COLLEGE OF SCIENCE AND TECHNOLOGY

TITLE: ANALYSIS OF THE EFFECT OF CLIMATIC VARIABILITY ON HEALTH IN RWANDA, STUDY AREA: GATSIBO DISTRICT

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A dissertation submitted in partial fulfilment of the requirements for the degree of Master of Science in atmospheric and climate sciences.

In College of Science and technology

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Submission date: November 2024

DECLARATION

I declare that this dissertation is my original work, except where explicitly stated otherwise. It has undergone an anti-plagiarism check and is compliant, and this is the officially approved final version of the thesis:

Jean Claude UWIMANIDUHAYE

Signature ………………

Date : ..../........./2024

DEDICATION

I dedicate this project to:

- ✓ My God
- ✓ My lovely wife
- ✓ My daughter
- ✓ My parents
- ✓ My little sister

CERTIFICATION

This is to certify that this thesis has undergone an anti-plagiarism review and has been found compliant, and this is the officially approved final version of the thesis. **"*Analysis of the effect of climatic variability on health in Rwanda, study area: Gatsibo district*"**

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My first thanks go to my parents and my wife who mostly participated in all of my work by providing not only food and drinks but also life advice that allowed me to rise up to this high stage.

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Finally, I wish to also take this opportunity to thank the local students in atmospheric and climate science who hastened my adaption of different culture. May God bless all that have contributed to the success of this project research and the realization of this report.

Jean Claude UWIMANIDUHAYE

ABSTRACT

Malaria is an illness caused by protozoan parasites belonging to the genus Plasmodium, heavily influenced by climate and transmitted by Anopheles mosquitoes. Meteorological factors play a critical part in malaria morbidity by directly or indirectly affecting both the parasites and their vectors. Variations in temperature, rainfall, and humidity are linked to changes in malaria vector populations and, consequently, the disease's spread. This study aimed to discover the connection amongst climatic variability besides malaria morbidity in the Gatsibo region of Rwanda and to offer recommendations. To achieve this, I have used Spearman's correlation analysis and time-series analysis, drawing on data regarding climatic variables and malaria morbidity in Gatsibo from 2014 to 2023. The analysis using Spearman's correlation revealed that the monthly T_{av}, RH and rainfall are related by the monthly malaria morbidity within the research area. The research showed that monthly mean temperature is the most meteorological variable to correlate with malaria morbidity with correlation, r=0.032256 followed by relative humidity with correlation, r=0.3028 and the rainfall with correlation, r=0.01693, where the months with high mean temperature above 23^{o} ($T \geq 23^{o}$) corresponds to high peak of malaria morbidity in study area and the months with relative humidity above 60% (RH≥60%) corresponds to the high peak of malaria morbidity in study period of 2014-2023.

Keywords: Climate variability, malaria morbidity, Malaria vectors, Plasmodium, Malaria parasites.

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LIST OF ACRONYMS

CST- College of Science and Technology

UR- University of Rwanda

HC-Health Center

INSAT-Indian National Satellite System

ITNs –Insecticide Treated mosquito Nets

IRS - Indoor Remaining Showering

RH- Relative Humidity

Tav- Average Temperature

Tmin- Minimum Temperature

Tmax- Maximum Temperature

GHGs- Green House Gases

CHAPTER 1. INTRODUCTION AND BACKGROUND

1.1 BACKGROUND

The disease malaria is resulting from protozoan strongly influenced by climate and transmitted by Anopheles mosquitoes. Meteorological factors significantly influence malaria morbidity by impacting both the bloodsuckers and their paths, either straight or secondarily. Temperature, rainfall, and humidity are linked to the undercurrents of malaria path inhabitants and, consequently, the disease's transmission. Notably, the average temperature is crucial for the life cycle of malaria vectors. The bloodsucker is transmitted to individuals over the mouthfuls of disease-ridden parasites. Those infected with malaria typically experience severe illness characterized by high fever and shaking chills.

In Rwanda, malaria disease is additionally a public health concern since the whole populace is at risk of contracting this irresistible infection. Jungle fever has been the most cause of horribleness and mortality in Rwanda for a few long time [2]. It may be a life-threatening malady caused by disease via the mouthful of a feminine Anopheles parasite. It is mainly predominant among children and among pregnant ladies in malaria-prone ranges such as the Eastern Territory and Southern Area which together accounted for 79% of intestinal sickness cases in Rwanda in 2017 [8]. The Government of Rwanda has set up an obligatory wellbeing protections conspire known as mutuelle de santé which has made a difference the citizens of Rwanda to get to private or open wellbeing centers, clinics and healing center administrations. In expansion, the government has executed different methodologies to anticipate malaria sickness, such as dispersing insecticide-treated mosquitoes (ITNs) and utilizing indoor remaining showering (IRS) inside the family units.

The effect of climatic variability to the disease malaria morbidity within the country of Rwanda, case study of Gatsibo district is the most concern of this study. In Rwanda, numerous individuals particularly kids underneath the oldness of five and prenatal ladies are influenced by the malaria disease which is caused by climatic variability. Our investigation about has intervened on the techniques of malaria eradication. Rwanda is profoundly defenseless to climate variability [2] and is progressively encountering climate variability impacts. Rainfall has gotten to be progressively seriously, and the variability is anticipated to extend by 5% to 10% [3]. Most parts of Rwanda are

anticipated to involvement a rise within the normal rainfall with shorter and more seriously blustery seasons [4].
In addition, temperature rise have also been experienced, and a rise in temperature is anticipated over Rwanda within the coming a long time up to 2050, particularly amid the dry seasons [3]. Variations in temperature and rainfall with their conveyances constitute the key climate drivers and weather-related catastrophes that contrarily influence Rwandans and the in general economy.

In Rwanda, malaria morbidity is additionally a public health concern since the whole population is at risk of contracting this irresistible infection. Malaria disease has been the most cause of horribleness and mortality in Rwanda for a few a long time [2]. It may be a life-threatening malady caused by disease via the nibble of a feminine mosquito. The Government of Rwanda has set up an obligatory wellbeing protections conspire known as mutuelle de santé which has made a difference the citizens of Rwanda to get to private or open wellbeing centers, clinics and healing center administrations. In expansion, the government has executed different methodologies to anticipate malaria sickness, such as dispersing insecticide-treated mosquitoes (ITNs) and utilizing indoor remaining showering (IRS) inside the family units.

1.2 PROBLEM STATEMENT

Malaria disease is killing many people around the world, in Rwanda especially eastern province malaria is threatening many people especially young children and pregnant women. Climate variability has a great influence on malaria morbidity in Rwanda. Therefore, in this study we will intervene on the strategies for malaria eradication and provide some recommendations.

1.3. OBJECTIVES

1.3.1. Main Objective

The key aim of this research is to evaluate the relation among climate parameters variability and malaria morbidity within Rwanda and provide the specific future recommendations to the society about its prevention.

1.3.2. Specific Objective

To estimate the relationship between monthly average temperature, relative humidity, rainfall as well as monthly the malaria disease morbidity within Rwanda, Gatsibo district and providing some useful recommendations for malaria prevention and eradication.

1.4. SIGNIFICANCE OF THE STUDY

Human activities are increasingly impacting the climate through the scorching of remains firewood which lead to the increase of earth temperature in global warming. These actions release substantial amounts of GHGs into the sky. As the concentration of these gases (from both natural and human sources) rises, the climate changes more rapidly, leading to an increase in malaria transmission. Thus, it is crucial to address this issue before it escalates into an irreversible threat.

1.5. SCOPE AND LIMITATION OF THE STUDY

Primary concern of this research was climate parameters variabilities (Temperature, Precipitation, Humidity, Atmospheric pressure, Cloudiness, Wind, Solar radiation).This research focused on only those 3 parameters (temperature, precipitation and relative humidity) because they are the parameters which mostly affect mosquitoes spreading malaria.

1.6. ORGANIZATION OF THE STUDY

Our project contains of five chapters: Chapter One: Introduction to malaria morbidity in RWANDA, Gatsibo district and effect of different meteorological parameters variability on malaria morbidity in RWANDA. This contains a summary of our project. **Chapter two**: Literature review, this includes review on different factors affect malaria morbidity. **Chapter three**: materials and methodology, this includes materials and methods used in this research. **Chapter four**: Results and discussions. **Chapter five**: Summary, conclusion and recommendations.

CHAPTER 2. LITERATURE REVIEW

2.1 Climate variability within Rwanda

Temperature plays a crucial role in climate and weather prediction. Analyzing its behavior is crucial for grasping fluctuations in climate that can vary locally and temporarily on local, regional, and global levels. A couple of recent discussions on global temperature trends suggest that the Earth's lower atmosphere temperatures have rose by 0.5 °C to 0.7 °C throughout the 20th century. By analyzing temperature data collected from ten weather stations, this study examined fluctuations in climate in Rwanda between 2014 and 2023. Mateo Rwanda provided the data on temperature. During the recent analysis, the researchers employed software tools like Excel 2007 and INSTAT to manage the quality of the raw data. The analysis of maximum and minimum temperatures showed that the highest temperature trends were positive and significant at weather stations, while the trends for lowest temperatures were observed at 10 weather stations

2.2 Overview on malaria transmission and its causes

Malaria is a result of protozoan parasites of the genus Plasmodium. It ranks among top reasons for sickness and mortality globally. 90% of these fatalities happen in the continent of Africa, with remaining 10% in Asia and Latin America, making it the highest common transmitted by vectors illness globally. In developing countries, it ranks as the fourths highest foremost origin of decease among kids below the stage of five besides expectant mothers [22, 35]. Furthermore, the illness continues to be a major contributor to human sickness and death, with significant medical, financial, and emotional repercussions globally. Over half of the global population faces the possibility of contracting malaria, with the percentage rising annually due to declining healthcare systems, increasing resistance to medication and insecticides, along with the effects of climate change and natural calamities [2, 23].

