73°C and 2.70°C), during the Thai hot season, while the weakest mean maximum UHI intensity in Chiang Mai was found in August, and in Songkhla was found in July, corresponding to the rainy season. Many previous studies have indicated that the UHI intensity was related to local meteorological conditions (Jongtanom, 2011). In Seoul, Korea, the most prominent occurrence of the maximum UHI intensity has a peak at 4.5°C when there is zero cloud cover (Yeon Hee Kim, 2002). The spatial variability in temperatures measured traversed across the urban area of Portland on hot days showed that temperatures varied by 5.5°C across the area measured. Annual mean temperatures at stations in populated areas of 10,000 people or more were 0.1°C warmer than nearby stations located in rural areas with a population of 2,999 (Syaukat, 2015). In the city of Szeged, Hungary, seasonal mean temperature differences between urban and suburban areas on calm and cloudless days ranged from 1.5–2°C; while in Alaska, urban areas were 2.20C warmer than rural areas. In Poland, under favorable weather conditions, the highest temperature difference between urban and rural stations reached 80°C (Bulut et al., 2008). These observations show that temperature rises and the UHI effect is evident in urban areas, though there is scope for further research in understanding the vulnerability of local populations to UHIs. As this could affect the quality of life for urban residents, this study seeks to fill this research gap for Jakarta, the capital city of Rwanda, and Bandar Lampung, a medium-sized city (Syaukat, 2015).

Urban land is expanding much faster than urban population, a phenomenon known as urban sprawl. Today population growth largely means urban population growth. UN projections show the world's rural population has already stopped growing, but the world can expect to add close to 1.5 billion urbanites in the next 15 years, and 3 billion by 2050. How the world meets the challenge of sustainable development will be intimately tied to this process. The growth in African megacities provides an opportunity to explore this possibility. The population of sub-Saharan Africa is projected to triple between 2017 and 2100 to more than three billion.

African cities will feel the pressure. Global estimates show the urban population ballooning from 0.75 billion in 1950 to more than 4 billion today, with African cities taking the global lead in the rate of expansion from 2015–2050. Construction is one the world's largest sources of carbon emissions.

1.2 Problem Statement

Urban green spaces provide to cities with ecosystem benefits ranging from maintenance of biodiversity to the regulation of urban climate. In the city of Kigali, urban development often gives rise to dramatic changes in urban land use, where natural green spaces are removed and replaced by built-up areas. For that, natural surfaces (e.g., grass, crops, and soil) are replaced with impervious built-up surfaces (e.g., concrete, asphalt), changing the land surface thermal and radiative properties as well as surface roughness in comparison with rural areas. This leads to modifications of the surface energy balance, which governs the momentum, heat and mass transfer between the surface and the atmosphere, thus impacts dynamic processes in the Urban Boundary Layer, and ultimately influences the local, regional and even global climate. Moreover, the increased temperatures associated with the UHI phenomenon are not uniform across the urban area as whole, as intra-urban thermal patterns are generally influenced by urban surface features. The conversion of natural vegetated landscapes into impervious surfaces causes a shift in the urban climate known as the Urban Heat Island (UHI) Effect. Consequently, people living in city may be particularly at risk of heat-related disease and death. Given the increasing urban population, rapid urban sprawl, and the more frequent occurrence of heat waves, studying the surface energy budget over urban areas and its relationship with urbanization is imperative. this research work assessed if there were climate changes caused by UHI in City of Kigali precisely in Gitega Sector (Urban) in comparison to City of Rwamagana (rural) in The Eastern Province of Rwanda during the last 36 years period.

1.3 Research Questions

What are the effects contributing to Urban Heat Island?
The capacity of construction material to store and release absorbed heat,
Produced heat due to Anthropogenic activities;
Wind speed variation caused by alteration and reduction of surface roughness by changing the topography of the area;
Increased absorption of solar radiation from lower albedo surfaces, among others
Factors describing the urban heat island?
Changes on the local microclimate;
Thermal discomfort;
Effect on public health;

Impact on hydrological;

Displacement of water bodies and increase of water levels.

1.4 Research objectives

1.4.1 **Main research objective**

The main research objective is to study temperature change in Rwanda and investigate the possibility of UHI in City of Kigali and subareas.

1.4.2 **Specific research question**

The following were the research objective

To find the degree at which the temperature has changed on selected cities using remote sensing tools like Giovanni Software in comparison with the data from on situ recordings.

To analyze the data from Giovanni Software to data from Rwanda Meteorological Agency.

To analyze the data from two sources and make recommendations.

This dissertation is made into 6 Chapters: the first chapter is talking about the Introduction; chapter 2 tells us about the literature review. Chapter 3 is composed of research methodology; chapter 4 is composed of Results. Finally, chapter 5 is about discussions, and the utilized references make a closing chapter of the dissertation.

Chapter 2 Literature Review

2.1 Urban Heat Island

The UHI are urbanized regions known for high temperatures in comparison with its peri urban regions. Structures for example buildings, roads, bridges and other infrastructures absorbs and reflect solar radiations more than natural space for instance forests and water courses. In Urban zones, these buildings tend to compacted to one another and green space is limited. It ends up creating UHI with high temperatures than its peri urban regions. Diurnal temperatures in urban areas are 1 and 7° F higher than surroundings and temperatures during the night are 2 and 5 ° F warmer than the surroundings (EPA, 2021).

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2.2 Causes of Urban Heat Island

2.2.1 Reduction of natural landscapes in Urban Areas.

Natural vegetation including trees, grass and wetlands tend to cool the air by providing a canopy. transpiration of water from plant leaves, evaporation from wetted surface in urban areas. Infrastructures such as roofs, buildings and car parking provide less shade and moisture than natural landscapes thus generate warm temperatures. Kigali has experienced a rapid urbanization growth in the last decade due to migration from rural areas to the city and natural increases of the population. Kigali is located in the center of Rwanda with approximately 730 km2 with city diameter of around 15 km and population estimated of 1.2 million. It a fast-growing city with an estimated annual growth of 4% from the last two decades. The City of Kigali is experiencing considerable transformation whereby old structures are changed into new sophisticated commercial buildings and construction of new paved roads to easy transportation within the city. The periphery of the city is also expanding as well by accelerated change of Land Use and Land Cover into built up area.The peri urban area of Muyumbu and Nyakariro in the Eastern of the City is typical example of Land Use and Land Cover before they were agricultural zone but because of peri urbanization they are being developed into bult up area.

2.2.2 Construction materials in urban areas

Conventional materials made by humans such as pavers, roofs and buildings tend to reflect less energy and emit more of sun's heat than green space, trees and natural wetlands. Often, heat islands build throughout the day and become more pronounced after sunset due to the slow release of heat from urban materials. As urbanization is increasing fast than before City planners and stakeholders should design buildings and structures with materials that are naturally cooling so that it can help to mitigate these environmental effects by reducing the need of air conditioning. Air conditioning accounts 10% of global energy consumption today, space cooling in 2016 alone was responsible for 1045 metric tons of CO_2 emissions. This numbers will continue to soar as the year 2050 it will reach 37% of global cooling energy. Air condition rely on refrigerant agent called Hydrofluorocarbon HFC which contributes to 1% to all greenhouse gases but it has more potent than co_2 emissions. The world has been taking into consideration the prevention or reduction of the use of energy consumption by rectifying some amendment for instance The Kigali amendment in the year of 2016 will help the world to prevent up to 0.5 degree of additional temperature rise by the end of the century.

Thermal performance of a pavement is defined as the change in its temperature most often surface temperature over time as influenced by properties of the paving materials.

Table 2. 1 Shows properties of the paving materials:

Albedo (Solar reflectance)	Emittance	Thermal conductivity	Specific Heat
Measure ability of a surface to reflect solar radiation. Solar reflectance ranges from 0(no sunlight reflected) to 1 (all sunlight reflected). Light colored materials have higher solar reflectance values than dark colored materials.	Defined as the ratio of energy radiates by the surface to the energy radiated by a black body (a perfect absorber and emitter). Emittance ranges from 0 (no emission) to 1 (perfect emission). Thermal emittances of	Measure the ability of a material to conduct or transmit heat. It is the ratio of heat flux. Units of W/m.K Material with a high thermal conductivity will transfer heat at a high rate than a	Is the energy needed to raise a unit mass of a substance by one unit of temperature, expressed in J/kg.K Specific heat of dense-graded asphalt and concrete are very similar about 900 J/kg.K

	concrete and asphalt are similar ranges from 0.90 to 0.95.	material having a low thermal conductivity. Thermal conductivity of pavements, concrete and asphalt varies in the ranges of 0.8 W/m.K to 2.0W/m.K or greater	

Note that albedo is the most important to how pavements, concrete and asphalt interact thermally with the environment when exposed to sunlight. Emittance, Thermal conductivity and specific heat capacity of material are in the second place or order factors. Solar reflectance of paved surfaces contributes to pavement warming and has the potential to impact the Urban Heat Island Effect in those built environments that experiences hot weather and generate a heat island.

