IMPACTS OF CLIMATE VARIABILITY ON MALARIA TRENDS IN RWANDA

Niyomufasha Theogene

College of Science and Technology

School of Science

Master of Science in Atmospheric and Climate Science

2018

Impacts of Climate variability on malaria trends in Rwanda

By

Theogene NIYOMUFASHA

2017290868

A dissertation submitted in partial fulfilment of the requirements for the degree of

MASTER OF SCIENCE IN ATMOSPHERIC AND CLIMATE SCIENCE

In the College of Science and Technology

Supervisor: Prof. Bonfils SAFARI

Co-Supervisor: Dr. Jean Pierre BIZIMANA

October, 2018

DECLARATION

I declare that this Dissertation is my own work except where specifically acknowledged and it has not been presented for a degree or any other award in any university.

Theogene Niyomufasha
REG NO: 217290868

Signature:

Date:

ACKNOWLEDGEMENT

I sincerely thank University of Rwanda-College of Science and Technology particularly the Physics Department for giving me the opportunity to carry out this study.
My special thanks go to my supervisor Prof Bonfils Safari and my Co-supervisor Dr. Jean-Pierre Bizimana for the constant support in terms of advice, guidance, constructive comments and time sacrificed to read through my work from the time I started till the end. May the almighty be your strength always and forever. I am also highly indebted to the lecturers in the Department of Physics (Masters of science in atmospheric and climate science) at the University of Rwanda-College of Science and Technology, Prof Bonfils Safari, Prof Ron Prinn, Prof. Umaru Garba WALI, Prof Joseph Mwalichi Ininda, Dr. Denis NDANGUZA, Dr. Omar MUNYANEZA, Dr. MAHARA I., Dr. Banzi Wellaris, Dr. Jimmy Gasore, Dr. Joshua Ngaina, among others for having contributed to the completion of my studies.

Thanks are also directed to the Director General of Rwanda Biomedical Center (RBC) who ensured that I obtained data from the Presidential Malaria Initiative (PMI) Stations. I also thank to Dr. Aimable Mbituyumuremyi the Head of Malaria and Other Parasitic Disease Division, Mr Emmanuel Hakizimana the Director of Vector Contol Unit and Alphonse Mutabazi the GIS Officer for Malaria Program for their for the constant cooperation and advice that helped me to complete my thesis. I feel greatly indebted to my classmates who support me in everything and also to my family especially my Parents, my Brother and Sisters. Lastly, glory be to the Almighty God for taking good care of me during the dangerous journeys I made in the process of writing this thesis.

ABSTRACT

In recent years malaria was observed to be global health issue in 21st century because 3.3 billion people were at risk malaria of malaria in 2010. I this year, the populations living in sub-Saharan Africa have the highest risk of acquiring malaria where 81% of cases and 91% of deaths are estimated to have occurred in the WHO African Region. The social and economic costs of malaria were also huge and include considerable costs to individuals and households as well as high costs at community and national levels where the economic burden of malaria is estimated as an average annual reduction in economic growth of 1.3% for those African countries. In Rwanda, malaria burden has significantly reduced from 2005 to 2011 due to successful implementation and scale-up of malaria control interventions. However, since 2012, malaria incidence increased every year in Rwanda from 48 per 1,000 in 2012 to 403 per 1,000 in 2016. The research is aiming at investigating the role of climatic parameters in that unusual increase of malaria morbidity in Rwanda. The study utilized malaria morbidity and meteorological data that were collected in Rwanda Biomedical Center (RBC) from 2011 to 2017 from the health centers. The collected data were analyzed using time-series analysis and Pearson's correlation analysis. Both time series analysis and statistical analysis were analysed using Python 3.6.1 and MS Excel 2013. The researcher found that among the selected climatic parameters, the results shown that malaria morbidity trend in the study area was influenced by the maximum temperature in lowlands (Busoro at 29% and Rukara at 17.9%) and minimum temperature in highlands (Bungwe). The other parameters (rainfall and relative humidity) was observed to affect malaria morbidity positively or negatively but were not the indicators of malaria morbidity trend in the surveillance period.

Adaptive strategies should be put in place in the study areas in order reduce malaria morbidity trend and also on the whole country. It is recommended also to consider the climate variability in malaria interventions because climate variability occurrences are common issue and will continue to affect the health sector in case of malaria cases and economic loss due to different malaria interventions. The further researches were also recommended on the other parameters both climatic and non-climatic to reveal their impact on malaria morbidity trend in the study sites during the same surveillance period.

KEY WORDS

- Climate Parameters
- Climate variability
- Malaria incidence
- Malaria case
- Malaria Morbidity

LIST OF ACRONYMS

ACT: Artemisinin-based Combination Therapy

DHS: Demographic and Health Survey

EIP: Extrinsic Incubation Period

GoR: Government of Rwanda

HC: Health Center

TB: Tuberculosis

HMIS: Rwanda Health Management Information System

IPCC: Intergovernmental Panel on Climate Change

IRS: Indoor Residual Spraying

ITN: Insecticide-Treated mosquito Net

LLIN: Long-Lasting Insecticidal Nets

MDGs: Millenium Development Goals

MOPDD: Malaria and Other Parasitic Disease Division

NGOs: Non-Governmental Organisation

NMCP: National Malaria Control Program

PMI: President's Malaria Initiative

RBC: Rwanda Biomedical Center

RBM: Roll Back Malaria

RDTs: Rapid Diagnostic Tests

RH: Relative Humidity

SDGs: Sustainable Development Goals

TPR: Malaria Test positivity Rate

UNDP: United Nations Development Programme

UNEP: United Nations Environment Programme

WHO: World Health Organisation

MOH: Ministry of Health

RF: Rainfall

RH: Relative Humidity

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: GENERAL INTRODUCTION

1.1 Background to the study

Malaria in early 21st century was taken worldwide as a priority global health issue [1] because an estimated 3.3 billion people were at risk of malaria. For example in 2010, the populations living in sub-Saharan Africa have the highest risk of acquiring malaria; in this year 81% of cases and 91% of deaths are estimated to have occurred in this region with children under five years of age and pregnant women being most severely affected [2]. Africa is also known as the hotspot of malaria transmission where more than 90% of malaria deaths every year occur [3]. The socio-economic burden of malaria infection in sub-Saharan Africa resulted in school children absenteeism and adults missing to their work. Malaria infection is hampering the educational achievements, causing food insecurity and opening the doors to poverty [4]**.** The social and economic costs of malaria were huge because it reduces the economic growth of African countries by 1.3% on average [5].

All those risks were due to the changing of the world we live in where the vectors that include mosquitoes, flies and bugs had new opportunities to transmit infectious diseases. The rapid unplanned urbanization, climate and environmental change, and increased global travel and trade were the main drivers of emergence or re-emergence of malaria disease [6]. According to IPCC report, is proof that much of the global warming observed over the last 50 years had led to the emergence of large-scale environmental hazards affecting human health such as the global spread of infectious diseases [7]. Malaria is a major vector-borne parasitic disease transmitted to humans by Anopheles mosquitoes. Malaria transmission cycle is a complex function of climatic factors, which non-linearly affect the development of vectors and parasites [3]. Many researchers found that the climatic parameters have been associated with transmission of malaria vectors [8] where the changes in temperature and rainfall found to extend malaria incidence risks to the cooler highland areas [9]. The changing temperature and rainfall also limit malaria transmission to the warm, humid regions of Africa especially the highlands which have been previously regarded as areas of low malaria transmission because low temperatures of highlands prevent the development of mosquitoes and parasites [10].

Malaria in East African countries is the first cause of morbidity and mortality in both children and adults. This agreed with IPCC recent climatological analysis of Eastern Africa which reveals that the region is likely to experience heightened temperatures and increased rainfall, which cause the region to be likely to the increase malaria incidences [11]**.** Malaria in Rwanda is a public health concern problem because the entire population is at risk for malaria, including an estimated 2.2 million children under five years of age and 443,000 pregnant women [12]**.** In endemic zones, malaria transmission occurs year-round with two seasonal peaks in May–June and November–December (PMI, 2016). Malaria in Rwanda has caused a significant morbidity where 7.8% of all febrile patients presenting at the health centers (HC) had malaria and 12.9% of all age mortality were malaria associated in 2010 [13].

As malaria is greatly influenced by climatic conditions, we can assume that malaria transmission increases as a result of climate variability in Rwanda highlands [14]. Many factors play role in malaria distribution and occurrence of malaria epidemics, but climate is considered to be the major determinant. Temperature, rainfall and humidity affect the breeding and survival of vector mosquitoes and the development of malaria parasites within the mosquitoes [10].

1.2 Problem statement

When the world moved from the MDGs to the Sustainable Development Goals (SDGs), the fight against malaria was continued but malaria was estimated to cause 214 million cases and 438 000 deaths in 2015. What was stranger is that most of these cases (89%) and deaths (91%) occurred in sub-Saharan Africa. This means that the progress might be accelerated to account for the bulk of that burden [15]. In countries where malaria transmission is endemic, efforts to reduce and eliminate malaria are increasingly viewed to have a high-impact on strategic investments that generate significant returns for public health and help people to alleviate poverty, to improve equity and to contribute to overall development [1]. Even though different interventions were putted in place to fight against malaria, malaria is still the major killer and was estimated to take the life of a child every 2 minutes [16].

In Rwanda, malaria was an epidemic with significant impact on the health systems and the socioeconomic of Rwandans. Nevertheless, the malaria control strategies that the GoR and partners have implemented since 2000 can be considered successful [17]. From 2005 to 2011, Rwanda achieved significant reductions in malaria burden through the successful implementation and scale-up of malaria control interventions [18]. Interventions to fight against malaria in Rwanda have resulted in small decline of malaria incidence. But this achievement is slow as local malaria transmissions remain and the risk of getting malaria infection is also explained by social and environmental factors. Due to temperature and rainfall change in Rwanda, malaria reoccurs even though, the government has put control mechanisms such use of Long-Lasting Insecticidal Nets (LLIN), indoor residual spraying (IRS) and malaria case treatment with artemisinin-based combination therapy (ACT) and have been proven to reduce malaria incident, but may not lead to malaria eradication [20].

The problem raised since 2012 where malaria incidence start to increase from 48 per 1,000 in 2012 to 403 per 1,000 in 2016. Rwanda has seen more than an 8-fold increase in reported malaria cases, from 567,407 in 2012 to 4,794,778 in 2016. Increases in malaria cases have been observed in all 30 districts but it is more intense in ten districts, primarily in the Eastern and Southern regions. The number of cases tripled in the Eastern Province (from 460,460 in 2013–2014 to 1.4 million in 2015–2016), and doubled in the Southern Province (from 554,035 in 2013–2014 to over 1.1 million in 2015– 2016). Additionally, the Demographic and Health Survey (DHS) 2014–2015 revealed an increase of malaria prevalence among children under five years of age (from 1.4% in 2010 to 2.2%) and stable prevalence among women aged 15–49 years (from 0.7 % in 2010 to 0.6%). According to preliminary analysis conducted by the Malaria and Other Parasitic Disease Division (MOPDD), the vast majority of this increase is among persons over five years of age [19].

The purpose of this research was, therefore, to investigate the impact of climatic parameters (rainfall, temperature and relative humidity) on unusual increase of malaria in Rwanda. Different measure are taken to eradicate malaria but still increasing, the study on malaria-climatic parameters trends will help the decision-makers to sort out the reliable measure for that epidemic for achieving the vision of WHO and the global malaria community which is about having a world free of malaria. Although other similar studies have been carried out elsewhere, Rwanda is unique and the studies should reflect the uniqueness.

1.3 Justification of the study

Fifteen years ago, the global leaders have identified malaria as a serious public health problem and one of the highest hindrances to global development, particularly in the poorest countries. Fifteen countries mainly in sub-Saharan Africa account for 80% of malaria cases and 78% of deaths globally [15]. A powerful and coordinated global response together with continued investment in research and development are therefore needed to eradicate malaria [1]**.**

It has been observed over the past few years in Rwanda malaria morbidity rates were increased and it is clearly observed that it is due to the fluctuations of climatic parameters like rainfall, minimum temperature, maximum temperature and relative humidity. As climate change is predicted to increase the range and intensity of malaria transmission, plans to mitigate the effects of climate change and variability are likely to include an increased commitment to controlling and eliminating malaria and vice versa. Given the association between malaria transmission and climate, long-term malaria efforts will be highly sensitive to changes and variabilities in the climate. It is expected that without mitigation – climate change and variability will increase the malaria burden in several endemic regions of the world, particularly in densely populated tropical highlands of Rwanda. This will then potentially spread the disease to areas that have already eliminated it. Substantive investments in resilience and preparation need to be undertaken as soon as possible [21].

The economic development, urbanization and deforestation are expected to contribute to changes in malaria transmission dynamics, while the projected population growth in areas where malaria risk is very high will increase the need to optimize coverage of interventions [1]**.** This study is an effort to reach goal number six of the Millennium Development Goals which was to combat HIV and AIDS, Malaria, TB and other diseases. It will also help the decision makers to set other strategies rather than the one used in previous years or to improve them. This well increase the economy of the country because it will reduce the founding used to in different malaria interventions. Then this study will reveal the impact of climatic parameters on malaria morbidity trend which is a menace to the people in the study area.

1.4 Research Questions

The study was guided by the following research questions:

i. What are trends of the selected climatic parameters and malaria morbidity in the study areas?

ii. What is the relationship between the variability of the climatic parameters and malaria morbidity in the study area?

1.5 Objectives

1.5.1 General Objective

The general objective is to investigate the impact of the variation of the selected climatic parameters (maximum temperature, minimum temperature, rainfall and relative humidity) on malaria morbidity in lowlands and highlands of Rwanda from 2011 to 2017.

1.5.2 Specific Objectives

i. To analyze the relationship between climatic parameters (maximum temperature, minimum temperature, rainfall and relative humidity) and malaria morbidity in different study sites of Rwanda.

ii. To compare the trends of climatic parameters (maximum temperature, minimum temperature, rainfall and relative humidity) and malaria morbidity in Rwanda.

1.6 Research Hypotheses

i. There is significant correlation between climatic parameters (maximum temperature, minimum temperature, rainfall and relative humidity) and malaria morbidity between 2011- 2017 in the study area.

ii. There are significant relationship between the trends of selected climatic parameters and malaria morbidity during the surveillance period.

1.7 Significance of the Study

In Malaria prevention and elimination, decision-makers need to be aware of the risk of transmission in space and time. This study will therefore provide the necessary information for Rukara HC, Busoro HC in lowlands and Bungwe HC in highlands of Rwanda.

The findings of this study could be relevant to the policy-makers and other stakeholders such as NGOs in formulating viable policies and intervention programmes to remedy the problem of malaria burden in Rwanda. Again, it was part of the nationwide campaign to control, eradicate and manage expending malaria into the highlands of Rwanda as the result of climate change and variability.

This study will also help to acquire the most current existing data for both the selected climatic parameters and malaria morbidity. Finally, due to the ever changing climatic conditions, there is need to keep track of its (climate) impact on malaria to be able to apply different strategic approaches and intervention that are specific the given situation at a particular time and place. This research has therefore, provided information on the latest situation of study area. This will help the National Malaria Control Program to achieve its ambitious goal of malaria pre-elimination nationwide and near zero malaria deaths by 2018.

1.8 Scope and limitation of the study

The study analyzed only the impacts of the climatic parameters (maximum temperature, minimum temperature, rainfall and relative humidity) on malaria morbidity. Although malaria prevalence is low in most parts of Rwanda but it is re- emerging from 2011 in Eastern and southern region of Rwanda due to a combination of climatic and non-climatic factors. However, this study focuses only on climatic influence and did not consider the non-climatic factors. It was further limited by shortage of data as the appropriate data in HMIS of RBC stats from 2011 because many malaria cases that were not reported in the system in the previous years; some incomplete data records. For this reason, collected data had to be interpolated (by linear interpolation and extrapolation) and compared for effective harmonization and fair representation. For more conclusive results, more geographical locations would have been studied; however, this was not possible due to financial and other logistical constraints such as time and duration of the study.

CHAPTER 2: CONCEPTUAL SETTING

2.1 Introduction

The climatic parameters have been found associated with transmission of vector borne diseases. In those days, meteorological data was integral part of health data and medical officers utilized meteorology for understanding the disease dynamics. After 1990, with greater awareness about climate change and its effect on human health and other sectors, scientists have started re-inventing the usefulness of climatic parameters in understanding the relationship between climate variables/climate change and health aspects including vector borne diseases as whereas malaria [8]. Malaria is the most important tropical and parasitic disease in the world [21] and it is a global health problem that causes an estimated 438,000 deaths annually where 88% of which occur in the sub-Saharan Africa [22]

From the review of various existing research, its incidents is climate-dependent and is mostly driven by three meteorological parameters: temperature; rainfall and relative humidity. The impacts of these parameters vary from one place to another as will be revealed in the foregoing literature review. This chapter reviewed literature on the relationship between the variation of meteorological parameters and malaria morbidity with particular interest to Rukara health center, Busoro health center, Bungwe health center- Rwanda.

2.2 Definition of the key concepts

- **Climate change**

Climate change refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use. Note that the United Nations Framework Convention on Climate Change (UNFCCC), in its Article 1, defines climate change as: ‘a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods’. The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition, and climate variability attributable to natural causes [23].

Causes of climate change

Anthropogenic greenhouse gas emissions have increased since the pre-industrial era, driven largely by economic and population growth, and are now higher than ever. This has led to atmospheric concentrations of carbon dioxide, methane and nitrous oxide that are unprecedented in at least the last 800,000 years. Their effects, together with those of other anthropogenic drivers, have been detected throughout the climate system and are extremely likely to have been the dominant cause of the observed warming since the mid-20th century.

Anthropogenic greenhouse gas (GHG) emissions since the pre-industrial era have driven large increases in the atmospheric concentrations of carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O). Between 1750 and 2011, cumulative anthropogenic CO2 emissions to the atmosphere were 2040 ± 310 GtCO2. About 40% of these emissions have remained in the atmosphere (880 ± 35 GtCO2); the rest was removed from the atmosphere and stored on land (in plants and soils) and in the ocean. The ocean has absorbed about 30% of the emitted anthropogenic CO2, causing ocean acidification. About half of the anthropogenic CO2 emissions between 1750 and 2011 have occurred in the last 40 years (high confidence) [24].

Impacts of climate change

In recent decades, changes in climate have caused impacts on natural and human systems on all continents and across the oceans. Impacts are due to observed climate change, irrespective of its cause, indicating the sensitivity of natural and human systems to changing climate. Evidence of observed climate change impacts is strongest and most comprehensive for natural systems. In many regions, changing precipitation or melting snow and ice are altering hydrological systems, affecting water resources in terms of quantity and quality (medium confidence). Many terrestrial, freshwater and marine species have shifted their geographic ranges, seasonal activities, migration patterns, abundances and species interactions in response to ongoing climate change (high confidence). Some impacts on human systems have also been attributed to climate change, with a major or minor contribution of climate change distinguishable from other influences. Assessment of many studies covering a wide range of regions and crops shows that negative impacts of climate change on crop yields have been more common than positive impacts (high confidence). Some impacts of ocean acidification on marine organisms have been attributed to human influence (medium confidence) [24].

- **Climate variability**

Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability) [23].

This includes changes in average weather conditions on earth, such as a change in average global temperature, as well as changes in how frequently regions experience droughts, heavy rain falls, and floods. It is important to note that changes in individual weather events will potentially contribute substantially to changes in climate.

Causes of climate variability

Climate variability varies naturally as a result of several factors: the way the ocean and the atmosphere interact with each other, changes in the earth's orbit and changes in energy received from the sun. However, there is evidence that the recent global warming is not only

- **Malaria incidence**

  Incidence is a measure of disease that allows us to determine a person's probability of being diagnosed with a disease during a given period of time. Therefore, incidence is the number of newly diagnosed cases of a disease. An incidence rate is the number of new cases of a disease divided by the number of persons at risk for the disease. If, over the course of one year, five women are diagnosed with malaria, out of a total female study population of 200 (who do not have malaria at the beginning of the study period), then we would say the incidence malaria in this population was 2,500 per 100,000 women-years of study [25].

- **Malaria prevalence:** It is a proportion of a specified population with malaria infection at one time. Prevalence, sometimes referred to as **prevalence rate**, is the proportion of persons in a population who have a malaria disease or attribute at a specified point in time or over a specified period of time. Prevalence differs from incidence in that prevalence includes all cases, both new and preexisting, in the population at the specified time, whereas incidence is limited to new cases only [26].

- **Incidence vs. prevalence**

  Incidence should not be confused with prevalence, which is the proportion of cases in the population at a given time rather than rate of occurrence of new cases. Thus, incidence conveys information about the risk of contracting the disease, whereas prevalence indicates how widespread the disease is. Prevalence is the proportion of the total number of cases to the total population and is more a measure of the burden of the disease on society with no regard to time at risk or when subjects may have been exposed to a possible risk factor. Prevalence can also be measured with respect to a specific subgroup of a population. Incidence is usually more useful than prevalence in understanding the disease etiology: for example, if the incidence rate of a disease in a population increases, then there is a risk factor that promotes the incidence.