Meteorological conditions play an essential involvement in the spread of malaria by impacting both parasites and vectors among the disease, either directly or indirectly. Temperature, precipitation, moisture levels were linked to fluctuations of mosquito inhabitants and consequently, to the transmission of the illness. In particular, the ambient temperature is crucial in determining conditions of the mosquitoes. Temperature also contribute to the life of the parasite inside the parasite during the sporogonic cycle. At temperatures below 16°C, parasite growth and development, taking approximately 9 to 10 days at 28°C. The minimum temperatures required for development are around 16°C [25]. The vector's daily survival is also temperature-dependent. Daily survival is approximately 90% within the temperature range of 15°C to 34°C. The greatest number of vectors that survive the development phase noted at hotness ranging from 27 Celsius to 31 Celcius [14, 25]. Rain creates suitable conditions for mosquitoes to deposit their eggs and helps maintain a RH of 50 to 60%, which is necessary for mosquito survival.

Many studies have connected changes in malaria rates to weather conditions over time, but there is inconsistency in the key factors identified and their respective impact estimates. Moreover, there is limited documentation on how individual characteristics may alter the potential effects. This research aims to investigate how meteorological conditions impact Guangdong, China, and determine which sub-populations are more vulnerable. Spearman correlation analysis was used to determine which climatic variables were impacting malaria.

Malaria has plagued Ethiopia for years, hindering public health and socioeconomic development. Understanding the drivers of disease malaria prevalence over given region is key towards effective avoidance and control policies. Over time, malaria incidence and species composition fluctuate due to factors such as prior climate conditions. Weather influences malaria transmission through its impact on vector survival, longevity, and parasite development rates. Sentence structures and lengths vary, demonstrating complexity, while climatic determinants remain crucial to plasmodium propagation and mosquito-borne infection patterns. Regional analyses of malaria trends and associated weather covariates facilitate well-targeted responses

2.3 Anopheles mosquito transmitting malaria

While water represents life for many creatures, it also fosters propagation for mosquitoes seeking sites for spawning offspring. Females flit between sky and sea, descending upon aquatic habitats to deposit clusters of fertile eggs afloat the surface or in low-lying places where seasonal inundation might one day submerge and stimulate hatching. When rains replenish drying pools and warming airs breathe into being, the eggs awaken and new larvae wriggle free, continuing the perpetual cycle that ever-multiplying mosquitoes perpetuate across the globe. With unvarying regularity, these winged vectors return to renew the generational circle, ensuring survival of their species through periods of feast and famine.

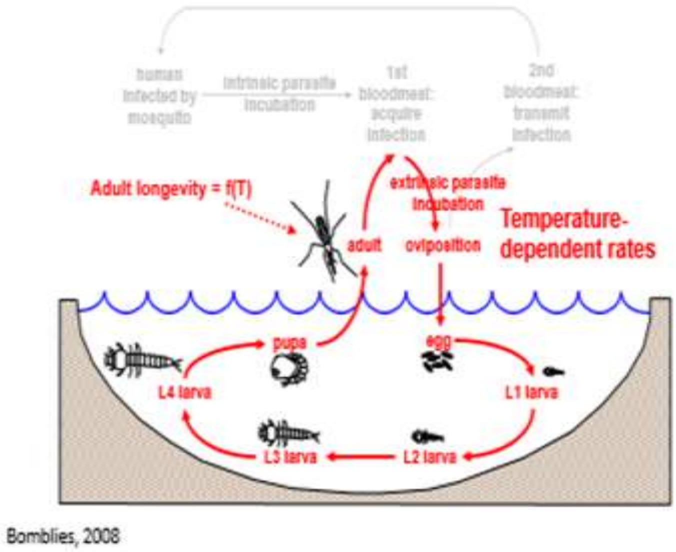

Figure 1: Anopheles mosquito life cycle

CHAPTER 3. RESEARCH METHODOLOGY

3.1. Overview

After finalization for research proposal, we have taken malaria case data from R.B.C making comparison with meteorological data which was gotten from Rwanda meteorology agency. SPSS statistical software version 15 for windows and ArcGIS were used to analyse the data, which helped in making some useful results that lead us towards the conclusion and further recommendations out of it.

3.2. Study area description

Gatsibo district is found in eastern province and it has 14 sectors, 69 Cells and 603 villages with a population of **551,164** inhabitants, its surface area is 1582.32 km^2.

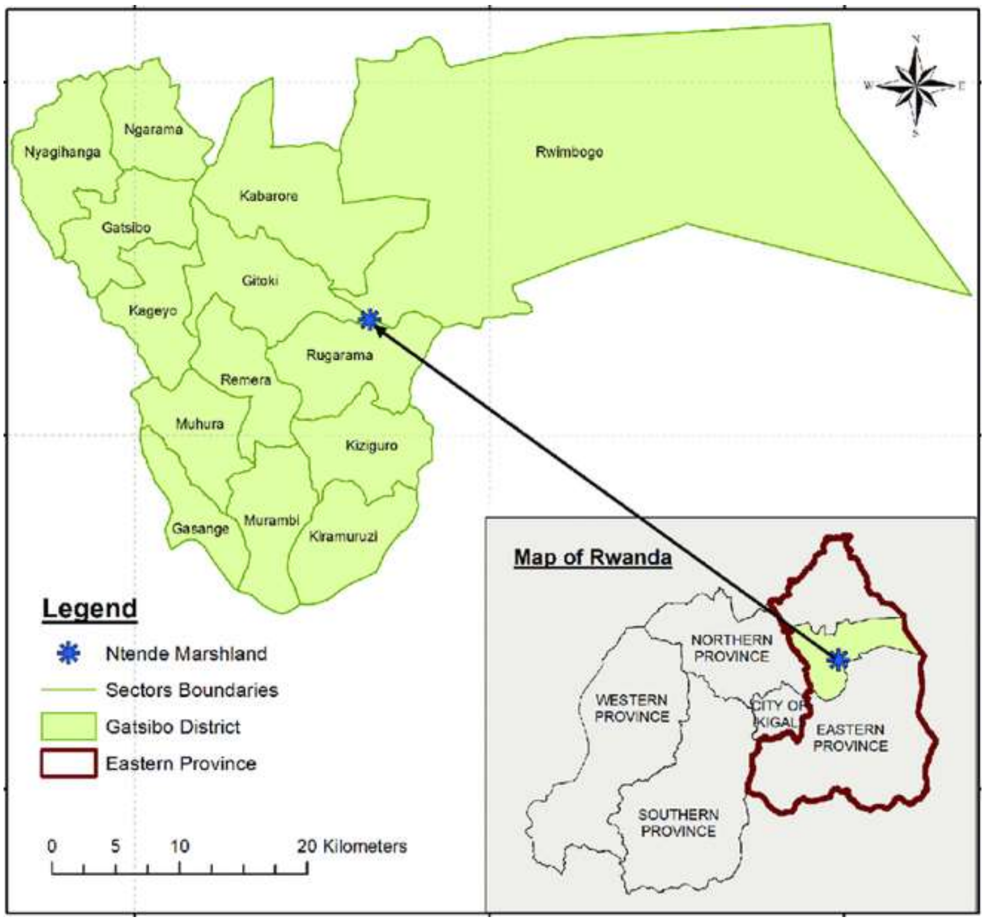

Figure 2:Map of Gatsibo district

3.3. Data Collection

Data for a period of 10 years from 2014-2023 on malaria cases were obtained from Rwanda Biomedical Centre (R.B.C) and 10 years (from 2014-2023) Meteorological or climatic data Tmin, Tmax, relative humidity and to rainfall) produced by Rwanda Meteorology Agency (Meteo Rwanda).

3.4. Data analysis Strategies

Data analysis includes gathering all the gotten information by giving them arrange, structure and meaning. The monthly rainfall, relative humidity, minimum temperature and maximum temperature (From January to december for each year) were recorded. Information from Rwanda meteorology organization and Rwanda biomedical Centre. We have used SPSS software v16 measurable computer program and ArcGIS was used to make spatial distribution.

For the purpose of studying meteorological factors and malaria morbidity, monthly cases were as dependent, while T_{max}, T_{min} , rainfall and RH values at each study area were considered independent variables. Spearman correlation analysis we used to detect relationship characteristic between meteorological factors and incidence of malaria.

3.5. Ethical consideration

Meteo Rwanda and R.B.C Staff allowed me to conduct my research using their data because; they understood well the use of this research corresponding with reducing the malaria incidence in Rwanda.

CHAPTER 4. OUTCOMES AND DISCUSSION

4.1. OUTCOMES

4.1.1. Spatial spreading of malaria cases in Gatsibo district, 2014-2023

The figures below indicate that there is spatial spreading of malaria cases in Gatsibo region.A variable development of malaria incidence observed in 2014 up 2023 has been detected. A rise in malaria belongings occurred in April 2018 and the lowest trend was observed in August 2022.

4.1.1.a Spatial spreading of malaria cases in Gatsibo district, January 2014-2023

The figure below shows the spatial spreading of malaria cases in Gatsibo region for January 2014-2023. The malaria morbidity is high in kiziguro sector with the average malaria cases of 414.964 and the low malaria cases for January 2014 up 2023 is observed in Rwimbogo sector with 255 malaria cases.