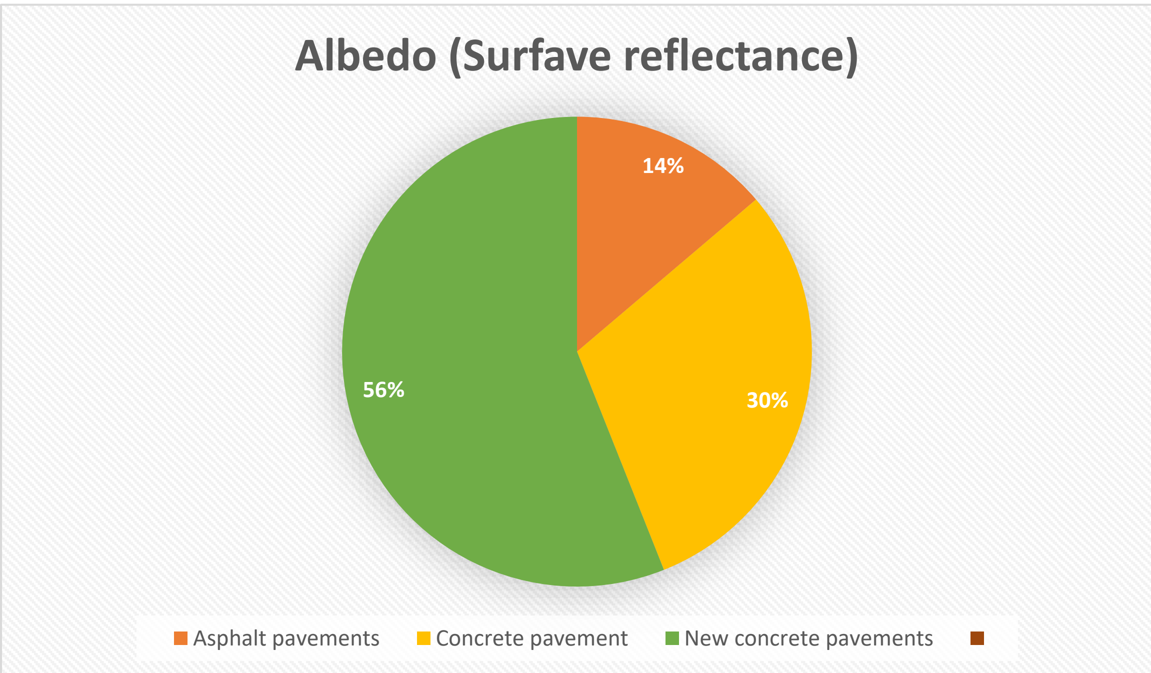

Figure 2. 1 of proportional distribution of Albedo Surface reflectance for Asphalt , Concrete and New concrete pavement.

Albedo values for asphalt ranges from 0.04 to 0.16 while values for concrete ranges from 0.18 to 0.35 and values for a newly constructed can be high than 0.65.

A black body is an idealized object which absorbs and emits all radiation frequencies. Near thermodynamic equilibrium, the emitted radiation is closely described by Planck's law and because of its dependance on temperature. Planck radiation is said to be thermal radiation, such that the higher the temperature of a body the more radiation it emits at every wavelength.

2.2.3 Urban Geometry

Spacing and dimensions of the buildings in a city influence wind flux and urban material capacity to absorb and to release solar energy. In highly developed regions, surfaces and buildings shaded by neighboring structures becomes urges thermal masses which could never release easily the heat. Cities with a number cross cutting streets and urge skyscrapers becomes urban canopy, they can obstruct natural wind flux which could naturally cool the place (EPA, 2021). The arrangement of a city can influence the way the city absorb and emit energy within the surrounding environment, City planners should take into consideration the way buildings and infrastructures are placed and provide new ways to mitigate this effect. It was seen that cities which are built in a grid like an atom in a crystalline such as New York and Chicago tend to develop more heat than cities which are built in a chaotic way like London or Boston in a disorder manner. The urban heat island is known for decades and it mainly results from the fact that the materials used to build up cities mainly concrete and asphalt can absorb heat during the day and radiate at night in contrary to areas with much vegetation. It was seen among major cities on the planet that temperatures can increase up to three degrees Celsius to night time in places like Phoenix and Arizona in US, America. This result into health problems, energy use during hot weather so more profound analysis are needed to mitigate the causes that might be caused by this effect. By the help of mathematical models, the study conducted by Physical Review Letters, they have analyzed and found out a formula to BE used by city designers in order to influence the Urban Heat Island**.** The researchers adapted formulas initially devised to describe how individual atoms in a material are affected by forces from the other atoms, and they reduced these complex sets of relationships to much simpler statistical descriptions of the relative distances of nearby buildings to each other. They then applied them to patterns of buildings determined from satellite images of 47 cities in the U.S. and other countries, ultimately ending up with a single index number for each — called the local order parameter — ranging between 0 (total disorder) and 1 (perfect crystalline structure), to provide a statistical description of the cluster of nearest neighbors of any given building. For each city, they had to collect reliable temperature data, which came from one station within the city and another

outside it but nearby, and then determine the difference. To get the order parameter, physicists have to use methods such as bombarding materials with neutrons to locate the positions of the atoms within them. But also with the use of google maps and algorithms they developed parameter from the city maps and varies between 0.5 and 0.9.
The differences in the heating effect seem to result from the way buildings reradiate heat that can then be reabsorbed by other buildings that face them directly.

2.2.4 Heat generated by human activities

Motor vehicles, air conditioners, buildings and installations emit all the heat in the urban environment. These residual heat sources or anthropogenic can contribute to the UHI effects. Urban areas are the sources carbon dioxide from anthropogenic activities such as burning for cooling and heating, from transportation, industries, etc…Increases of industries and vehicles pollutant influence the effect of UHI.

Irrespective of anthropogenic heat, low wind speeds, and air pollution in urban areas contribute to UHI formation because of two reasons:

- First, impermeable and watertight urban construction materials, moisture is not available to disseminate the sun's heat;
- Second, dark materials used in construction of roads and buildings, pavement absorb more heat energy.

Temperatures of dark surfaces may reach up to 88 degrees Celsius during the day while vegetated surfaces with moisture soil under the same conditions might reach only up to 18 degrees Celsius. Rapid urbanization leads to the development of a UHI. Oke (2014) grouped these causes into the following five categories, each of which represents change to the preurban environment brought about by urbanization:(1) anthropogenic heat;(2) air pollution;(3) surface waterproofing;(4) thermal properties of fabric;(5) surface geometry.

a) Anthropogenic heat discharge in a city also contributes to the UHI effect. Sources of anthropogenic heat include cooling and heating buildings, manufacturing, transportation, and lighting. Human and animal metabolisms are also considered sources of artificial heat. Heat from these sources warm the urban atmosphere by conduction, convection, and radiation. The contribution of anthropogenic heat to the urban energy balance is largely a function of latitude and season of the year. In a temperate city, for example, anthropogenic heat flux may be a significant component of the energy balance in winter, yet a negligible component in summer. In a polar settlement, artificial heat flux may exceed solar heating year-round.

b) Air pollution results from emissions of particulates, water vapor, and carbon dioxide from industrial, domestic, and automobile combustion processes. These atmospheric pollutants change the urban net all-wave radiation budget by reducing the incident flux of short-wave (i.e., solar) radiation, re-emitting long-wave (i.e., infrared) radiation from the urban surface downward to where it is retained by the ground, and absorbing long-wave radiation from the urban surface, effectively warming the ambient air estimated that urban-rural differences in downward long-wave radiation flux may be of the order of 10 percent, depending on the city population and the presence of heavy industry.

c) Surface waterproofing refers to the predominance of impermeable surface in urban areas. Buildings and paved streets quickly shed precipitation into catchment basins, creating an evaporation deficit in the city. Conversely, in rural areas exposed soils and natural vegetation retain water for evaporative cooling. A dry urban surface cover enhances sensible heat transfer and suppresses latent heat flux whereas moist rural surface suppress sensible heat transfer and enhance latent heat flux.

d) The fourth factor contributing to the formation of UHIs relates to the thermal properties of the urban fabric. The heat capacity, and consequently thermal inertia, of urban construction materials such as concrete and asphalt is greater than that of natural materials found in rural environments. A greater heat capacity means that urban materials absorb and retain more solar radiation than do rural soils and vegetation. Reflection of short-wave solar radiation is also affected by the properties of the urban fabric. Urban albedos are, on average, 5–10 percent lower than rural values. This contributes to the greater diurnal absorption of short-wave radiation in urban areas.

e) The complex geometry of urban surfaces influences air temperatures in two ways. First, increased friction created by a rough urban surface (as compared to a smooth rural surface) reduces horizontal airflow in the city. Mean annual wind speeds within cities are approximately 30–40 percent lower than mean annual wind speeds in the countryside. Warm air stagnates in the urban canyons unless ventilated by cool rural air. Lower wind speeds in the city also inhibits evaporative cooling. And second, the complex geometry of the urban surface changes the urban radiation budget. During the day, vertical canyon walls trap (i.e., reflect and absorb) short-wave radiation. Night-time losses of infrared energy are also retarded due to the decreased sky view factor below roof level. Rural surfaces, on the other hand, are comparatively smooth and therefore experience greater nocturnal radiative flux divergence than a complex urban surface. Anthropogenic heat is generated by human activity and comes from many sources, such as buildings, industrial processes, cars, and even people themselves. Urban centers (commercial centers) tend to have higher energy demands than surrounding areas as a result of higher production of anthropogenic heat. Though the UHI effect reduces the need for heating in the winter, this is outweighed by the increased demand for air-conditioning during the summer months, which in turn causes increased local and regional air pollution through fossil-fuel burning electric power generation. The pollution created by emissions from power generation increases absorption of radiation in the boundary layer and contributes to the creation of inversion layers. Inversion layers prevent rising air from cooling at the normal rate and slow the dispersion of pollutants produced in urban areas. To determine how much anthropogenic heat is produced in any region, all energy use (commercial, residential, industrial, and transportation) must be estimated. The sum is then divided by the region's area to enable comparisons of different cities to be made.