For example, consider a disease that takes a long time to cure and was widespread in 2002 but dissipated in 2003. This disease will have both high incidence and high prevalence in 2002, but in 2003 it will have a low incidence yet will continue to have a high prevalence (because it takes a long time to cure, so the fraction of individuals that are affected remains high). In contrast, a disease that has a short duration may have a low prevalence and a high incidence. When the incidence is approximately constant for the duration of the disease, prevalence is approximately the product of disease incidence and average disease duration, so prevalence = incidence × duration. The importance of this equation is in the relation between prevalence and incidence; for example, when the incidence increases, then the prevalence must also increase. Note that this relation does not hold for age-specific prevalence and incidence, where the relation becomes more complicated [27].

- **Malaria case:** Occurrence of malaria infection in a person in whom the presence of malaria parasites in the blood has been confirmed by a diagnostic test [26].

  A suspected malaria case cannot be considered a malaria case until parasitological confirmation. A malaria case can be classified as imported, indigenous, induced, introduced, relapsing or recrudescent (depending on the origin of infection); and as symptomatic or asymptomatic. In malaria control settings, a "case" is the occurrence of confirmed malaria infection with illness or disease. In settings where malaria is actively being eliminated or has been eliminated, a "case" is the occurrence of any confirmed malaria infection with or without symptoms.

- **Population at risk:** Population living in a geographical area where locally acquired malaria cases have occurred in the past 3 years

- **Vulnerable population:** Groups of people who are particularly vulnerable to malaria infection in certain situations or contexts, such as mobile workers. Each country should define the populations that are particularly vulnerable in the epidemiological and social context.

- **Malaria Morbidity:** Morbidity is a diseased state, disability, or poor health due to malaria. The term may be used to refer to the existence of any form of disease, or to the degree that the health condition affects the patient. Among severely ill patients, the level of morbidity is often measured by ICU scoring systems. Comorbidity is the simultaneous presence of two or more medical conditions, such as schizophrenia and substance abuse.

  In epidemiology and actuarial science, the term "morbidity rate" can refer to either the incidence rate, or the prevalence of a disease or medical condition. This measure of sickness is contrasted with the mortality rate of a condition, which is the proportion of people dying during a given time interval. Morbidity rates are used in actuarial professions, such as health insurance, life insurance and long-term care insurance, to determine the correct premiums to charge to customers. Morbidity rates help insurers predict the likelihood that an insured will contract or develop any number of specified diseases [28].

- **Malaria transmission**

Malaria spreads when a mosquito infected with malaria parasites bites a noninfected human. The parasites enter that person's bloodstream and migrate to the liver. When the parasites mature, they leave the liver and infect red blood cells. Mosquitoes become infected when they feed on infected people.

- **Climate variability and malaria**

Changes in temperature, rainfall and relative humidity due to climate change are expected to directly influence malaria transmission dynamics, by modifying the behavior and geographical distribution of malaria vectors while shortening the sporogonic cycle of the parasite in the vector [30].

The combined influence of rainfall, temperature and humidity, re-grouped underneath weather (short-term) and climate (long-term) on malaria is very complex, especially for extreme weather conditions. Direct effects of climate on vector and parasite development are easy to see but indirect effects may also be important such as the effects of previous exposure (related to direct effects), nutritional status, and co-infection may help determine the disease outcome.
Just as climate is one of the determinants of malaria endemicity, climate variability is one of the main factors behind inter-annual fluctuations of malaria [31].

Because temperature and precipitation affect physiology, climate can affect species distributions. Climate and infectious diseases sometimes covary geographically and over time, suggesting that climate change should lead to changes in the geographic distribution of infectious diseases and their vectors. In some places, climate change will likely lead to increases in some infectious diseases. Many insect vectors prefer the warm, wet conditions predicted under some climate change scenarios. This alarms public health officials who rightly worry that climate change will broadly increase important infectious diseases such as malaria [32].

- **Effect of Temperature on Malaria cycle**

Plasmodium: Genus of protozoan blood parasites of vertebrates that includes the causal agents of malaria. *P. falciparum*, *P. malariae, P. ovale* and *P. vivax* cause malaria in humans. Human infection with the monkey malaria parasite *P. knowlesi* and very occasionally with other simian malaria species may occur in tropical forest areas.

Because malaria parasites complete their life cycle by alternating between the human and mosquito bodies, they are exposed to a large difference in temperature between humans and mosquitoes. However, the malaria parasites seem to be able to use this large difference for the regulation of their bionomics. Malaria parasites are exposed to high temperature in humans ranging from 37 to 41°C during febrile episodes in the patient. Although these results might suggest the positive effect of high temperature on the whole life cycle of the parasite, the lack of heat shock proteins in the sporozoite, which is the transmission form from the mosquito to the human, indicates that this crucial stage of the parasite life cycle is susceptible to deleterious effects of high temperature. When a mosquito ingests human blood with malaria parasites, the sexual forms (gametocytes) of malaria parasites undergo further development in the mosquito midgut. In a male gametocyte, the nucleus divides into four to eight nuclei, each of which forms a long ßagellum. The development of the malaria parasites in their mosquito host and that of their vector mosquitoes are gradually inhibited in temperatures far from the intrinsic optimum temperature, particularly at temperatures 23-24°C. If the present temperature in the sub-Saharan region further increases with global warming, malarial endemicity in this region should decrease because of the negative effect of high temperature [33].

2.3 Main Climatic Factors of Malaria Transmission

The main influential climatic factors of malaria transmission are rainfall, temperature and relative humidity. Below are the role of each parameter.

2.3.1 Role of Temperature on Malaria Transmission

Temperature affects the development of malaria; the parasite does not develop below 18 °C and over 40 °C. A rise in temperature can reduce the time for production of new generations and also shortens the incubation period of the parasite in mosquitoes. Sporogonic cycles take about 9 to 10 days at temperatures of 28 °C, but temperatures above 30 °C and below 16 °C have a negative impact on parasite development. The highest proportion of vectors surviving the incubation period is observed at temperatures between 28 and 32 °C. In the study done in Mozambique, the average maximum temperature recorded was 26.8 °C ranging between 22.3 and 31 °C suggesting that Chimoio is the ideal location for malaria breeding. Minimum temperature in that study was below 18 °C from week 10 to 40, coinciding with an accentuated reduction in malaria occurrence. It was found the mean temperature to be a significant predictor for malaria occurrence [34].

Different studies present empirical evidence that the key mosquito-related traits that combine to determine malaria transmission intensity (i.e., parasite infection, parasite growth and development, immature mosquito development and survival, length of the gonotrophic cycle, and adult survival) are all sensitive to daily variation in temperature. Given that certain of these traits affect transmission as quadratic or exponential terms, even small changes could have large biological significance [35]

In the study done in china both multivariate and univariate analysis by increase in the mean, minimum and maximum temperature, the incidence rate of malaria increases significantly. Also the increase of maximum temperature in one definite month had a positive effect on the incidence of that month and one month later. The relation between temperature and malaria has been studied in many studies from the tropical and semi-tropical regions of the world. The maximum and minimum temperature had the highest positive relation with monthly incidence and this relation was also seen with one month lag and 1 °C increase in minimum temperature resulted in 12 to 16% increase in incidence and minimum temperature was more effective than maximum temperature. Temperature increase, particularly minimum temperature increase in some regions increases the survival of plasmodiums and anopheles in winter and therefore results in faster transmission and distribution of malaria in populations. [36]

In Africa a model incorporating rainfall and temperature is analysed regarding malaria transmission. Results from the model suggest that the optimum temperature window for peak falciparum malaria transmission is 30–32^{o}C [37]

In the study done in east African highlands revealed that a 1^{o}C increase in minimum temperatures with a lag of 2-5 months led to an 8-95% increase in number of malaria outpatients [38].

The current study showed that temperature was positively associated with malaria incidence in Guangzhou area. They found also that relative humidity was positively associated with malaria incidence of the same month. Taken together, we have reported that weather factors had significant influence on occurrence and transmission of malaria in Guangzhou, southern China. A rise in temperature and relative humidity may increase the risk of malaria infection [39]

Furthermore, a positive correlation was observed between temperature (minimum, maximum and average) and malaria cases at different lag periods in the studied areas. If we are to optimize control efforts and develop appropriate adaptation or mitigation strategies for future climates, we need to incorporate into predictive models the effects of daily temperature variation and how that variation is altered by climate change.

2.3.2 Role of Rainfall on Malaria Transmission

Different malaria vectors use a variety of sites in which to lay their eggs (irrigation canals, tire ruts, mangrove swamps, pools, etc.) as long as the water is clean, not too shaded and, for most species, relatively still. The association between rainfall and malaria epidemics has been recognized for many decades but while increasing precipitation may increase vector populations in many circumstances by increasing available anopheles breeding sites, excessive rains may also have the opposite effect by flushing out small breeding sites, such as ditches or pools or by decreasing the temperature, which in regions of higher altitude can stop malaria transmission [31]**.**

In Senegal, the risk of malaria transmission is modulated by climate patterns, including the amount and intensity of rainfall, consistently with. Wet years are very often related to high malaria burden because rainfall promotes the multiplication of breeding sites for anopheles mosquitoes. Rainfall also affects malaria transmission in an indirect way, because it increases the relative humidity and generally decreases temperature. For all Senegal stations, there is a long dry season, so anopheles populations are rarely developed throughout this season. The rate and amount of rainfall are key factors that determine the abundance of mosquitoes and the length of the malaria transmission season for the different sites under study [40].

At species level, both P. vivax and P. falciparum showed a positive association with rainfall at different lag effects in the three districts (Rajasthan, Bikaner and Barmer) in India. The findings revealed that P. vivax is strongly associated with short lag and P. falciparum with a long lag period. [41]

In the study done in Ghana, the simulated results reveal intra- and inter-agro-ecological variability in terms of intensity and duration of malaria transmission that are predominantly controlled by rainfall [42]. The onset of rain in Mozambique occurs in mid-November. This indicates that malaria occurrence has a strong association with rainfall six to eight weeks before, coinciding, with the malaria cycle three components: (i) the growth of the Anopheles female mosquito from egg to adult to parasite transmission; (ii) the development of the Plasmodium parasites (gametocyte to sporozoites) that are able to infect humans; and (iii) the incubation period in the human host from infection to malaria symptoms. Thus malaria occurrence peak can be expected 45 to 60 days after the onset of rain. [34]. Rainfall is considered to be the predominant climatic factor and their influence on the malaria transmission is complex because it is found to have a great influence on the completion of the life cycle of the malaria parasite and it modifies the effects of temperature and increases the effects of humidity. In addition, evaporation of pools keeps relative humidity at a high level which prolongs longevity of vector mosquitoes [43].

Furthermore, results from model analysis suggest that daily rainfall in the range of 15–17mm is ideal for the spread of malaria. Perhaps the most interesting but unexpected result is that by 2040 malaria is projected to die out on the southern fringe of the disease in Africa. In other words, the result offers hope that the international goal of shrinking the malaria map may be achieved in southern Africa. [37]

2.3.3 Role of Relative humidity on Malaria Transmission

Relative humidity (RH) also plays a role in malaria episodes, and mosquitoes become more active when humidity rises. If the average monthly relative humidity is below 60%, it is believed that the life of the mosquito is so short that very little or no malaria transmission is possible. In the study done in Mozambique, the relative humidity was 72.1% and only four weeks of the year presented RH less than 60% implying that humidity does not restrict malaria occurrence in Chimoio [34].

In the study done in Iran, it was revealed that humidity plays important role in the life cycle of the mosquito because in presence of high humidity values, the parasite would complete the necessary life cycle in order to increase transmission of the infection to more humans [38]. Relative humidity seems to have an indirect effect on not only the development of parasites but also the activity and survival of anopheline mosquitoes. Relative humidity has been found to be one of the key determinants for the transmission of malaria, with low humidity observed to limit the distribution and abundance of mosquito vectors in China. According to their estimates, the minimum temperature and humidity have significant effects on malaria, with the range of relative risk from 1.02 to 1.03 on P. vivax, and from 1.04 to 1.07 on P. falciparum for a 1°C increase in minimum temperature, and from 1.02 to 1.04 on P. vivax, for a 10% increase in relative humidity [43]

The current study reveals that the relative humidity is positively associated with malaria transmission next to rainfall and temperature at different lag periods in P. vivax and P. falciparum. It is noteworthy that relative humidity plays an important role in determining the lag period in P. vivax and It indicates that relative humidity is also considered to be third significant predictor of malaria outbreak as it increases the longevity of vectors; therefore vectors gets enough time to acquire and transmit the parasite which will lead to increase in the malaria cases [41]

Unlike temperature, water can persist in the environment and can increase larval habitat as things dry out and pooling occurs. In principle, the amount of larval habitat that leads to abundance of biting vectors and higher humidity caused by rainfall leading to survival of mosquitoes should have an important effect on malaria transmission [33].

2.3.4 Role of the Non - Climatic Factors on Malaria Transmission

Different studies revealed that the malaria periodicity and outbreaks have been recognized to be associated with climate and climate fluctuations globally, but the important influence of none-climatic factors such as socio-economic, agricultural trends, level of awareness, healthcare, local habitat and vector control, etc. cannot be left behind because they infer the malaria risks in many regions. The Anthropic changes in the environment, in land use, deforestation, in hydraulic network, also induce continuous changes in the intensity of malaria transmission [31].

For example in the study done in China, they revealed that housing types could also influence malaria incidence. The open walls of bamboo-slat houses or thatched roofs are a particular problem with endophagic mosquitoes such as *A. Anthropophagus*, *A. minimus*, and *A. pseudowilmori* because they can readily go indoors and feed on inhabitants [44].

2.3.5 Role of the other Climatic Factors on Malaria Transmission

The study revealed that an increase of 1 $m.s^{-1}$ of wind speed can lead to an increase of about 164% and 171% in the monthly occurrence of malaria at 95% confidence interval in derived savanna and humid forest zone respectively. Also, an increase of 1 ºC in air temperature and sea surface temperature is associated with 53.4% and 29% increase in monthly malaria occurrence (CI: 95%) in derived savanna while an increase of 1 ºC in air temperature and sea surface temperature is associated with 56.4% and 15.4% increase in monthly malaria occurrence at 95% confidence interval in humid forest zone of Ondo State. The meteorological parameter with the highest effect on malaria occurrence in the Ondo State in Nigeria is wind speed. The association between wind speed and malaria occurrence is an interesting one, this means that the rate of speed at which mosquito will fly is very important in the transmission of malaria. The wind speed of the study area is generally low, this means that low wind speed or gentle wind is more comfortable or suitable for malaria vector (mosquito) to fly due to the nature of mosquito.

The association between sea surface temperature and reported malaria cases is indication that climatic fluctuation due to El Nino phenomenon that originating from the tropical Pacific Ocean has health implication in the study area; the reason for this could be because the study area shares a border with Gulf of Guinea in the North Atlantic Ocean. The results in the study area showed that there is also significant association between air temperature, solar radiation, mean radiant temperature, physiologically equivalent temperature and universal thermal climate index and malaria cases [45].

2.4 Malaria in the highlands

Vector-borne diseases such as malaria under warmer climatic conditions were shifted to highlands [46]. The results from the current study suggest that due to climate change endemic malaria will become an increasing problem in the African highlands. A warming trend is the likely factor driving the projected increase in malaria endemicity in the highlands, though socioeconomic factors such as land use change and drug resistance can also be attributed to increases in malaria incidences in highlands too. [37]

Malaria continues to be the number-one cause of disease and mortality in Kenya. The disease is now re-emerging in the western Kenyan highlands, which were previously malaria-free, due to a combination of climate and non-climate factors. Of the former, the combination of unusually high temperatures, rainfall and humidity are conducive to malaria epidemics [47]. In Kenya highland zone, peaks in malaria cases seems to follow the low peaks of rainfall while the declines were associated with high peaks of rainfall and decrease in maximum temperatures [22]. Without any intervention, the projected rising temperatures and changes in rainfall patterns may intensify existing malaria risks and create new ones [47].

It is, therefore, very important that each geographical area be studied independently to establish the situation at each geographical region so as to effectively apply the relevant adaptive strategies in the management of malaria.

2.5 Climate variability and Malaria Transmission in Rwanda

Mozambique, Cross-correlation analysis showed that mean temperature, and precipitation presented significantly lagged correlations with malaria cases. The Chimoio climate seems ideal for malaria occurrence. A seasonal pattern was observed in malaria occurrence in Chimoio with peaks during weeks 1 to 12 (January to March) [34].

In Senegal, Wet years are very often related to high malaria burden because rainfall promotes the multiplication of breeding sites for anopheles mosquitoes. For all Senegal stations, there is a long dry season, so anopheles populations are rarely developed throughout this season. The rate and amount of rainfall are key factors that determine the abundance of mosquitoes and the length of the malaria transmission season for the different sites under study [40]. Except for the malaria-free high areas of Rwanda, the annual occurrence of malaria illnesses shows that, local anomalies excepted, the entire country is to be classified as a risk area for at least ten months of the year, if not all year round. This means that October and November mark the onset of the malaria season, then gradually diminishing or suspending entirely between May and July [48].

2.5.1 Malaria situation in Rwanda

In recent years Rwanda has seen an increase in reported malaria cases, from an estimated 225,176 cases in 2011 to 1,598,055 in 2014 and more in 2015 as malaria parasites are difficult to handle and they ability to develop is complex.

2.5.2 Malaria and Environment

Due to temperature and rain fall change in Rwanda malaria reoccurs even though, the government has put control mechanisms such use of Long-lasting insecticidal nets (LLIN), indoor residual spraying (IRS) and malaria case treatment with artemisinin-based combination therapy (ACT) and have been proven to reduce malaria incident, but may not lead to malaria eradication.

Global environmental change is expected to increase the incidence of vector-borne diseases, especially malaria. In Rwanda due to malaria increase in its neighboring countries such as DRC

Congo, Burundi because of monthly rainfall and minimum temperatures which were the top environmental predictors for malaria risk and Uganda, Kenya and Tanzania, malaria increased due to El Niño. Malaria has increased dramatically and this is due climate change and temperature raise [49].

2.5.3 Malaria and population

The densely populated highlands and urbanised areas are biologically most susceptible to malaria. The biological susceptibility is mainly related to demographic pressure, such as a high number of children under five years of age, high number of old people, high number of child-bearing aged women, and high HIV prevalence are combined with the low immunity to exacerbate the biological susceptibility to malaria. The generic susceptibility of malaria is high in both highland and lowland areas, the biological susceptibility is generally high in highlands and urbanised areas, where malaria transmission is very low and unstable, causing a lack of immunity in local populations. The recent malaria occurrence in the highland zone may be explained by the interplay of socioeconomic factors such as population pressures, land use change, poverty, population movements and migrations, and local climate change [50].

2.5.4 Local Climate Modifications

The modification in rainfall totals during this measurement period was comparable, with a trend toward a decrease in the rainfall amount (−240 mm). It ploted a new, regional climatic division for the country based on 1996-2011 data. The manifest local climatic changes implied that Rwanda’s old, four-part climate zone scheme no longer reflects the current situation. It was replaced by a new, six-part local or regional climatic breakdown.

The “East- Rwandan dry and hot lowland zone” spreaded farther west.

In the entire climate zone (“East-Rwandan dry and hot lowland zone”), the rainfall reaches maximum values of around 900 mm and the annual average temperature is 21°C. Because of the west-moving dryness, the climatic features of the “Temperate zone of the central highlands” are shifting east and to higher elevations. Comparable with the “East-Rwandan dry and hot lowland zone”, rain- fall is evidently decreasing in these areas as well (−160 mm), while, on the other hand temperatures are increasing (+1.2 K).

The most significant modification within the temperate climate zone can be observed in the high mountainous region around Rewere. Initially defined as “Mountain climate”, in comparison with other Rwandan locations, this area registers the highest rainfall decrease and a strong temperature increase being anomalous for these altitudes. This development is similar in the high mountain regions in the country’s north as well as in the south. A markedly more temperate climate is evident on the Rift ridge and also on the Virunga volcano range. Population pressures have been growing in the recent years in these regions because of the changes in the region’s climate. On top of the generally strong population growth rate, people are migrating from the eastern, drier parts of the country to the central high- land searching of better farming conditions and food security. Due to the declining precipitation, cultivation of some agricultural products is no longer possible in parts of the "East-Rwandan hot and dry lowland zone" or only with great effort.