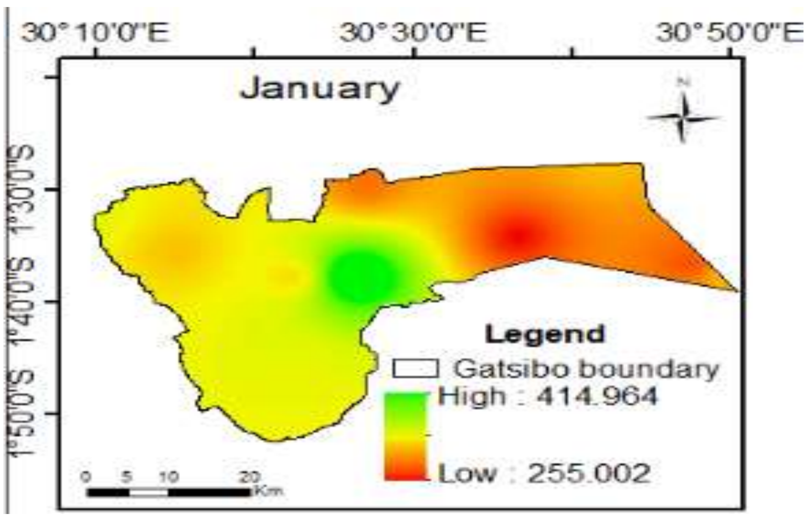

Figure 3: Spatial spreading of malaria cases in Gatsibo district, January 2014-2023

4.1.1.b Spatial spreading of malaria cases in Gatsibo district, February 2014-2023

The figure below shows the spatial spreading of malaria cases in Gatsibo region for February 2014-2023. The malaria morbidity is high in Kabarore sector with the average malaria cases of

300.751, the lowest -8-malaria cases for February 2014-2023 is observed in Rwimbogo sector with 134.366 malaria cases.

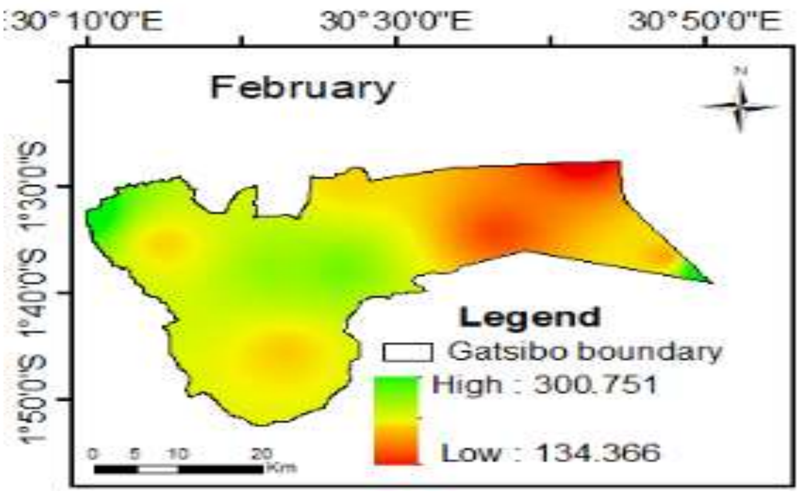

Figure 4: Spatial spreading of malaria cases in Gatsibo district, February 2014-2023

4.1.1.c ***Spatial distribution of malaria cases in Gatsibo district, March 2014-2023***

The figure below shows the spatial spreading of malaria morbidity in Gatsibo region for March 2014-2023. The malaria morbidity is high in Kiramuruzi sector with the average malaria cases of 199.995, the lowest malaria cases for March 2014-2023 is observed in Gitoki sector with 100.006 malaria cases.

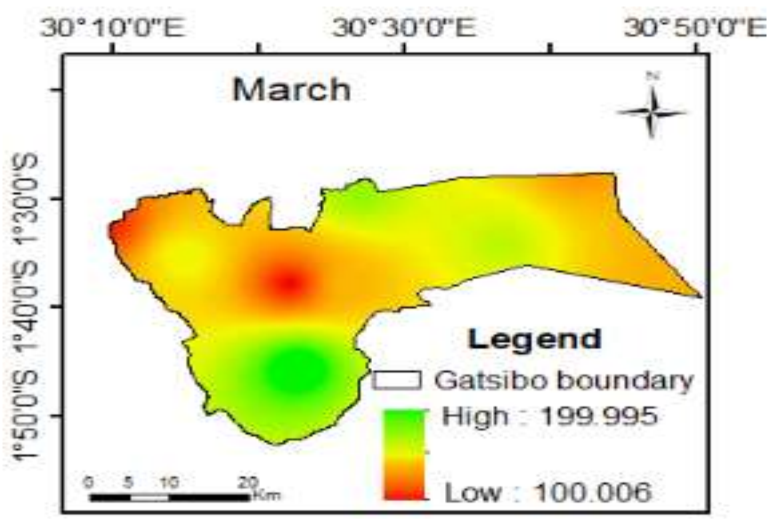

Figure 5: Spatial distribution of malaria cases in Gatsibo district, March 2014-2023

4.1.1.d ***Spatial spreading of malaria cases in Gatsibo district, April 2014-2023***

The figure below shows the spatial spreading of malaria morbidity in Gatsibo region for April 2014-2023. The malaria morbidity is high in Kiziguro sector with the average malaria cases of 523.987 and the lowest number of malaria cases for April 2014-2023 is observed in Rwimbogo sector with 128.356 malaria cases.

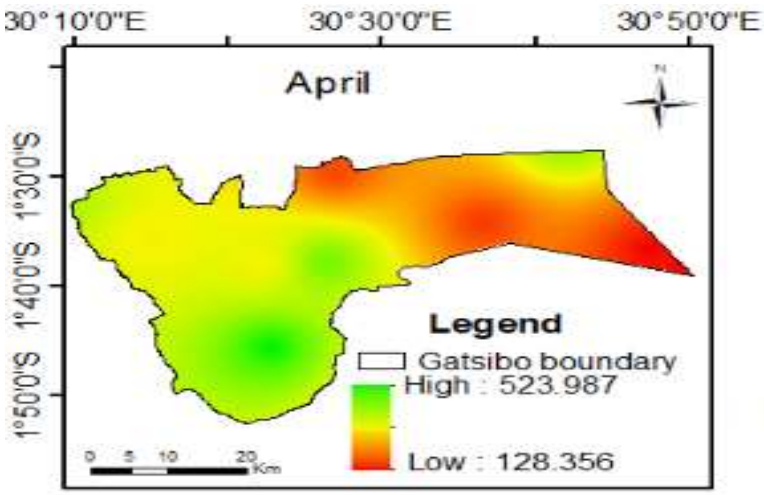

Figure 6: Spatial spreading of malaria cases in Gatsibo district, April 2014-2023

4.1.1.e Spatial spreading of malaria cases in Gatsibo district, May 2014-2023

The figure below shows the spatial distribution of malaria morbidity in Gatsibo region for May 2014-2023. The malaria morbidity is high in Rwimbogo sector with the average malaria cases of 164.993, the lowest malaria cases for May 2014-2023 is observed in Rugarama sector with 98.0128 malaria cases.

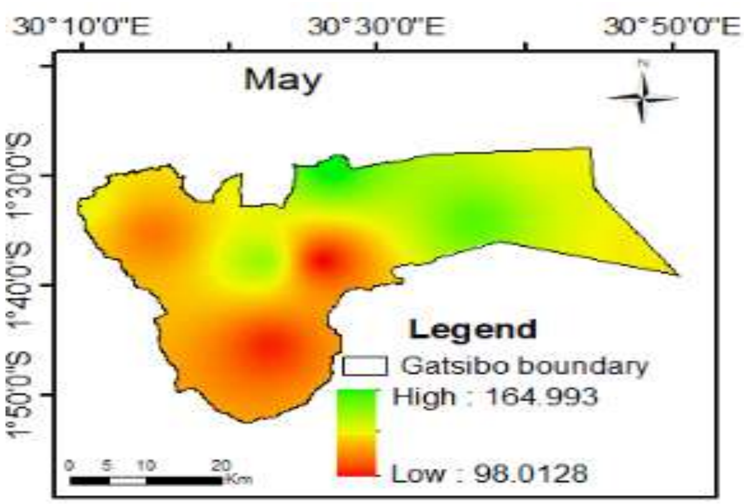

Figure 7: Spatial spreading of malaria cases in Gatsibo district, May 2014-2023

4.1.1.f Spatial spreading of malaria cases in Gatsibo district, June 2014-2023

The figure below shows the spatial spreading of malaria morbidity in Gatsibo region for June 2014-2023. The malaria morbidity is high in Rwimbogo sector with the average malaria cases of 155.998, the lowest malaria cases for June 2014-2023 is observed in Kiziguro sector with 98.6157 malaria cases.

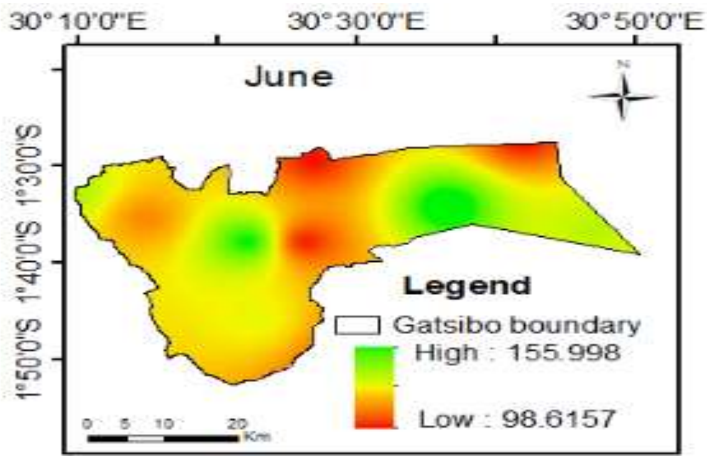

Figure 8: Spatial spreading of malaria cases in Gatsibo district, June 2014-2023

4.1.1.g Spatial spreading of malaria cases in Gatsibo district, July 2014-2023

The figure below shows the spatial distribution of malaria morbidity in Gatsibo region for July 2014-2023. The malaria morbidity is high in Rwimbogo sector with the average malaria cases of 320.996, the lowest malaria cases for July 2014-2023 is observed in Kabarore sector with 149.028 malaria cases.

