THE UNIVERSITY OF ZAMBIA

SCHOOL OF MEDICINE

DEPARTMENT OF PUBLIC HEALTH

TRENDS OF CLIMATIC FACTORS AND MALARIA INCIDENCE IN THE LOW, MODERATE AND HIGH TRANSMISSION ZONES OF ZAMBIA

BY

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A dissertation submitted in partial fulfilment of the requirements towards the awarding of Master of Science Degree in Epidemiology.

(November, 2016)

Contents

DECLARATION

I, HANNAH MZYECE, hereby declare that this dissertation for the Master of Science in Epidemiology is my original work and has not been presented for any other awards at the University of Zambia or any other university.

Signature: ____________________

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CERTIFICATE OF COMPLETION OF DESERTATION

I……………………………………………………………………………………………

Hereby certify that this dissertation is the product of my own work and, in submitting it for the Degree of Master of Science in Epidemiology programme, further attest that it has not been submitted to another University in part or whole for the award of any programme.

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having supervised and read this dissertation is satisfied that this is the original work of the author under whose name it is being presented.

I confirm that the work has been completed satisfactorily and is ready for presentation to the examiners.

Supervisor's Name: ……………………………………………………………………………….

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CERTIFICATE OF APPROVAL

The University of Zambia approves this dissertation of Hannah Mzyece in partial fulfilment of the requirements for the award of the degree in Master of Science in Epidemiology.

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ABSTRACT

Background-Malaria causes about 1-3 million deaths annually in the world, out of which, more than 90% occur in Africa (World Health Report, 2012). Studies have shown that high incidence of malaria has been exacerbated by the effects of variations in climatic factors (Murray, et al. 2013). Despite the huge burden malaria imposes in Zambia, detailed data of how climate variation has influenced malaria incidence is very limited. A study to examine the influence of climatic factors on malaria incidence in the low, moderate and high malaria transmission zones of Zambia was conducted from June 2014 to January 2016.

Methods-Multi stage sampling was used to select the districts from the malaria transmission zones. The first stage involved random selection of five provinces which was subsequently followed by random selection of five districts. The third stage involved collection of secondary data from the Ministry of health data base, Health Management Information System (HMIS) and also from the Meteorological Department. Only confirmed malaria cases from 2009 to 2013 were included in the study. Negative Binomial Regression analysis was used to measure the effect that the climatic parameters, have on malaria case counts. A Poisson regression model was used to fit mixed effects model on correlated panel data for count response variable. In this study, a model quasi-Poisson model can also account for dispersion.

Results-Results showed that an incidence rate ratio of 1.002 for rainfall which meant that the incidence of confirmed malaria cases in Zambia increased by 0.2 % with every 1 mm increase in rainfall (P = .028). Humidity had an incidence rate ratio of 1.002 which indicated that malaria incidence increased by 2 % for every 10 % increase in humidity (P = .294). The correlation between rainfall and all malaria cases was positive and highly significant (r = 0.197; P = .0006).

Discussion-Results from this study found that there is a significant positive association between Rainfall and confirmed malaria cases. Findings of this study also shows that malaria cases increased at the onset of the rains. In March/April, however, the drop in rainfall led to an increase of in malaria cases from March to April. From this study it can be concluded that monthly total rainfall was the only variable influencing incidence of confirmed malaria cases.

Conclusion-In conclusion, this study found evidence that rainfall was positively associated with the number of confirmed malaria cases. This study failed to find a significant correlation between relative humidity and malaria incidence in the three malaria epidemiological zones. This can be attributed to the fact that there was paucity of humidity data.

Key words: climatic factors, temperature, rainfall, humidity, malaria transmission zones malaria

DEDICATION

This dissertation is dedicated to my two beloved daughters Natasha Mapalo Ngo and Natwange Kunda Ngo and my late mother Esnelly Mzyece.

ACKNOWLEDGEMENTS

This dissertation would not have been possible without the concerted effort and support of many people.

I would like to express my warm gratitude to my supervisors, Professor C. Michelo who is the Head of Department for Public Health, Ms Lungowe Sitali who is a lecturer at the University of Zambia, School of Medicine for the good technical support and advice during my study.

I also want to thank Rozalia Dambe, Mumbi Chola from the University of Zambia, Public Health Department for the technical support throughout the process. Special thanks also goes to Dr M. Makungu who assisted me with the data analysis.

Many thanks go to my husband Lloyd Chabala Ngo for his unwavering support during my studies. I also wish to thank my colleagues, course mates, friends and relatives for the roles they played towards the completion of this dissertation.

Above all, I would like to thank my God for giving me grace and strength to do this work and allowing it to go to completion.