Rwanda's mountain climate had experienced the most far-reaching climatic changes, which used to be concentrated in the regions of the Virunga volcano chain in the north and the Nyungwe mountain rain forest in the south. This simple division can no longer be maintained in light of the current data. In fact the local climates of the two regions must be demarcated from each other. While the area in southern Rwanda, especially around the Nyungwe rainforest, exhibits modest temperature changes (+0.5 K) and continues to register rainfall amount of >1400 mm, around the Virunga volcanos the temperature ranges about 2 K higher while total rainfall has clearly dropped (−250 mm). This calls for a new division of the Rwandan "Mountain climate" into the "South-Rwandan humid mountain climate" and the "North-Rwandan dry mountain climate".

Nearly unchanged physically as a regional climate zone is the area along Lake Kivu. The locale climate peculiarity arising from the prevailing land-lake-wind circulation continues to cause climatic conditions that remain roughly the same, with slightly rising temperatures (+0.5 K) and a decrease in rainfall of about 50 mm.

2.5.5 Local Malaria Modifications

Along with rising temperatures throughout the country the risk that the anopheles mosquito will spread as a function of temperature and rainfall grows as well. This may result in a higher risk for transmission of the infectious disease malaria. For a highland country like Rwanda, where many parts of the country fell below the epidemiological relevant line in the past, a rise in temperatures may now lead to the increased probability of malaria transmission. Especially in areas, in which malaria hardly appeared, chances are that the trend will be especially pronounced, because the population's immunity in this area is limited. However, it is not only the temperature that regulates which space the anopheles mosquito occupies, but also the presence of rain. Vectors like the anopheles mosquito spend part of their life cycle in water habitats. Hence, their range also strongly depends on hydrological changes. An expansion of the population is adapted to the change from rainy to dry seasons with the decisive criterion for the insect's development being the intertwining of the wet phase's duration with the intervening dry period. On the one hand, high humidity values stimulate the vector dynamic or the metabolic system of the anopheles mosquito. On the other hand, a lasting dry spell or low humidity clearly raises their bite frequency. Since an analysis of Rwanda‘s climate measurement series can demonstrate both an increase in dry phases but also noticeable more intense, heavy rains during recent decades, we could also expect more frequent outbreaks of water- and vector-borne diseases. In addition, wet paddy rice cultivation in many parts of the country no doubt is a factor not to be ignored in the anopheles mosquito's spread.

What emerges from the vector-induced illnesses is that there were two areas in Rwanda being described as endemic where the probability to be infected was >70%: the tropical wet southwest border area with the Democratic Republic of Congo in the Bugarama Rift Country and the south-eastern area bordering Burundi on Lake Rweru. The latter was discarded as not significant due to the extremely low population density of the area. Furthermore, a uniform picture emerges of the almost malaria-free area between the Virunga volcano chain in the north, the western Central Highlands up to Lake Kivu and the Nyungwe rainforest in the south. The eastern Central Highlands between Butare and Gitarama and the area east of Kigali present a minimal risk of malaria (5% to 15%). Akagera's risk is also at 15%. Solely, the capital Kigali exhibits a 30% higher reading. However, this is not necessarily due to local climatic changes in this area, but also especially owing to the fact that this area exhibits the highest population density in the country [48]. The health of people in the most vulnerable district will not improve unless poverty and expanding inequality are reduced and this includes the effort to control malaria on a large scale. But nothing can be accomplished without positioning the problem in social and cultural contexts of Rwanda. Increasing the community resilience in terms of bed net provision, housing improvement, poverty reduction and access to health care facilities and treatment can be seen as a promising approach for policy makers to be proactive towards malaria in the most vulnerable districts. Besides, improved land-use planning and environmental management can reduce community susceptibility to malaria in Rwandan highlands [51]

2.6 Conceptual Framework

Based on the above literature, it clear that each area should be studied to establish which of the elements is responsible for the variation. This study will therefore determine what happens in Rwanda. The researcher developed the conceptual framework below to give a better understanding of the relationship between climate variation and malaria morbidity. In considering climate, we paid attention to three major components that determine climate: rainfall, temperature and relative humidity. These three are dynamic and their variation influences the prevalence of malaria in many ways. As has been observed from the conceptual setting, rainfall is basically responsible for the provision of the larval habitat through the water that remains stagnant after the rain has fallen. Temperature of between 15^0C and 30^0C is optimal in improving the mosquito's rate of digestion, feeding frequency (biting rate), reproductive rate and sporogeny. Humidity on the other hand ensures longevity. Variability in these elements is, therefore, responsible for variability in the mosquitoes' population which in turn determines the biting frequency and therefore, the spread of malaria. However, this study focus only on the climatic influence and did not consider the non-climatic factors.

CHAPTER 3: METHODOLOGY

3.1 Introduction

This chapter focused on the steps to be followed for achieving the research objectives of the study. They included: the study area, the research design, target population, sample and the sampling techniques, the data collection and data analysis.

3.2 Study Area

Rwanda is a small (26,338 km^2), land-locked country in the Great Lakes region of Eastern Africa, bordered by Uganda, Burundi, the Democratic Republic of the Congo, and Tanzania. It has a population of approximately 12 million people (projection from 2012 census results), making it the most densely populated country in continental Africa. Administratively, the country is made up of 30 districts, which are divided into sectors, cells. The entire population is at risk for malaria, including an estimated 1.8 million children under five years of age (14.6% of the population) and 443,000 pregnant women/year (30.2% standardized birth rate; projections based on 2012 census results) [4]. The annual average temperature of Rwanda is about 18^{o}C, the maximum temperature being around 25˚C and the minimum being about 13˚C and there are two rainy seasons, March-May (MAM) and September-December (SOND) with an annual average rainfall of about 1,295 mm. The highest monthly average rainfall observed in April is about 157mm**.** Rukara HC with average altitude of 1600m, Busoro HC with average altitude of 1400m for lowlands and Bungwe HC with average altitude of 2300m for highlands of Rwanda have been selected for study.

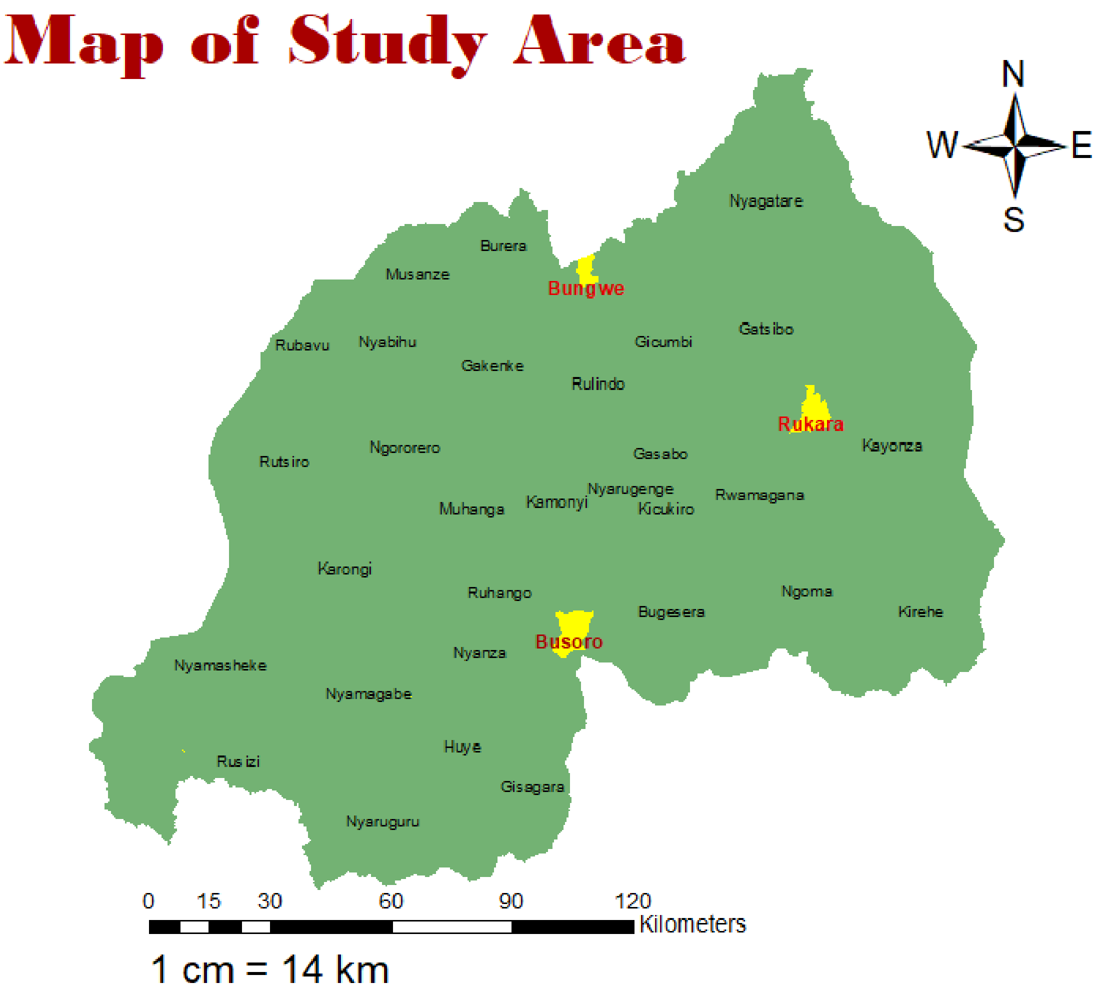

FIGURE 3 1: MAP OF STUDY AREA (RWANDA)

3.3 Research Design

The study used the case study design to investigate the relationship between climate variability and malaria morbidity trend in Rukara-Kayonza district, Busoro-Nyanza district and Bungwe-Burera district. Malaria data and climate data (rainfall, temperature and relative humidity) records were obtained from Rwanda Biomedical Center (RBC) in Rwanda. Both were obtained for 7 years from 2011 up to 2017. After processing, Pearson's product moment correlation coefficient were used to establish variations within the years while patterns and trends were shown on graphs. The results of climate data and malaria morbidity were then compared, discussed and summarized

3.4 Target Population

The target population was the at-risk population which is the entire Rwanda population which consisted of 12 million people (projection from 2012 census results).

3.5 Sampling Procedure

The study sites were chosen based on the topography of the country and they are enough representative to the whole country. Malaria was influenced by climatic factors both in lowlands and in highlands, this study look on those parameters in order to know clearly the impacts of climatic parameters on malaria morbidity. The study site were chosen because of availability of both meteorological and malaria data corrected at the same site in the same condition on Presidential Malaria Initiative (PMI) stations where they record both Malaria and meteorological parameters. Those sites also were not spared in Indoor Residual Spraying (IRS) programmes.

This study utilized data on malaria morbidity from three health center two in lowland of Rwanda and one in highland of Rwanda with respect to the local topography across by considering 7 years from 2011 to 2017 and the period is chosen due to availability of data both Malaria and meteorological data in HMIS of RBC. This means that all the malaria morbidity cases recorded in the health facilities in the study area gave a flooded sample for the study. In terms of climate variability data from Presidential Malaria Initiative (PMI) meteorological station collected in Rwanda Biomedical Center (RBC) were conveniently selected and climatically representative enough for the study site.

3.6 Types, Sources and Methods of Data Collection

The study utilized unpublished secondary data in report format on malaria morbidity from the health centers in study area. The data were obtained from the individual health centers – Rukara Health Centre, Busoro Health Centre and Bungwe Health Centre where monthly data for the mentioned health centers in the study area were collected on monthly basis. Since all these facilities operated on out- patient basis, they were not report malaria data for December in 2015 and 2016 in HMIS of RBC. Malaria morbidity data combined both clinical and confirmed cases. Almost all the facilities save for the study site were managed by nurses and community health workers who were not qualified enough to handle serious clinical matters. It was difficult to categorize data in terms of gender and age because most of the facilities combined them and those that separated did not do so for the whole surveillance period. Records taken were harmonized and used. Climate data on the other hand included: mean monthly relative humidity, total monthly rainfall, average monthly minimum temperature, average monthly maximum temperature and average monthly relative humidity obtained from Presidential Malaria Initiative (PMI) meteorological station given by Rwanda Biomedical Center (RBC). For both Malaria and climate, the data were collected via desk top review of records to acquire both monthly and yearly entries.

3.6.1 Data collection

Records of total monthly malaria cases in respect of above referred three health centers from January2011–December 2017 were procured from Rwanda Biomedical Center (RBC), Kigali. The monthly data of mean minimum and maximum temperature (°C), average monthly relative humidity and average monthly rainfall also were corrected from the Rwanda Biomedical Center (RBC), Pune for the same above period.

3.6.2 Data analysis

A time-series analysis was conducted for data on monthly climatic variables and monthly malaria morbidity basis for the period 2011–2017.

The data was analysed using time-series analysis and Pearson's correlation analysis. Time series analysis accounts for the fact that data points taken over time may have an internal structure (such as autocorrelation, trend or seasonal variation) that should be accounted for. Time series analysis is a statistical technique that deals with time series data, or trend analysis. Time series data means that data is in a series of particular time periods or intervals and Correlation is a technique for investigating the relationship between two quantitative, continuous variables, for example, Malaria and Rainfall. Pearson's correlation coefficient (r) is a measure of the strength of the association between the two variables. Pearson's correlation coefficient(r) for continuous (interval level) data ranges from-1 to +1. Positive correlation indicates that both variables increase or decrease together and it is a strong relationship when it is equal to +1, whereas negative correlation indicates that one variable increases, so the other decreases, and vice versa and it is a strong relationship when it is equal to -1. One of the most commonly used Pearson's correlation coefficient formula is $r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}}$ [52]. The monthly cases of malaria was treated as the dependent variable and the meteorological parameters such as monthly mean temperature (minimum, maximum and average), monthly total rainfall and monthly mean relative humidity as independent variables. Missing data values of independent variables were interpolated by linear interpolation. Pearson correlation analysis was conducted to examine the strength of the relationship between meteorological variables and malaria cases and also it is used to observe the independent impact of each independent variable on the outcome. Both time series analysis and statistical analysis were analysed using Python 3.6.1 and MS Excel 2013.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Introduction

This chapter discusses the results of different analysis done on the data collected from the study sites. It begins by comparing the malaria morbidity at different study sites, then goes to an overview of the kind of relationship that exists between each climatic parameters and malaria morbidity, followed by the comparison of trends of malaria morbidity and selected climatic parameters. The chapter ends by discussing on indicators of malaria trend in the study sites.

4. 2 Comparing Malaria Morbidity for different study sites during 2011-2017

In this study, we explored the dynamics of the evolution of malaria incidence over time in the selected study sites. The figure 4.1 presents the space-time evolution of malaria incidence over time in the study areas. The results suggest that malaria risk increased significantly over time in lowlands than in highlands during the study period. From table 4.1 malaria morbidity was fund to be highest in Busoro- Nyanza district (total malaria cases of 50904 in 2017), followed by Rukara-Kayonza district (total malaria cases of 38576 in 2017) and lowest in Bungwe-Burera district (total malaria cases of 242 in 2014) over the entire study period. It is clear that malaria morbidity in the surveillance period increase with the decrease of altitude and increases also with time.

4. 3 Comparing Climatic Parameters for different study sites during 2011-2017

Table 4.2 presents summary statistics for the maximum temperature, minimum temperature, rainfall and relative humidity. In Busoro is where the highest monthly total rainfall was recorded (112.42mm) and the lowest average monthly rainfall in the study regions was recorded in Rukara (84.76mm). The highest average monthly relative humidity was recorded in Bungwe (72.12%) and the lowest one was recorded in Busoro (61.14%). The average monthly maximum temperature was highest in Busoro (26.67 °C) and lowest in Bungwe (20.10°C) and finally, the highest average monthly minimum temperature was recorded in Rukara (15.09°C) and the lowest in Busoro (11.99°C) during the surveillance period.

4.4 Relationship between the Variability of Climatic Parameters and Malaria Morbidity

4.4.1 Case of Busoro

Table 4.3 and Figure 4.1 presents correlations between all selected climatic variables and malaria that we are considering in this study for Busoro-Nyanza district site. In the table 3 and figure 3, the results suggest that malaria morbidity was most highly correlated with maximum temperature (r=0.54) with a significance value (P=1.28533123488e-07) and a small positive correlation with rainfall (r=0.066) but witch is insignificant. There was a negative correlation between malaria and relative humidity (r=-0.42) with a significant level (P=6.36065596056e-05) because when the temperature increase the relative humidity decreases and a very small negative correlation with minimum temperature (r=-0.071). Therefore, it is clear that malaria morbidity is directly influenced by the maximum temperature among the selected parameters and the other parameters like rainfall contribute indirectly on malaria incidence because are insignificant in Busoro study site.

4.4.2 Case of Bungwe

Bungwe-Burera district, table 4.4 and figure 4.3 present correlations between all selected climatic variables and malaria that we are considering in this research study. The results in the table and figure above suggest that malaria incidence was positively correlated with minimum temperature (r=0.24) with a significant level (P=0.0279161365366). There was a negative correlation between malaria and rainfall (r=-0.29) witch are significant with significant level (P=0.00681241799657) and a very small negative correlation with maximum temperature (r=-0.072) and relative humidity (r=-0.057). Therefore, it is clear from the results that malaria morbidity was positively influenced by minimum temperature among the selected parameters and rainfall was negatively influence the malaria morbidity because the increase in rainfall destroy the breeding sites for mosquitoes. The other parameters like maximum temperature and relative humidity can affect malaria morbidity but insignificantly for this study site.

4.4.3 Case of Rukara

Table 4.4 presents correlations between all selected climatic variables and malaria that we are considering in this study for the case of Rukara-Kayonza district study site. In the table 4.5 and figure 4.4, the results suggest that malaria incidence was correlated with maximum temperature (r=0.38) with a significance level (P=0.00032000924969). There was a positive correlation with minimum temperature with a correlation coefficient r=0.175 but it was not significant (P=0.111510247075). There was a weak negative correlation between malaria and relative humidity (r=-0.155) and a very small negative correlation with rainfall of correlation coefficient r=-0.035. Therefore, it is clear that malaria morbidity was positively influenced by maximum temperature among the selected parameters and the remaining parameters could indirectly influence the malaria morbidity in Rukara study site.

4.5 Comparison between Malaria Morbidity and Selected Climatic Parameters Trends

4.5.1 Trends of Malaria Morbidity and Maximum Temperature (Busoro)

From the Figure 4.5, maximum temperature trend in the seven years of study period was positive (y=0.0361x+25.134). This means maximum increased at the rate of 3.61% per month during the study period (2011-2017). With the co-efficient of determination of R^2=0.5036, this time accounted for 50.36% of the changes in the spatio-temporal maximum temperature observed. During this period also, the overall monthly malaria morbidity in this area showed an increase in trend. It grew at the rate of 52.087% per month. The co-efficient of determination of R^2=0.5433 implies that the period (2011-2017) accounted for 54.33% of the temporal variation in malaria morbidity observed. Correlating morbidity against the years, the researcher found that r-value is equal to 0.74. From that observation, morbidity had a significantly positive trend.

From the above observations, both maximum temperature and malaria morbidity had positive trends and they had the significant trends. It was also noted that even an increase in maximum temperature can significantly increase malaria occurrence. The other studies showed that malaria incidence had a positive relation with mean maximum temperature and one 1°C increase in temperature was associated with 17.7% increases in malaria incidence after 3 week and in the same week [36]. Therefore, we can confidently said that the positive trend of maximum temperature explains the positive trend in malaria during the study period. This also predicts the future of malaria in relation to the changing climate.

4.5.2 Trends of Minimum Temperature and Malaria Morbidity (Busoro)

The figure 4.6 shown that minimum temperature trend in the seven years of study period was negative (y=-0.0049x+12.204), it means minimum temperature decreased at the rate of 0.49% per month during the surveillance period (2011-2017). The co-efficient of determination of R^2=0.0306, this time accounted for 3.06% of the changes in the spatio-temporal minimum temperature results recorded. It is clear that its trend was not significant. During this period of seven years, the overall mean malaria morbidity in this area showed an increase in trend. It grew at the rate of 52.087% per month. The co-efficient of determination of R^2=0.5433 implies that the period (2011-2017) accounted for 54.33% of the temporal variation in malaria morbidity observed. Correlating morbidity against the years, we found that r-value of 0.74. From the observation, morbidity had a significantly positive trend.

In comparing the two trends, it can be observed that while malaria morbidity had a significantly positive trend, minimum temperature had an insignificant negative trends one. This means that minimum temperature did not positively promotes malaria morbidity trend in the study period. The small decrease in minimum temperature correspond to a large increase of malaria in the study area, there could be other factors rather than minimum temperature that are responsible to the increase of malaria trend over the study period.

4.5.3 Trends of Relative Humidity and Malaria Morbidity (Busoro)

The figure 4.7 shown that relative humidity trend in the seven years of study period was negative (y=-0.1244x+66.428), this means relative humidity decreased at the rate of 12.44% per month during the surveillance period (2011-2017). It had the co-efficient of determination of R^2=0.3942 and this time accounted for 39.42% of the changes in the spatio-temporal relative humidity results observed. It is clear that this trend was negatively significant. During this period also, the overall monthly malaria morbidity in this area showed an increase in trend. It grew at the rate of 52.087% per month. The co-efficient of determination of R^2=0.5433 implies that the period (2011-2017) accounted for 54.33% of the temporal variation in malaria morbidity observed. Correlating morbidity against the years, we found that r-value of 0.74. From the observation, morbidity had a significantly positive trend.