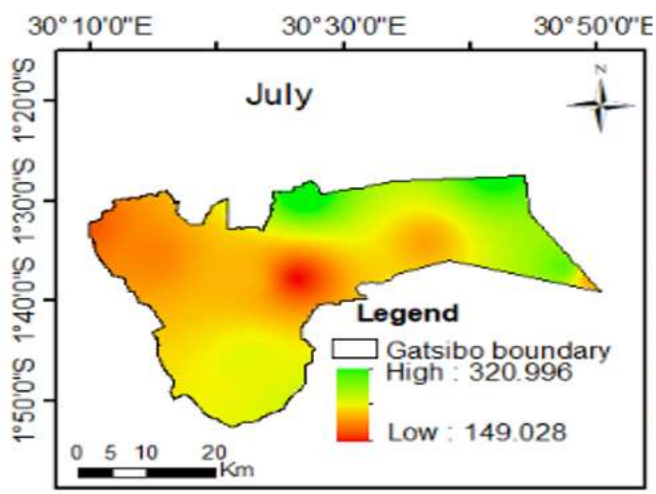

Figure 9: Spatial spreading of malaria cases in Gatsibo district, June 2014-2023

4.1.1.h ***Spatial spreading of malaria cases in Gatsibo district, August 2014-2023***

The figure below shows the spatial distribution of malaria morbidity in Gatsibo region for August 2014-2023. The malaria morbidity is high in Murambi sector with the average malaria cases of 132.998 and the lowest malaria cases for August 2014-2023 is observed in Rwimbogo sector with 68.8679 malaria cases.

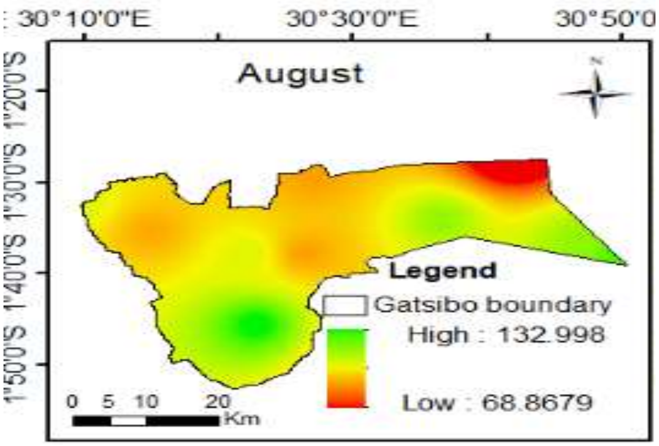

Figure 10: Spatial spreading of malaria cases in Gatsibo district, August 2014-2023

4.1.1.i Spatial spreading of malaria cases in Gatsibo district, September 2014-2023

The figure below shows the spatial distribution of malaria morbidity in Gatsibo region for September2014-2023. The malaria morbidity is high in Rwimbogo sector with the average malaria cases of 203.988, the lowest malaria cases for September 2014-2023 is observed in Nyagihanga sector with 100.015 malaria cases.

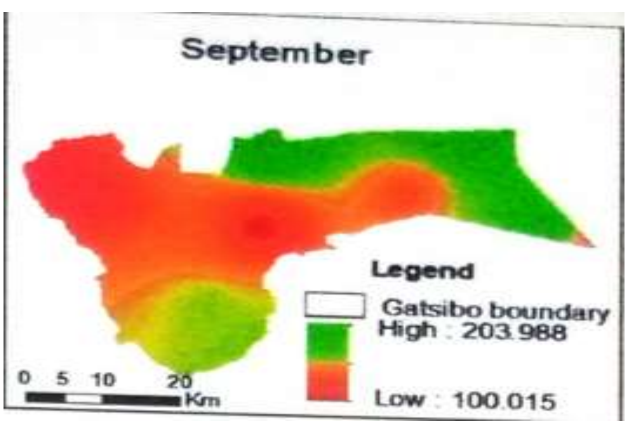

Figure 11:Spatial spreading of malaria cases in Gatsibo district, September 2014-2023

4.1.1.j Spatial spreading of malaria cases in Gatsibo district, October 2014-2023

The figure below shows the spatial distribution of malaria morbidity in Gatsibo region for October 2014-2023. The malaria morbidity is high in Rwimbogo sector with the average malaria cases of 239.984, the lowest malaria cases for October 2014-2023 is observed in Rugarama sector with 111.015 malaria cases.

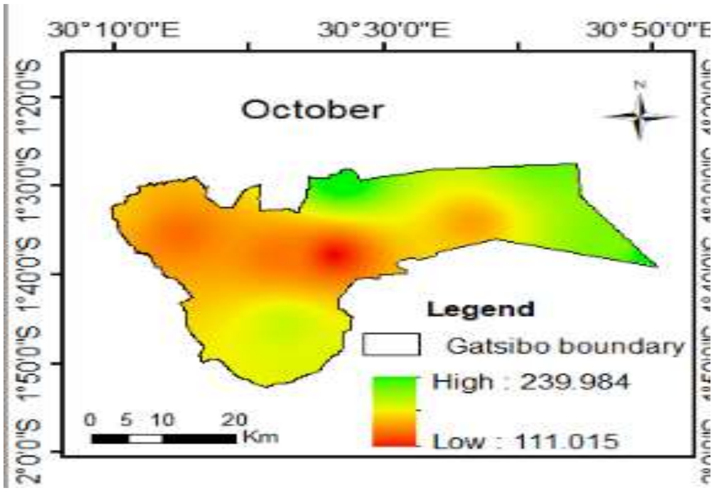

Figure 12: Spatial spreading of malaria cases in Gatsibo district, October 2014-2023

4.1.1.j **Spatial spreading of malaria cases in Gatsibo district, November 2014-2023**

The figure below shows the spatial distribution of malaria morbidity in Gatsibo region for November 2014-2023. The malaria morbidity is high in Rwimbogo sector with the average malaria cases of 311.977, the lowest malaria cases for November 2014-2023 is observed in Gitoki sector with 132.008 malaria cases.

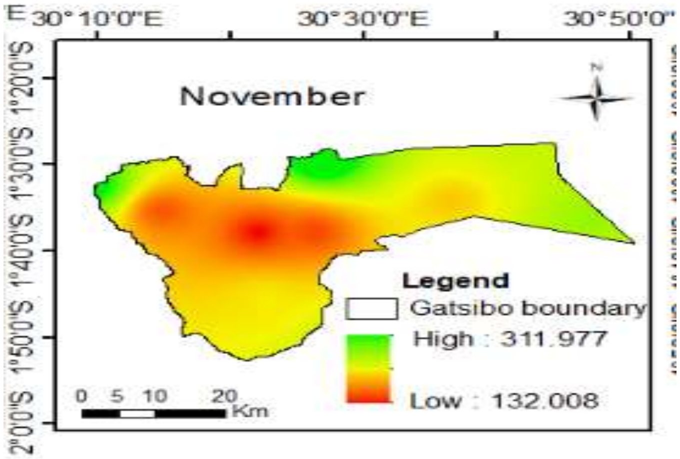

Figure 13: *Spatial spreading of malaria cases in Gatsibo district, November 2014-2023*

4.1.1.k **Spatial spreading of malaria cases in Gatsibo district, December 2014-2023**

The figure below shows the spatial distribution of malaria morbidity in Gatsibo region for December 2014-2023. The malaria morbidity is high in Rwimbogo sector with the average malaria cases of 320.996, the lowest malaria cases for December 2014-2023 is observed in Ngarama sector with 149.028 malaria cases.

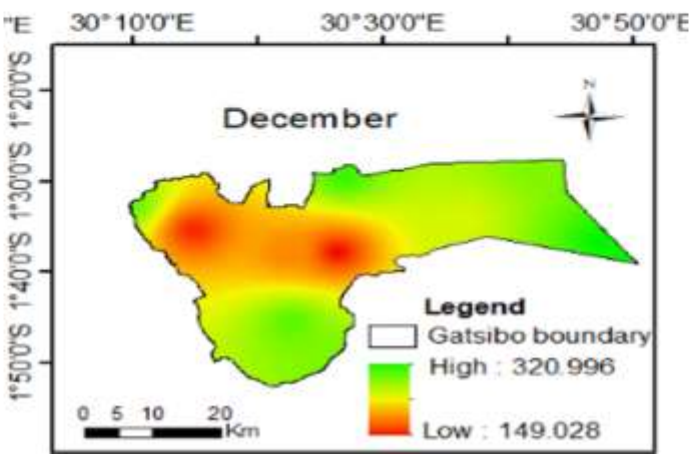

Figure 14: *Spatial spreading of malaria cases in Gatsibo district, December 2014-2023*

4.1.2. Relationship between the occurrence of malaria and climatic factors within Gatsibo district

We have used the equation for the relationship factor to examine a relationship amongst malaria occurrence in Gatsibo with climatic parameter (climatological parameter):

Carrel(x,y) = $(\Sigma((x - \bar{x})(y - \bar{y}))) / (\sqrt{(\Sigma(x - \bar{x})^2)} * \sqrt{(\Sigma(y - \bar{y})^2)})$

where $\bar{x}$ and $\bar{y}$ are the sample means average(Malaria incidence) and average(Climatic parameter).

As much as the relationship coefficient is closer to +1 or -1, it demonstrates positive (+1) or negative (-1) relationship between the 2 parameters. Positive relationship implies that in case the values in one cluster are expanding, the values within the other cluster increment as well. A relationship coefficient that's closer to 0, demonstrates no relationship.

Table 1: Relationship among meteorological factors and monthly incidence of malaria disease in Gatsibo district, 2014-2023.

Correlation	**Mean temperature(°c)**	**Relative humidity(%)**	**Rainfall(mm)**
Malaria incidence	0.032256	0.02128	0.01693

The table above indicates that the monthly T_{av}, RH, and rainfall are all positively associated with the monthly incidence of jungle fever in Gatsibo region throughout the research timeframe, with the monthly average temperature exhibiting the strongest correlation, followed by monthly relative humidity.

