Spatio-Temporal Changes in Malaria Seasonality Over Ghana Using a Weather-Driven Dynamical Mathematical Malaria Model.

by

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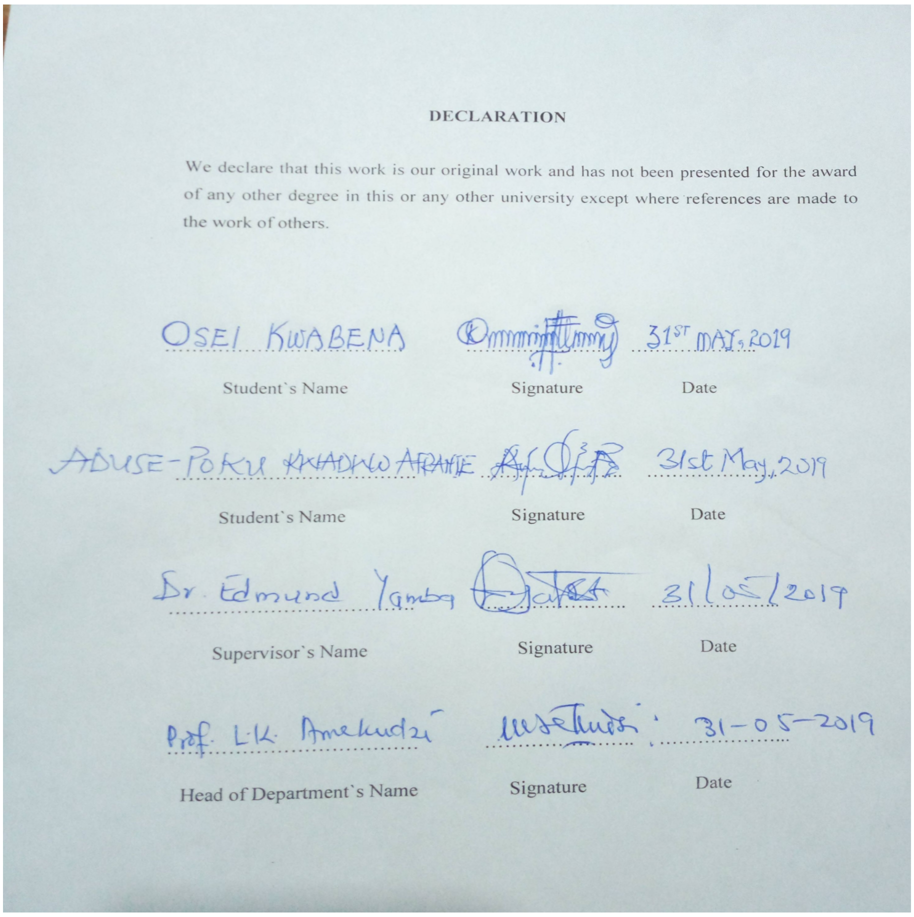
Declaration

We hereby declare that this thesis is our own work towards the achievement of BSc, and to the best of our knowledge, it contains no material or whatsoever previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.



DECLARATION

We declare that this work is our original work and has not been presented for the award of any other degree in this or any other university except where references are made to the work of others.

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Dedication

This research study is dedicated to God Almighty for His grace and strength throughout the study. Also, we dedicate this work to our parents for their support, guidance and motivation and to everyone who made this project a success.

Acknowledgment

To God Almighty be the glory, honour and praise for making it possible for us to attempt such a project and for a fruitful fulfillment. We would like to express our profound gratitude to our supervisor Dr Edmund I. Yamba under whose valuable guidance we undertook this project. We are also grateful to Prof. Leonard K. Amekudzi and all lecturers in the Department of Physics, we are extremely thankful and indebted to them for sharing their expertise and encouragement. We also thank our parents for the unceasing encouragement, support and attention. We express our gratitude to the Ghana Meteorological Agency (GMet) for providing the observed data used in this study. Finally, we appreciate the efforts of all, who directly or indirectly have lent their hand in this project.

Abstract

Malaria is one of the public health challenges in Ghana. Available research works in Ghana provide limited information on the seasonal variability of malaria throughout the year. This study therefore assesses the seasonal contrast in monthly malaria rather than whether there is malaria in a month or not. A weather-driven dynamical mathematical malaria model, VECTRI was used to simulate Entomological Inoculation Rates (EIR) for Ghana using climate and population density data. The seasonal malaria regimes were then classified from the EIR using a seasonality index. The result revealed that malaria seasonality is concentrated in more months of the year as one traverses from the north towards the south especially towards the forest areas. Trends in malaria seasonlity were insignificant across the country with the exception of Accra which showed a significant increase in the seasonality of the disease. The findings also suggested that the degree of malaria seasonality within the country is more closely linked to the variation in temperature and rainfall patterns in the country as well as the population density. The outcome of this study provide useful information for the health sector regarding malaria control and possible elimination. The VECTRI model is useful for evaluation of malaria outcome in Ghana.

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CHAPTER 1

Introduction

1.1 Background

Malaria is one of the most dangerous vector-borne diseases in the world (Dhingra et al., 2010). This life-threatening disease is caused by parasites that are transmitted to people through the bites of infected female Anopheles mosquitoes (Holt et al., 2002; Beck-Johnson et al., 2013). There are a number of reported malaria cases every year, which is accompanied by a high mortality rate in both adults and infants with the latter standing a higher risk of mortality (Rowe et al., 2006). In Africa an estimated 300-500 million cases of malaria occur each year resulting in approximately 1 million deaths. More than 90% of these are in children under 5 years of age (Maslove et al., 2009). According to the World Health Organization (WHO), in 2017 there were an estimated 219 million cases of malaria in 90 countries. Malaria deaths reached 435,000 in 2017. The WHO also proposed that the African region carries a disproportionately high share of the global malaria burden. In 2017, the region was home to 92% of malaria cases and 93% of malaria deaths. The whole of Ghana is at risk of malaria. Malaria in Ghana accounts for 4% of the global burden and 7% of the malaria burden in West Africa. Malaria was responsible for 19% of all recorded deaths in Ghana in 2015. Malaria-attributable mortality has declined significantly from 19% (2010) to 4.2% (2016). Malaria under 5 years' case fatality rate declined from 15% to 11% from 2010 to 2016. The health facility case fatality rate among children under five years of age declined from 14 percent in 2000 to less than half a percent in 2016. Malaria admissions increased from 280,000 to 340,000 persons between 2000 and 2017. National malaria death rates are difficult to assess because reliably diagnosed malaria is likely to be cured, and deaths in the community from undiagnosed malaria could be misattributed in retrospective enquiries to other febrile causes of death, or vice-versa (Dhingra et al., 2010). Malaria cases show seasonal peaks in most endemic settings, and the choice and timing for optimal malaria control may vary by seasonality (Roca-Feltrer et al., 2009). Malaria seasonality is therefore a characteristic of a time series in which the malaria statistics or data experiences regular and predictable changes that recur every calendar year (Platt et al., 2018). As a matter of fact, knowing the seasonality of malaria would help the health sector in many ways such as aiding in localized policymaking and targeting of interventions (Roca-Feltrer et al., 2009).