In comparing the two trends, it can be observed that while malaria morbidity had a significantly positive trend, relative humidity had a significant negative trend. This means that relative humidity did not positively promotes malaria morbidity trend in the study area, it means that there are other factors rather than relative humidity that are responsible to the increase in malaria morbidity trend over the study period.

4.5.4 Trends of Rainfall and Malaria Morbidity (Busoro)

The figure 4.8 shown that rainfall trend in the seven years of study period was positive (y=-0.134x+118.11). This means rainfall decreased at the rate of 13.4% per month during the study period (2011-2017). With the co-efficient of determination of R^2=0.0015, this time accounted for 0.15% of the changes in the spatio-temporal rainfall occurrences recorded. This trend was not significant. During this period of seven years, the overall mean malaria morbidity in this area showed an increase in trend. It grew at the rate of 52.087% per month. The co-efficient of determination of R^2=0.5433 implies that the period (2011-2017) accounted for 54.33% of the temporal variation in malaria morbidity observed. Correlating morbidity against the years, we found that r-value of 0.74. From the observation, morbidity had a significantly positive trend. From that observation, morbidity had a significantly positive trend.

In comparing the two trends, it can be observed that while malaria morbidity had a significantly positive trend, rainfall had an insignificant negative trend. This means that relative rainfall did not positively promotes malaria prevalence in the study area, there are the other factors rather than rainfall that are responsible to the malaria trend increase over the study period.

4.5.5 Trends of Maximum Temperature, Relative Humidity and Malaria Morbidity (Bungwe)

The figure 4.9 and 4.10 shown that maximum temperature and relative humidity during the study period from 2011-2017 were established to have a positive trend with regression equation y_1 = 0.0437x + 18.24 and y_2= 0.0389x + 70.465 means that they increased at the rate of 4.37% and 3.89% per monthly, respectively during the surveillance period (2011-2017). A co-efficient of determination of R_1^2 = 0.5108 and R_2^2 = 0.2481 implied that the period 2011-2017 accounted for 51.08% and 24.81% of the temporal changes recorded, respectively. The trend of figure 4.9 was insignificant while the trend of figure 4.10 was significant. Similarly, during this period, the overall monthly malaria morbidity also showed a negative trend and it was decline at the rate of 31.24% per month. The co-efficient of determination of R^2 = 0.13 implied that the period (2011-2017) accounted for 13% of the temporal variation in malaria morbidity observed. With an r-value of 0.36, morbidity had an insignificantly negative trend.

From the above observations, both maximum temperature and relative humidity had positive trends while malaria morbidity had a negative trend. The relative humidity and malaria morbidity had insignificant trends and maximum temperature had a significant one. It could also be noted that the relative humidity and maximum temperature did not positively promotes malaria morbidity trend in the study area, it means there were other factors that are directly responsible to the increase in malaria morbidity trend over the study period.

4.5.6 Trends of Minimum Temperature and Malaria Morbidity (Bungwe)

The figure 4.11 shown that the trend of minimum temperature in the seven years of study was positive (y=0.0009x+12.587), this means that minimum temperature increased at the rate of 0.09% per month during the study period (2011-2017) with a co-efficient of determination of R^2=0.0022. This time accounted for 0.22% of the changes in the spatio-temporal minimum temperature results recorded and it is clear that the trend was not significant. Similarly, during this period, the overall monthly malaria morbidity also showed a negative trend where it declined at the rate of 31.24% per month. The co-efficient of determination of R^2 = 0.13 implied that the period (2011-2017) accounted for 13% of the temporal variation in malaria morbidity observed. With an r- value of 0.36, morbidity had an insignificantly negative trend.

In comparing the two trends, it can be observed that while malaria morbidity had an insignificantly negative trend, minimum had also an insignificant positive trend. This means that a small fluctuations in minimum temperature affects malaria morbidity trend in the study area.

4.5.7 Trends of Rainfall and Malaria Morbidity (Bungwe)

The figure 4.12 shown that rainfall trend in seven years of study period was negative (y=-0.2256x+117.57). This means that rainfall decreased at the rate of 22.56% per month during the study period (2011-2017) with the co-efficient of determination of R^2=0.0058 where this time accounted for 0.58% of the changes in the spatio-temporal rainfall occurrences observed. This trend was not significant. Similarly, during this period, the overall monthly malaria morbidity also showed a negative trend and it decline at a rate of 31.24% per month. The co-efficient of determination of R^2 = 0.13 implied that the period (2011-2017) accounted for 13% of the temporal variation in malaria morbidity observed. With an r- value of 0.36, morbidity had an insignificantly negative trend.

In comparing the two trends, it can be observed that while malaria morbidity had an insignificantly negative trend, rainfall had also an insignificant negative trend. This means that there was no significance between malaria morbidity trend and rainfall in the study area.

4.5.8 Trends of Maximum Temperature, Minimum Temperature and Malaria Morbidity (Rukara)

The figure 4.13 and 4.14 shown that maximum and minimum temperature during the study period from 2011-2017 were established to have a positive trend with regression of $y_1 = 0.0132x + 14.526$ and $y_2= 0.0382x + 23.931$ means that they increased at the rate of 0.0132% and 0.382% per monthly, respectively during the surveillance period (2011-2017). A co-efficient of determination of $R_1^2 = 0.1664$ and $R_2^2 = 0.3103$ implied that the period 2011-2017 accounted for 16.64% and 31.03% of the temporal changes of data recorded, respectively. The trend of figure 4.13 was significant while the trend of figure 4.14 was not significant. Similarly, during this period, the overall monthly malaria morbidity also showed a positive trend. It grew at the rate of 39.158% per month. The co-efficient of determination of $R^2 = 0.5358$ implied that the period (2011-2017) accounted for 53.58% of the temporal variation in malaria morbidity observed. With an r- value of 0.732, morbidity had a significant positive trend.

From the above observations, both maximum temperature, minimum and malaria morbidity had positive trends. While minimum temperature had an insignificant trend, malaria morbidity and maximum temperature had a significant trend. It must also be noted that even a very small increase in minimum temperature can greatly increase malaria occurrence. These results are in line with the study conducted by Klutse et al. [53] where they revealed that maximum temperature was the better predictors of malaria morbidity trends than minimum temperature.

4.5.9 Trends of Rainfall and Malaria Morbidity (Rukara)

The figure 4.15 shown that rainfall trend in the seven years of study period was negative ($y=-0.1419x+90.787$) which means that means the rainfall decreased at the rate of 14.19% per month during the surveillance period (2011-2017). With the co-efficient of determination of $R^2=0.0019$, this time accounted for 0.19% of the changes in the spatio-temporal rainfall occurrences observed. From that, it is clear that the trend was not significant. Similarly, during this period, the overall monthly malaria morbidity also showed a positive trend where it grew at the rate of 39.158% per month. The co-efficient of determination of $R^2 = 0.5358$ implied that the period (2011-2017) accounted for 53.58% of the temporal variation in malaria morbidity observed. With an r- value of 0.732, morbidity had a significantly positive trend.

In comparing the two trends, it can be observed that while malaria morbidity had a significantly positive trend, rainfall had an insignificant negative trends one. This means that rainfall did not positively promotes malaria morbidity trend in the study area.

4.5.8 Trends of Relative Humidity and Malaria Morbidity (Rukara)

The figure 4.16 shown that relative humidity trend in the seven years of study period was negative (y=-0.1052x+66.667) which means that relative humidity decreased at the rate of 10.52% per month during the surveillance period (2011-2017). With the co-efficient of determination of R^2=0.1049, this time accounted for 10.49% of the changes in the spatio-temporal relative humidity occurrences recorded. It is clear that its trend was not significant. Similarly, during this period, the overall monthly malaria morbidity also showed a positive trend where it grew at the rate of 39.158% per month. The co-efficient of determination of R^2 = 0.5358 implied that the period (2011-2017) accounted for 53.58% of the temporal variation in malaria morbidity observed. With an r- value of 0.732, morbidity had a significantly positive trend.

In comparing the two trends, it can be observed that while malaria morbidity had a significantly positive trend, relative humidity had an insignificant negative trend. This means that relative humidity does not positively promotes the malaria morbidity in the study area.

4.6 Relationship between Temperature and Malaria Morbidity

The results shown that the malaria morbidity was influenced by the variability of maximum temperature in lowlands among all selected climatic parameters and its influence decrease with altitude. The results are similar to the findings of a research done in Ghana in lowlands regions where they suggested that the maximum temperature to be the most important parameter that affects malaria morbidity [54]. The study found also that the trend of maximum temperature in the lowlands was associated with malaria morbidity trend during the surveillance period.

The results also shown that malaria morbidity in highlands was primary influenced by the variability of minimum temperature among all selected climatic parameters. The results are similar to the findings of studies done in Ethiopia and in East African Highlands witch suggested that mean minimum temperature was the most significant factor that correlated with monthly malaria cases occurrence or incidence in highlands regions [55] [56]. This agreed with the study done in Iran witch shows that the temperature increase, particularly minimum temperature increase in some regions increases the survival of plasmodiums and anopheles in winter and therefore results in faster transmission and distribution of malaria in populations [36].

Therefore a rise of temperature, especially minimum temperature, would enhance the survival of Plasmodium and Anopheles during different seasons and thus accelerate the transmission dynamics of malaria and spread it into populations that are currently malaria free in highlands and immunologically naïve [55].

4.7 Relationship between rainfall and Malaria Morbidity

Rainfall in lowlands act as an indicator of malaria prevalence, the period following the rain season was characterised by the increase of malaria (May) in Busoro and May, June and December in Rukara. For both sites in April and November Malaria is decreased and it provide the breeding sites for mosquitos and it is agreed with the research done in Ethiopia and suggested that Rainfall plays an important role in malaria epidemiology because water not only provides the medium for the aquatic stage of the mosquitoes' life cycle but also increases the relative humidity and then the longevity of the adult mosquitoes [55]. In highlands of Rwanda, increase in rainfall destroy the breeding sites for mosquitoes but it is followed by malaria increase in May, June, July and December but it is not explaining the malaria morbidity trends in all study areas.

4.8 Relationship between Relative Humidity and Malaria Morbidity

The recent study in china revealed that humidity was related to the number of malaria cases in China, where a relative humidity below 60% shortened the life span of the mosquito so that below 60%, there was a decline in the risk of clinical malaria while above 60% relative humidity the infection rate increased significantly. It was also confirmed that the malaria risk at 80% humidity was twice as high as that of 60% [57]. It could be interpreted that relative humidity also has great influence in the life cycle of mosquito and behavior of biting humans because it was the greatest influence factor which affected the mosquito survival directly [58].

In our study, we found that there was not greatly influence of relative humidity on malaria morbidity but some pattern is observed in few months but further studies are needed to establish the relationship between humidity and malaria morbidity in Rwanda.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study established the relationship between the selected climatic parameters and malaria morbidity over the study period 2011-2017 in lowlands and highlands of Rwanda. Malaria prevalence in the lowland was shown to be increased with time and it had a peak in 2017 at Busoro. Malaria trends was observed to be increase due to the increase in maximum temperature among the selected climatic parameters and they was also an effect of rainfall which increases malaria morbidity in the months following the increased rainfall but it is insignificant on malaria morbidity trend. The findings was significant due to that the ambient temperatures required for parasite growth within the Anopheles mosquito; optimum temperatures for mosquitoes are between 25ºC and 30ºC [59], which is the range of maximum temperature we had in study sites (lowlands).

In highlands, the results from our study revealed that minimum temperature was the indicators of malaria morbidity in the study area in all selected climatic parameters and other parameters affect it indirectly during the surveillance period (2011-2017) and their effects were not significant to the malaria morbidity trend. The findings also shown that the influence of temperature on malaria morbidity shifted from maximum temperature to minimum temperature as the altitude increases.

Kurup et al, in 2017 found that climatic parameters in combination with environmental factors, drug resistance, preventative factors and even geographical locations, create opportune environments for mosquito breeding, parasite development and infection rates work together to influence malaria morbidity trend [59]. Then, it is not only selected climatic parameters that influence the malaria trends in the surveillance period because their R^2 was very small which means that they were not only selected climatic variable that are responsible to the malaria morbidity trend because there were some other factors as found by Gebretsadik et al. in 2018; the immunity of the population, environmental changes, infrastructures in the study area, societal awareness, accessibility of malaria control and prevention tools and the socio-economic changes of the society [60] are responsible to the malaria morbidity increase in the study area during the surveillance period.

5.2 Recommendations

Adaptive strategies should be put in place in the study areas in order reduce malaria morbidity trend and also on the whole country. Members of the community should be encouraged to drain out the pools of water that remains after the rains during the rainy season and to clear their compounds of the unwanted vegetation that has been grew due to rainfall and in swamps near the residential area in order to reduce the availability of the larval habitats. They should also be encouraged for not planting crops like sorghum too close to residential area as this will also increase mosquito breeding sites during and before long after the rains. The health policy makers and meteorologists should constantly work together in order to predict and be able to control epidemics by educating and advising the public to seek medical attention before and whenever they suspect the malaria occurrences. There should be awareness medical campaigns to help alert the population of when malaria increases will be expected especially the period following weather events like rain season and El Niño that are conducive for malaria transmission.

To accommodate the endemicity, the health facilities should always be well-equipped with both the drugs and qualified staff. Particular attention should be paid to the months of May, June, July, October, November and December. These are months that showed progressive malaria increase within each year in the study period. Indoor residual spray should be expanded to study area especially in the lowlands (Rukara and Busoro) and to encourage the community to use appropriately Insecticide-treated nets (ITNs) and long-lasting insecticidal nets (LLINs) which are the most widely used intervention for malaria control. These have been done in the past but without strong consistency and with very long time lag which may encourage drug and insecticide resistance. Members of the community should be empowered to self-malaria rapid testing in order to help them not mostly affected by this disease. The fact that only the selected climatic parameters did not show a full positive significance in indicating malaria morbidity trends in the study area, it means that further researches are need to indicate the role of other parameters both climatic and non-climatic on malaria morbidity trend and to study on the shift of the impact of the maximum temperature to minimum temperature on malaria morbidity in the study sites.

Most of the areas in Rwanda are sensitive and vulnerable to climate variability. This is because the impacts of climate variability to the health sector and the general population have been very strong in terms of malaria cases and economic loss due to different malaria interventions. The major and reasonable options to adapt the situation is to integrate climate variation issues in the health policies and sector and to ensure that all programmes take climate variability in concerns in all their plans and operations. Therefore, all sectors will be able to adapt and minimize the direct and indirect impacts. As the other plans based on a village level, anti-malaria strategies also must be based the village and each district possibly facilitated to have a climate specialist to work with health policy makers of the district to set the appropriate strategies that adaptive to individual district. Since climate variability occurrences are common issue, all the health sectors must cooperate with other sectors so as to have an effective and efficient adaptation mechanisms and structure that will help them to cope with climate variability effect because climate will continue to vary in the predictable future. All the suggested recommendations are helpful in reducing malaria morbidity and spread as they play great role in reducing the numbers of adult mosquitoes, destruction of mosquito larvae, reduction of mosquito breeding sites and prevention of mosquitoes from feeding on man. Naturally, each of these methods is not exclusive, and usually all or most of them are used either sequentially or jointly.

References

[1] WHO, "Global technical strategy for malaria 2016-2030," WHO, Geneva, Switzerland, 2015.

[2] WHO, "World Malaria report 2011," World Health Organization, Geneva, Switzerland, 2011.

[3] Noriko Endo, Teresa Yamana, Elfatih A B Eltahir, "Impact of climate change on malaria in Africa: a combined modelling and observational study," *The Lancet,* vol. vol. 389, p. S7, 2017.

[4] PMI, "Eleventh Annual Report to Congress," U.S. President's Malaria Initiative, Washington, 2017.

[5] Boko, M., I. Niang, A. Nyong, C. Vogel, A. Githeko, M. Medany, B. Osman-Elasha, R. Tabo and P. Yanda, "Africa. Climate Change2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the IntergovernmentalPanel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Ha," *Cambridge University Press,* Vols. 433-467, p. Cambridge UK, 2007.

[6] WHO, "Global vector control response 2017–2030," World Health Organization, Geneva, 2017.

[7] IPCC, "Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth AssessmentReport of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A.(eds.)]," IPCC, Geneva, Switzerland, 2007.

[8] Dhiman, Ramesh C., "Climatic Variables and Malaria Transmission: Intricacies of Application," *Vayu Mandal,* vol. 42, no. 2, pp. 98-105, 2016.

[9] UNEP, "Rwanda from Post-Conflict to Environmentally Sustainable Development," United Nations Environment Programme, Hertfordshire, UK, 2011.

[10] Aboda Caroline, An Assessement of The Impact of Climate Variability on Malaria, Trondheim, Norway.: Norwegian University of Science and Technology, 2012.

[11] Odhiambo, Samwel Olela, Effects of Variability of Selected Climatic Elements on Malaria Prevalence in Awendo Division, Rongo District, Migori County, Kenya, 2013.

[12] Jean-Pierre Bizimana, Emmanuel Twarabamenye, Stefan Kienberger, "Assessing the social vulnerability to malaria," *Malaria Journal,* vol. 14:2, 2015.

[13] Rulisa S, Kateera F, Bizimana JP, Agaba S, Dukuzumuremyi J, et al, "Malaria Prevalence, Spatial Clustering and Risk Factors in a Low Endemic Area of Eastern Rwanda: A Cross Sectional Study," *Plos One,* vol. Volume 8, no. Issue 7, 1 July 2013.

[14] Bizimana Jean Pierre, "Malaria hotspots in Rwanda- relative influence of climate variability and interventions," p. 1–14, 2014.

[15] WHO, UNICEF, "Achieving the malaria MDG target: reversing the incidence of malaria 2000-2015," WHO, Geneva, Switzerland, 2015.

[16] WHO, "World malaria report 2016" World Health Organization, Geneva, 2016.

[17] UNDP, GoR, "Rwanda National Human Development Report 2014: “Decentralisation and Human Development: Accelerating Socio-Economic Transformation and Sustaining Accountable Governance”," United Nations Development Programme and Government of Rwanda, Kigali, 2014.

[18] PMI, "Malaria Operational Plan FY 2017," President’s Malaria Initiative Rwanda, Kigali, 2017.

[19] PMI-Rwanda, "Malaria Operational Plan FY 2018," President’s Malaria Initiative Rwanda, Kigali, 2018.

[20] Kamuhanda, James Kant, "Review of Malaria Epidemiology in Rwanda," *Imperial Journal of Interdisciplinary Research (IJIR),* Vols. Vol-2, no. Issue-9, 2016, pp. 1240-1242, 2016.

[21] Haque U, Hashizume M, Glass GE, Dewan AM, Overgaard HJ, et al., "The Role of Climate Variability in the Spread of Malaria in Bangladeshi Highlands," *PLoS ONE,* vol. 5, no. 12, 16 December 2010.

[22] Edwin K. Kipruto, Alfred O. Ochieng, Douglas N. Anyona, Macrae Mbalanya, Edna N. Mutua, Daniel Onguru, Isaac K. Nyamongo and Benson B. A. Estambale, "Effect of climatic variability on malaria trends in Baringo County, Kenya," *Malaria Journal,* vol. 16, no. 220, pp. 1-11, 25 May 2017.

[23] IPCC, "Summary for Policymakers. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R.Pichs-Madruga, Y. Sokona, E. Farahani]," IPCC, Cambridge, United Kingdom and New York, NY, USA., 2014.

[24] IPCC, "Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer," IPCC, Geneva, Switzerland, 2014.

[25] Howard Zucker M.D., "Basic Statistics: About Incidence, Prevalence, Morbidity, and Mortality - Statistics Teaching Tools," April 1999. [Online]. Available: https://www.health.ny.gov/diseases/chronic/basicstat.htm.

[26] CDC, "Principles of Epidemiology in Public Health Practice, Third Edition An Introduction to Applied Epidemiology and Biostatistics," 18 May 2012. [Online]. Available: https://www.cdc.gov/ophss/csels/dsepd/ss1978/lesson3/section2.html.

[27] wikipedia, "Incidence (epidemiology)," 29 May 2018. [Online]. Available: https://en.wikipedia.org/wiki/Incidence_ (epidemiology).

[28] Wikipedia, "Disease-Wikipedia," 14 August 2018. [Online]. Available: https://en.wikipedia.org/wiki/Disease#Morbidity.

[29] Mayo Clinic, "Malaria transmission cycle," 2018. [Online]. Available: https://www.mayoclinic.org/diseases-conditions/malaria/multimedia/malaria-transmission-cycle/img-20006373.