4.1.2.1. Malaria incidence compared to meteorological factors

Relationship assessment indicates statistical significant relationship amongst meteorological parameters (T_{av}, Rain and RH) and malaria incidence (***Table 1***). Monthly mean temperature shows the highest positive correlation, r =0.032256 followed by relative humidity with the positive correlation, r = 0.02128 and the weakest one is the rainfall with positive correlation, r= 0.01693.this implies that if the temperature rises the mosquitoes transmitting malaria will be able to survive for an extended period of time. While the humidity besides rainfall has a great role in mosquito life cycle as rain provides water to lay eggs.

4.1.2.1.a. Monthly malaria cases and climatic conditions, 2014

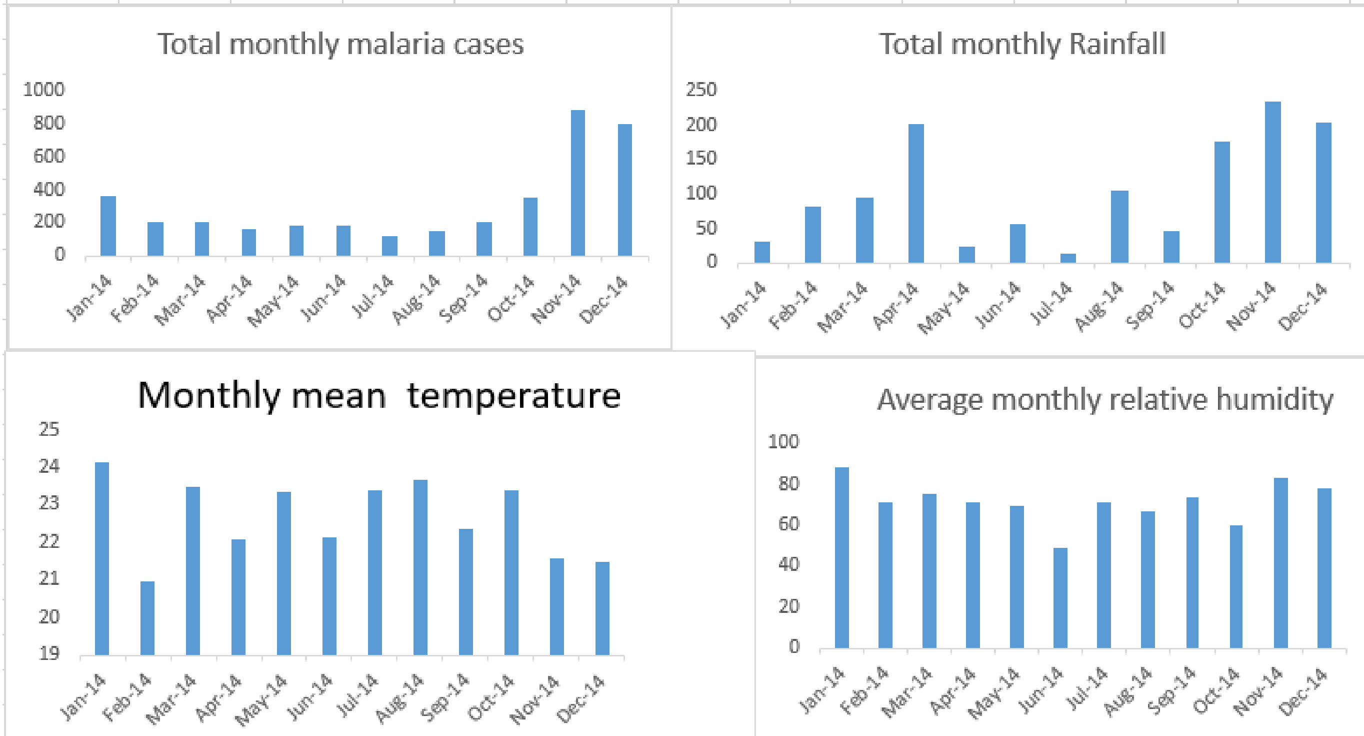

Figure 14: Monthly malaria cases and climatic conditions, 2014

The character above shows that within 2014, the highest disease malaria incidence arisen in November, with 800 cases, while the lowest was recorded in July, with 180 cases. The peak total monthly rainfall also took place in November, reaching 220 mm, compared to the lowest in July, at 20 mm. The highest average monthly temperature was recorded in January at 24°C, while the lowest was in February at 21°C. Additionally, the peak total monthly relative humidity was observed in January at 88%, with the lowest recorded in June at 50%.

4.1.2.1.b. Monthly malaria cases and climatic conditions, 2015

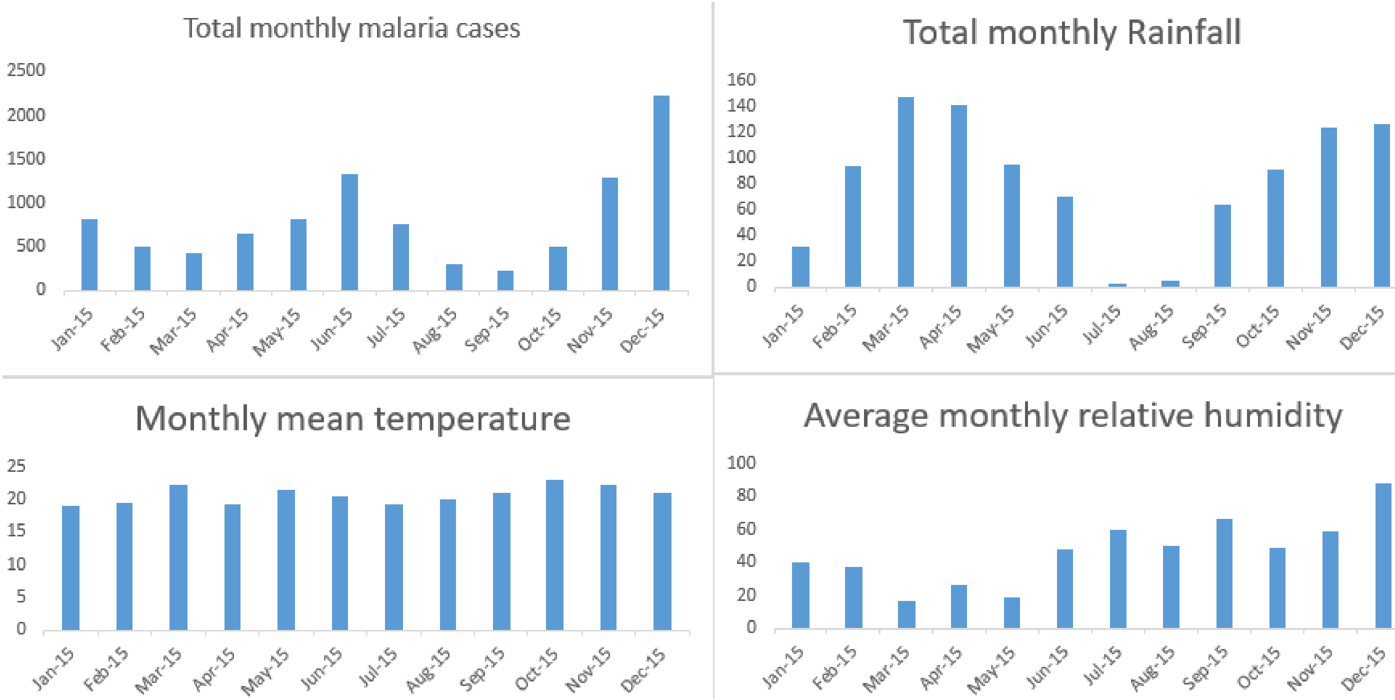

Figure 15: Monthly malaria cases and climatic conditions, 2015

The figure above reveals that in 2015, the highest malaria incidence occurred in December, with 2,200 cases, while the lowest was in September, with 100 cases. The peak monthly rainfall was recorded in March at 150 mm, whereas the lowest was in July at 5 mm. The highest average monthly temperature was noted in October at 23.5°C, while the lowest was in April at 16°C. Additionally, the peak monthly relative humidity was observed in December at 85%, with the lowest recorded in March at 20%.