1.2 Statement of problem

Malaria seasonality plays an important role in aiding localized policymaking and targeting of interventions (Roca-Feltrer et al., 2009). Many research works have been conducted to determine Malaria seasonality. Most of these studies focused on how climatic factors influence malaria transmission. However, none of those works focused on the changes in the spatial and temporal seasonality of malaria transmission.

For instance, Mabaso et al. (2005) adapted a seasonality concentration index used previously for rainfall to quantify malaria case load during the peak transmission season based on monthly values. They found that combinations of mean monthly temperature (range 28–32°C), maximum temperature (24–28°C) and high rainfall provide suitable conditions for seasonal transmission.
Mabaso et al. (2007) compiled published and unpublished monthly EIR data from as many different sites across sub-Saharan Africa as they could find. The degree of EIR seasonality in each site was quantified using an index previously used for rainfall. The results showed that seasonality of rainfall, minimum temperature, and irrigation were important determinants of seasonality in EIR.
Briët et al. (2008) developed a simple seasonality index by making use of the bimodal seasonality of both malaria and rainfall. The malaria seasonality index was regressed against the rainfall seasonality index taking spatial autocorrelation into account. They found that despite the presence of spatial autocorrelation, the coefficient for the rainfall seasonality index in explaining the malaria seasonality index was found to be significant.
Ermert et al. (2013) used the MARA Seasonality Model (MSM) to predict how Climatic conditions such as relatively cold temperatures and dryness are able to limit malaria transmission using ensemble data from Reginal Model(REMO). They found that malaria projections of the MSM showed a decreased length of the malaria season in West Africa. The northern Sahel is no more suitable for malaria in the projections and shorter malaria seasons are expected for various areas farther south. In East Africa, higher temperatures and nearly unchanged precipitation patterns lead to longer transmission seasons and an increase in highland malaria.
Hamad et al. (2002) compared Seasonal malaria case incidence with the number of vectors detected and with climatic variables. They deduced that, following the end of the short rainy season in October the number of A. arabiensis detected dropped gradually until February when neither outdoor human bait trapping nor indoor spray catches revealed any mosquitoes. Vectors re-appeared in June as humidity rose with the onset of rain. Despite the apparent absence of the vector at the height of the long, hot dry season between February and May, sporadic asymptomatic malaria infections were detected in the two villages.

Also, others' research work focused on marked seasonality. For instance, Roca-Feltrer et al. (2009) undertook a series of systematic literature reviews to identify studies reporting on monthly data for full calendar years on clinical malaria, hospital admission with malaria and Entomological Inoculation Rates (EIR). Sites were defined as having 'marked seasonality' if 75% or more of all episodes occurred in six or less months of the year. It was found that most sites showed year-round transmission with seasonal peaks for both clinical malaria and hospital admissions with malaria, with a few sites fitting the definition of 'marked seasonality'. For these sites, consistent results were observed when more than one outcome or more than one calendar year was available from the same site. The use of monthly EIR data was found to be of limited value when looking at seasonal variations of malaria transmission, particularly at low and medium intensity levels.

Most research works are centered or focused on how climatic factors influence the transmission of malaria seasonality with limited information on how malaria seasonality changes spatially and temporally. There was therefore the need to research in this area since Ghana would heavily benefit from its outcome. This will help in the taking of required measures to make targetted interventions and put policies in place to curb the mortality and morbidity associated with changes in malaria seasonality. As a matter of fact, this study would therefore employ the use of a weather-driven dynamical mathematical malaria model (VECTRI-model) to assess changes in the seasonality of the disease.

1.3 Study Question

To find solutions to the outlined problems, the study asked the following questions:

1. Does malaria seasonality differ for different areas in Ghana?
2. Are there temporal patterns and variability in malaria seasonality in Ghana?
3. Does malaria seasonality vary with time?

1.4 Objectives

The main objective of this study is to assess the spatio-temporal changes in malaria seasonality over Ghana using a weather-driven dynamical mathematical malaria model. Specific objectives include:

1. Construct a malaria seasonality map for Ghana that shows changes in malaria seasonality.
2. Describe the malaria seasonality regimes for Ghana.
3. Examine the temporal and spatial variability of seasonal incidence of malaria in Ghana.

1.5 Significance of Study

Having knowledge of the changes in the seasonality of malaria over Ghana will be of great importance to the country. This will result in many benefits. Having such kind of information will facilitate the implementation of appropriate policies by the health sector. Such as the allocation of health facilities in various locations, especially in endemic and epidemic areas. Also, effective measures would be put in place to help curb malaria in endemic areas. As a country, we face an inevitable challenge pertaining to the high mortality rate especially in infants, which threatens the future of Ghana. As a matter of fact, this study moves to outline the pattern associated with the influence of climatic and non-climatic factors on the changes in malaria seasonality in Ghana. With this knowledge, targetted interventions can be made to counter the mortality and morbidity of malaria in Ghana especially in infants. The outcome of this study would be of much importance to the various advocate units that educate people on vector-borne diseases. This is because, it would help in facilitating the degree of advocacy that should occur in various locations across the length and breadth of the country, most especially in endemic areas. In doing so, it would help increase the knowledge and the awareness of the individual of the dangers associated with malaria and measures to prevent this disease.