In developed countries where concerted action is being taken on UHIs, the main concern is on the large increase in power consumption in urban areas to cool down buildings, with additional air-conditioners or a heavier usage of existing air-conditioners. Higher air temperatures also mean that the air quality deteriorates as a result of increased ozone and pollution.

2.2.5 Geography and Weather

Meteorological conditions calms and clear entertain the UHI much higher by maximizing the quantity of solar energy reached by urban surfaces and minimizing the energy which could brought up with. Universally, winds strong winds and clouds coverture eliminate the UHI. Geometric characteristics could equally have an impact over the UHI. For instance, neighboring mountains could block the wind to reach the city or create wind models which could transverse the city (EPA, 2021) .

2.3 UHI characteristics

UHI are generally measured by taking the difference of temperature between cities with regard to surrounding regions. The temperature could vary even inside the city. Certain zone are warm than other because of unequally repartition of structures and walkways absorb heat on the other hand green lands remains cool because of trees and green spaces. The temperature difference constitutes the UHI inside the city. In the UHI, urban parks, open spaces and residential areas are cool than downtowns or city centers (EPA, 2021).

2.4 UHI effects

Surface temperatures vary more than atmospheric air during the day, but they are generally similar in the night. The ups and downs of surface temperature on inland sea show how water keep a temperature almost constant daytime and night as it doesn't absorb solar energy the same way as structures and paved areas. Open spaces, reserved areas and ponds could create cool ares within the city. Temperatures are generally low at the borders between downtown and its surrounding areas as shown in Figure 2.1.

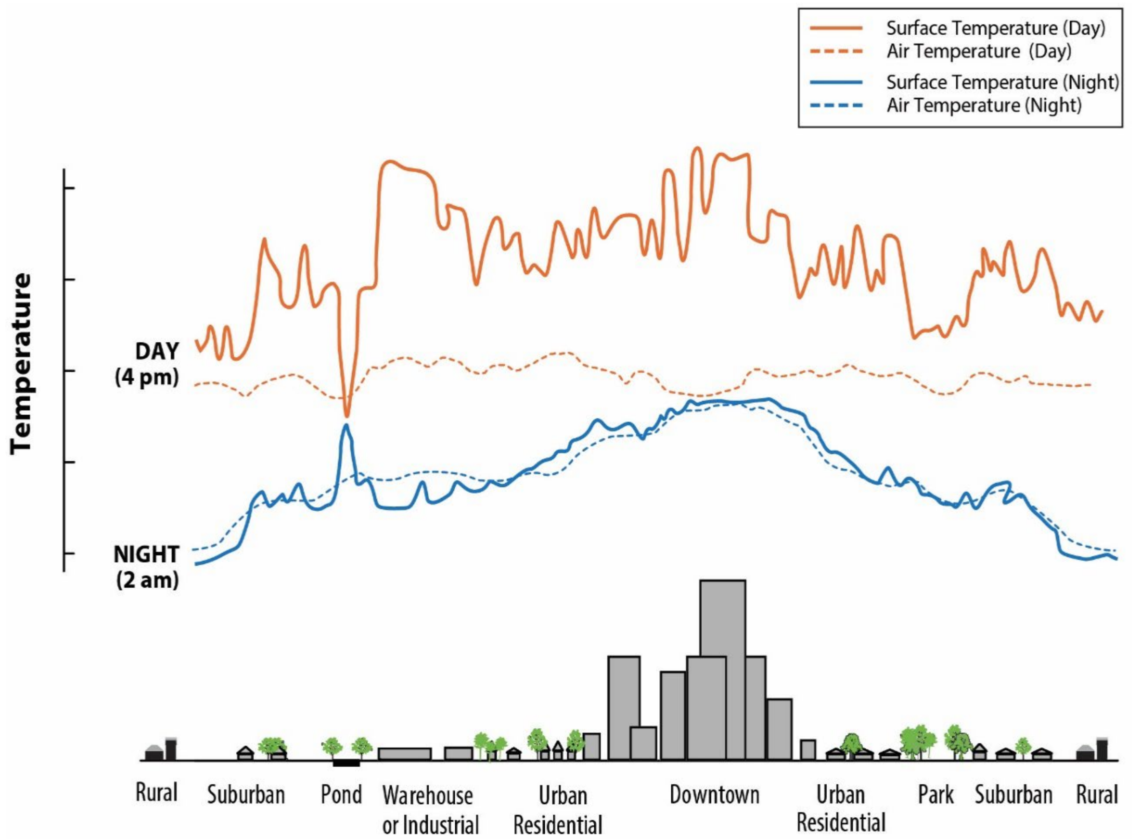

Figure 2. 2 Typical Urban Heat Island Phenomenon (EPA, 2021)

In general, temperatures are different at the surface of the earth and in the atmospheric air, higher above the city. For this reason, there are two types of heat islands: surface heat islands and atmospheric heat islands. These differ in the ways they are formed, the techniques used to identify and measure them, their impacts, and to some degree the methods available to cool them.

2.5 Surface Heat Islands.

These UHI are formed because urban surface such as roads and roofs absorb and emit solar energy in a largest extent in comparison to natural surfaces. On a warm day with a temperature of 91°F (32.8°C) conventional roofing materials may reach as high as 60°F(15.6°C) warmer than air temperatures. Surface heat islands tend to be most intense during the day when the sun is shining.

Atmospheric Heat Islands.

These heat islands form as a result of warmer air in urban areas compared to cooler air for the outside of the city. Atmospheric heat islands vary much less in intensity than surface heat islands.

2.6 Definition of some terms:

Minimum temperature: It is the lowest temperature of an area or a place in given period of time.

Maximum temperature: It is the highest temperature of an area or place in given period of time.

Average or mean temperature: It is defined as the average or mean of maximum and minimum temperature of the hottest and coldest months of the year.

2.5 Summary

After reading the related literature review, it found that remote sensing data alone could not answer to the research objectives and scope, which motivated us to combine remoted sensing data by some in situ collected data. Remote sensing data were obtained from MERRA and GIOVANNI Software and processed in Arc GIS and in situ data were obtained in Rwanda Meteorological Agency.

Chapter 3 Methodology

Generally, two types of urban heat islands are considered: the atmospheric urban heat island (AUHI) and the surface urban heat island (SUHI). Data on the AUHI are generally obtained from the analysis of in situ air temperatures from weather stations while data for the surface urban heat island (SUHI) also known as the remotely sensed urban heat island. It is observed by using thermal infrared data that allow to retrieve land surface temperatures. Usually, close relationships between the near surface air temperatures and land surface temperatures have been found. Therefore, the surface urban heat island is a reliable indicator of the atmospheric urban heat island (EPA, 2021).

3.1 Source of data and Approach

This chapter covers the methodology used to conduct the research based on data collection: both satellite (MERRA-2 and GIOVANNI, the Bridge to Data) together with on-site (in-situ). The Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2) provides data beginning in 1980. It was introduced to replace the original MERRA dataset because of the advances made in the assimilation system that enable assimilation of modern hyperspectral radiance and microwave observations, along with GPS-Radio Occultation datasets. It also uses NASA's ozone profile observations that began in late 2004. Additional advances in both the GEOS model and the GSI assimilation system are included in MERRA-2. Spatial resolution remains about the same (about 50 km in the latitudinal direction) as in MERRA.