[30] Tay S.C.K., Danuor S.K., Mensah D.C., Acheampong G., Abruquah H.H., Morse A., Caminade C., Badu K., Tompkins A., Hassan H.A., "Climate Variability and Malaria Incidence in Peri-Urban, Urban and Rural Communities around Kumasi, Ghana: a Case Study at three Health Facilities; Emena, Atonsu And Akropong," *International Journal of*

Parasitology Research, vol. 4, no. 2, pp. 83-89, 06 July 2012.

[31] Ceccato P., Connor S.J., Jeanne I., Thomson M.C. , "Application of Geographical Information Systems and Remote Sensing technologies for assessing and monitoring malaria risk," *Parassitologia,* vol. 47, pp. 81-96, 2005.

[32] Lafferty kevin D., "The ecology of climate change and infectious diseases," *Ecology,* vol. 90, no. 4, p. 888–900, 2009.

[33] Ikemoto Takaya, "Tropical Malaria Does Not Mean Hot Environments," *Journal of Medical Entomology,* vol. 45, no. 6, pp. 963-969, 2008.

[34] João Luís Ferrão, Jorge M. Mendes and Marco Painho, "Modelling the influence of climate on malaria occurrence in Chimoio Municipality, Mozambique," *Parasites & Vectors,* vol. 10:260, 25 May 2017.

[35] Krijn P. Paaijmans, Simon Blanford, Andrew S. Bell, Justine I. Blanford, Andrew F. Read and Matthew B. Thomas, "Influence of climate on malaria transmission depends on daily temperature variation," *PNAS,* vol. 107, no. no. 34, p. 15135–15139, 24 August 2010.

[36] Minoo Mohammadkhani, Narges Khanjani, Bahram Bakhtiari, Khodadad Sheikhzadeh, "The relation between climatic factors and malaria incidence in Kerman, South East of Iran," *Parasite Epidemiology and Control,* vol. 1, p. 205–210, 2016.

[37] Ngarakana-Gwasira E. T. , Bhunu C. P. , Masocha M. and Mashonjowa E., "Assessing the Role of Climate Change in Malaria Transmission in Africa," *Hindawi Publishing Corporation,* vol. 2016, p. 7, 23 February 2016.

[38] Farid Zayeri, Masoud Salehi, Hasan Pirhosseini, "Geographical mapping and Bayesian spatial modeling of malaria incidence in Sistan and Baluchistan province, Iran," *Asian Pacific Journal of Tropical Medicine,* pp. 985-992, 2011.

[39] Tiegang Li, Zhicong Yang and Ming Wang, "Temperature, relative humidity and sunshine may be the effective predictors for occurrence of malaria in Guangzhou, southern China, 2006–2012," *Parasites & Vectors,* vol. 6, 30 May 2013.

[40] Ibrahima Diouf, Belen Rodriguez-Fonseca, Abdoulaye Deme, Cyril Caminade, Andrew P. Morse, Moustapha Cisse, Ibrahima Sy, Ibrahima Dia, Volker Ermert, Jacques-André Ndione and Amadou Thierno Gaye, "Comparison of Malaria Simulations Driven by Meteorological Observations and Reanalysis Products in Senegal," *International Journal of Environmental Research and Public Health,* vol. 14, no. 1119, 25 September 2017.

[41] Lingala Mercy A.L., "Effect of meteorological variables on Plasmodium vivax andPlasmodium falciparum malaria in outbreak prone districts ofRajasthan, India," *Journal of Infection and Public Health,* vol. 10, p. 875–880, 2017.

[42] Amekudzi, Ernest O. Asare and Leonard K., "Assessing Climate Driven Malaria Variability in Ghana Using a Regional Scale Dynamical Model," *Climate,* pp. 5-20, 5 March 2017.

[43] Yan Bi, Weiwei Yu, Wenbiao Hu, Hualiang Lin, Yuming Guo, Xiao-Nong Zhou and Shilu Tong, "Impact of climate variability on Plasmodium vivax and Plasmodium falciparum malaria in Yunnan Province, China," *Parasites & Vectors,* vol. 6, p. 357, 2013.

[44] Grace An, "Influence of Climate on Malaria in China," *Penn McNair Research Journal,* vol. 3, no. 1, 16 December 2011.

[45] Omonijo A.G., Matzarakis A., Oguntoke O. and Adeofun C.O., "Influence of Weather and Climate on Malaria Occurrence Based on Human-Biometeorological Methods in Ondo State, Nigeria," *Journal of Environmental Science and Engineering,* vol. 5, pp. 1215-1228, 20 September 2011.

[46] IPCC, "Climate Change: The IPCC 1990 and 1992 Assessments," Intergovernmental Panel on Climate Change , Canada, 1992.

[47] UNDP, BCPR, "Climate Risk Management for Malaria Control in Kenya: The Case of the Western Highlands," United Nations Development Programme (UNDP), Bureau for Crisis Prevention and Recovery (BCPR), New York, 2013.

[48] S. M. Henninger, "Local climate changes and the spread of malaria in Rwanda," *Health,* vol. 5, pp. 728-734, 2013.

[49] Bizimana Jean-Pierre, Twarabamenye Emmanuel and Kienberger Stefan , "Assessing the social vulnerability to malaria in Rwanda," *Malaria Journal,* vol. 14, no. 2, pp. 1-21, 2015.

[50] Bizimana Jean Pierre, Kienberger Stefan, Hagenlocher Michael , "Modelling homogeneous regions of social vulnerability to malaria in Rwanda," *Geospatial Health,* vol. 11(s1), no. 404, pp. 129-146, 2016.

[51] Kamuhanda, James Kant, "Review of Malaria Epidemiology in Rwanda," *Imperial Journal of Interdisciplinary Research (IJIR),* vol. 2, no. 9, pp. 1241-1242, 2016.

[52] [Online]. Available: https://www.itl.nist.gov/div898/handbook/pmc/section4/pmc4.htm.

[53] Nana Ama Browne Klutse, Fred Aboagye-Antwi, Kwadwo Owusu, Yaa Ntiamoa-Baidu, "Assessment of Patterns of Climate Variables and Malaria Cases in Two Ecological Zones of Ghana," *Open Journal of Ecology,* vol. 4, pp. 764-775, 2014.

[54] Nana Ama Browne Klutse, Fred Aboagye-Antwi, Kwadwo Owusu, Yaa Ntiamoa-Baidu, "Assessment of Patterns of Climate Variables and Malaria Cases in Two Ecological Zones of Ghana," *Open Journal of Ecology,* vol. 4, pp. 764-775, 2014.

[55] Abebe Alemu, Gemeda Abebe, Wondewossen Tsegaye, Lemu Golassa, "Climatic variables and malaria transmission dynamics in Jimma town, South West Ethiopia," *Parasites & Vectors,* vol. 4, no. 30, pp. 1-11, 2 March 2011.

[56] David J. Rogers, Sarah E. Randolph, "The Global Spread of Malaria in a Future, Warmer World," *The Pediatric Infectious Disease Journal,* vol. 289, pp. 1763-1766, 8 SEPTEMBER 2000.

[57] Ubydul Haque, Masahiro Hashizume, Gregory E. Glass, Ashraf M. Dewan, Hans J. Overgaard, Taro Yamamoto, "The Role of Climate Variability in the Spread of Malaria in Bangladeshi Highlands," *PLoS ONE,* vol. 5, no. 12, December 2010.

[58] Fang Huang, Shuisen Zhou, Shaosen Zhang, Hongju Wang, Linhua Tang, "Temporal correlation analysis between malaria and meteorological factors in Motuo County, Tibet," *Malaria Journal,* vol. 10, no. 54, 2011.

[59] Rajini Kurup, Geetanjali Deonarine and Abdullah Adil Ansari, "Malaria trend and effect of rainfall and temperature within Regions 7 and 8, Guyana," *International Journal of Mosquito Research,* vol. 4, no. 6, pp. 48-55, 2017.

[60] Gebretsadik Daniel , Getacher Feleke Daniel, Fiseha Mesfin , "Eight-year trend analysis of

malaria prevalence in Kombolcha, South Wollo, north-central Ethiopia: a retrospective study," *Parasites & Vectors,* vol. 11, no. 55, pp. 1-6, 2018.

Addendum

Addendum 1: Tables

TABLE 4.1: TOTAL ANNUAL MALARIA CASES 2011-2017

Sites/Year	2011	2012	2013	2014	2015	2016	2017
Rukara	644	1679	2405	5662	11103	20320	38576
Bungwe	519	771	527	242	319	463	391
Busoro	1530	8181	11770	23196	43847	26038	50904

TABLE 4.2: AVERAGE MONTHLY CLIMATIC PARAMETERS 2011-2017

Sites/Parameters	Avg Temp Max (ºC)	Avg Temp Min(ºC)	Avg Hum (%)	Total RF(mm)
Rukara	25.55	15.09	62.19	84.76
Bungwe	20.10	12.62	72.12	107.98
Busoro	26.67	11.99	61.14	112.42

TABLE 4.3: CORRELATIONS BETWEEN MALARIA AND ALL CLIMATIC VARIABLES CONSIDERED IN BUSORO-NYANZA DISTRICT

Parameters/coefficients	R^2 Value	R-Value	P-Value
Monthly Tmin	0.005	-0.0713363702208	0.519034545625
Monthly Tmax	0.290	0.538272234852	1.28533123488e-07
Monthly Rainfall	0.004	0.0656153165036	0.553179147001
Monthly RH	0.178	-0.422079780708	6.36065596056e-05

TABLE 4.4: CORRELATIONS BETWEEN MALARIA AND ALL CLIMATIC VARIABLES CONSIDERED IN BUNGWE-BURERA DISTRICT

Parameters/coefficients	R^2 Value	R- Value	P- Value
Monthly Tmin	0.058	0.239951239454	0.0279161365366
Monthly Tmax	0.005	-0.0720117939612	0.515075167221
Monthly Rainfall	0.086	-0.293112877352	0.00681241799657
Monthly RH	0.003	-0.0566279612699	0.608904374828

TABLE 4.5: CORRELATIONS BETWEEN MALARIA AND ALL CLIMATIC VARIABLES CONSIDERED IN RUKARA-KAYONZA DISTRICT

Parameters/coefficients	R^2 Value	R- Value	P- Value
Monthly Tmin	0.031	0.174919881539	0.111510247075

Monthly Tmax	0.147	0.383269806244	0.00032000924969
Monthly Rainfall	0.001	-0.0346645108519	0.754250932068
Monthly RH	0.024	-0.154771637966	0.15980221325

Addendum 2: Figures

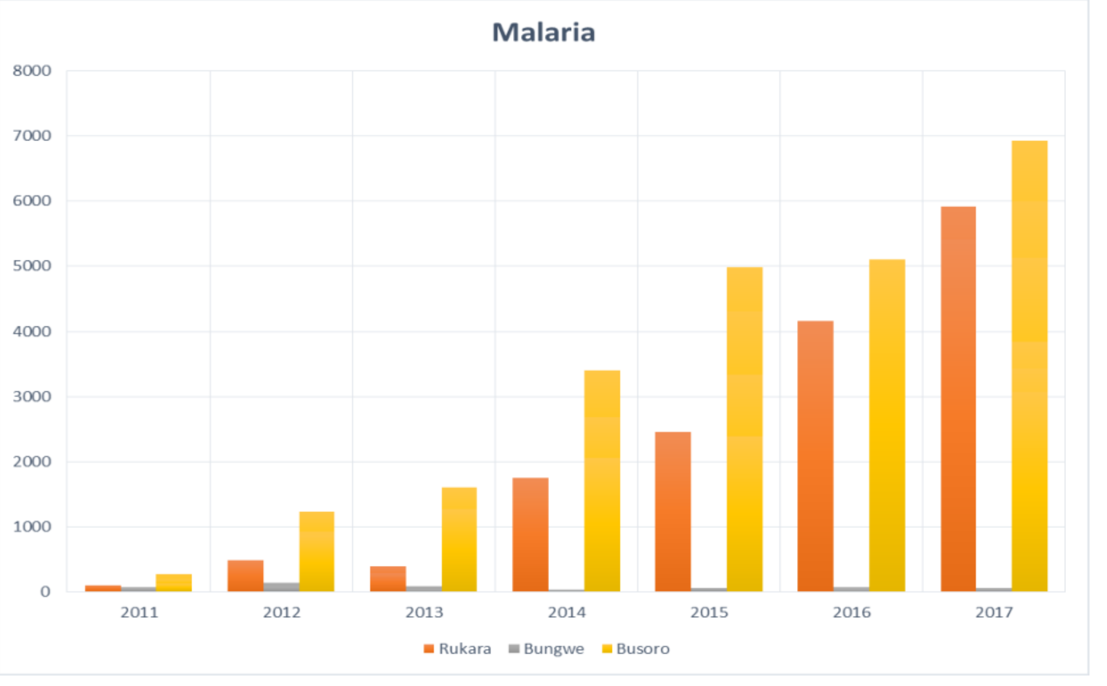

FIGURE 4.2: MALARIA CASES IN THE STUDY SITES (2011-2017)