1.6 Organization of project

The project was organized into five chapters. Chapter one comprises the research background, statement of problem, objectives as well as the significance and motivation of the research. Chapter two also reviews literature works on malaria seasonality. The study area, data and method employed in this project, were captured under chapter three of this paper. Chapter four contains the results and discussion with chapter five taking care of recommendations and references.

CHAPTER 2

Literature review

2.1 Malaria

Malaria is a non-contagious fatal or life threatening disease which shows symptoms of chills, fever, and sweating, Hlongwana et al. (2009); Deressa et al. (2003), occuring few weeks after being bitten by a female Anopheles mosquito(Holt et al., 2002; Beck-Johnson et al., 2013). Malaria affects both adults and children, but children stand at a greater risk of mortality than adults(Rowe et al., 2006). Malaria transmission occurs globally, but major areas affected are sub-Saharan Africa and South Asia(Sutherland et al., 2010). Although malaria can be a deadly disease, illness and death from malaria can usually be prevented(Organization et al., 2014). Malaria is caused by a parasite that commonly infects a certain type of mosquito which feeds on humans, if one receives infected blood from someone during a blood transfusion, organ transplant, or the shared use of needles or syringes contaminated with blood or may also be transmitted from mother to fetus during pregnancy(congenital malaria)(Holt et al., 2002; Beck-Johnson et al., 2013).

A diagram showing malaria observatory in Ghana:

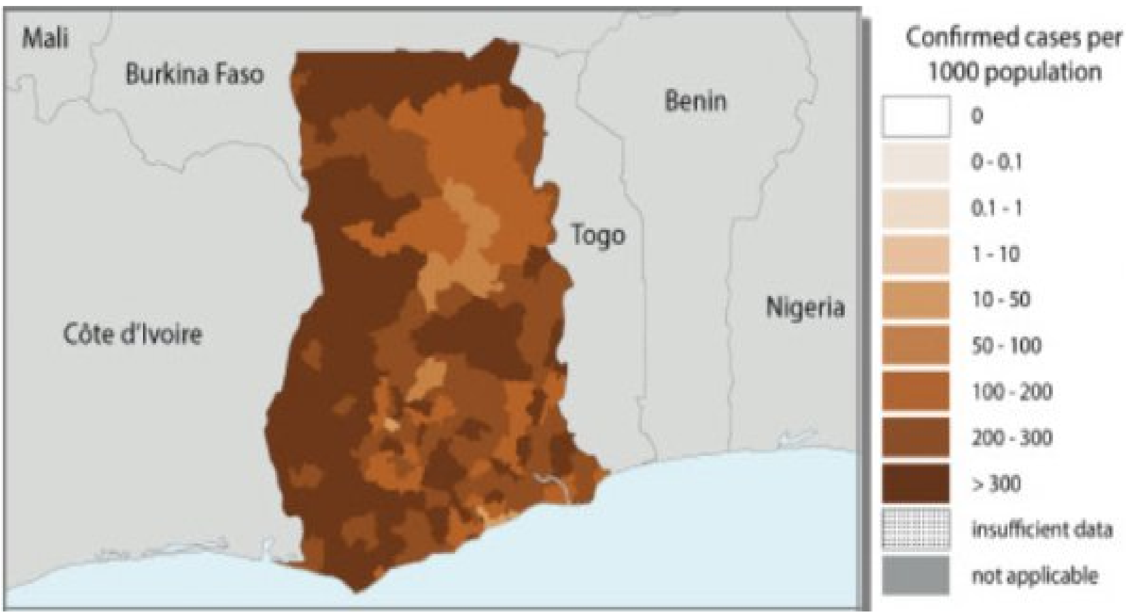

Figure 2.1: Malaria-observatory in Ghana (Source: severemalaria.org)

2.2 Life cycle of malaria

According to the World Health Organization (WHO), the mosquitoes that carry Plasmodium parasite get it from biting a person or animal that's already been infected. The parasite then goes through various changes that enable it to infect the next creature the mosquito bites. Once it's in the person, it multiplies in the liver and changes again, getting ready to infect the next mosquito that bites that person. It then enters the bloodstream and invades red blood cells. Consequently, the infected red blood cells burst. This sends the parasites throughout the body and causes symptoms of malaria. Four kinds of malaria parasites infect humans: Plasmodium falciparum, P. vivax, P. ovale, and P. malariae according to WHO. In addition, P. knowlesi, a type of malaria that naturally infects macaques in Southeast Asia, also infects humans, causing malaria that is transmitted from animal to human ("zoonotic" malaria)(White, 2008; Tan et al., 2008). In sub-Saharan Africa, infections with Plasmodium falciparum cause most of the malaria-associated illness and death(Tjitra et al., 2008). There are two main factors that influence malaria transmission. Climatic factors: this includes temperature, rainfall and relative humidity and Non-climatic factors: including differences between human hosts, human migration, and development projects, can also affect the pattern of malaria transmission and the severity of the problem(Alemu et al., 2011).

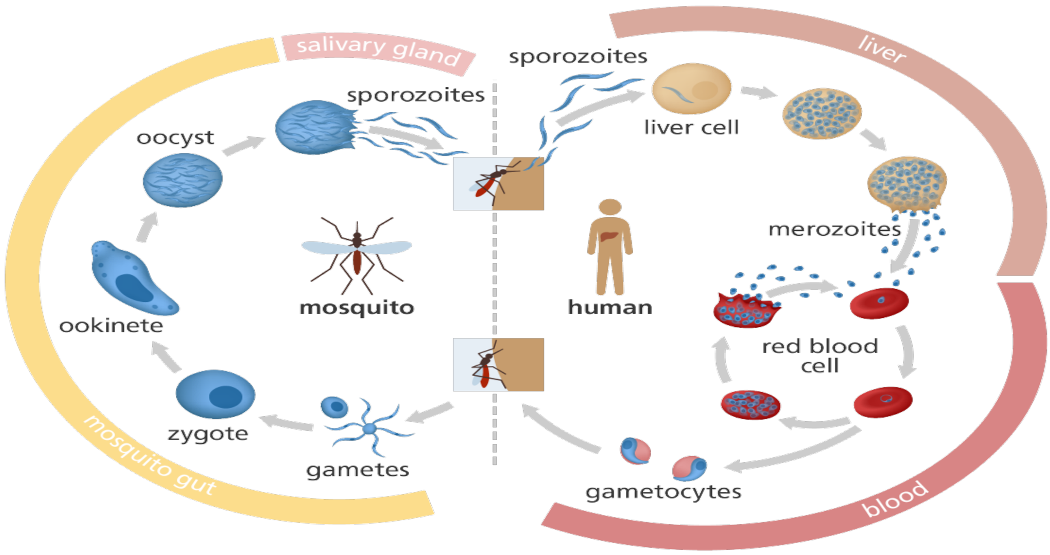

Figure 2.2: The life cycle of malaria (Source: yourgenome.org)