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LIST OF ACRONYMS

ACT	Artemisinin combined therapy
CC	Climate Change
CSO	Central Statistics Office
DALYS	Disability Adjusted Life Years
ERES	Excellence in Research Ethics and Science
HMIS	Health Management Information System
IRB	Institutional Research Board IRB
IRS	Indoor Residual Spraying
ITNs	Insecticide Treated Nets
IPTp	Intermittent Preventive Therapy in pregnancy
NMCC	National Malaria Control centre
MD	Meteorological Department
MoH	Ministry of Health
MDG	Millennium Development Goals
RDTs	Rapid Diagnostic Tests
WHO	World Health Organisation
ZNMIS	Zambia National Malaria Indicator Survey

CHAPTER ONE: BACKGROUND

1.1 Introduction

Malaria has been reported to be the most serious and complex public health problem in the world (WHO/WMO/UNEP, 2009). Malaria causes about 1-3 million deaths annually in the world, out of which, more than 90% occur in Africa (World Health Report, 2014). Similarly, Sachs and Malaney (2013) reported that malaria causes about 300 million cases of acute illness in the world yearly. It is the deadliest killer of the elderly, pregnant women and children in Africa (Greenwood and Mutabingwa, 20012). In Zambia, 5 498 children under 5 years died of malaria in 2001 and 3 783 died in 2007 (WHO, 2010). According to Sachs and Malaney, (2013) African countries prone to malaria suffer a loss of US$12 million per year resulting in a 1.3 % reduction in economic growth. Similarly, the Zambia National Malaria Indicator Survey (ZNMIS) (2010) reported that Zambia is also susceptible to suffer from such economic loses because malaria is endemic throughout the country and has continued to be a major public health problem. The persistent public health problems associated with malaria have been exacerbated by the effects of climate change (IPCC, 2008).

About 6 % of the worldwide malaria incidence in 2007 was attributed to the effects of climate change (WHO, 2008). Climatic factors such as temperature and rainfall were observed to influence malaria incidence in Zimbabwe, Ethiopia, Rwanda and Pakistan (Tulu, 2008; Loevinsohn, 1994). The increase in temperatures has been observed to amplify the malaria incidence throughout the world (Patz and Lindsay, 2007). Similarly Kigotho, (2009) reported that an increase in both the temperature and relative humidity resulted in malaria outbreaks in Kenya.

Several studies have shown that there is a relationship between malaria incidence and climatic variables such as rainfall, temperature and relative humidity (Loevinsohn, 1994; Patz and Lindsay, 2007; IPCC, 2008; Tulu, 2008). Malaria is the reason for hospital attendance in 4 out of every 10 patients seen in Zambian clinics and hospitals (Kasali, 2008). In Zambia, about four million clinical cases and 50,000 deaths, including up to 20% maternal mortality are reported yearly (ZNMIS, 2010). However, the incidence of malaria in Zambia has not conclusively been tied to any specific factors. Other researchers have reported that climate change can lead to an expansion of the areas suitable for malaria transmission and therefore, increase risk of the disease (Githeko, 2009). Still others attribute the increase in the incidence of malaria to inter-annual variations in average temperature, rainfall and vapour pressure (Musawenkoi et al., 2006). It was important therefore, to undertake a study so that the knowledge of climate change and its influence on the incidence of malaria can be used to predict malaria occurrences and hence provide early warning system for the control of the disease. An integrated understanding of the factors that affect malaria incidence is therefore imperative.

1.2 Statement of the Problem

Studies have shown that malaria is responsible for an estimated 300–500 million clinical attacks globally, and more than 1 - 3 million deaths each year mainly among children less than five years of age living in sub-Saharan Africa (WHO, 2012). In Zambia malaria is a national health disaster accounting for nearly 40% morbidity of all outpatient attendances at health facilities and about 50, 000 deaths annually, including up to 20% of maternal mortality (Kasali, 2008).

It has been shown that high incidence of malaria has been exacerbated by the effects of variations in climatic factors (Murray, et al. 2013). Despite the huge burden malaria imposes on our country, detailed data of how climate variation has influenced malaria incidence does not exist or is very limited. Some of the potential climatic factors that are closely related to malaria incidence are humidity, rainfall and temperature (Ndiaye, 2010). However, in Zambia the integration of these climate parameters with malaria incidence is largely unexplored. The link between climate variation and malaria has not been well defined.

The paucity of data on the correlation of climatic factors with malaria incidence in Zambia makes the problem worse because it cripples the prospect of incorporating mitigation and adaption measures in malaria prevention strategies.

Decision-makers need information on the extent of the damage attributable to variations in climatic factors and on types of damage which can be avoided through proposed adaptation measures. The role that variations in climatic factors play in altering human health, particularly in the spread of malaria, is an evolving area of research. It is therefore, important to understand the association of climatic factors on malaria incidence because if not urgently addressed, it will compound the already significant burden of diseases on the economy of Zambia.