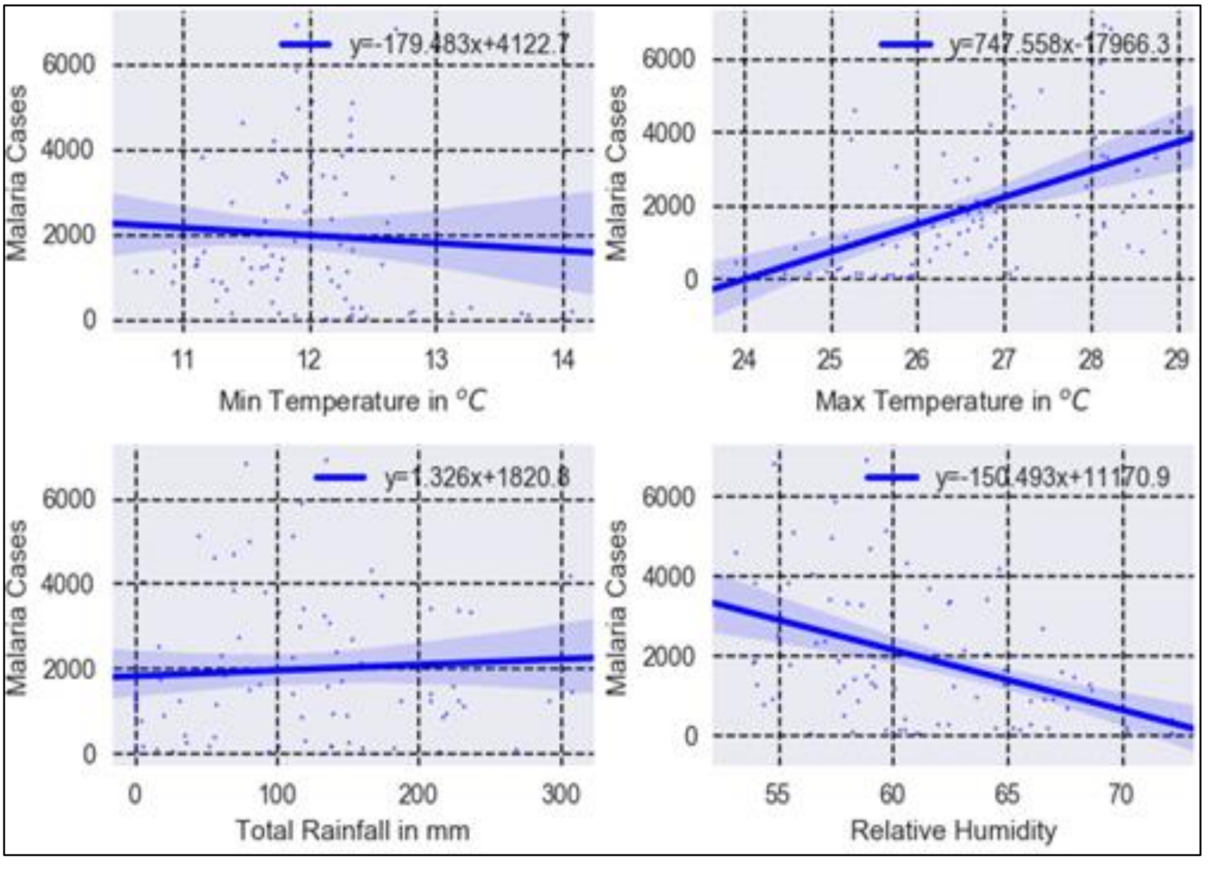

FIGURE 4.3: SCATTER PLOTS CORRELATING MALARIA AND CLIMATIC PARAMETERS IN BUSORO-NYANZA DISTRICT

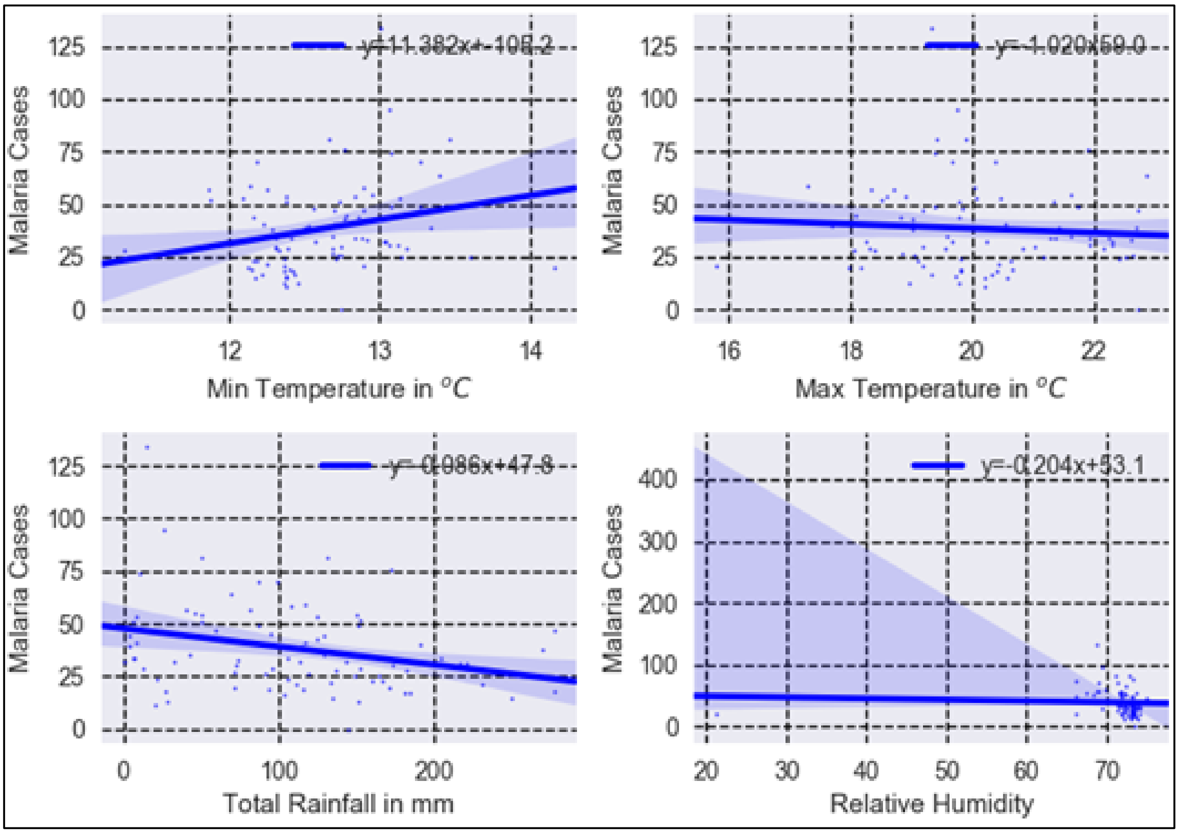

FIGURE 4.4: SCATTER PLOTS CORRELATING MALARIA AND CLIMATIC PARAMETERS IN BUNGWE-BURERA DISTRICT

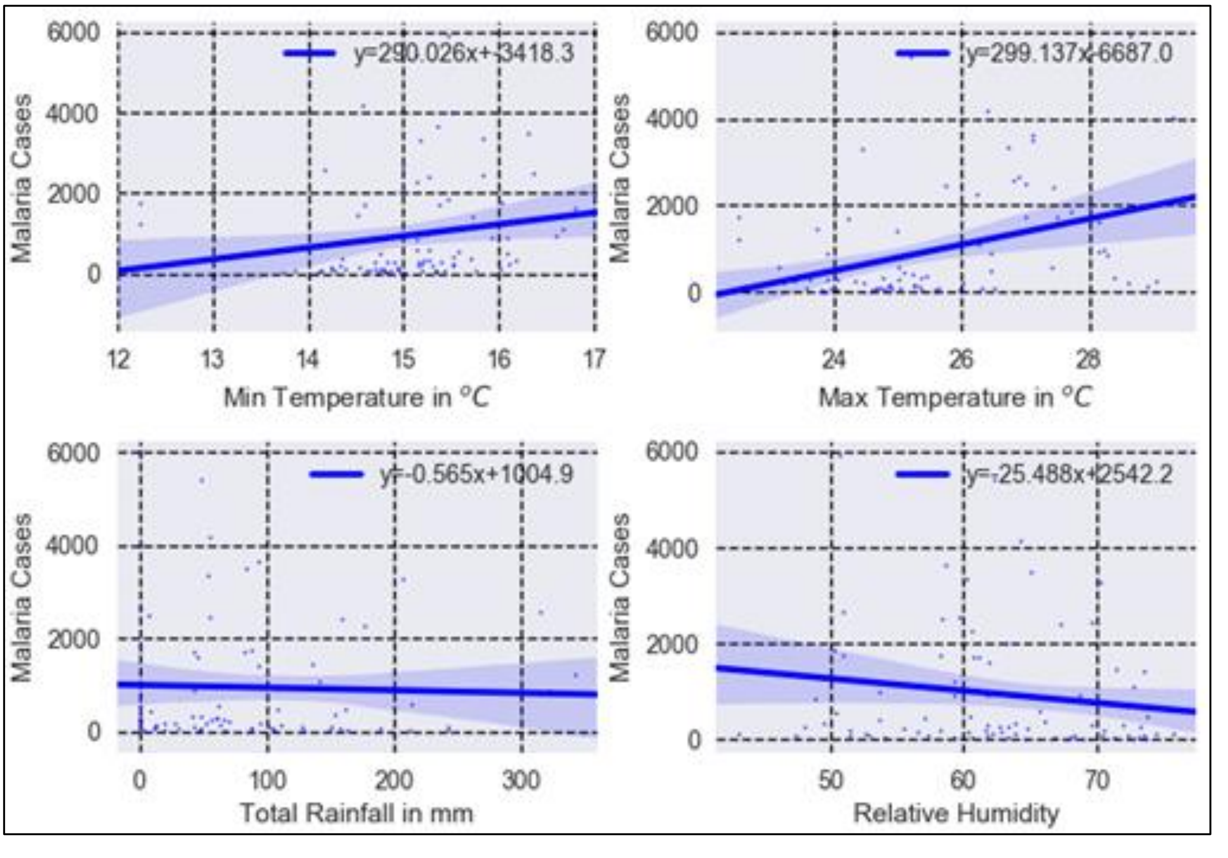

FIGURE 4.5: SCATTER PLOTS CORRELATING MALARIA AND CLIMATIC PARAMETERS IN RUKARA-KAYONZA DISTRICT

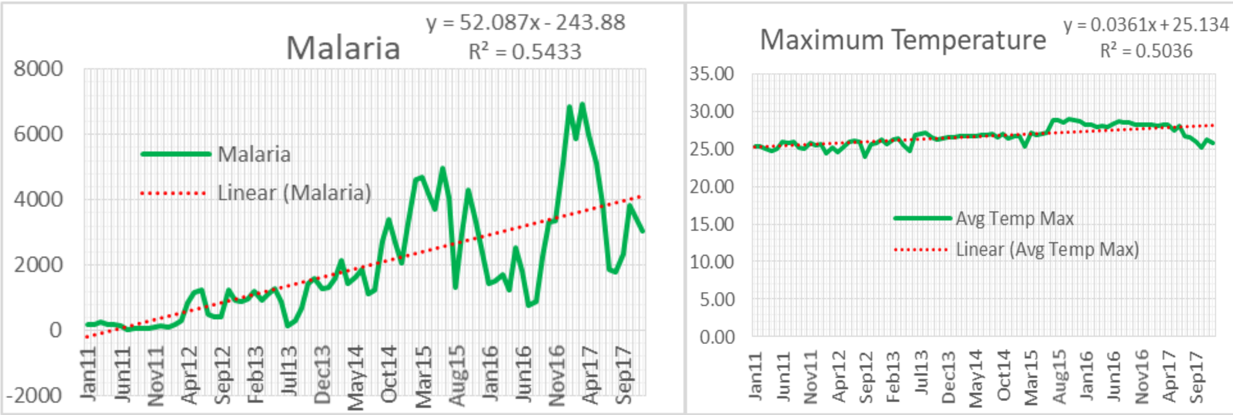

FIGURE 4.6: TRENDS OF MONTHLY MAXIMUM TEMPERATURE AND MONTHLY MALARIA MORBIDITY IN BUSORO

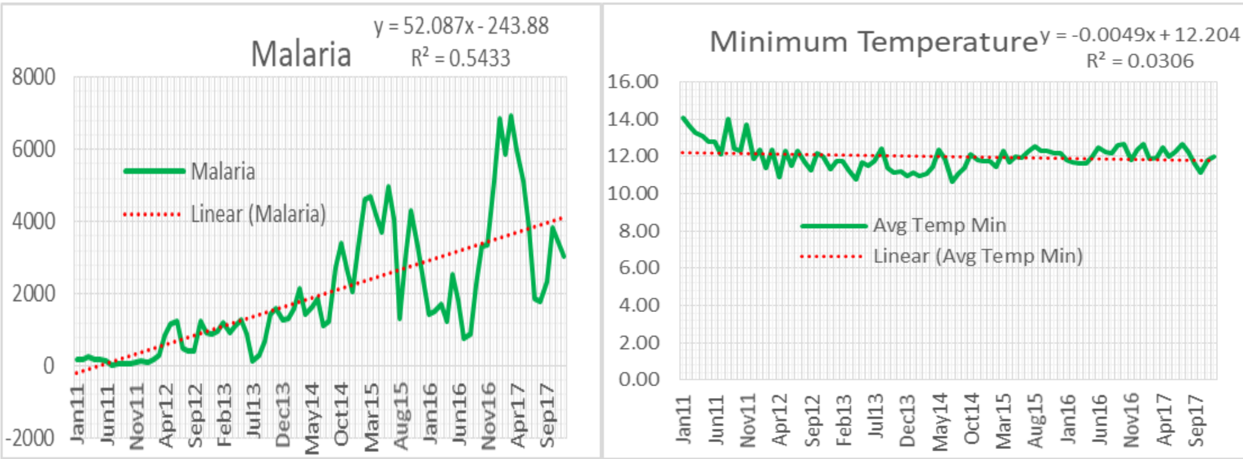

FIGURE 4.7: TRENDS OF MONTHLY MINIMUM TEMPERATURE AND MONTHLY MALARIA MORBIDITY IN BUSORO

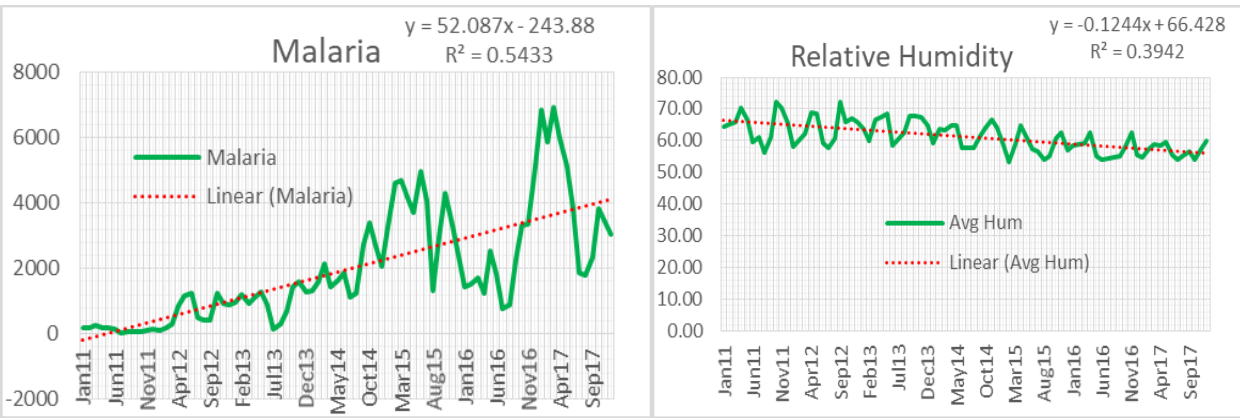

FIGURE 4.8: TRENDS OF MONTHLY RELATIVE HUMIDITY AND MONTHLY MALARIA MORBIDITY IN BUSORO

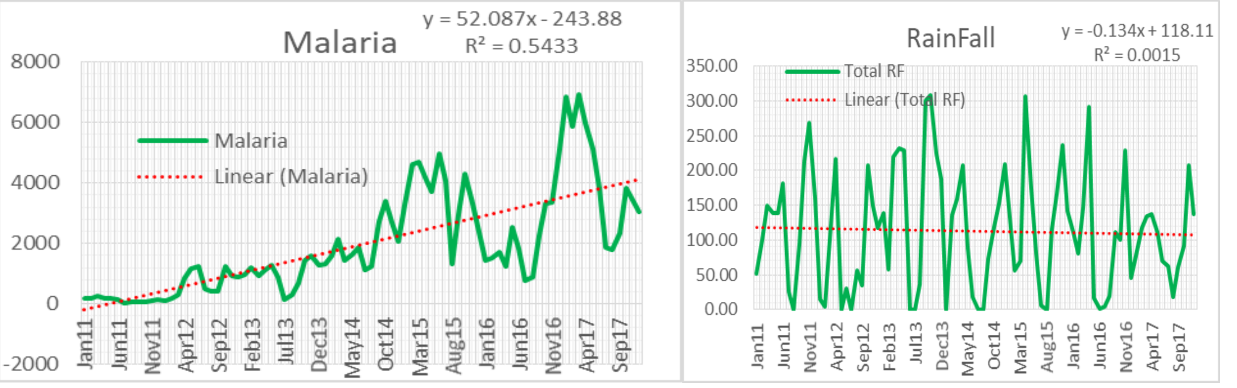

FIGURE 4.9: TRENDS OF MONTHLY RAINFALL AND MONTHLY MALARIA MORBIDITY IN BUSORO (2011-2017)