2.3 Reviewed works

There are so many works which have been done on the seasonality of malaria. In order to know what had been done already and what had not been done, this work reviewed a series of articles or research works. For instance; Mabaso et al. (2005) obtained a seasonality model that predicted quantitative variation in transmission between months. They described the relationship between seasonality in malaria and environmental covariates for the period 1988–1999, by fitting a spatio-temporal regression model within a Bayesian framework to provide smoothed maps of the seasonal trend. They found that combinations of mean monthly temperature (range 28–32°C), maximum temperature (24–28°C) and high rainfall provide suitable conditions for seasonal transmission. They concluded that the use of a covariate adjusted empirical model may prove useful for predicting the seasonal risk pattern across southern Africa.

Mabaso et al. (2007) analyzed the relationship between seasonality in the entomologic inoculation rate (EIR) and environmental factors in sites across sub-Saharan Africa with the objective of predicting seasonality from environmental data. They compiled published and unpublished monthly EIR data from as many different sites across sub-Saharan Africa as they could find.The degree of EIR seasonality in each site was quantified using an index previously used for rainfall. The EIR is the number of infective mosquito bites per human per unit time. The results showed that seasonality of rainfall, minimum temperature, and irrigation were important determinants of seasonality in EIR. Model fit was poor in areas characterized by two rainfall peaks and by irrigation activities. Two rainfall peaks probably dampen seasonality and irrigation creates perennial breeding habitats for vectors independent of rainfall. This complex interplay between the seasonal dynamics of environmental determinants and malaria pose a great challenge and highlights the need for improved models of malaria seasonality.

Roca-Feltrer et al. (2009) presented an approach to describe the seasonality of malaria, to aid localized policy-making and targeting of interventions.A series of systematic literature reviews were undertaken to identify studies reporting on monthly data for full calendar years on clinical malaria, hospital admission with malaria and entomological inoculation rates (EIR). Sites were defined as having 'marked seasonality' if 75% or more of all episodes occurred in six or less months of the year. Most sites showed year-round transmission with seasonal peaks for both clinical malaria and hospital admissions with malaria, with a few sites fitting the definition of 'marked seasonality'. For these sites, consistent results were observed when more than one outcome or more than one calendar year was available from the same site. The use of monthly EIR data was found to be of limited value when looking at seasonal variations of malaria transmission, particularly at low and medium intensity levels. They concluded that the approach discriminated well between studies with 'marked seasonality' and those with less seasonality. However, a poor fit was observed in sites with two seasonal peaks. Furtherwork is needed to explore the applicability of this definition on a wide-scale, using routine health information system data where possible, to aid appropriate targeting of interventions.

Briët et al. (2008) studied the correlation in space between seasonality of malaria and seasonality of rainfall in Sri Lanka. They developed a simple seasonality index by making use of the bimodal seasonality of both malaria and rainfall. The malaria seasonality index was regressed against the rainfall seasonality index taking spatial autocorrelation into account. They found that despite the presence of spatial autocorrelation, the coefficient for the rainfall seasonality index in explaining the malaria seasonality index was found to be significant. They concluded that the results suggested that rainfall is an important driver of malaria seasonality.

Ermert et al. (2013) revisited a previous assessment of the potential impacts of climate change on the seasonality of malaria in Africa. They used a bias-corrected regional climate projections with a horizontal resolution of 0.5 from the Regional Model (REMO), which include land use and land cover changes. The malaria model employed was the climate-driven seasonality model (MSM) from the Mapping Malaria Risk in Africa project for which a comparison with data from the Malaria Atlas Project (MAP) and the Liverpool Malaria Model (LMM), and a novel validation procedure lends more credence to results. They found that the malaria projections of the MSM show a decreased length of the malaria season in West Africa. The northern Sahel is no more longer suitable for malaria in the projections and shorter malaria seasons are expected for various areas farther south. In East Africa, higher temperatures and nearly unchanged precipitation patterns lead to longer transmission seasons and an increase in highland malaria. They concluded that The results of this simple seasonality model are similar to previous projections from the more complex LMM.However, a different response to the warming of highlands is found for the two models. It is concluded that the MSM is an efficient tool to assess the climate-driven malaria seasonality and that an uncertainty analysis of future malaria spread would benefit from a multi-model approach.

Carneiro et al. (2010) undertook a pooled analysis of existing data from multiple sites to enable a comprehensive overview of the age-patterns of malaria outcomes under different epidemiological conditions in sub-Saharan Africa. A systematic review using PubMed and CAB Abstracts (1980–2005), contacts with experts and searching bibliographies identified epidemiological studies with data on the age distribution of children with P. falciparum clinical malaria, hospital admissions with malaria and malaria-diagnosed mortality. They found that Clinical malaria incidence was relatively evenly distributed across the first 10 years of life for all transmission scenarios. Hospital admissions with malaria were more concentrated in younger children, with this effect being even more pronounced for malaria-diagnosed deaths. For all outcomes, the burden of malaria shifted towards younger ages with increasing transmission intensity, although marked seasonality moderated this effect. They concluded that the most severe consequences of P. falciparum malaria were concentrated in the youngest age groups across all settings. Despite recently observed declines in malaria transmission in several countries, which will shift the burden of malaria cases towards older children, it is still appropriate to target strategies for preventing malaria mortality and severe morbidity at very young children who will continue to bear the brunt of malaria deaths in Sub-Saharan Africa.