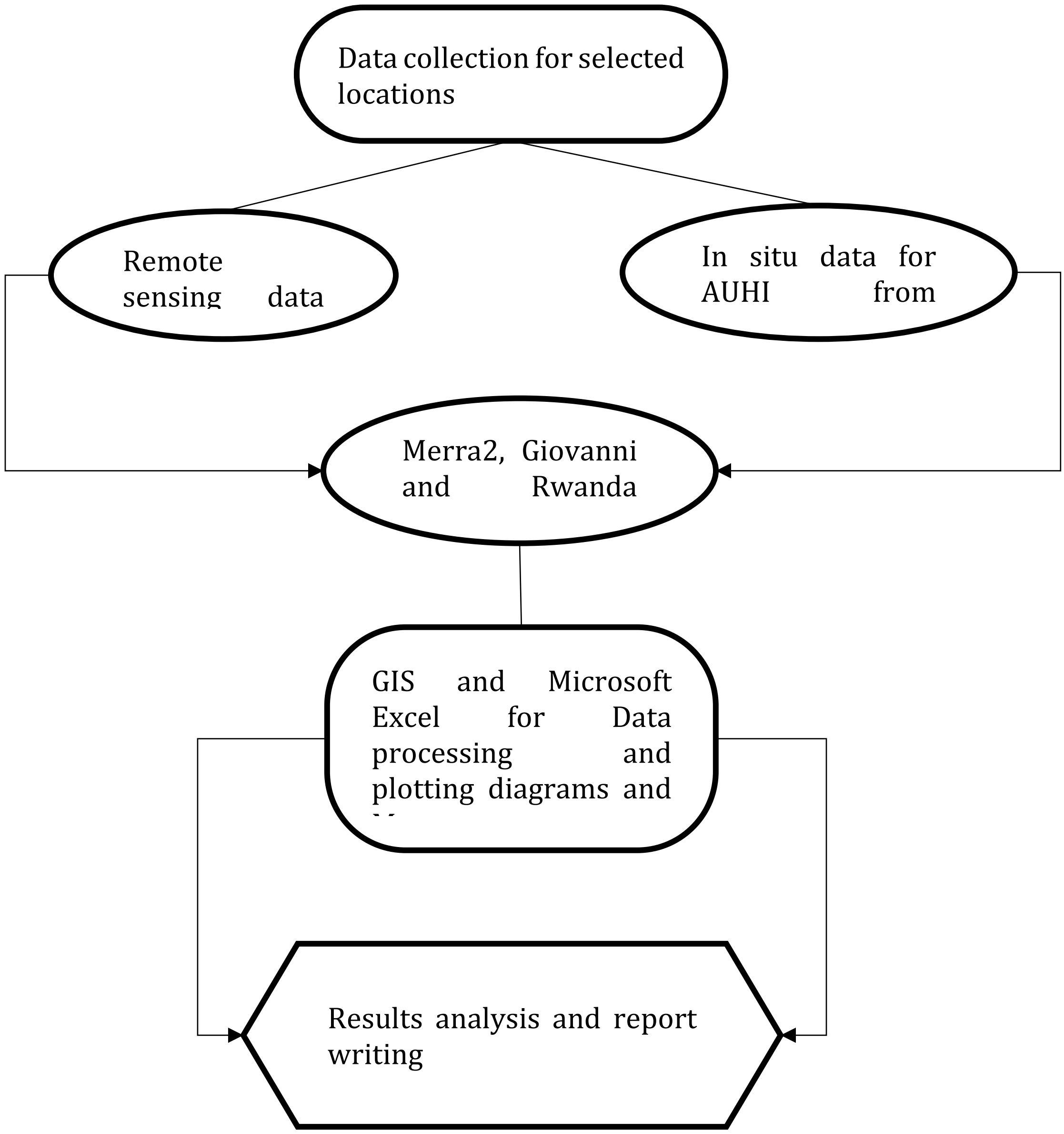

Table 3. 1 Source of Data and Approach

Giovanni stands for Goddard Interactive Online Visualization and Analysis Infrastructure: It helps to easily obtain information on the atmosphere, ocean and land around the world.

Why using Giovanni in getting the data?

First, there is no need to learn data formats to retrieve and process data.

Second, you can try various parameter combinations measured by different instrument.

Last but not least, all the statistical analysis is done via a regular web browser (NASA, 2022).

Steps to get information

Step 1: Log in and Sign in

Choose the research discipline of your interest (Aerosols, Atmosphere Chemistry, Atmospheric Dynamics, Cryosphere, Hydrology, Ocean Biology, Oceanography, Water and Energy Cycle.

For our case within the Giovanni Platform, we followed this map:

Step 2: Select Plot (Time Series, Recurring Average) Select Seasonal Dates (DJF, MAM, JJA, SON between year of 2000-2015)

Select Region (Select data by extraction -18, -35,52,40); This is the African Region.

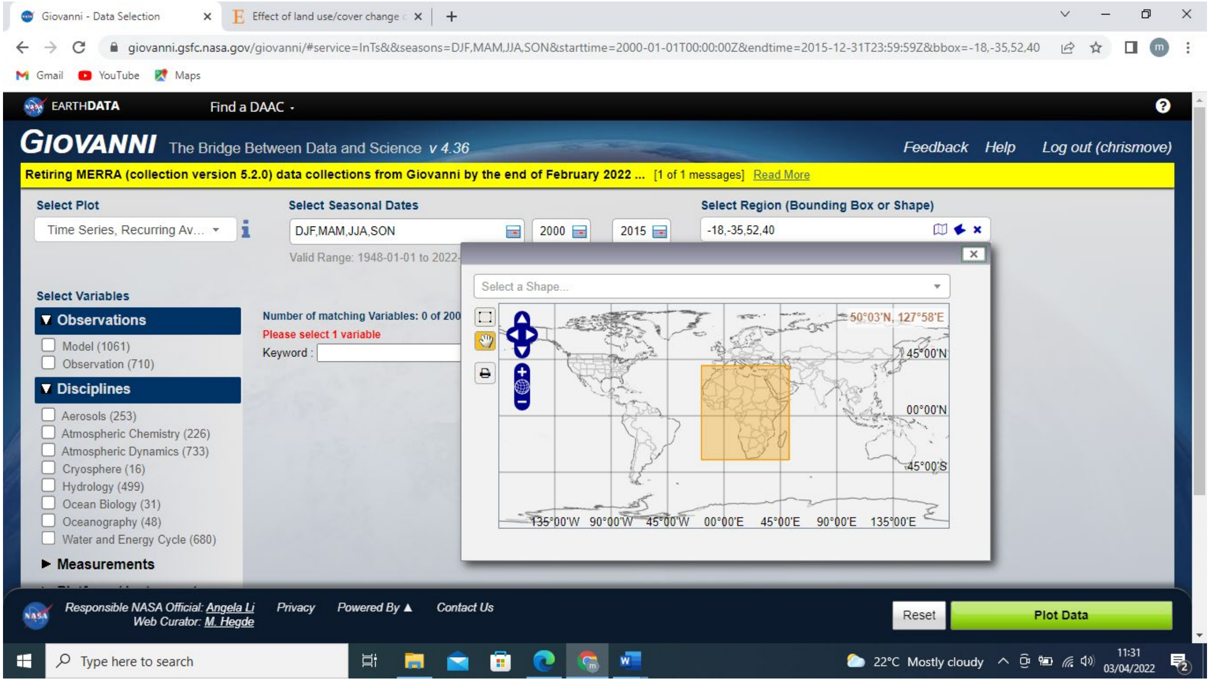

Figure 3. 1: Selected Region Data extracted between -18,-35,52,40 for Africa.

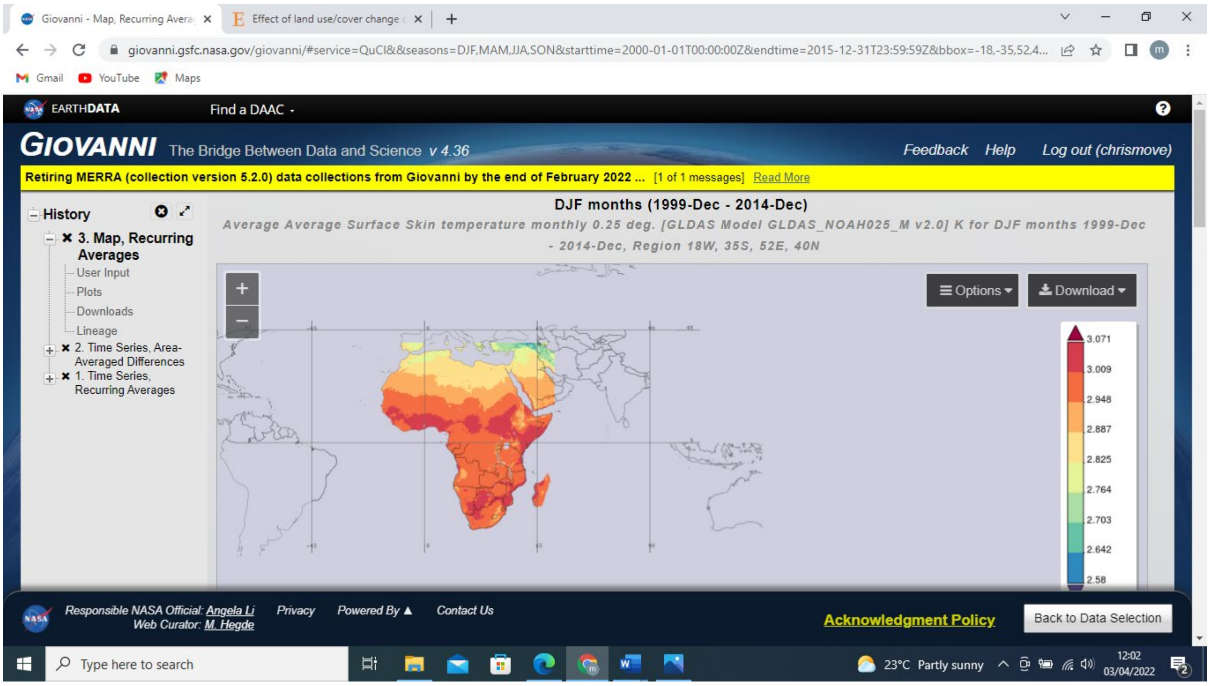

Figure 3. 2: The time average map: data from Merra 2 Model.

Step 3: After downloading as NetCDF format, The Image Processing is done using ArcGIS through the following Steps:

Copy and save in GIS data folder-> Go to Arc toolbox->Multidimensions tool->Make Net CDF to Raster layer (Input net CDF, Open Data) then Click OK.