1.3 Rationale of Study

Controlling malaria is crucial if Zambia is to achieve the MDG of halving the incidence of infectious diseases such as malaria, by 2015. Knowledge of climatic factors and malaria pattern will be useful in predicting malaria occurrences and hence provide early warning system for the control of the disease. This will also stimulate further research on variations in climatic factors and health. Furthermore, the effects of climatic factors on malaria incidence in the three malaria transmission zones in Zambia have not well been documented. This is compounded by the fact that there is a dearth of information on the relationship between malaria incidence and climatic factors in Zambia. Previous studies in Zambia have focused on control measures such as the use of Artemisinin combined therapy (ACT), the use of insecticide treated bed nets (ITNs), indoor residual spraying of insecticide (IRS), and Intermittent Preventive Treatment (IPTp) for pregnant women and children have been implemented (MOH, 2012). Despite all these efforts, the prevalence of malaria infection remains considerably high.

Therefore, this study will gather unequivocal empirical evidence to understand the effects of climatic factors on the incidence of malaria in the three malaria zones. This is critical in predicting malaria occurrences, influencing policy development and formulation of a national policy on climate change to reduce the health impact of climate-related diseases such as malaria. Zambia has not yet developed climate informed policies for the health sector. This is due to paucity of information about the effects of climatic factors on health. The results of this study are therefore valuable for the development of a more effective and efficient malaria control programs.

1.4 Research Question

How has climate variation influenced malaria incidence in the low, moderate and high transmission zones of Zambia?

1.5 Objectives

1.5.1 Aim

To examine the influence of climatic factors on malaria incidence in low, moderate and high transmission zones of Zambia.

1.5.2 Specific Objectives

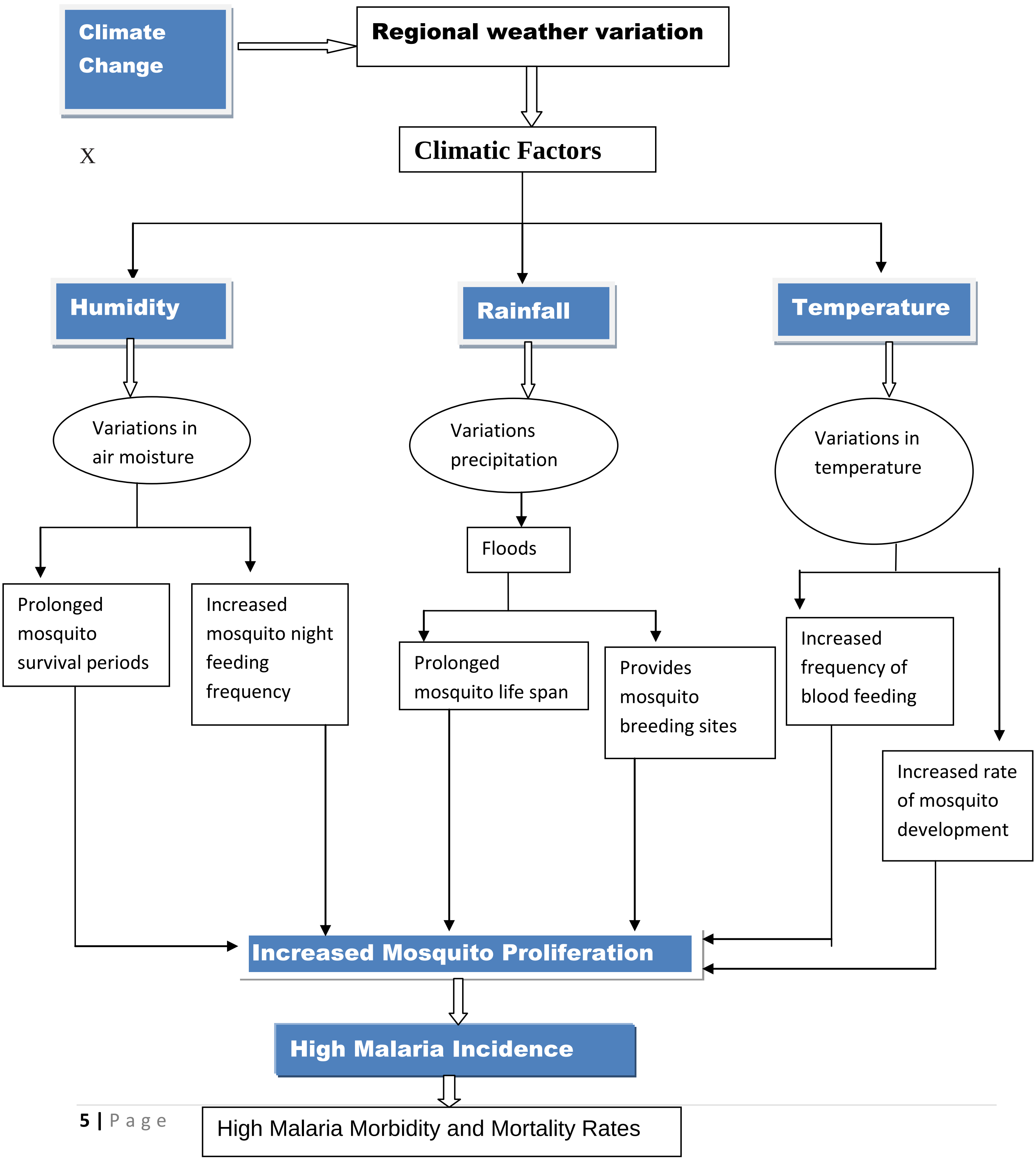
1. To establish annual trends in malaria incidence in the low, moderate and high transmission zones;