Roca-Feltrer et al. (2010) Understood the relationship between transmission intensity, seasonality and the age-pattern of malaria which is needed to guide appropriate targeting of malaria interventions in different epidemiological settings. A systematic literature review identified studies which reported the age of paediatric hospital admissions with cerebral malaria (CM), severe malarial anaemia (SMA), or respiratory distress (RD). They found that A shift in the burden of CM towards younger age groups was seen with increasing intensity of transmission, but this was not the case for SMA or RD. Sites with 'no marked seasonality' showed more evidence of skewed age-patterns compared to areas of 'marked seasonality' for all three severe malaria syndromes. They concluded that although the peak age of CM will increase as transmission intensity decreases in Africa, more than 75% of all paediatric hospital admissions of severe malaria are likely to remain in under five year olds in most epidemiological settings.

Hamad et al. (2002) investigated the ecology of Anopheles arabiensis and its relationship to malaria transmission in two villages in eastern Sudan. Seasonal malaria case incidence was compared with the number of vectors detected and with climatic variables. They found that following the end of the short rainy season in October the number of A. arabiensis detected dropped gradually until February when neither outdoor human bait trapping nor indoor spray catches revealed any mosquitoes. Vectors re-appeared in June as humidity rose with the onset of rain. Despite the apparent absence of the vector at the height of the long, hot dry season between February and May, sporadic asymptomatic malaria infections were detected in the two villages. They concluded that the entomological inoculation rate (EIR) was estimated to be around two to three infective bites per person per year, although heterogeneity in the transmission indices of malaria between the two villages was observed.

Dery et al. (2010) acquired knowledge of the local pattern of malaria transmission and the effect of season on transmission is essential for the planning and evaluation of malaria interventions. Entomological surveys were carried out in the forest-savannah transitional belt of Ghana (Kintampo) from November 2003 to November 2005 in preparation for drug and vaccine trials.They found that Infection rates with Plasmodium falciparum were 4.7% and 1.5% for Anopheles gambiae and Anopheles funestus, respectively. Entomological inoculation rates (EIRs) were 269 infective bites per person per year in the first year (November 2003-October 2004) and 231 the following year (November 2004–November 2005). They concluded that The dynamics and seasonal abundance of malaria vectors in the Kintampo area was influenced by microecology, rainfall and temperature patterns.The information provided by the study will help in planning intensified malaria control activities as well as evaluating the impact of malaria interventions in the middle belt of Ghana.

McKenzie et al. (2001) incorporated stochastic, densitydependent seasonal recruitment in adult Anopheles mosquito populations in a discreteevent model of Plasmodium falciparum malaria transmission. They found the probabilities of parasite extinction higher than with perennial transmission. They found that Seasonal fluctuations in vector populations act to synchronize the dynamics of infection and immunity in host populations, leading to fluctuations in parasite prevalence greater than expected solely on the basis of high and lowseason vector densities. They concluded that this synchronization also biases frequencies of infection with multiple parasite phenotypes or genotypes.

Bouvier et al. (1997) investigated the impact of malaria on low birthweight in Bougoula village (Sikasso region, Mali). In two successive years, pregnant women were followed until delivery. Phase I (1992) was observational, with 135 complete observations. Phase II (1993) included 126 participants, who were offered malaria prophylaxis with proguanil (200 mg/day) and chloroquine (300 mg/week). The results showed that; Infants of first and second pregnancies had lower birth weights compared with higher rank pregnancies. Also, strong seasonal variation in birthweight was observed in Phase I, with an annual cycle. Then again, parasitemia measured during pregnancy was associated with lower birthweight in infants from first and second pregnancies, but not from higher parity mothers and malaria prophylaxis taken for 20 weeks or more in Phase II suppressed the seasonal variation of birthweight and the effect of low parity. They concluded that malaria in pregnancy has an important negative impact on birthweight in first and second pregnancies. Prophylaxis with proguanil and chloroquine is an effective prophylaxis when taken for 20 weeks or more.

Even though these previous works provide information on the seasonal outcome of malaria, they mostly have limited information on the spatio-temporal variation in malaria prevalence. Most research works are centered on how climatic factors influenced the transmission of malaria seasonality. Specifically, there is limited information on the seasonal contrast in monthly malaria rather than whether there is malaria in a month or not. Examining the spatio-temporal changes in malaria is therefore important. Information from such study will provide the required measures to make regarding targetted interventions and put policies in place to curb the mortality and morbidity that comes with changes in malaria seasonality. As a matter of fact, this study would employ the use of a weather-driven dynamical mathematical malaria model (VECTRI-model) to assess imminent changes in the seasonality of malaria.

2.4 Mathematical malaria models

There are several malaria models. Some of which are; the Ross model, Macdonald model, Anderson and May model(Mandal et al., 2011), MARA Seasonality Model(MSM), Liverpool Malaria Model(LMM), VECTRI Model and others.
The Liverpool Malaria Model(LMM) is a weather-driven malaria model which represents a significant improvement in the modelling of a weather-driven malaria transmission cycle. The LMM is suitable for the use in malaria early warning systems as well as for malaria projections based on climate change scenarios, both in epidemic and endemic malaria areas(Ermert et al., 2011).

However, this study would be focused on the VECTRI-Model. VECTRI-model (Vector-borne Disease Community Model of International Centre of Theoretical Physics, Trieste) is a mathematical dynamical model for malaria transmission that accounts for the impact of climate variability and population. VECTRI attempts to incorporate a simple but physically based treatment of surface hydrology, and more importantly it accounts for the population density when calculating biting rates and transmission probabilities. This is important, since it allows the model to represent the difference in transmission rates between rural and peri-urban locations. Moreover, the link to population means that the model can be actively developed to incorporate immunity, migration, socioeconomic status, urbanisation and interventions. It does this in a framework that allows regional or even continental-wide simulations(Tompkins and Ermert, 2013).

CHAPTER 3

Data and Methodology

3.1 Study Area

Ghana is the area under study and it is located between longitude 4°W and 2°E and latitude 4°N and 11°N. It has a total area of 238,540 km^2. Its neighbouring countries are Côte d'Ivoire to the west, Burkina Faso to the north, Togo to the east and with the Atlantic Ocean to the south. Ghana has a warm, humid climate and two major seasons, the dry season and the wet/rainy season. Mean annual temperatures range from $21.0°C$ near the coast to $28.9°C$ in the extreme north. Mean annual rainfall also ranges from 1100mm to 2100mm. It has five major agro-ecological zones, namely; Sudan Savanna, Guinea Savanna, Transitional, Forest and the coastal zones. The Sudan and the Guinea Savanna have a monomodal rainfall pattern, whereas; the remaining ecological zones have a bimodal rainfall pattern. The rainfall patterns in these agro-climatical zones as well as the temperatures recorded in these zones are much infleunced by their positions relative to the movement of the Intertropical Convergence Zone (ITCZ).