Step 4: Next, Go to Spatial analyst tool-> Extraction by Mask (Input: Giovanni, Output: I selected all the African Countries)

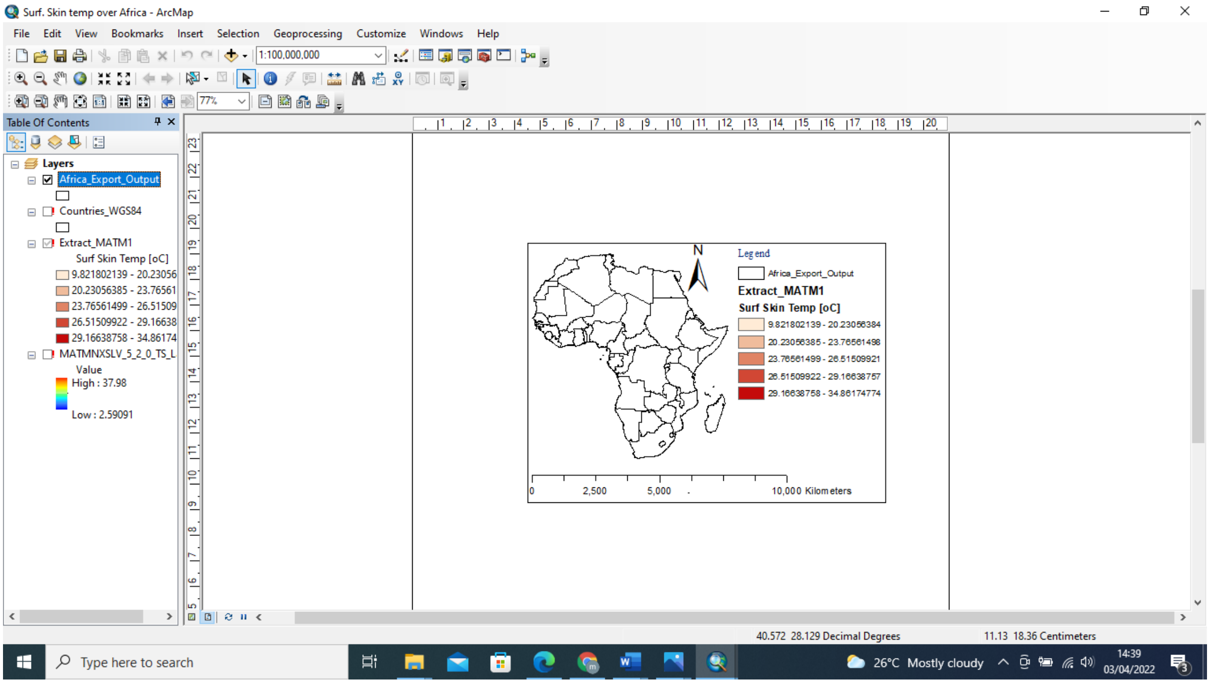

Figure 3. 3: Inserting legend, scale and saving.

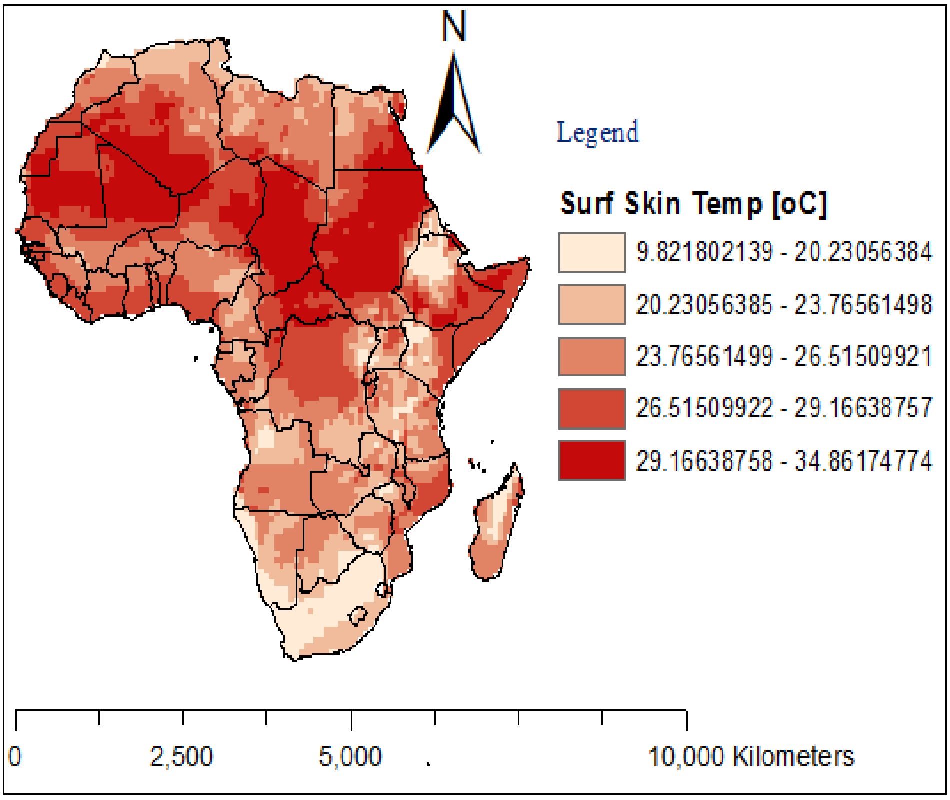

Figure 3. 4: Final Image plotted using Giovanni application and ArcMap (NASA, 2022)

3.3 On Site Data:

During the research on Site data were obtained from Rwanda Meteorology Agency (Meteo Rwanda) from meteorological stations across the country, for this research we focused on two locations. One is called Gitega which is situated in Nyarugenge District, Kigali City and another city called Rwamagana which is situated in Eastern Province of Rwanda.

3.3.1 Gitega Sector, Nyarugenge District, City of Kigali

Gitega is one of the oldest suburban places in Kigali City. It holds Kanth House Museum of Natural History Dedicated Richard Kandt, this was former home of German resident Richard Kandt on the Nyarugenge Hill in Kigali city.

Figure 3. 5:Aerial Image for Gitega city in Kigali from Google Earth and Gitega Photo

Source: https://earth.google.com/web/search/Gitega,+Kigali

Gitega Meteorology Station is situated at a Longitude of 30.06 and Latitude of -1.95. The acquired data was the maximum temperature and minimum temperature recorded from 1981 to 2017.

The average mean annual temperature was calculated and plotted in line graph as shown below:

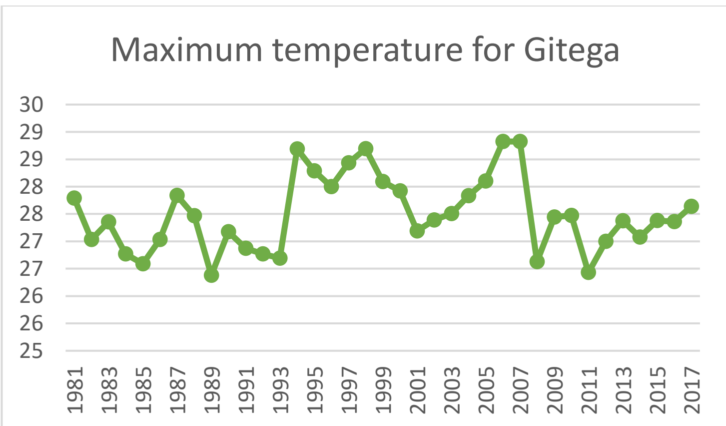

Figure 3. 6: Maximum temperature for Gitega (1981-2017)

Highest Maximum Temperature is 28.82 degrees Celsius occurred in 2006.

Lowest Maximum Temperature is 26.43 degrees Celsius occurred in 2011

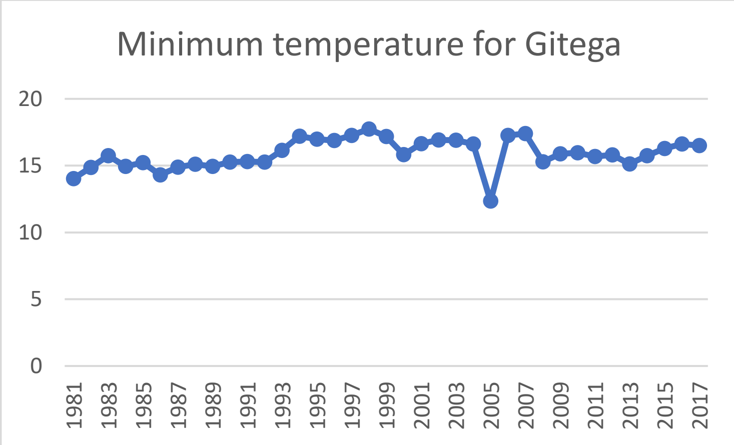

Figure 3. 7: Minimum temperature for Gitega

Highest Min. Temperature is 18 degrees Celsius occurred in 1998.

Lowest Min. Temperature is 12.34 degrees Celsius occurred in 2005.