2. To establish annual trends in climatic factors (temperature, rainfall and humidity) in the low, moderate and high transmission zones;
3. To compare annual trends of climatic factors and malaria incidence in the low, moderate and high malaria transmission zones, and
4. To measure the effect of climatic factors on the (monthly incidence) malaria cases.

1.6 Conceptual framework

The influence of climatic factors on malaria incidence have been conceptualised in Fig. 2 whereby humidity, rainfall and temperature increases the proliferation of anopheles mosquitoes resulting in a corresponding enhanced transmission and consequently morbidity and mortality. The conceptual framework will help in answering the research question and to address the specific objectives.

Figure 1: Climatic factors associated with malaria incidence



1.8 Operational Definitions

Climate change: Climate change is a long-term continuous change (increase or decrease) in climatic factors.

Climate variation: Year-to-year climate difference.

Transmission zones: Refers to the low, moderate and high malaria transmission zones of Zambia.

Climatic factors: In this study refers to rainfall, temperature and relative humidity.

CHAPTER TWO: LITERATURE REVIEW

2.1 Effects of Climate Change on Malaria Incidence

The Intergovernmental Panel on Climate Change (IPCC, 2001) estimated that the average global surface temperature will rise by 1.4 – 5.8 ^{o} C during the 21 century. Similarly the United Nations Development Programme (UNDP) climate change country profile of Zambia (2008) reports that the mean annual temperature in Zambia has increased by 1.3 °C since 1960, a rate of change which is confidently projected to continue. This translates to a rate of about 0.6 ^{o}C per decade which is ten times higher than the global or Southern African rate of increase in temperature (Zambia Briefings, 2010). Other researchers also observed that an increase in maximum temperature of about 1^{o}C has been observed since early 1970s (Chipeta and Mumba, 2000; CEEZ, 2006). McSweeney (2008) reported that the average number of hot days per year in Zambia has increased by 11.8 %, while the number of cold days has decreased by 6 % between 1960 and 2003.

The UNDP climate change country profile of Zambia for 2008, further reports that the mean annual rainfall in Zambia has decreased by an average rate of 1.9 mm per month (2.3 %) per decade since 1960. This annual decrease is largely due to decreases in December-February rainfall, which has decreased by 7.1mm per month (3.5 %) per decade. There has also been a drift in the rainy season patterns in Zambia whereby the late onsets and early withdrawals have been observed since 1980 with increased storms and flooding (Chipeta and Mumba, 2000; Kasali, 2008). Because of the variability in climatic factors and the geographical position of the developing countries such as Zambia, they are likely to suffer the impacts of climate change more (IPCC, 2007). The disease burden will be exacerbated mainly because of the change in the distribution of vectors such as mosquitoes (IPCC, 2007).

In Zambia, extreme weather fluctuations has affected the country`s health sector (Kasali, 2008). The effects of climate change have exposed the country to an upsurge of diseases such as malaria resulting in increased morbidity and mortality levels (Chipeta and Mumba, 2000). The trend in the malaria incidence fluctuates with an observed increase in the 1970s to late 1980s (Masaninga et al., 2013). According to Masaninga et al. (2013), a 66 % reduction in the number of cases and deaths was reported from 2000 to 2008. The National Health Strategic Plan (NHSP) of the Ministry of Health of 2001–2005 aimed to reduce the incidence of malaria to 300 per 1,000 people by 2005. However, only a few provinces have almost achieved this with Luapula, Southern and Eastern provinces recording the highest fatality rates (Kasali, 2008; NMIS, 2010). Similarly, Masaninga et al. (2013) reported an upsurge in the incidence of malaria in 2009 – 2010. Such increases in malaria cases are the cause of about 50, 000 deaths annually in Zambia (NMCC, 2011). It causes about 20 % maternal mortality and accounts for 6.8 million DALYs (Kasali, 2008; Masaninga et al., 2013). Since the impacts of climatic factors on malaria have not well been documented (Kasali, 2008), there is an urgent need to commission a study to understand the relationship between climatic factors and malaria incidence in Zambia.