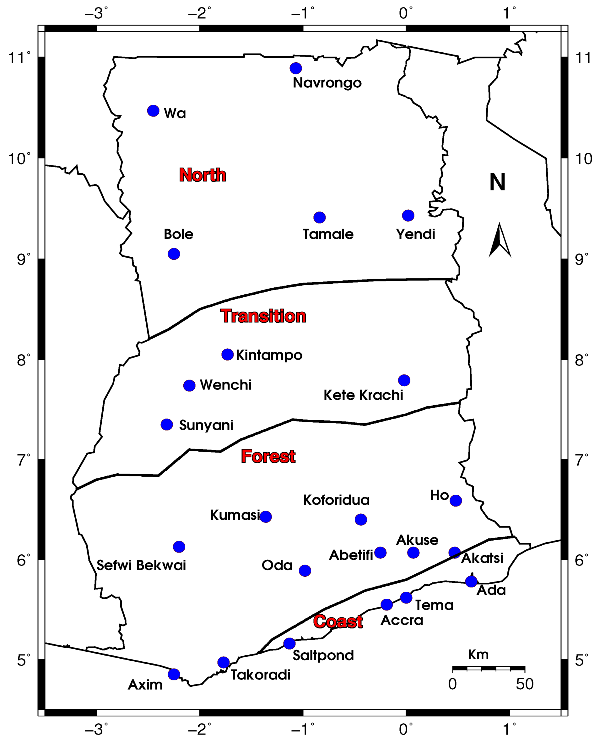

Figure 3.1: Agro-ecological zones map of Ghana (Source: Mansanas et al., 2014).

3.2 Data

3.2.1 Model input data

Daily rainfall and temperature data for Ghana were obtained from the Ghana Meteorological Agency (GMet) for the various areas. Also population density products were obtained from the Afripop dataset. The data for rainfall and temperature spanned the period 1980–2018. These are the actual rainfall and temperature values recorded at the various synoptic stations using the rain gauge and the dry and wet bulb thermometres respectively. The high resolution of the data allows users to observe rainfall phenomenon on local scales that cannot be captured by course climate datasets.

3.2.2 Model simulation of malaria

The VECTRI model requires the use of daily rainfall and temperature values as well as population density products as its input. The daily rainfall and the temperature values together with the population density data were inputted into the VECTRI model to simulate daily Entomological Inoculation Rates (EIR). EIR is the number of infectious mosquito bites per person per unit time. The daily EIR values were converted into monthly values. The simulation is represented in the schematic diagram below:

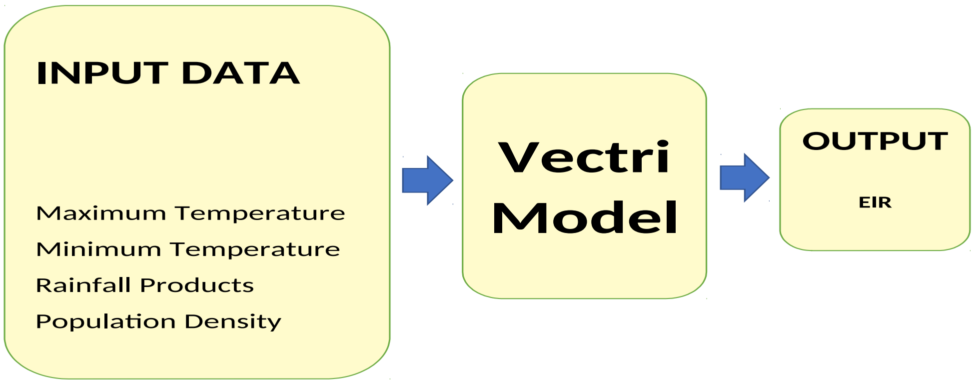

Figure 3.2: Schematic diagram for the model simulation

3.3 Analysis

A seasonality index proposed by Walsh and Lawler (1981) and previously applied to rainfall was adopted and applied on the monthly simulated EIR to determine the malaria seasonality regimes for Ghana. The seasonality index (SI_i) allows for the quantification of malaria cases variability throughout the year using a single value. These indices can show differences in relative seasonality even in areas with two or three malaria case peaks throughout the year (Livada and Asimakopoulos, 2005). The index is shown mathematically as:

$$SI_(i) = \frac{1}{R_i} \sum_{n=1}^{n=12} |X_{in} - \frac{R_i}{12}| \tag{3.1}$$

Where R_i is the total annual malaria case for a specific year i and X_{in} is the actual monthly malaria case for month n in the particular year under study. Seasonal Indices (SI_i) was calculated for the period 1980–2018. Average seasonality index for each year ($\bar{SI_i}$) was then found. According to Walsh and Lawler (1981), the SI is underestimated when mean values are used which is resolved by averaging the individual index (SI_i) to obtain ($\bar{SI_i}$).

$$\bar{SI} = \frac{1}{N} \sum_{n=i}^{n=j} SI_{ij} \tag{3.2}$$

Where N is the number of years under study. A spatial map of (SI_i) distribution was produced and trends of seasonality was assessed for randomly selected areas in Ghana using linear regression. The table below shows the seasonal regimes and their classifications:

Malaria(EIR) regime	SI class limits
Very equable	≤ 0.19
Equable but with a definite higher malaria case season	0.20 - 0.30
Rather seasonal with short lower malaria case season	0.40 - 0.59
seasonal	0.60 - 0.79
Markedly seasonal with a long lower malaria case season	0.80 - 0.99
Most malaria case in 3 months or less	1.00 - 1.19
Extreme, almost all malaria case in 1 - 2 months	≥ 1.20

Table 3.1: Seasonal Index class

The Mann-Kendall Trend Test was used to determine the temporal variability in malaria transmission in all the synoptic stations for the years under study. After that, the Mann-Kendall Sequential Trend Test was used to determine any significant changes in malaria seasonality with time, and to know the specific year for which those significant changes occured.