4.1.2.1.c Monthly malaria cases and climatic conditions, 2016

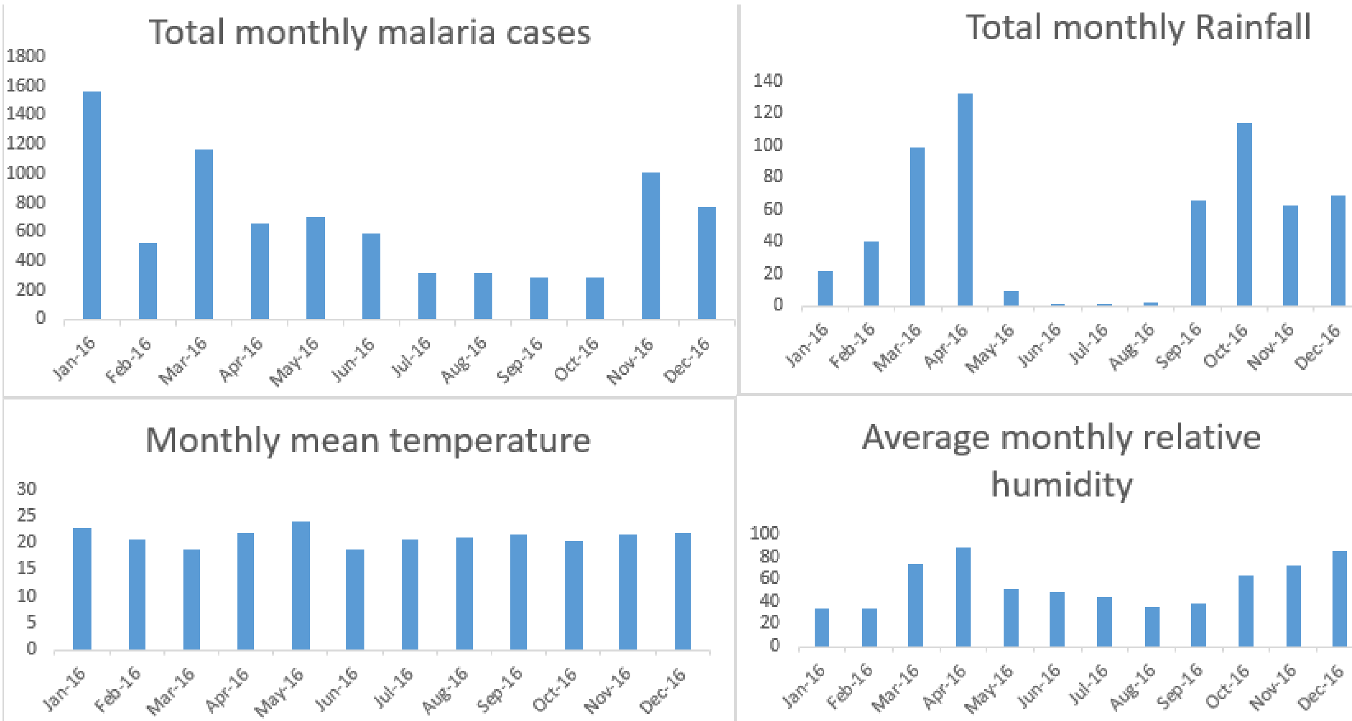

Figure 16: Monthly malaria cases and climatic conditions, 2016

The character above shows that in 2016, the highest disease malaria incidence happened in January, with 1,500 cases, while the lowest was recorded in July, with 250 cases. The peak monthly rainfall was observed in April at 130 mm, while the lowest was in July at 5 mm. The highest average monthly temperature was noted in May at 24°C, and the lowest was in March at 18°C. Additionally, the peak monthly relative humidity was recorded in April at 82%, with the lowest in August at 30%.

4.1.2.1.d Monthly malaria cases and climatic conditions, 2017

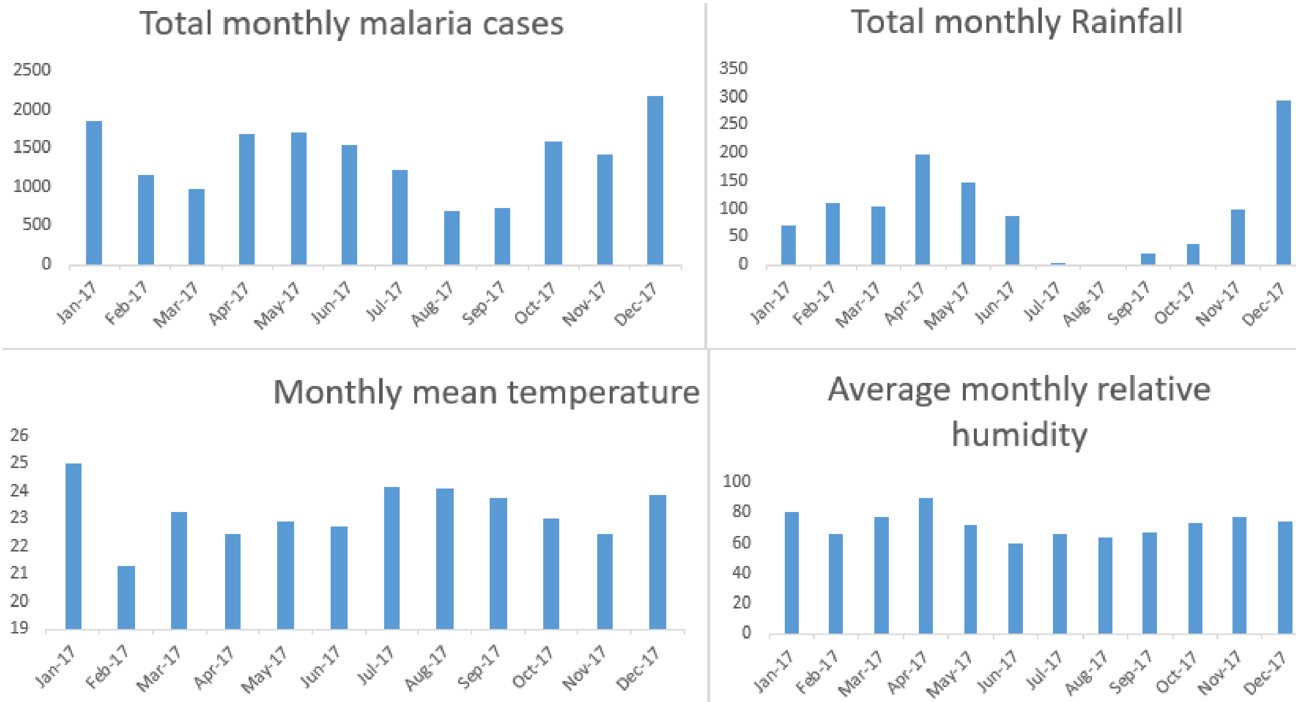

Figure 17: Monthly malaria cases and climatic conditions, 2017

The figure above illustrates that in 2017, the highest malaria incidence occurred in December, with 2,000 cases, while the lowest was noted in August, with 500 cases. The peak monthly rainfall was recorded in December at 250 mm, while the lowest was in August at 0 mm. The highest average monthly temperature was observed in January at 25°C, and the lowest was in February at 21°C. Additionally, the peak monthly relative humidity was observed in April at 82%, with the lowest recorded in June at 60%.

4.1.2.1.e. Monthly malaria cases and climatic conditions, 2018

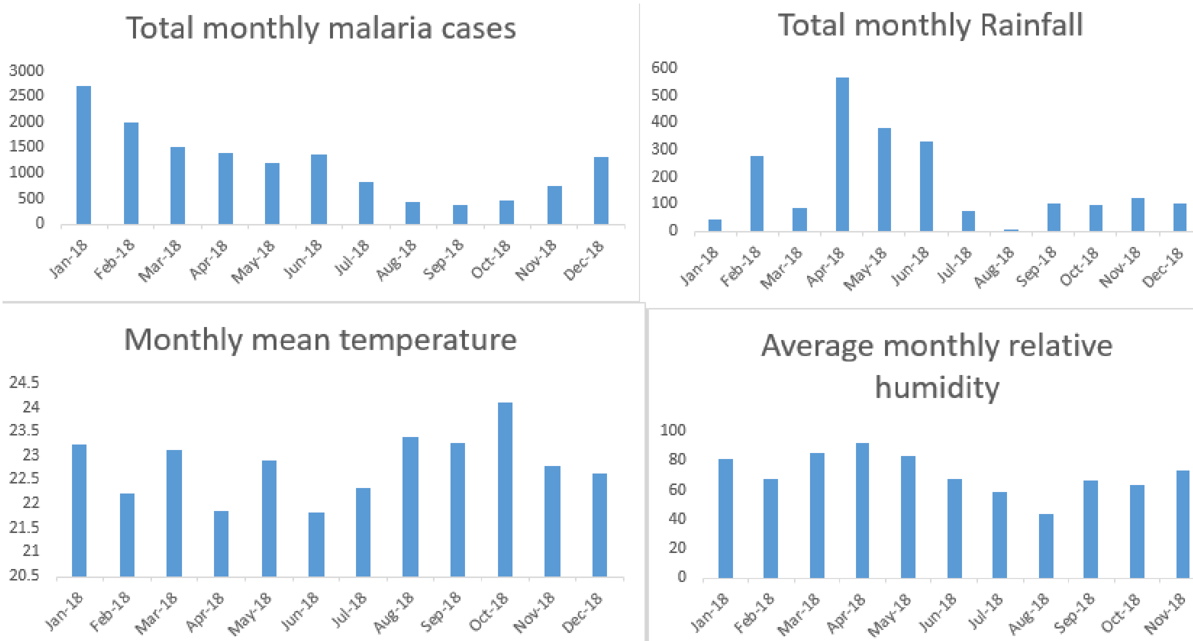

Figure 18: Monthly malaria cases and climatic conditions, 2018

The numeral above designates that in 2018, the highest disease malaria incidence befallen in January, with 2,600 cases, while the lowest was recorded in August, with 500 cases. The peak monthly rainfall was observed in April at 580 mm, whereas the lowest was in August at 6 mm. The highest average monthly temperature was noted in October at 24.2°C, while the lowest was in April at 21.5°C. Additionally, the peak monthly relative humidity was recorded in April at 89%, with the lowest in August at 40%.