2.2 Malaria Incidence in Zambia

The main plasmodium species responsible for malaria transmission in Zambia is Plasmodium falciparum which accounts for about 98% of the national reported cases of malaria in the country (NMCC, 2011). The main vectors are *Anopheles funestus, An. gambiae* and *An. Arabiensis.* Transmission of malaria is throughout the year with peaks in the rainy season from November to April. Zambia has been stratified into three distinct malaria epidemiological zones as follows:

Zone 1: Areas with less than 1% parasite prevalence (Lusaka district)

Zone II: has low to moderate malaria transmission and includes Central, Western, Copperbelt, North Western and Southern Provinces.

Zone III: moderate to high transmission, includes Eastern, Muchinga, Northern and Luapula Provinces.

Malaria is determined by climatic, non-climatic and biological factors (Pemola and Jauhari, 2006). The climatic factors include all the independent variables like temperature, rainfall, humidity, etc. while the non-climatic factors are human activities, socio-economic conditions like developmental changes, housing and living conditions, adopted control measures, ecological environment and drug resistance in malaria parasites (Pemola and Jauhari, 2006). The biological factors comprise of the abundance of Anopheles species, the propensity and frequency of the mosquitoes to bite human beings, its susceptibility to the parasite, the longevity of mosquitoes, the rate at which the parasite develops in mosquitoes, aquatic stages of maturity, etc. that are dependent on climatic variables (Peng et al.,2003).

2.3 Climatic Factors Influencing Malaria Incidence

Increases in temperature, rainfall and relative humidity due to climate change are expected to influence malaria directly by enhancing the survival of malaria vectors and by shortening the length of the life cycle of the parasite within the vector (Darkwah and Badu, 2011). Several studies have linked incidence of malaria time series to changes in temperature, rainfall and relative humidity due to climate change are expected to influence malaria directly by changing the length of the mosquito life cycle (Githeko et al., 2011.The intensity of malaria transmission in the rainy season increases because precipitation provides vector sites and prolongs the vector life span by increasing water availability (Van 2004). Therefore, the number of malaria cases in a particular geological setting can be affected by climatic factors such as rainfall, relative humidity and temperature (Loevinsohn, 1994; Briët et al, 2008). However, Zambia has not yet developed any climate-informed policies for the health sector (Kasali, 2008). This could be because of the paucity data on the relationship between climatic factors and malaria incidence making research on this topic indispensable.

2.3.1 Influence of Temperature on Malaria Incidence

The survival and multiplication of the anopheles mosquitoes depend on climatic factors such as temperature, humidity and rainfall (Mathers et al, 2009; Briet et al, 2008). Temperature affects the life cycle of the malaria parasite and this was revealed by Githeko and Ndegwa (2001) when they reported that development of the mosquito and of the malaria parasite is temperature-sensitive. They reported that the time required for the parasite to complete its development in the gut of the mosquito is about 10 days, but an increase in temperature can increase the rate of development. For example temperature increases the rate of development of some plasmodium species such as *Plasmodium vivax* and *Plasmodium falciparum*. These have the shortest development cycles and are therefore more common than P. ovale and Plasmodium. malariae which require favourable warmer temperatures to develop (Githeko and Ndegwa, 2001; Mathers et al, 2009).The minimum temperature threshold for parasite development of the *P falciparum* is 16 ^{o}C to 19 ^{o}C and the maximum temperature threshold is 33 ^{0}C to 39 ^{o}C (Reiter, 2001; Patz and Olson, 2006). Outside these thresholds, the parasite's development may slow or stop (Githeko, 2009).

Temperature can also influence the timing and intensity of malaria transmission by modifying the speed and frequency of blood feeding by adult female mosquitoes, and the time it takes malaria parasites to mature inside them (Githeko and Ndegwa, 2001). Similarly, Hui, Xu and Chen (2009) reported that 0.5ºC increase in temperature can result in proliferation of mosquitoes by 30–100%. Therefore, the relationship between ambient temperature and the extrinsic incubation period is very important for assessing the impact of climate change on the malaria incidence.