CHAPTER 4

Results and Discussion

4.1 Results

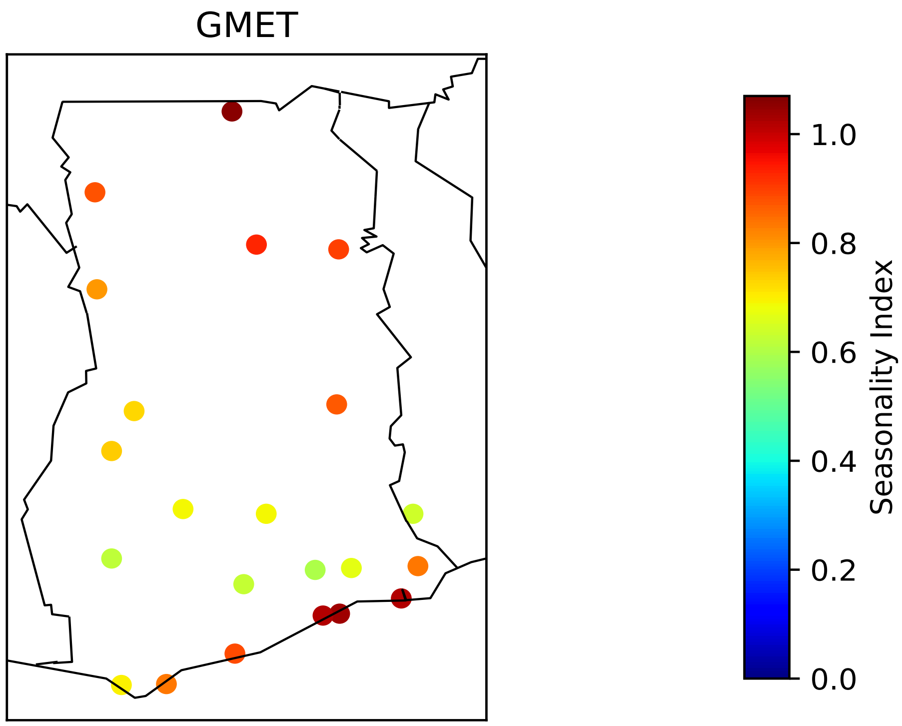

Figure 4.1: Spatial map of Ghana showing the seasonality indices for different locations.

Figure 4.1.1 shows the contrast in the indices of malaria seasonality in various locations in Ghana. It was found that the index was highest in northern-most(the Sudan Savannah and the Guinea Savannah) part of the country and lowest in the forest areas. Thus, the seasonality index generally decreased from North towards the forest zones. The coastal areas observed higher indices which was similar to that of the northern part of the country.

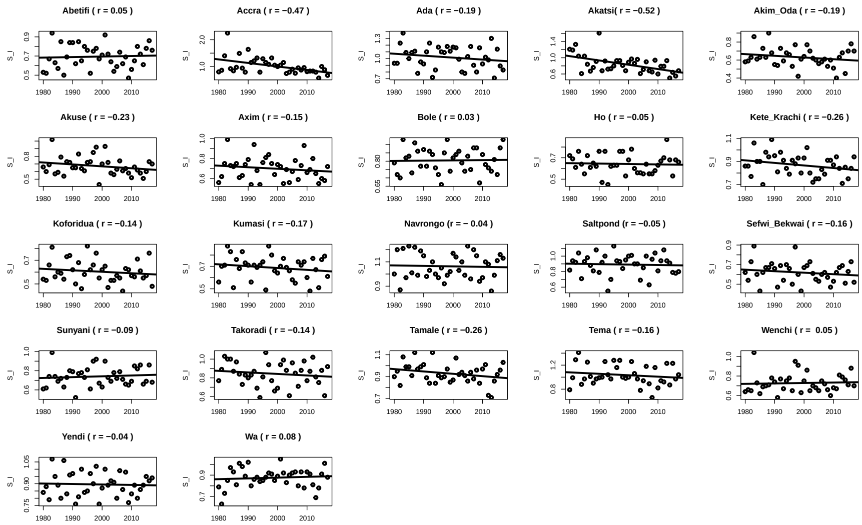

Figure 4.2: Mann-Kendall Trend Test in malaria seasonality.

Figure 4.1.2 shows the Mann-Kendall Trend Test in malaria seasonality at various locations. It could be seen that there were no trends in almost all the synoptic stations with regards to the seasonality of the disease with the exception of Accra and Akatsi. At these locations, there were significant trends in seasonality of malaria with time.

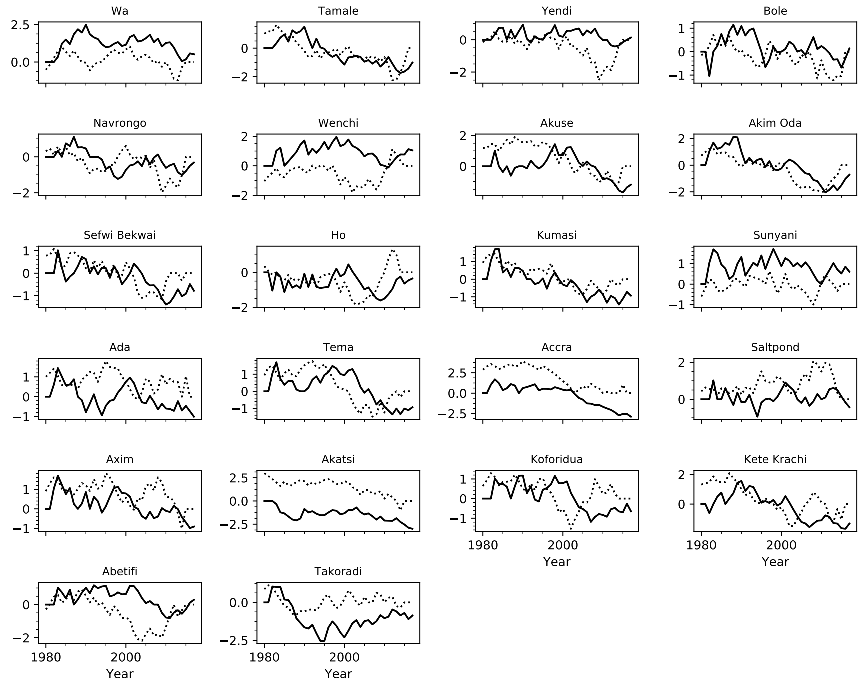

Figure 4.3: Mann-Kendall Sequential Trend Test in malaria seasonality.