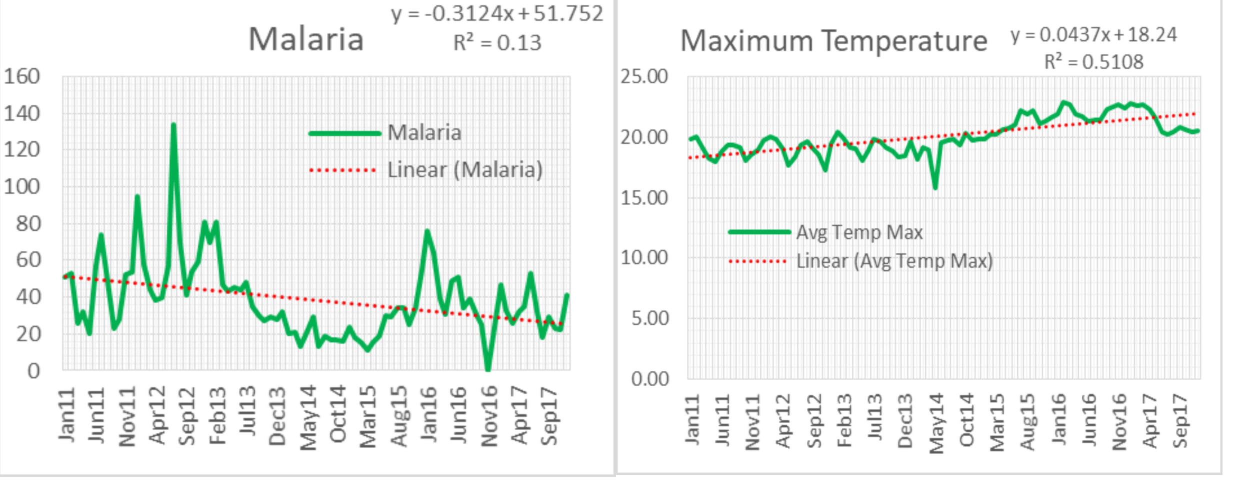

FIGURE 4.10: TRENDS OF MONTHLY MAXIMUM TEMPERATURE AND MONTHLY MALARIA MORBIDITY (2011-2017) FOR BUNGWE

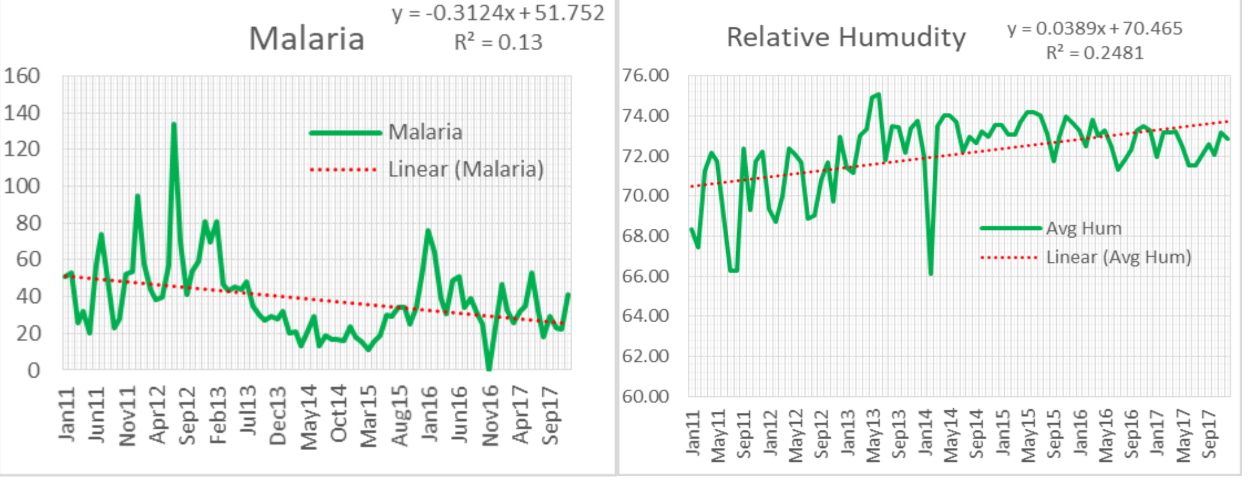

FIGURE 4.11: TRENDS OF MONTHLY RELATIVE HUMIDITY AND MONTHLY MALARIA MORBIDITY (2011-2017) FOR BUNGWE

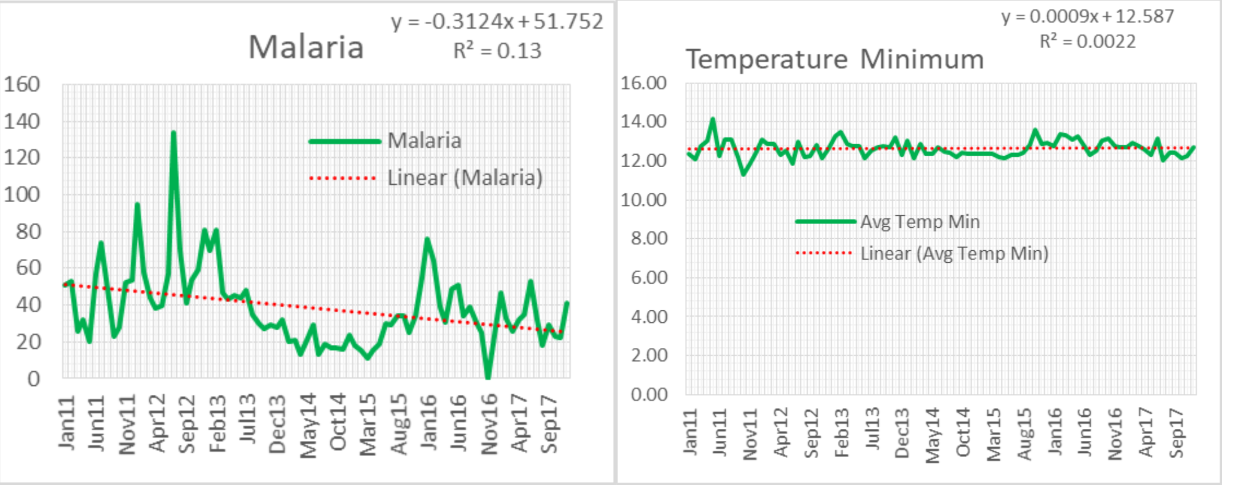

FIGURE 4.12: TRENDS OF MONTHLY MINIMUM TEMPERATURE AND MONTHLY MALARIA MORBIDITY (2011-2017) FOR BUNGWE

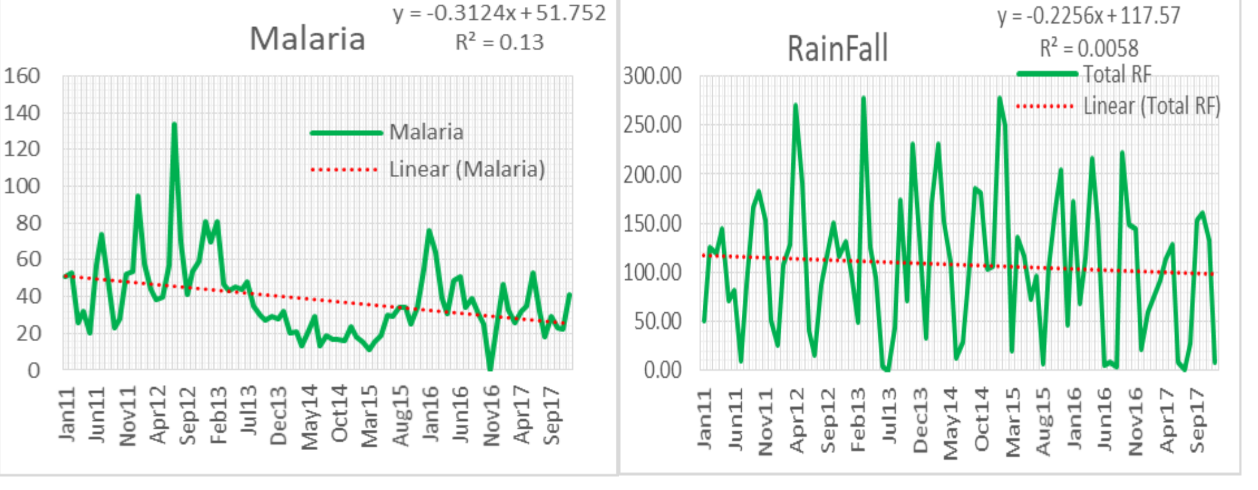

FIGURE 4.13: TRENDS OF MONTHLY RAINFALL AND MONTHLY MALARIA MORBIDITY (2011-2017) FOR BUNGWE

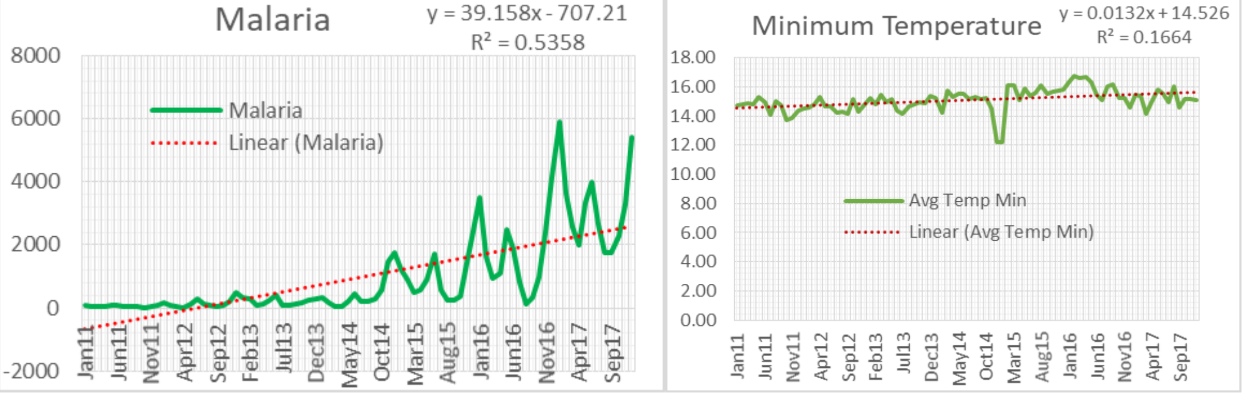

FIGURE 4.14: TRENDS OF MONTHLY MINIMUM TEMPERATURE AND MONTHLY MALARIA MORBIDITY (2011-2017) FOR RUKARA

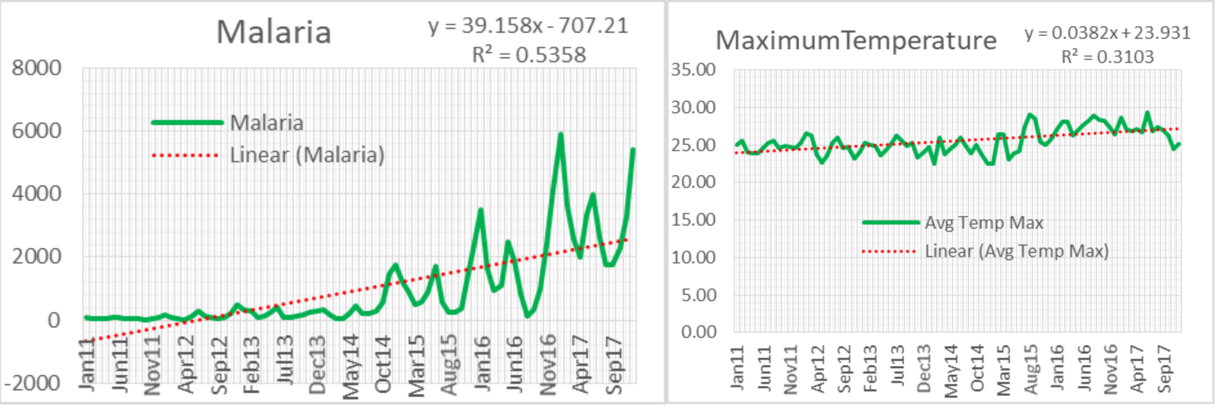

FIGURE 4.15: TRENDS OF MONTHLY MAXIMUM TEMPERATURE AND MONTHLY MALARIA MORBIDITY (2011-2017) FOR RUKARA

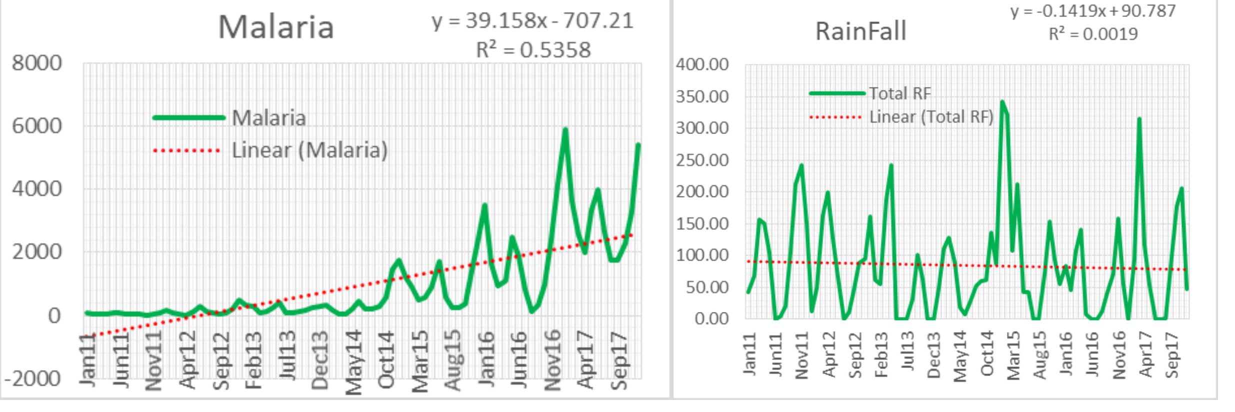

FIGURE 4.16: TRENDS OF MONTHLY RAINFALL AND MONTHLY MALARIA MORBIDITY (2011-2017) FOR RUKARA

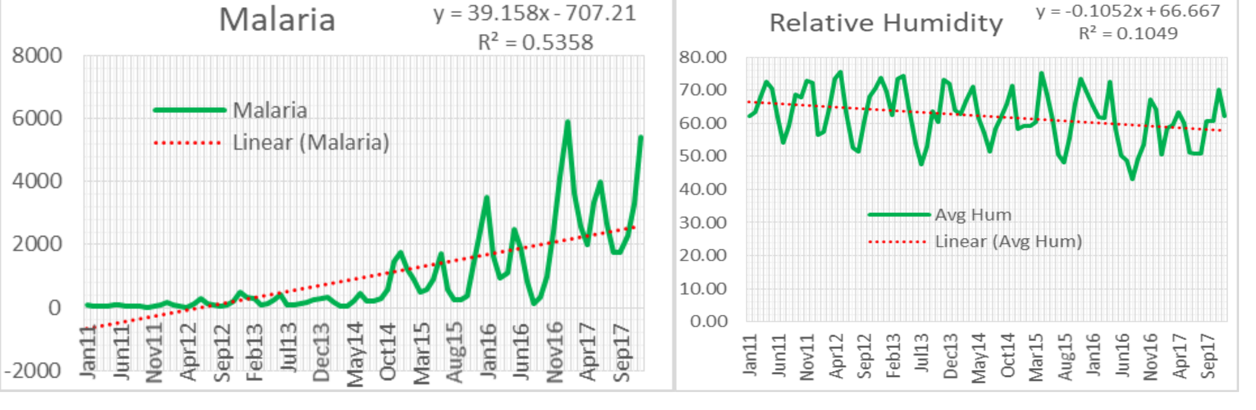

FIGURE 4.17: TRENDS OF MONTHLY RELATIVE HUMIDITY AND MONTHLY MALARIA MORBIDITY (2011-2017) FOR RUKARA

Appendix

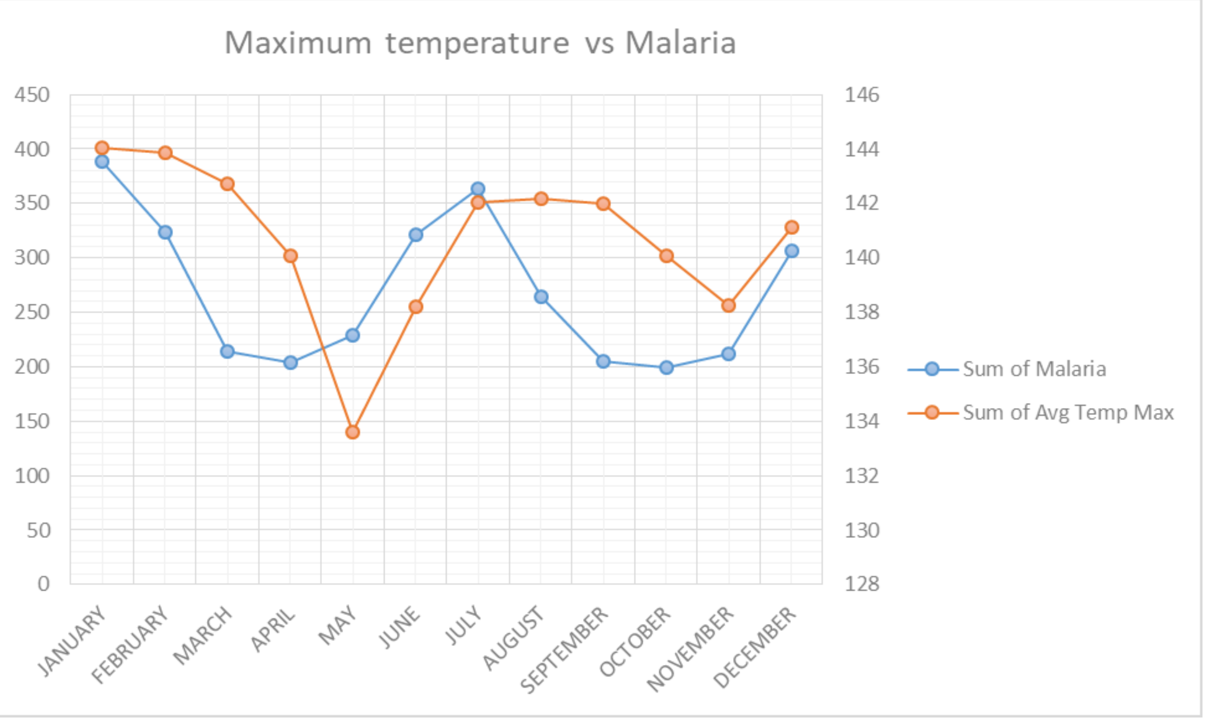

FIGURE 4.18: TOTAL MAXIMUM TEMPERATURE VERSUS TOTAL MALARIA MORBIDITY IN BUNGWE