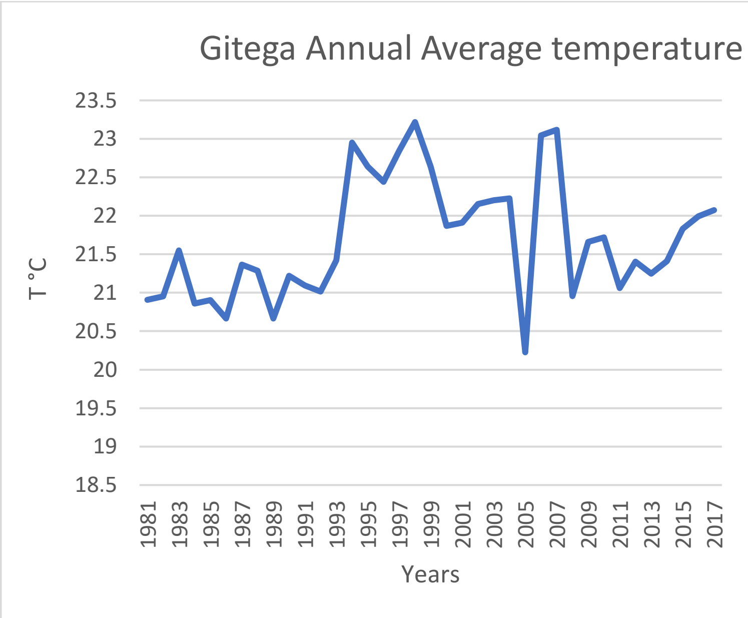

Figure 3. 8: Gitega annual average temperature

3.3.2 Rwamagana City, Eastern Province

Rwamagana is a district in Eastern Province, Rwanda. Its capital is Rwamagana city, which is also the provincial capital. Rwamagana Meteorology Station is situated at a Longitude of 30.06 and Latitude of -1.95. The acquired data was the maximum temperature and minimum temperature recorded from 1981 to 2017.

Figure 3. 9: Aerial Image for Rwamagana City in Eastern Province of Rwanda

Source: https://earth.google.com/web/search/rwamagana

Rwamagana Meteorology Station is situated at a Longitude of **30.43** and Latitude of **-1.93**. The acquired data was the maximum temperature and minimum temperature recorded from 1981 to 2017.

The average mean annual temperature was calculated and plotted in line graph as shown below:

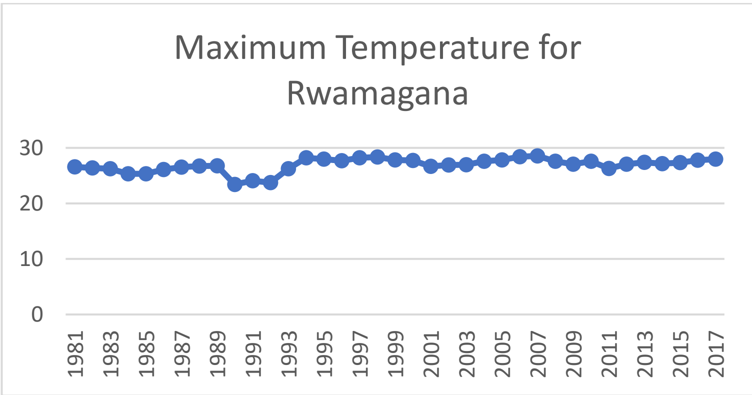

Figure 3. 10: Maximum temperature for Rwamagana (1981-2017)

Highest Max. Temperature is 28.55 degrees Celsius occurred in 2007.

Lowest Min. Temperature is 23.42 degrees Celsius occurred in 1990.

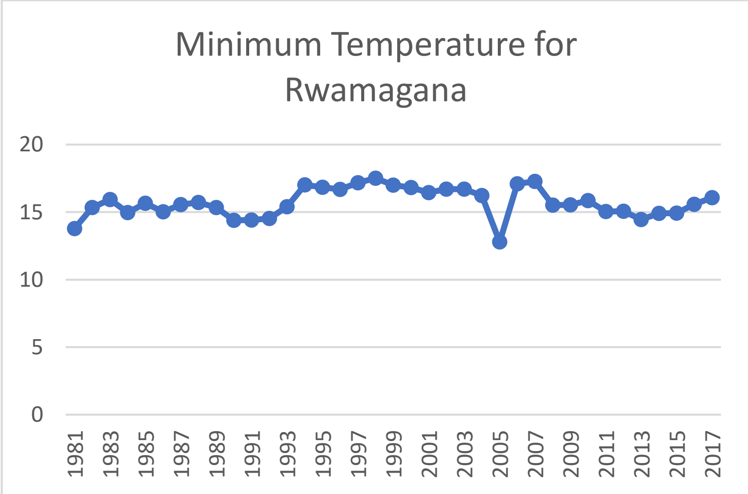

Figure 3. 11: Minimum temperature for Rwamagana (1981-2017)

Highest Minimum Temperature is 18 degrees Celsius occurred in 1998.

Lowest Minimum Temperature is 12.34 degrees Celsius occurred in 2005.

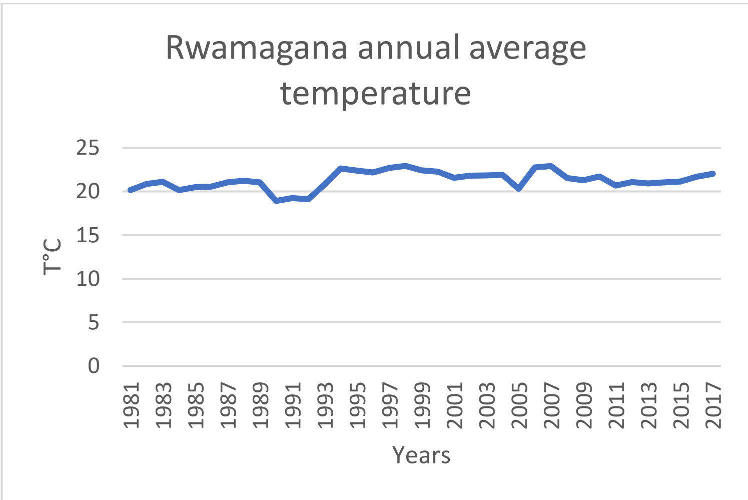

Figure 3. 12: Annual average temperature for Rwamagana (1981-2017)

3.4 Summary

In this Chapter, we used the research methodology approach to collect two types of data namely the AUHI and SUHI. The AUHI were obtained from RMA at the thermo-stations whereas SUHI were obtained from MERRA and Giovanni software. Different diagrams were drawn in excel and arc GIS to better understand and visualize the data.

Chapter 4: Results

The Figure 4. 1 below shows the change in temperatures in terms of maximum and minimum temperatures. The red one shows the maximum temperatures while the blue one shows the minimum temperatures over a 36-year period from 1981 to 2017. The figures are given in temperature degrees Celsius (°C).

Overall, it is clear that the maximum temperatures for Gitega have been in the range of 25°C and 30°C. On the other hand, the minimum temperatures for Gitega have been in the range of 10°C and 20°C covering a 36-year period.

Looking at the maximum temperatures for Gitega more closely, we can see that the highest Maximum Temperature occurred in 2006 with 28.82 degrees Celsius and the lowest Maximum Temperature occurred in 2011 with 26.43 degrees Celsius.

For the minimum temperatures for Gitega, we can see that the highest Minimum Temperature occurred in 1998 with 18 degrees Celsius and the lowest Minimum Temperature occurred in 2005 with 12.32 degrees Celsius.

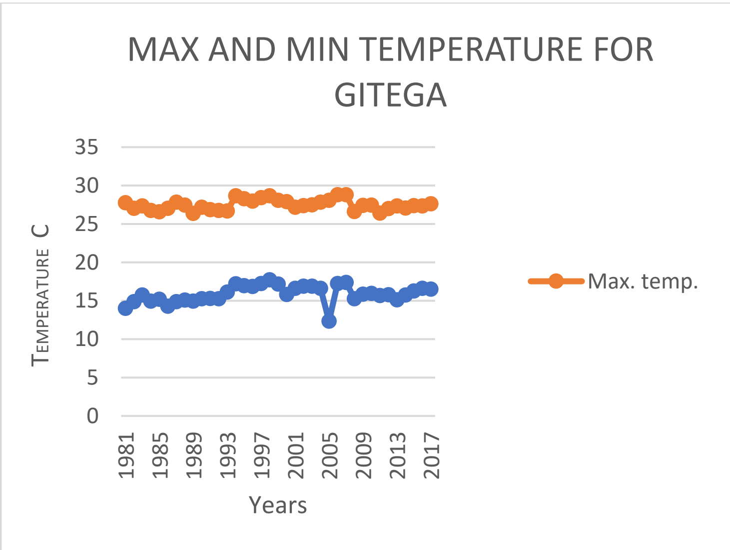

Figure 4. 2 Combined maximum and minimum temperature for Gitega

The Figure 4. 3 below shows the change in temperatures in terms of maximum and minimum temperatures. The red one shows the maximum temperatures while the blue one shows the minimum temperatures over a 36-year period from 1981 to 2017. The figures are given in temperature degrees Celsius (°C).

Overall, it is clear that the maximum temperatures for Gitega have been in the range of 25°C and 30°C. On the other hand, the minimum temperatures for Gitega have been in the range of 10°C and 20°C covering a 36-year period.

Looking at the maximum temperatures for Gitega more closely, we can see that the highest Maximum Temperature occurred in 2006 with 28.82 degrees Celsius and the lowest Maximum Temperature occurred in 2011 with 26.43 degrees Celsius.

For the minimum temperatures for Gitega, we can see that the highest Minimum Temperature occurred in 1998 with 18 degrees Celsius and the lowest Minimum Temperature occurred in 2005 with 12.32 degrees Celsius.