2.3.2 Influence of Rainfall on Malaria Incidence

Rainfall due to climate change has been reported to increase breeding sites for mosquitoes (Hunter 2003). Van Lieshout, (2004) and Jones et al. (2007) found that high malaria incidence was associated with increased rainfall and high maximum temperature in Tanzania. According to Van Lieshout (2004) the intensity of malaria transmission in the rainy season increases because precipitation provides vector breeding sites and prolongs the vector life span by increasing water availability. The availability of moisture induces lagged effect on the transmission of malaria (Alemu et al., 2011). In Sri Lanka, malaria incidence was reported to be lagging from zero to three months after rainfall (Briët et al., 2008). This is because the proliferation of mosquitoes is more pronounced with the availability of water, mainly stagnant water. Anopheles mosquitoes breed in water and the right amount of rainfall is often important for them to breed. Too much rainfall can flush away breeding habitats temporarily, but mosquitoes start breeding as soon as the rain stops (Alemu et al., 2011). Different anopheles mosquitoes prefer different types of water bodies in which to breed. In Zambia, water collections that support vector breeding appear mainly after the rains, and therefore, malaria transmission is highest following the rainy season.

2.3.3 Influence of Humidity on Malaria Incidence

Relative humidity refers to the amount of moisture in the air, expressed as a percentage (whereby 0% humidity would mean the air is completely free of moisture and 100 % humidity would mean the air is completely saturated with moisture (Alemu et al., 2011). Relative humidity affects malaria transmission through its effect on the activity and survival of mosquitoes. Mosquitoes survive better under conditions of high humidity (Van Lieshout, 2004). They also become more active when humidity rises. This is why they are more active and prefer feeding during the night since relative humidity of the environment is higher at night. Relative humidity also plays a role in the lifespan of the mosquito (Hui, Xu and Chen, 2009). In the presence of high relative humidity values, the parasite completes its life cycle at a fast rate in order to increase transmission of the infection to more humans. Therefore, an increase in humidity results in a corresponding increase in malaria incidence.

CHAPTER THREE: METHODS

3.1 Study Setting and population

The study was conducted in Zambia's three stratified malaria transmission zones. The zones are distinctly stratified as follows:

Zone 1: Areas with less than 1% parasite prevalence (Lusaka district)

Zone II: has low to moderate malaria transmission and includes Central, Western, Copperbelt, North Western and Southern Provinces (Choma and Kalabo).

Zone III: moderate to high transmission, includes Eastern, Muchinga, Northern and Luapula Provinces (Mbala and Lundazi).

The map in Figure 2 shows the three malaria transmission zones in Zambia.

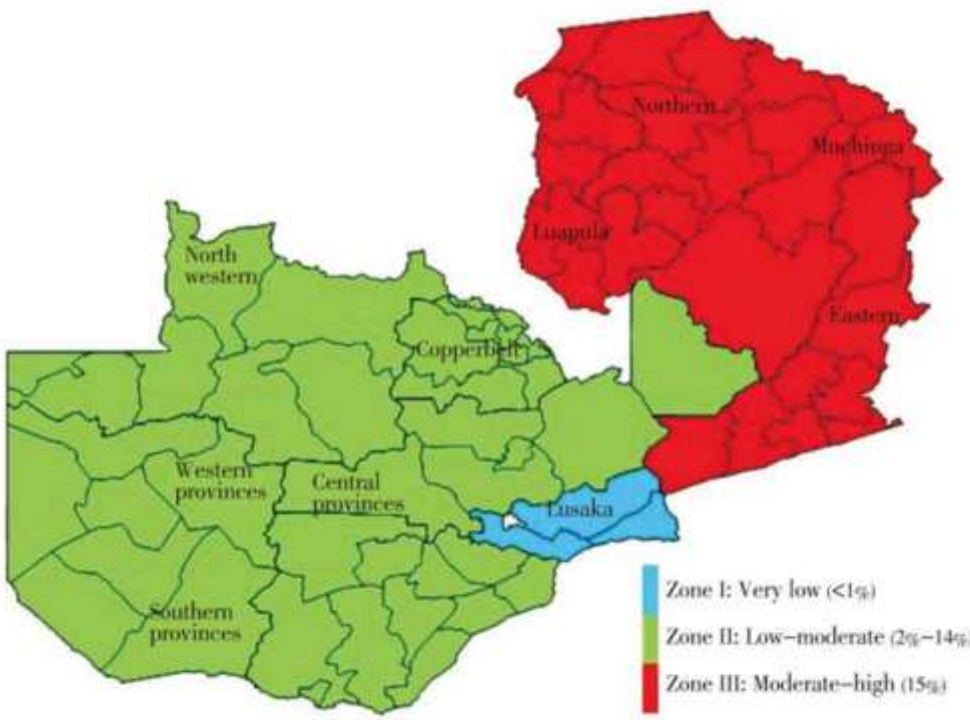


Figure 2: Malaria Transmission Zones in Zambia (Source: National Malaria Control Centre Action Plan, 2012).