Figure 4.1.3 shows the Mann-Kendall Sequential Trend Test in the seasonality of malaria. The Mann-Kendall Sequential Trend Test which shows the areas and years of significant change of the disease, the progressive and the retrogressive lines must cross each other and diverge continously from there. The sequential trend test therefore revealed that significant changes were ocurring only in Accra whereas, the changes were found to be insignificant in all the other areas.

4.2 Discussion

The study aimed at assessing the spatio-temporal changes in malaria seasonality over Ghana using a weather-driven dynamical mathematical malaria model (VECTRI model). The research found that the seasonality indices were generally high at the northern-most part of the country and decreased to lower values as one traversed towards the south especially the forest zone. However, the indices were observed to be high at the coastal areas which were similar to that of the northern part of the country. The Mann-Kendall trend test revealed that, almost all of the synoptic stations with the exception of Accra and Akatsi, showed trend in malaria seasonality. Accra and Akatsi showed a tremendous decrease in the seasonality indices which actually implied that seasonality of the disease was increasing with time. The Mann-Kendall sequential trend test revealed that, the seasonality of malaria occuring in all other areas were insignificant with the exception of Accra.

The results for the seasonality indices were expected because the northern part of the country has a mono-modal rainfall pattern with very high temperatures which provides unfavorable conditions for the transmission of malaria. However, a bi-modal rainfall pattern is experienced in the southern and middle sectors, which provides optimum temperatures as well as more productive breeding sites for mosquitoes which leads to an increase in malaria transmission in these areas. As a matter of fact, the population of mosquitoes is more in the transitional and the forest zones as compared to the the zones in the northern sector. The results obtained could also be attributed to the fact that the northern sector has higher temperatures because it is closer to the sahara desert which creates unfavorable conditions for the breeding of mosquitoes. However, the southern sector experiences relatively lower temperatures compared to the northern sector which makes it possible for mosquitoes to breed under this condition. Also, since the results showed that seasonality index increases from the south towards the north, it suggests that malaria is concentrated in more months within a year in the south and in less months in the north as explained by the SI class limit. However, the Coastal zone showed some discrepancy of recording a higher index which is similar to what is observed in the north. The reason may be attributed to the population densities in these areas, especially Accra, Ada and Tema. The study therefore showed that different areas of the country have different seasonality in malaria which means that malaria seasonality varies spatially from one place to another.

From the Mann-Kendall trend test, the study revealed that there were insignificant trends in the seasonality of malaria in all the synoptic stations with the exception of Accra and Akatsi. However, the Mann-Kendall sequential trend test emphasized on the fact that Accra is the only area which shows a very significant change in the seasonality of the disease. This was deduced from the fact that the progressive and the retrogressive lines crossed each other and after that they diverged continously in the plot of the sequential trend of Accra. However, this deductions were not seen or revealed in the sequential trend plots of the remaining synoptic stations.

A major cause for the insignificant change in the trend in the seasonality of the disease in all the other synoptic stations may be attributed to the fact that there are no serious urbanization into those areas. However, one reason that may account for the significant change in the trend in Accra is the fact that urbanization is done in an uncontrolled manner because there is no legal binding. Hence, rapid urbanization of areas within the outskirts of urban centres like Accra is commonly done in an uncontrolled fashion or without thought or planning. The settlers are mainly migrant workers from rural villages. Conditions are crowded; housing is often of poor quality or is of temporary construction; and the provision of health care and sanitation is often inadequate. Settlers tend to dig several pits to extract stone and soil for house construction creating numerous breeding grounds for mosquitoes. This can lead to explosive growth of mosquito vectors, increase exposure of the population to vectors due to poor housing and amplification of diseases to epidemic proportions through lack of effective treatment.

CHAPTER 5

Conclusions and recommendations

5.1 Conclusions

This study was undertaken to quantify the seasonal contrast in seasonal malaria within a year using a seasonality index. It also described the seasonality regimes of malaria in different areas. Also, the temporal patterns and the variability of the seasonal incidence of malaria was determined. The average SI during the period 1983–2018 therefore showed distinctive areas with different malaria seasonality regimes. The seasonality indices depicted higher values at the northern-most part of the country and decreased to lower values as we traverse towards the southern part, especially at the forest zones. The indices at the coastal areas also mimicked values which were observed in the northern part of the country. This means that malaria is concentrated in more months of the year in the forest zone, and decreased to lesser months as one traverses towards the northern part of the country. Also, seasonality of malaria with time showed no trends in all areas with the exception of Accra and Akatsi. But the sequential trend revealed that seasonal malaria trends in Akatsi were insignificant whereas, that of Accra was significant.

The quest to find out whether the seasonality of malaria differed for different areas of the country was answered by the study revealing that different areas of the country have different seasonality indices, which actually means that malaria seasonality varies spatially. Also, this study revealed that there exist temporal patterns and variability in the seasonal incidence of malaria within Ghana from year to year.

Having knowledge of the changes in the seasonality of malaria over Ghana will be of great importance to the country. It will facilitate the implementation of appropraite policies by the health sector with regards to the allocation of health facilities in various locations especially in endemic and epidemic areas. Also, effective measures would be put in place to help curb malaria in endemic areas. The country faces an inevitable challenge pertaining to the high mortality rate especially in infants, which threatens the future of Ghana. With this knowledge, targetted interventions can be made to counter the mortality and morbidity of malaria in Ghana especially in infants. The outcome of this study would be of much importance to the various advocate units that educate people on vector-borne diseases by facilitating the degree of advocacy that should occur in various locations of the country. This will help increase the knowledge and the awareness of the individual about the dangers associated with malaria and measures to prevent this disease.

5.2 Recommendations

The study recommends that:

1. Future works should focus on using more dense guage data so as to get more accurate information.

2. Malaria awareness should be increased in areas of increasing transmission.

3. Government should provide more facilities to combat Malaria transmission especially in areas of increasing transmission, such as the distribution of treated mosquito nets, spraying etc.

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