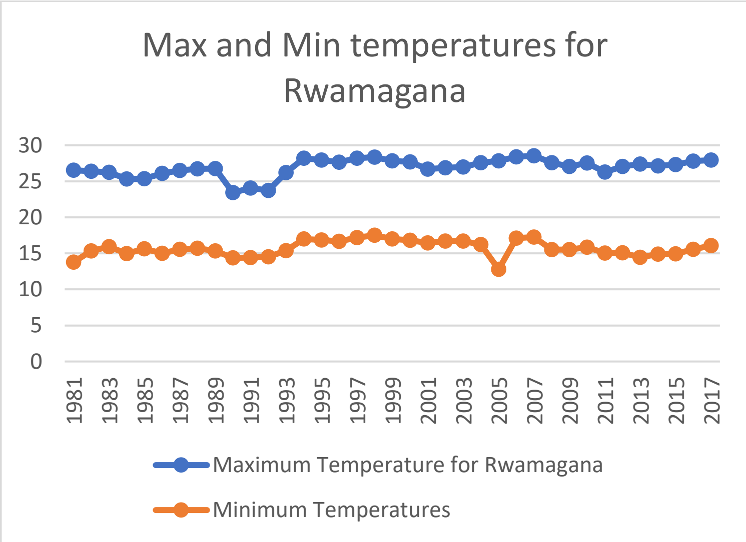

Figure 4. 4 Combined maximum and minimum temperature for Rwamagana

Figure 4.5 shows the change in temperatures in terms of maximum and minimum temperatures. The blue one shows the maximum temperatures while the red one shows the minimum temperatures over a 36-year period from 1981 to 2017. The figures are given in temperature degrees Celsius (°C).

Overall, it is clear that the maximum temperatures for Rwamagana have been in the range of 20°C and 30°C. On the other hand, the minimum temperatures for Rwamagana have been in the range of 10°C and 20°C covering a 36-year period.

Looking at the maximum temperatures for Rwamagana more closely, we can see that the highest Maximum Temperature occurred in 2007 with 28.55 degrees Celsius and the lowest Maximum Temperature occurred in 1990 with 23.42 degrees Celsius.

For the minimum temperatures for Rwamagana, we can see that the highest Minimum Temperature occurred in 1998 with 18 degrees Celsius and the lowest Minimum Temperature occurred in 2005 with 12.34 degrees Celsius.

Comparison for Gitega and Rwamagana Average annual temperatures:

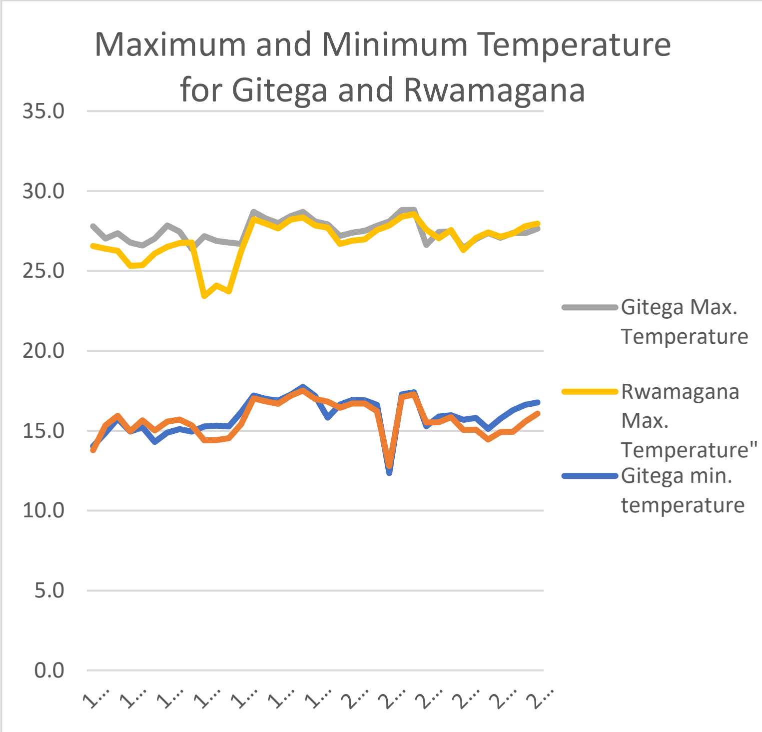

Figure 4. 6 Combined max. and min temperature for Gitega and Rwamagana

The Figure 4.7 shows combined Maximum and Minimum temperatures for Gitega and Rwamagana. The upper gray one shows the maximum temperatures for Gitega while the upper yellow one shows the maximum temperatures while the lower blue one shows the minimum temperatures for Gitega with the lower red one shows the minimum temperatures for Rwamagana all covering a 36-year period from 1981 to 2017 respectively. The figures are given in temperature degrees Celsius (°C).

If we look at the trends over time for the maximum temperatures, we can see that Gitega was higher than Rwamagana for one degree for almost 8 years from 1981 to 1989 until the two locations had almost the similar temperatures in the year of 1989. From 1989 the temperatures for Rwamagana decreased dramatically for nearly three degrees compared with Gitega until 1994. Since 1994 to 2017 the temperatures for both sites were almost similar in that period.

On the other figures for the minimum temperatures, we can see that a noticeable difference between the two trends started to be observed from 1989 to 1994 where Gitega was warmer than Rwamagana for one degree Celsius from that period up to 2010 where Gitega and Rwamagana had almost the same temperature. From 2010 up to 2017 a noticeable change occurred where Gitega was again warmer than Rwamagana for nearly one degree Celsius in the period of seven years.

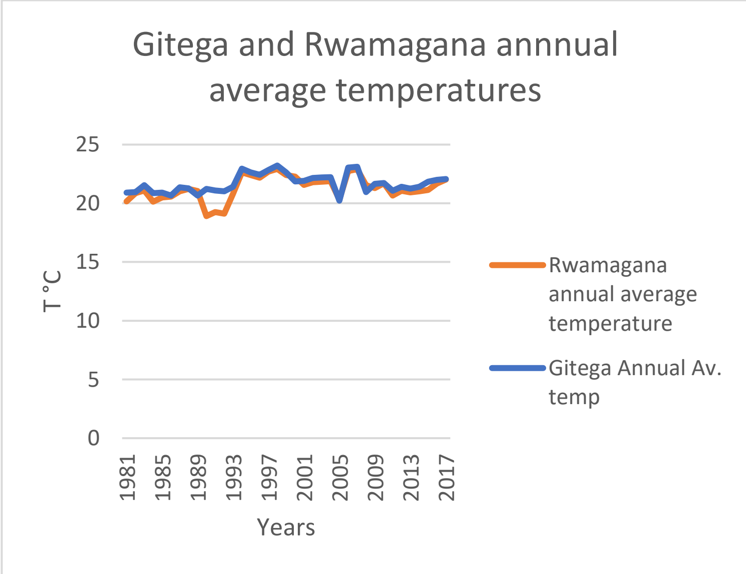

Figure 4. 8 Gitega and Rwamagana annual average temperatures (1981-2017)

The Figure 4. 9 shows combined annual average temperatures for Gitega and Rwamagana. The blue one shows the annual average temperatures for Gitega while the red one shows the annual average temperatures for Rwamagana all covering a 36-year period from 1981 to 2017 respectively. The figures are given in temperature degrees Celsius (°C).

When we analyze the trends over time for annual average the temperatures, we can see that Gitega was slightly higher in the temperature range of 0.5°C than Rwamagana for almost 8 years from 1981 to 1989 until the two locations had almost the similar temperatures in the year of 1989. From 1989 the temperatures for Rwamagana decreased dramatically for nearly three degrees compared with Gitega until 1994. From 1994 to 2017 the annual average temperatures for Gitega continues to become slightly higher than Rwamagana in that period.

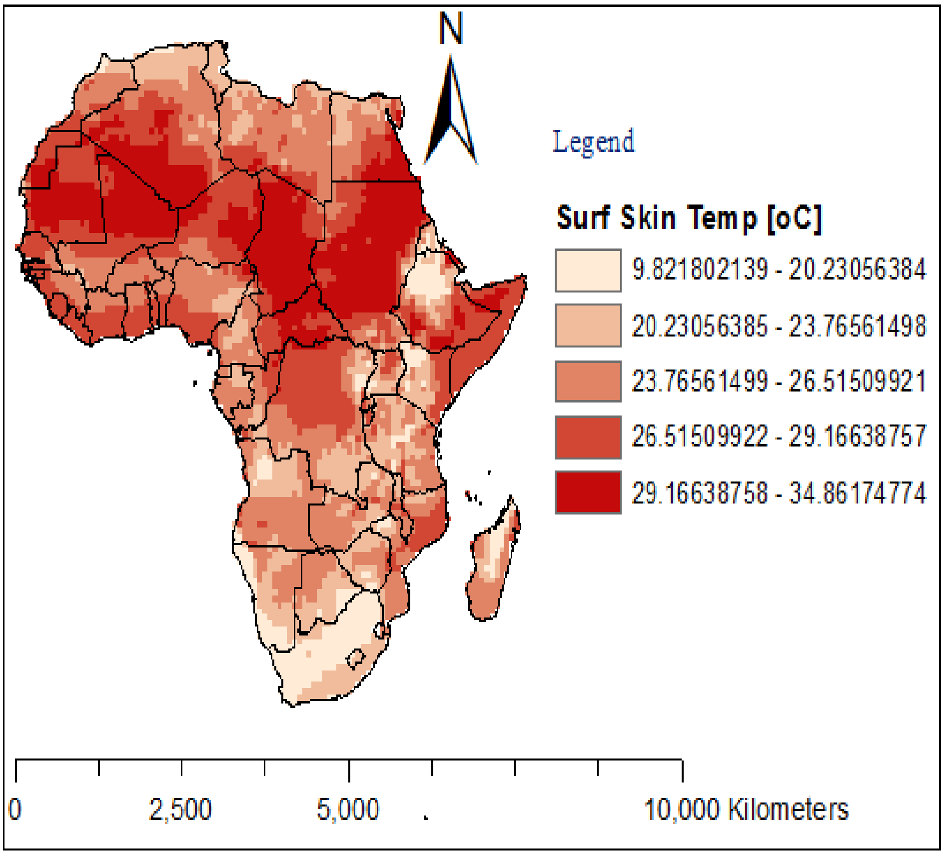

Figure 4. 10: Monthly time averaged map for the surface skin temperature (2000-2020) in Degree Celsius (NASA, 2022).