Data was collected from Ministry of Health - Health Management Information System (HMIS) data base and the Zambia Meteorology Department. All malaria recorded cases for a five (5) year priod from 2009 to 2013 were included in the study. From 2009 to 2013 malaria cases have been segregated whereby both confirmed and non-confirmed cases are reported separately. Hence, non-confirmed malaria cases from 2009 to 2013 were excluded from this study. Exclusion of non-confirmed malaria cases in the analysis awarded the study internal validity.

3.2 Study Design

Secondary data from Ministry of Health (MOH) and Meteorological Department (MD) was used in this study. This was an ecological study because the unit of analysis was population based data and not individual level based. An ecological study can use data from populations with widely differing characteristics or extracted from different data sources. The major disadvantage of this study is that it cannot be used to make inferences because climatic conditions are not the same in all the districts. Climatic factors and malaria incidence for a five (5) year period from 2009 to 2013 was collected for analysis. Table 1 below shows the dependent and independent variables.

Table 1: Study Variables

	Variable	Indicator	Measure of Interest	Scale of Measurement
	Dependent variable			
1.	Monthly malaria case count	Monthly malaria count	Number of cases	Continuous
	Independent variables			
1.	Rainfall	Monthly Rainfall in mm per zone	Mean	Continuous
2.	Humidity	Monthly Relative Humidity per zone	Mean	Continuous
3.	Temperature	Monthly Minimum Temperature per zone	Mean	Continuous
		Monthly Maximum Temperature per zone		

3.3 Sampling Procedure

Multistage sampling technique was used to select districts from the three transmission zones. The first stage involved random selection of the provinces from each of the three malaria transmission zones. Four provinces (two in the moderate and two in the high transmission zones) were randomly selected. Southern and Western provinces were selected from the moderate transmission zone while Eastern and Northern were selected from the high zone. Lusaka province was automatically selected in the low transmission zone because it is the only province in this zone. All the districts from the selected provinces with both meteorological and malaria data for the period under study were listed.

The second stage of sampling involved random selection of districts with meteorology stations from the randomly selected provinces. One district was randomly selected from each selected province in the high and moderate malaria transmission zones. Mbala and Lundazi districts were selected from the high zone while Choma and Kalabo were selected from the moderate zones. In the low transmission zone, Lusaka district was selected, as it was the only district with meteorology station. This translated into five districts; two from the moderate, two from the high and one from the low malaria transmission zones.

Zone 1: Lusaka district

Zone II: Choma and Kalabo

Zone III: Mbala and Lundazi

Random selection made use of the lottery method of sampling by randomly selecting names of provinces and districts placed in a translucent bag.

3.4 Data Collection

3.4.1 Malaria data

Malaria data was obtained from the Ministry of Health's Health Management Information System (HMIS). The HMIS was established in 1996 and it captures data on disease morbidity and mortality, maternal and child health services, service delivery, surveillance and financial services from all the 72 districts of Zambia. This study extracted malaria confirmed cases data from the HMIS database from 2009 to 2013. The disease data was aggregated monthly from 2009 to 2013.

3.4.2 Climatic data

The Zambia Meteorological Department is responsible for capturing, processing and publication of climatic data. Climatic data including average maximum and minimum temperature, relative humidity and total rainfall from 2009-2013 was extracted from Zambia meteorology database. Climate data is recorded on a daily basis for each district and is disseminated electronically to Meteorological Department in Lusaka.

3.4.3 Data Management

Malaria data was extracted from the HMIS database into Microsoft excel and hence required cleaning and coding. Climatic data was also extracted from the National Meteorological database into Microsoft excel. Monthly total rainfall, maximum temperature and relative humidity were extracted.

3.5 Data Analysis

Climatic and malaria data was transferred to Stata version.10.1 data analysis software for coding, cleaning and labelling. Stata estimation commands were employed to obtain means, proportions and counts for variable appropriate for reporting the objectives. Graphical representations of trends and patterns were conducted in Excel**.** The Negative Binomial Regression analysis was used to measure the effect that the climatic parameters, (the independent variables rainfall, humidity and temperature) have on the outcome (dependent variable) Malaria case counts. The data used in this study is referred to as longitudinal data. Longitudinal data containing counts are assumed to have a Poisson distribution and therefore uses a Poisson regression. A Poisson regression model was used to fit mixed effects model on correlated panel data for count response variable. In this study, a model quasi-Poisson model can also account for dispersion.

The analysis was conducted in Stata as described earlier using the Negative Binomial Regression modelling of the panel data set to report Incidence Rate Ratios (IRR). The Incidence Rate Ratio measures of effect were interpreted in order to report the degree to which the climatic variables affect malaria incidence. Stata estimation commands were used to obtain means, proportions and counts for variables appropriate for reporting our objectives. Graphical representations of trends and patterns were conducted in Excel.