4.1.2.1.f . Monthly malaria cases and climatic conditions, 2019

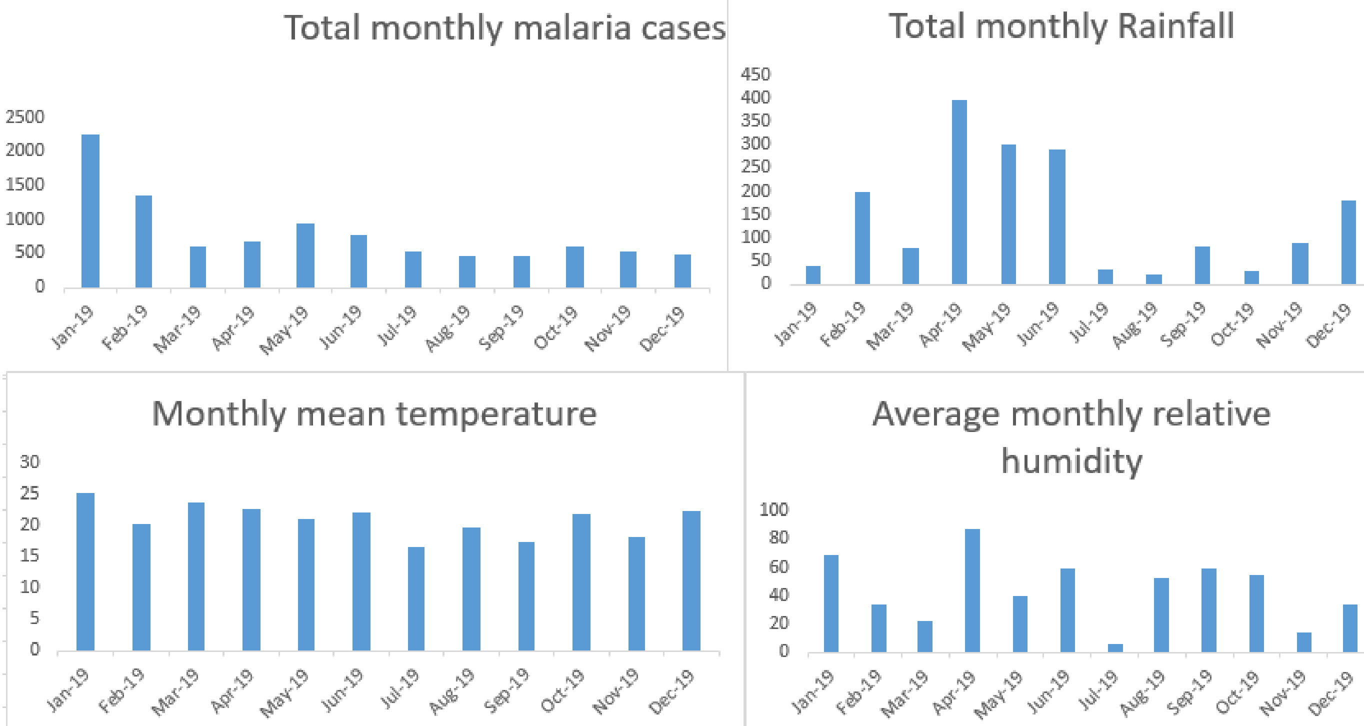

Figure 19: Monthly malaria cases and climatic conditions, 2019

The character above specifies that in 2019, the highest disease malaria incidence ensued in January, with 2,300 cases, while the lowest was recorded in August, with 505 cases. The peak monthly rainfall was observed in April at 400 mm, while the lowest was in August at 20 mm. The highest average monthly temperature was noted in January at 25°C, and the lowest was in September at 18°C. Additionally, the peak monthly relative humidity was recorded in April at 90%, with the lowest in July at 6%.

4.1.2.1.g. Monthly malaria cases and climatic conditions, 2020

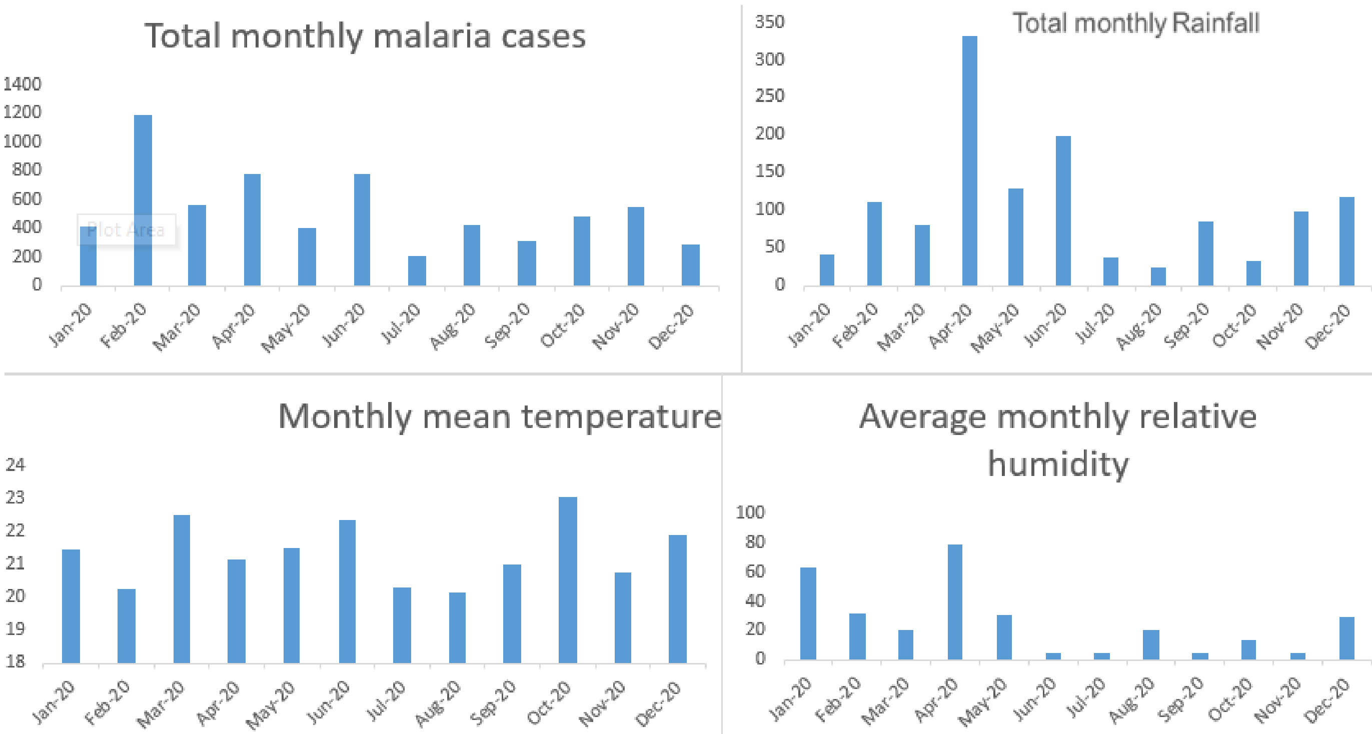

Figure 20: Monthly malaria cases and climatic conditions, 2020

The figure above shows that in 2020, the highest malaria incidence occurred in February, with 1,160 cases, while the lowest was recorded in July, with 200 cases. The peak monthly rainfall was observed in April at 340 mm, while the lowest was in August at 20 mm. The highest average monthly temperature was noted in October at 23°C, and the lowest was in February at 20°C. Additionally, the peak monthly relative humidity was recorded in April at 79%, with the lowest in June at 5%.

4.1.2.1.g. Monthly malaria cases and climatic conditions, 2021

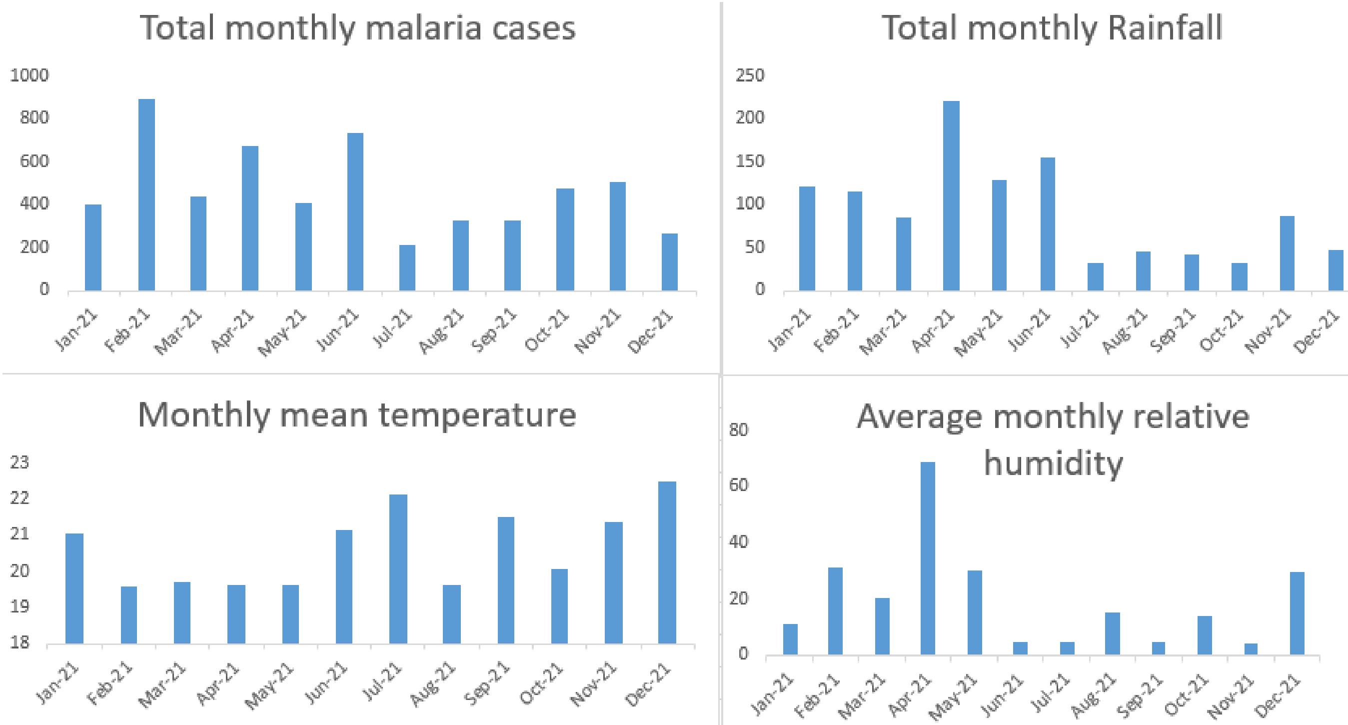

Figure 21: Monthly malaria cases and climatic conditions, 2021

The numeral above shows that in 2021, the highest disease malaria incidence arose in February, with 850 cases, while the lowest was recorded in July, with 190 cases. The peak monthly rainfall was observed in April at 220 mm, whereas the lowest was in July at 18 mm. The highest average monthly temperature was noted in December at 22.5°C, while the lowest was in February at 19.5°C. Additionally, the peak monthly relative humidity was recorded in April at 70%, with the lowest in June at 7%.