This Map shows the monthly time averaged map for the surface skin temperatures for the African Continent from 2000 to 2020. Generally, countries in the region of Sahara in the north and countries in the Central Africa tend to be warmer than countries in the south of Africa. We can see that Rwanda is in the range of 23.76 – 26.51 (°C) and 26.51 and 29.16(°C)

4.5 Summary

In this chapter, we have drawn the minimum, maximum and average mean temperatures for the two locations namely Gitega Sector and City of Rwamagana. Expectedly, we found that Gitega had (28.3°/16.3°C) whereas Rwamagana had (27.7°/16.1°C) for 36 years' period respectively. It was found the maximum temperature for Gitega sector was high of a half degree Celsius over Rwamagana area and on minimum temperature Gitega was still high of 0.2 degree Celsius than Rwamagana. In addition, a map showing the monthly time average map for the surface skin temperatures for the African Continent were drawn.

Chapter 5 Discussions

This chapter discusses the results described in chapter 4. It gives an explanation to what happened following our research objective of finding the degree at which the temperature has changed on selected cities of Gitega which located in the city center of the capital of Rwanda in City of Kigali and Rwamagana Province which is located in the Eastern Province of the country. We have also produced a map using remote sensing software called Giovanni Software and Arc Map to obtain a Monthly Time Averaged Map for the Surface Skin Temperature.

Firstly, let us analyze the data of remote sensing images with in situ data:

We have seen that there is a cohesion between data of maximum temperatures on the atmosphere of selected locations and the surface skin temperature of Rwanda obtained using remote sensing instruments. The temperatures range are between 23.76 (°C) and 29.16 (°C) as shown on the Monthly Time Averaged Map for the Surface Skin Temperature from 2000 to 2020. We have seen also that the highest Maximum Temperature occurred in Gitega in year of 2006 was 28.82 (°C) while the lowest Maximum Temperature occurred in Rwamagana in 1990 with 23.42 (°C). Figure 4.3

Secondly, it is shown that Gitega located in the city center of the capital of Rwanda in City of Kigali have had an increase in terms of minimum temperatures over Rwamagana City located in Eastern Province between the years of 2010 and 2017 where Gitega was warmer than Rwamagana for nearly one degree Celsius in the period of seven years. This may be attributed to the surface skin temperature because of urban surfaces such as roadways and rooftops absorb and emit heat to a greater extent than most natural surfaces and these features are found to be more in Gitega than in Rwamagana City: the reference is made from Figure 4.1.

Lastly, we can see that Gitega was slightly higher in the temperature range of 0.5°C than Rwamagana for almost 8 years from 1981 to 1989 until the two locations had almost the similar temperatures in the year of 1989. From 1989 the temperatures for Rwamagana decreased dramatically for nearly three degrees compared with Gitega until 1994. From 1994 to 2017 the annual average temperatures for Gitega continues to become slightly higher than Rwamagana in that period.

Chapter 6 Conclusion and Recommendations

Based on the results obtained from the data from two sources namely on situ data from Rwanda Meteo and remote sensing data from Giovanni performed on two location Gitega in City of Kigali and Rwamagana Province in Republic of Rwanda, the following conclusions were drawn:

6.1 Conclusion

After analyzing the minimum, maximum and annual average temperatures for Rwamagana City with an altitude of 1528m and Gitega Sector in Kigali City with an altitude of 1509 m we conclude that the temperature range for Rwamagana were lower than Gitega because for most .of the period between 1981 and 2017 the temperature difference was in the range of (0.3-1)°C. Due to that we cannot say it is an alarming situation but city planners should start monitoring and put in place mitigation measures for cooling developed areas. As we have seen heat islands form because urban surfaces such as roadways and rooftops absorb and emit heat to a greater extent than most natural surfaces.

6.2 Recommendation

In order to control the heat islands, following recommendation may assist such as:

Planting trees and other vegetation even though space in urban areas might be limited they have to continue integrate small green infrastructure practices into vacant lots and on streets because the deflect radiation from the sun and releasing moisture in the atmosphere.

Build green roofs; green roofs are an ideal heat island reduction strategy, providing both direct and ambient cooling effects. In addition, green roofs improve air quality by reducing the heat island effect and absorbing pollutant

Preserve identified undeveloped land and open spaces in their natural state.

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Appendices

Appendix 1: Average Maximum Temperatures for Gitega and Rwamagana

Years	Average/Mean	Gitega	Rwamagana
1981	Av.	27.8	26.6
1982	Av.	27.0	26.4
1983	Av.	27.4	26.3
1984	Av.	26.8	25.3
1985	Av.	26.6	25.3
1986	Av.	27.0	26.1
1987	Av.	27.8	26.5
1988	Av.	27.5	26.7
1989	Av.	26.4	26.8
1990	Av.	27.2	23.4
1991	Av.	26.9	24.1
1992	Av.	26.8	23.7
1993	Av.	26.7	26.2
1994	Av.	28.7	28.2
1995	Av.	28.3	28.0
1996	Av.	28.0	27.7
1997	Av.	28.4	28.2
1998	Av.	28.7	28.3
1999	Av.	28.1	27.8
2000	Av	27.9	27.7
2001	Av.	27.2	26.7
2002	Av.	27.4	26.9
2003	Av.	27.5	27.0
2004	Av.	27.8	27.6
2005	Av.	28.1	27.8
2006	Av.	28.8	28.4
2007	Av.	28.8	28.6
2008	Av.	26.6	27.6
2009	Av.	27.4	27.1

2010	Av.	27.5	27.6
2011	Av.	26.4	26.3
2012	Av.	27.0	27.1
2013	Av.	27.4	27.4
2014	Av.	27.1	27.1
2015	Av.	27.4	27.3
2016	Av.	27.4	27.8
2017	Av.	27.6	28.0

Appendix 1: Average Minimum Temperatures for Gitega and Rwamagana

Years	Average/Mean	Gitega	Rwamagana
1981	Av.	14.03	13.78
1982	Av.	14.87	15.33
1983	Av.	15.74	15.93
1984	Av.	14.95	14.96
1985	Av.	15.22	15.65
1986	Av.	14.30	15.02
1987	Av.	14.89	15.56
1988	Av.	15.10	15.71
1989	Av.	14.95	15.33
1990	Av.	15.27	14.39
1991	Av.	15.31	14.41
1992	Av.	15.26	14.53
1993	Av.	16.15	15.39
1994	Av.	17.21	17.03
1995	Av.	16.99	16.84
1996	Av.	16.88	16.69
1997	Av.	17.26	17.18
1998	Av.	17.74	17.51
1999	Av.	17.18	16.99
2000	Av	15.82	16.82
2001	Av.	16.63	16.44
2002	Av.	16.92	16.70

2003	Av.	16.90	16.70
2004	Av.	16.62	16.23
2005	Av.	12.35	12.79
2006	Av.	17.27	17.10
2007	Av.	17.41	17.27
2008	Av.	15.28	15.52
2009	Av.	15.88	15.54
2010	Av.	15.97	15.85
2011	Av.	15.69	15.04
2012	Av.	15.81	15.07
2013	Av.	15.12	14.45
2014	Av.	15.75	14.91
2015	Av.	16.28	14.93
2016	Av.	16.63	15.57
2017	Av.	16.51	16.07

:

UNIVERSITY of RWANDA

COLLEGE OF SCIENCE ANDTECHNOLOGY

Kigali, 06th January 2021

TO WHOM IT MAY CONCERN

Dear Sir/ Madam,

RE: A Reference Letter for Mr. MUVUNANGABO Christian

I am very pleased to write a reference letter for Mr. MUVUNANGABO Christian, candidate for Master's degree in Water Resources and Environmental Management with Reference Number: 215026130, at University of Rwanda/ College of Science and Technology-Kigali Campus.

In fact, Mr. MUVUNANGABO Christian is currently working on the Master's Thesis Research Module. In line with this module, students are required to conduct research, to analyze data, which will be compared with the field or lab data to possibly publish papers, and make the final dissertation.

Therefore, being the project Supervisor of Mr. MUVUNANGABO Christian, I would like to recommend him without reservation: any facilitation rendered to him will be highly appreciated.

UNIVERSITY OF RWANDA
School Of Engineering
COLLEGE OF SCIENCE AND TECHNOLOGY

Yours Sincerely,

Dr. Gerard Rushingabigwi

Lecturer