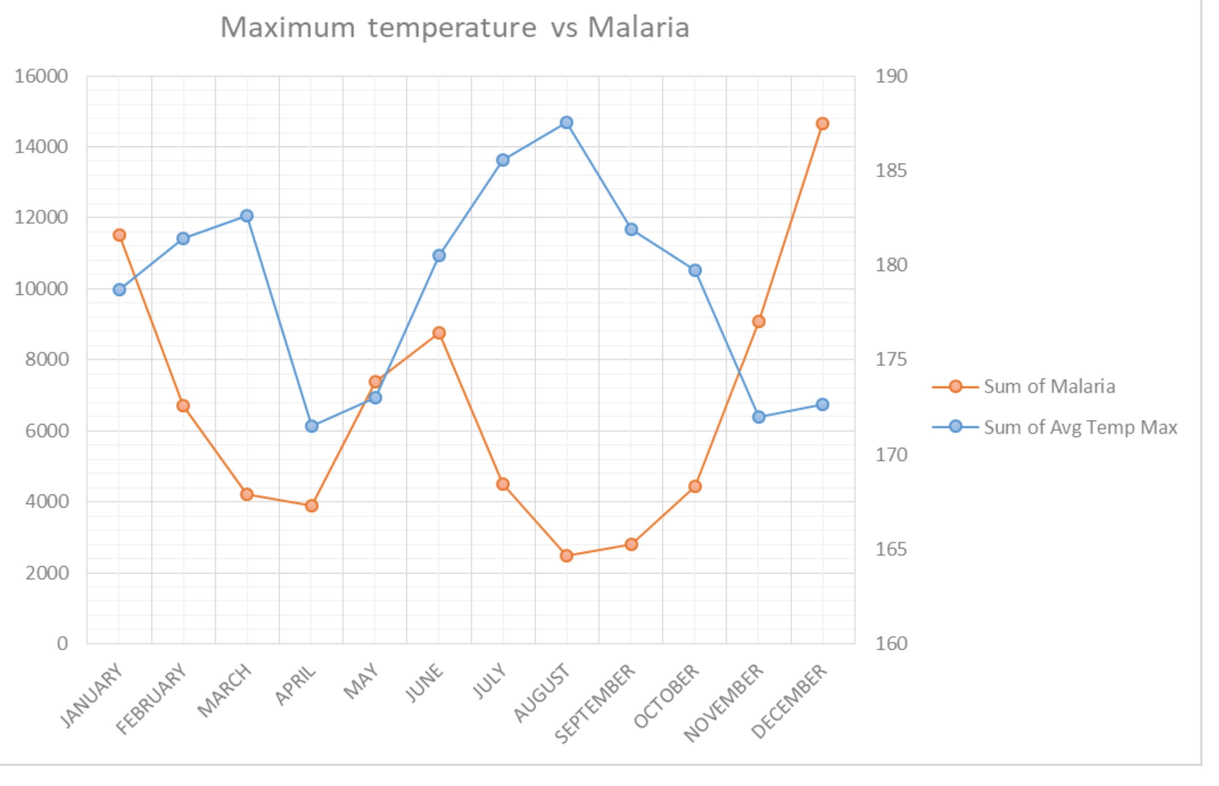

FIGURE 4.19: TOTAL MAXIMUM TEMPERATURE VERSUS TOTAL MALARIA MORBIDITY IN RUKARA

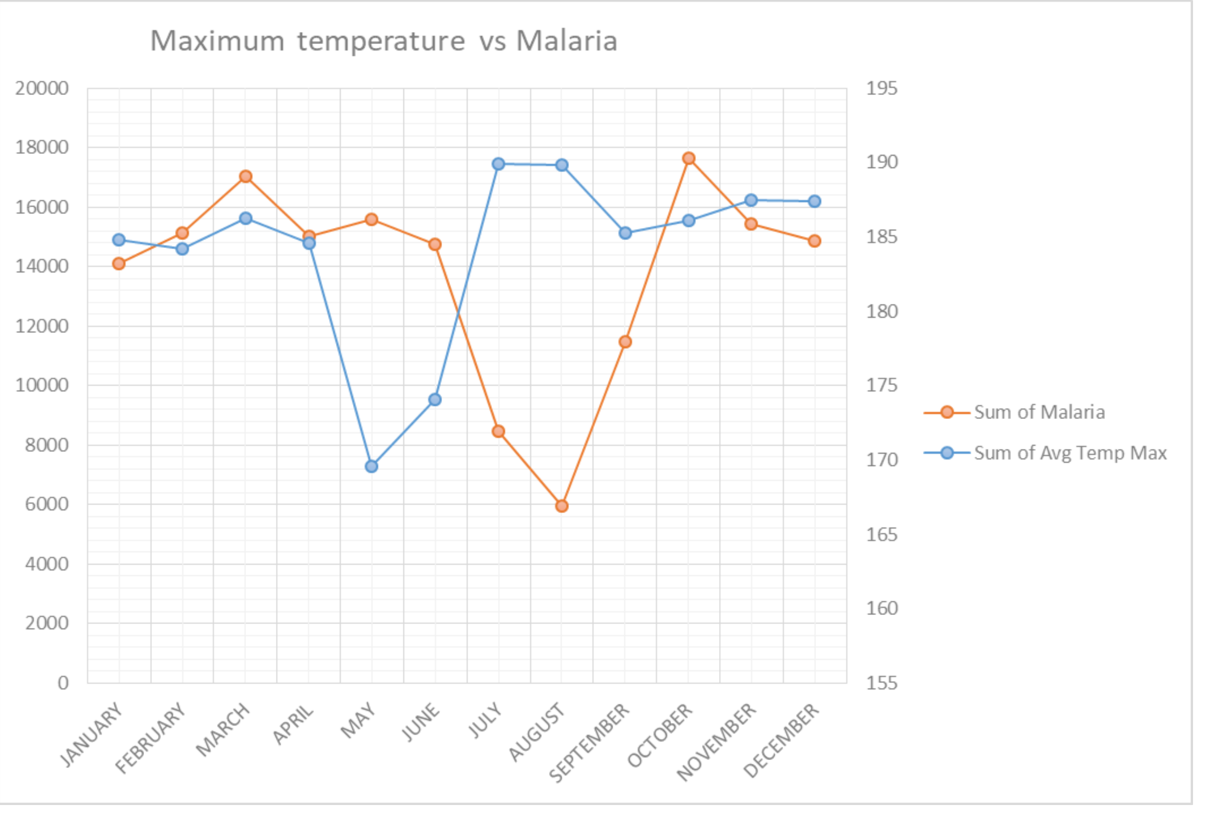

FIGURE 4.20: TOTAL MAXIMUM TEMPERATURE VERSUS TOTAL MALARIA MORBIDITY IN BUSORO

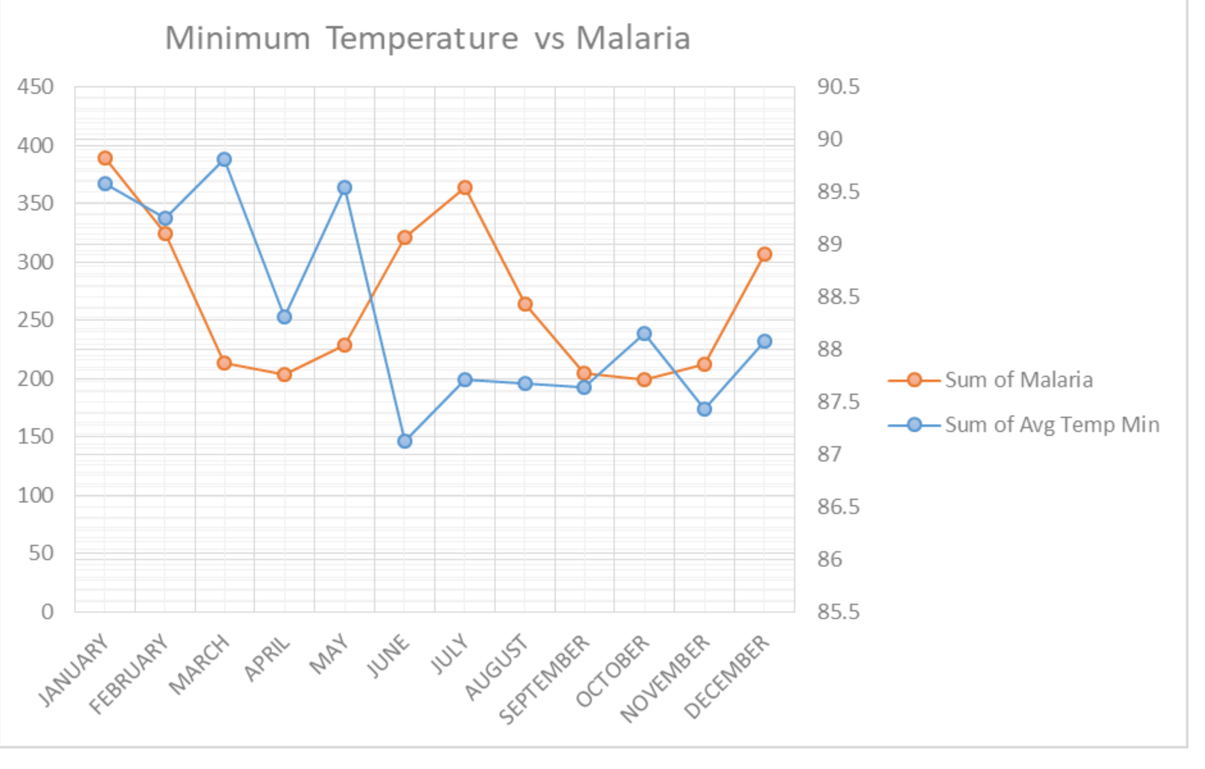

FIGURE 4.21: TOTAL MINIMUM TEMPERATURE VERSUS TOTAL MALARIA MORBIDITY IN BUNGWE

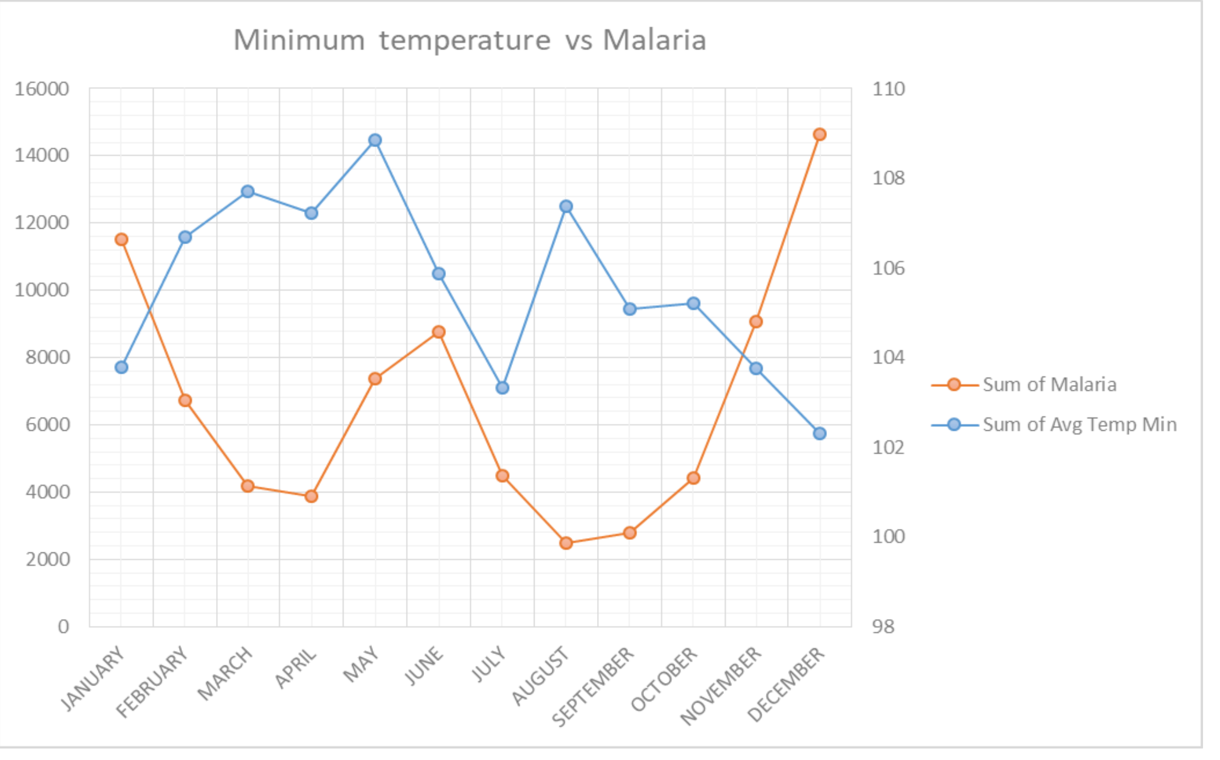

FIGURE 4.22: TOTAL MINIMUM TEMPERATURE VERSUS TOTAL MALARIA MORBIDITY IN RUKARA

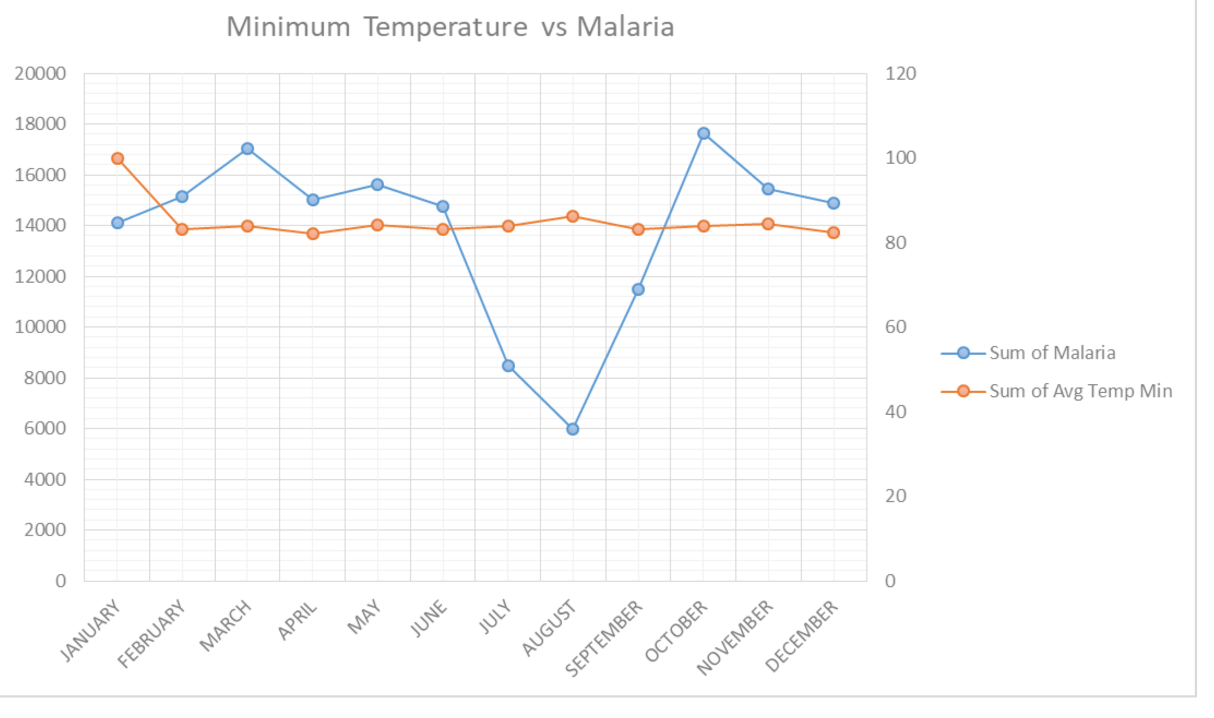

FIGURE 4.23: TOTAL MINIMUM TEMPERATURE VERSUS TOTAL MALARIA MORBIDITY IN BUSORO

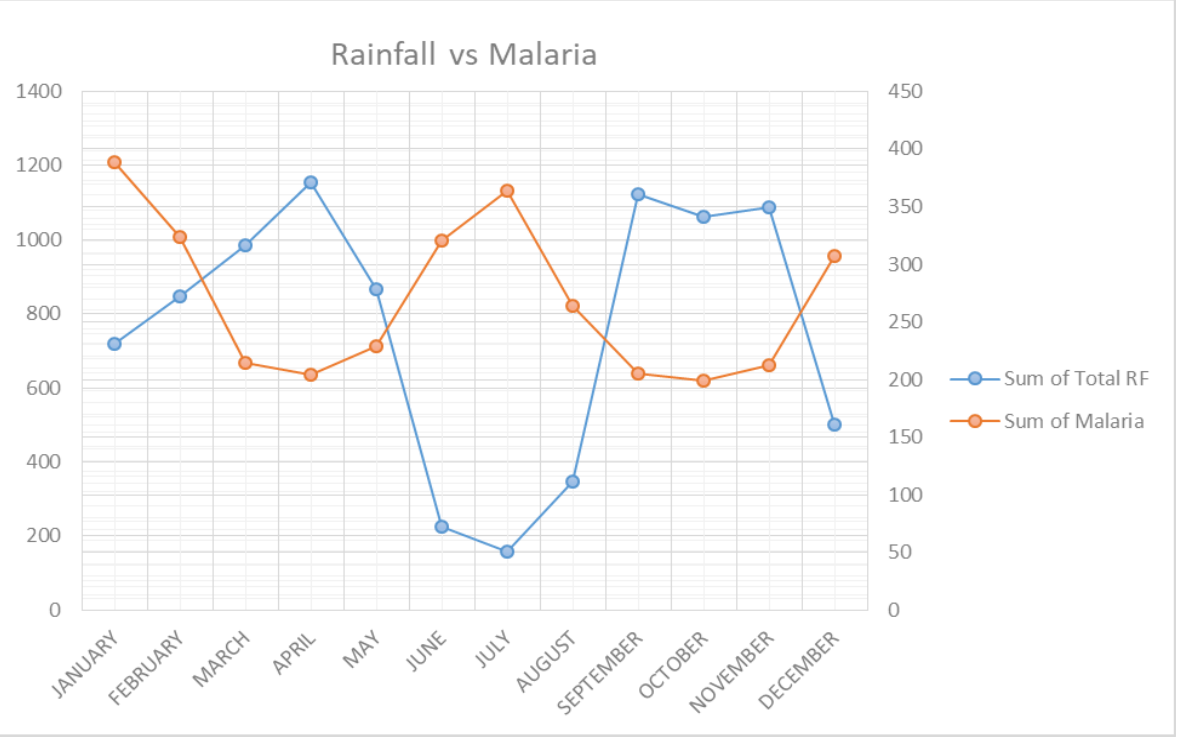

FIGURE 4.24: TOTAL RAINFALL VERSUS TOTAL MALARIA MORBIDITY IN BUNGWE

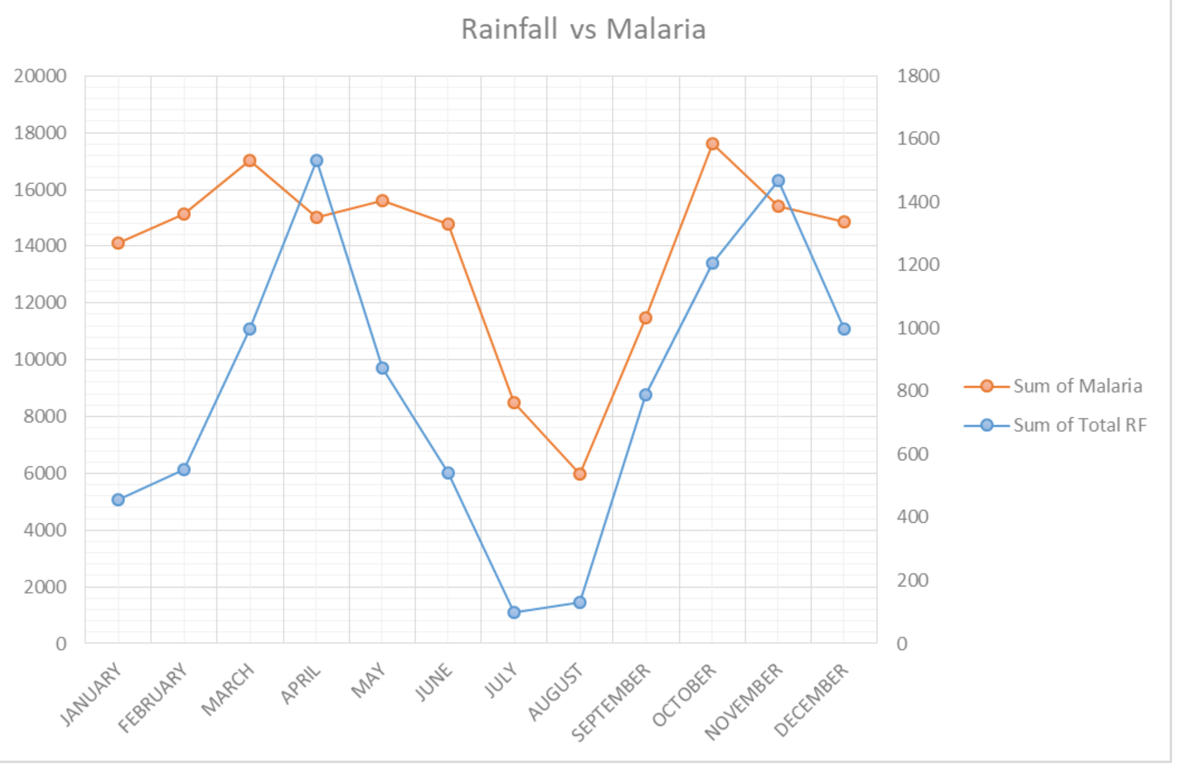

FIGURE 4.25: TOTAL RAINFALL VERSUS TOTAL MALARIA MORBIDITY IN BUSORO

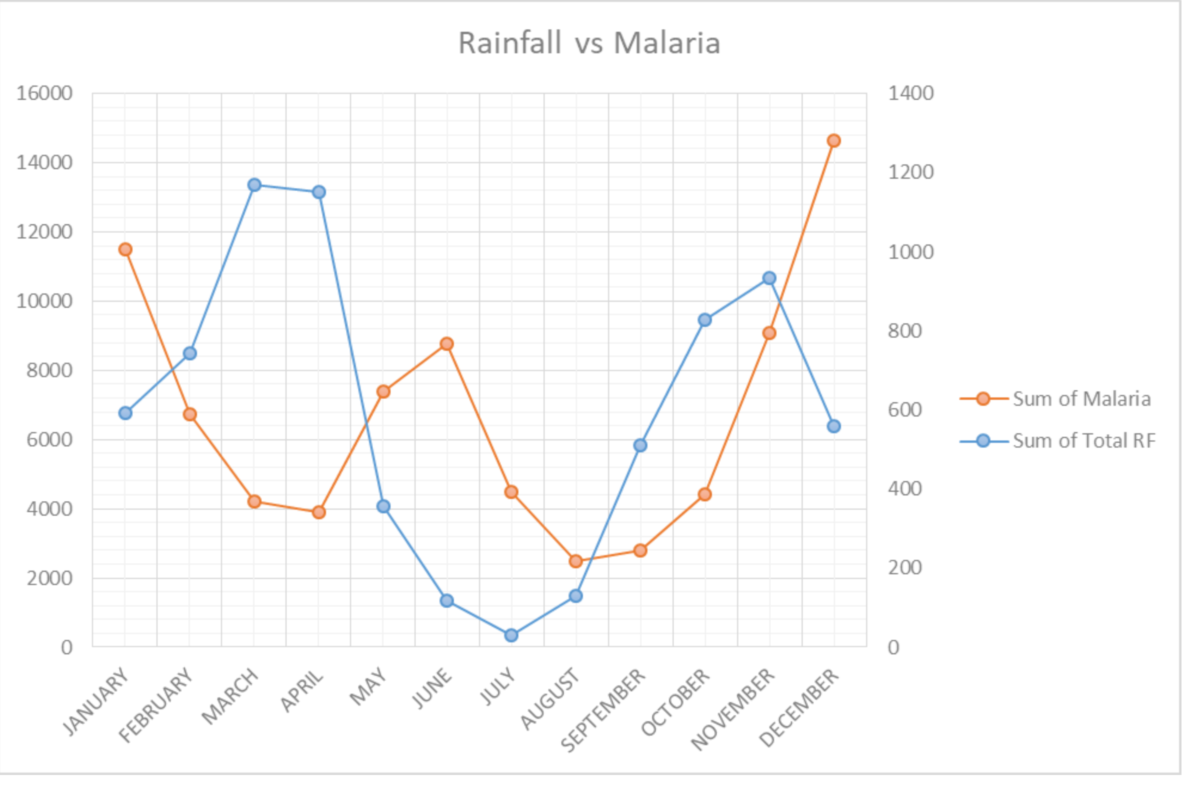

FIGURE 4.26: TOTAL RAINFALL VERSUS TOTAL MALARIA MORBIDITY IN RUKARA

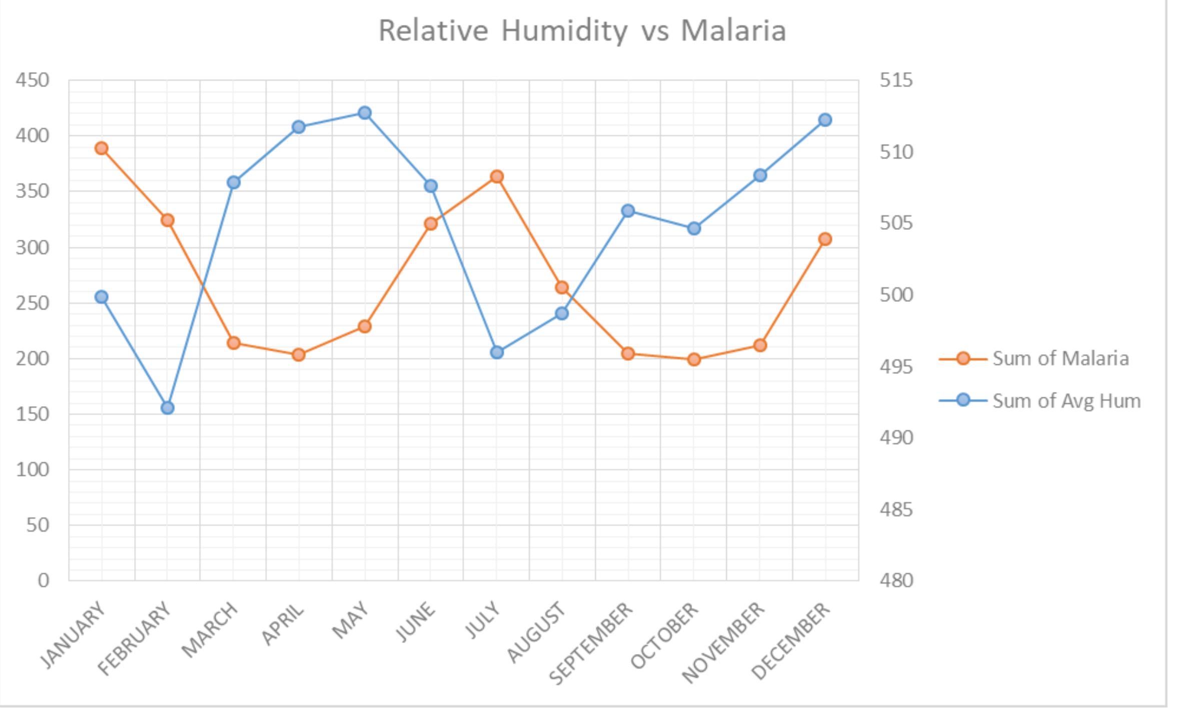

FIGURE 4.27: TOTAL RELATIVE HUMIDITY VERSUS TOTAL MALARIA MORBIDITY IN BUNGWE

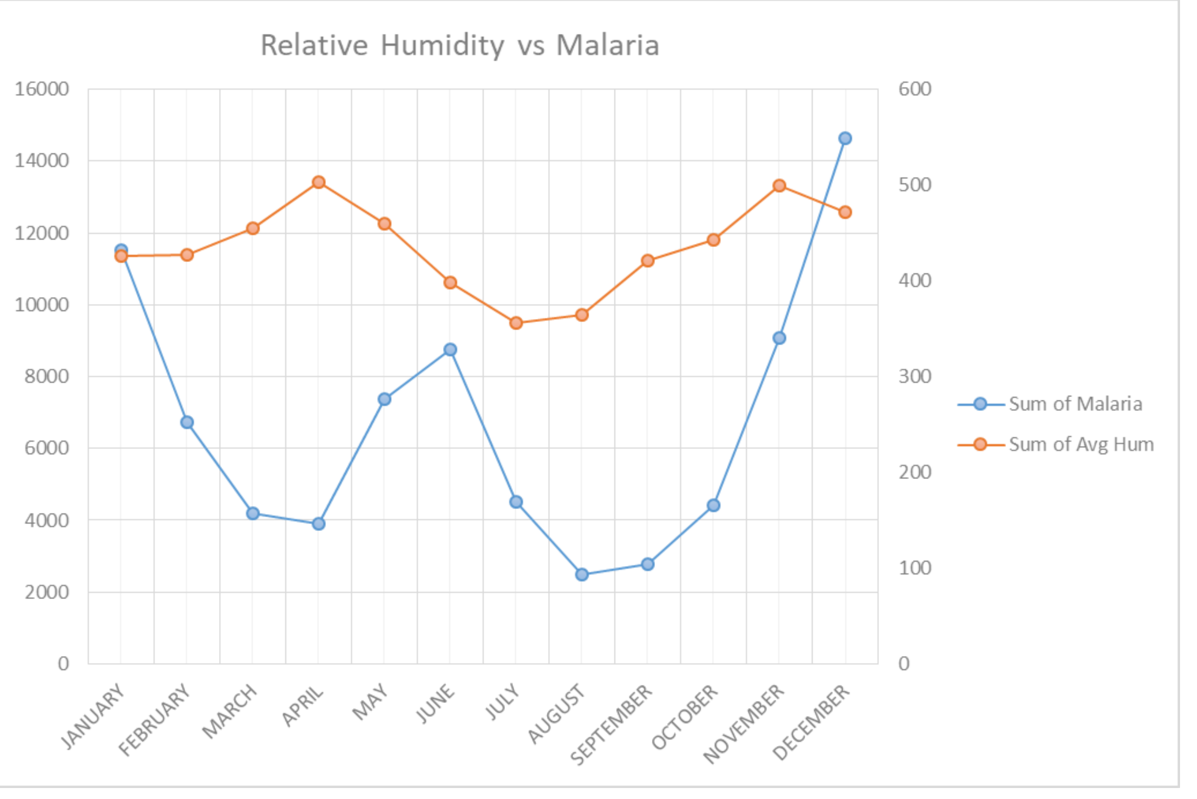

FIGURE 4.28: TOTAL RELATIVE HUMIDITY VERSUS TOTAL MALARIA MORBIDITY IN RUKARA

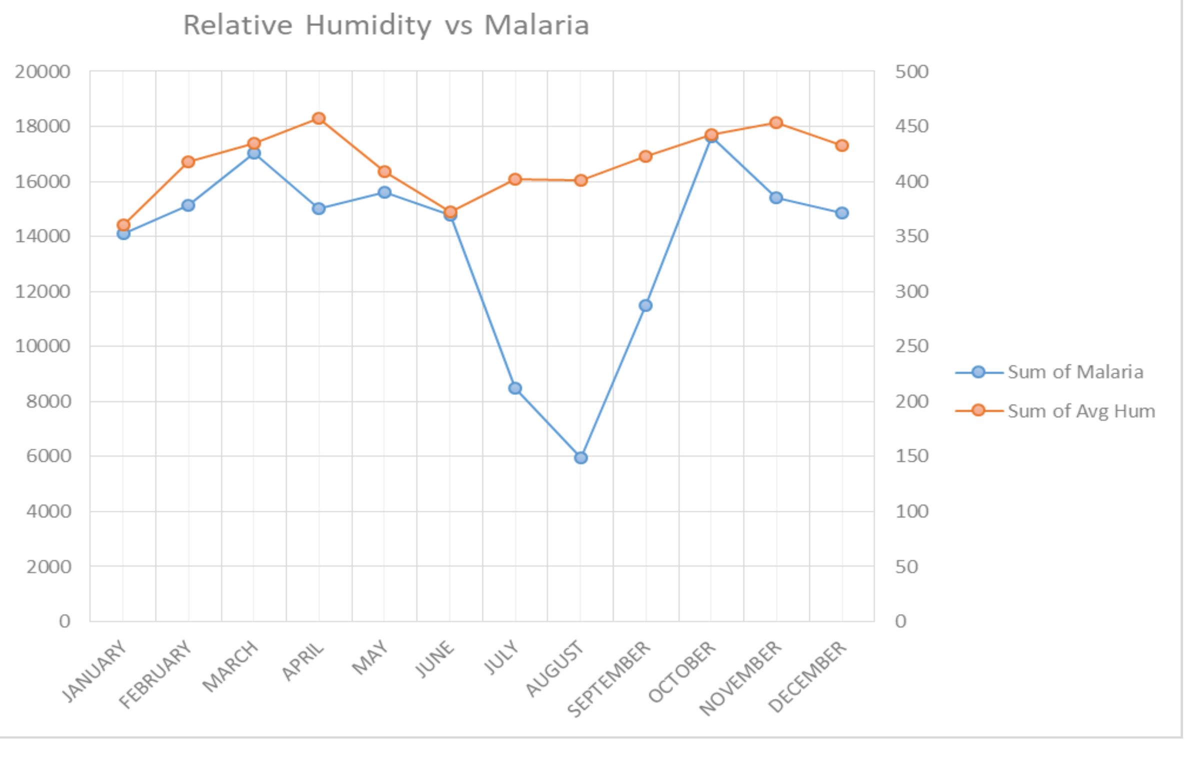

FIGURE 4.29: TOTAL RELATIVE HUMIDITY VERSUS TOTAL MALARIA MORBIDITY IN BUSORO