4.1.2.1.h. Monthly malaria cases and climatic conditions, 2022

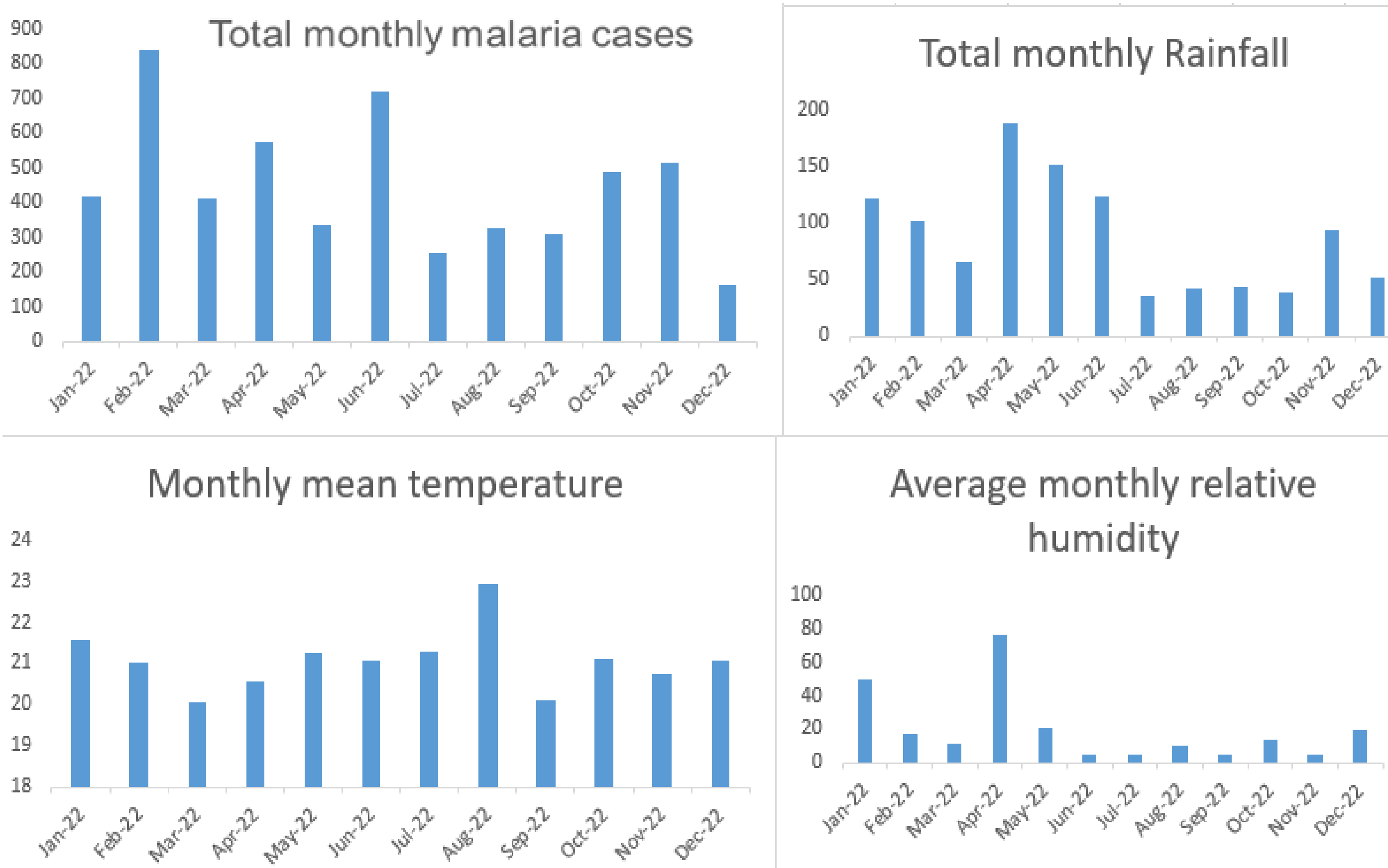

Figure 22: Monthly malaria cases and climatic conditions, 2022

The character above designates that in 2022, the highest disease malaria incidence befell in February, with 810 cases, while the lowest was recorded in December, with 150 cases. The peak monthly rainfall was observed in April at 180 mm, whereas the lowest was in July at 30 mm. The highest average monthly temperature was noted in August at 23.2°C, while the lowest was in September at 19.8°C. Additionally, the peak monthly relative humidity was recorded in April at 79%, with the lowest in June at 6%.

4.1.2.1.i. Monthly malaria cases and climatic conditions, 2023

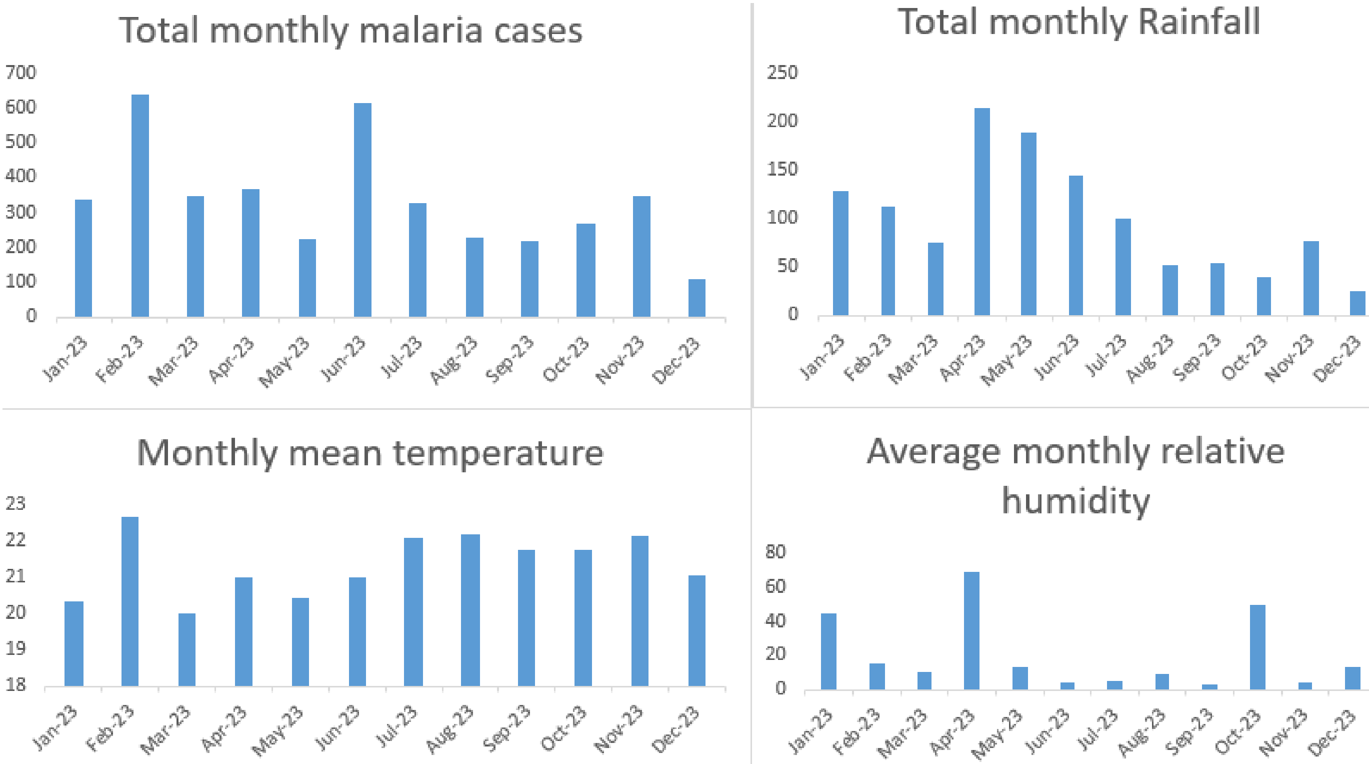

Figure 23: Monthly malaria cases and climatic conditions, 2023

The character above shows that in 2023, the highest malaria incidence occurred in February, with 620 cases, while the lowest was recorded in December, with 100 cases. The peak monthly rainfall was observed in April at 225 mm, whereas the lowest was in December at 24 mm. The highest average monthly temperature was noted in February at 22.8°C, while the lowest was in March at 19.6°C. Additionally, the peak monthly relative humidity was recorded in April at 68%, with the lowest in September at 5%.

In this research, the association coefficient for the relationship among monthly average temperature and malaria incidence is ; r=0.032256, r=0.02128 for relative humidity and r=0.01693 for rainfall with malaria cases. The months with high mean temperature above 23^{o} (T≥23^{o}) corresponds to high peak of malaria morbidity in study area and the months with relative humidity above 60% (RH≥60%) corresponds to the high peak of malaria morbidity in study period of 2014-2023.

Based on our findings, monthly mean temperature was the most important variable associated with malaria incidence in Gatsibo district. A temperature increase would improve the condition for Plasmodium and Anopheles to extend their lengthened season, leading to an earlier time of onset in malaria incidence as well as wider scale by inducing transmission into presently unaffected populations. In terms of importance, the only variable whose effect on malaria morbidity was more important than that of rainfall (but less so that relative humidity) was monthly total rainfall in each area. If a tiny amount of rainfall is present, water availability supports both the aquatic stage life cycle of the mosquitoes and increases relative humidity (enabling adult mosquito survival).

CHAPTER 5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

Although the outcomes specified that some meteorological variables show weak association with disease malaria incidence in Gatsibo district, changes within current month meteorological factors can impact malaria case occurrences in the following month. This provides an early warning that allows the healthcare method to be better equipped and assign limited resources successfully to lessen malaria-related death and sickness. In Gatsibo district, greater focus should be placed on microclimate changes resulting from human activities as well as other non-climatic elements influencing malaria patterns, instead of solely on climatic changeability associated with climate change or global warming.

5.2. Recommendation

- I encourage Rwandans to protect our environment to prevent climate change, which contributes to the development of Anopheles mosquitoes.
- I encourage Rwandans to cut down the bushes around their homes where mosquitoes hide and lay their eggs.

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