The data which was used comprised of monthly climatic data including rainfall (mm), minimum and maximum temperatures (°C) and humidity (%) from 5 districts that represent 3 malaria epidemiological zones in Zambia. However, temperature and rainfall data had a large number of missing values and was therefore used with reservations. The most important conclusions were drawn from rainfall effects.

The statistical relationship between climatic factors and malaria incidence over the period 2009-2013 in the low, moderate and high malaria transmission zones was examined. Pearson's correlation analysis which is for parametric data was used to examine the type and strength of association between malaria case count and climatic factors.

3.6 Ethical Considerations

Ethical clearance to undertake the study was sought from Excellence in Research Ethics and Science (ERES) Institutional Research Board (IRB). In addition, permission was also obtained from the Permanent Secretary of Ministry of Health and the Director for Meteorological Department for use of their databases. The study used secondary data and therefore there was no contact with individuals, hence there was less than minimal risk involved. In order to ensure distributive justice in the study, all confirmed malaria cases in the study sites were included in the sample. The study results are useful in formulating climate change and malaria interventional strategies directed at the reduction of morbidity and mortality due to malaria.

CHAPTER FOUR: RESULTS

This chapter presents the results of the study in answering research questions outlined in chapter one. The results first describes the effects of rainfall on the monthly case count. The relationship between climatic factors and malaria incidence in the three malaria transmission zones are also outlined in this chapter. Finally presentations on the annual trends in malaria incidence and climatic factors in the three malaria epidemiological zones will be presented in this chapter.

Table 2: Mean monthly distribution of confirmed malaria cases and rainfall from 2009-2013

Months	Zone 1		Zone 2		Zone 3	
	Cases	Rain (mm)	Cases	Rain(mm)	cases	Rain (mm)
January	1119.4	238.06	1086.2	146.4	5759.7	221.9
February	867.2	166.12	967.1	121.2	4400.2	159.7
March	685.2	107.3	1301.7	100.6	4175.4	184.5
April	1120.4	13.4	1812.8	7.4	4382	34.56
May	821	7.82	890.1	5.4	3654.4	4.6
June	434.6	0	586.5	0.5	3796.6	0
July	698.4	0	312.4	0	2323.9	0.15
August	352.8	0	217.3	0	1757.6	0
September	398.8	0	235	0.23	1802.7	0
October	208.6	0.8	261.7	5.7	2234.1	7.33
November	335.2	86.44	356.2	40.1	3444.9	79.7
December	649	175	879.2	75.8	5199.9	118.62
Overall Mean	**640.9**	**66.3**	**742.2**	**41.9**	**3,577.6**	**67.6**

Table 2 shows that the months of January recorded the highest number of confirmed malaria cases. This is followed by a gradual decline of cases in February then a steady increase in March. Most months within the rain season November to April recorded high malaria cases as compared to months of the dry season (August to October). Generally, malaria cases were recorded throughout the year in all the three malaria epidemiological zones of Zambia, as shown in both table 2 and figure 3. In March/April, however, the drop in rainfall led to an increase of in malaria cases from March to April.

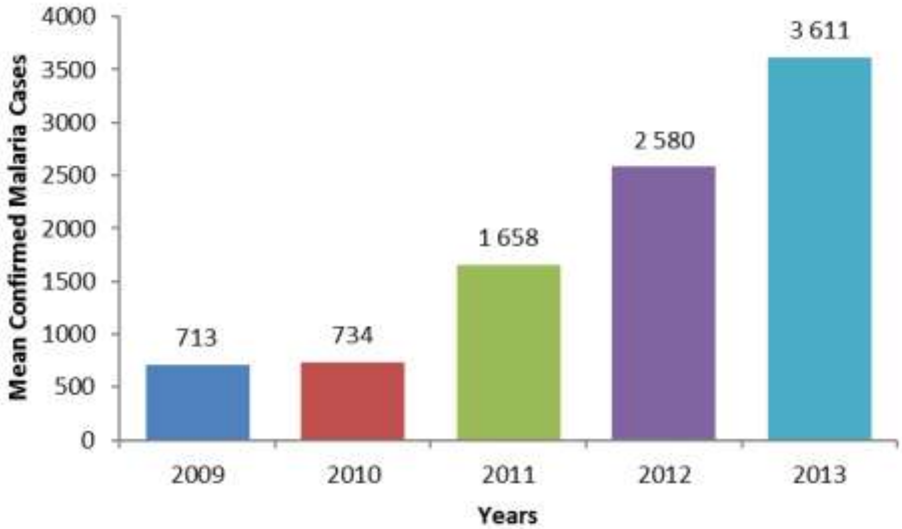


Figure 3: Mean monthly distribution of confirmed malaria cases (2009-2013)

Table 2 and Figure 3 shows an increase of confirmed malaria cases over the last 5 years.

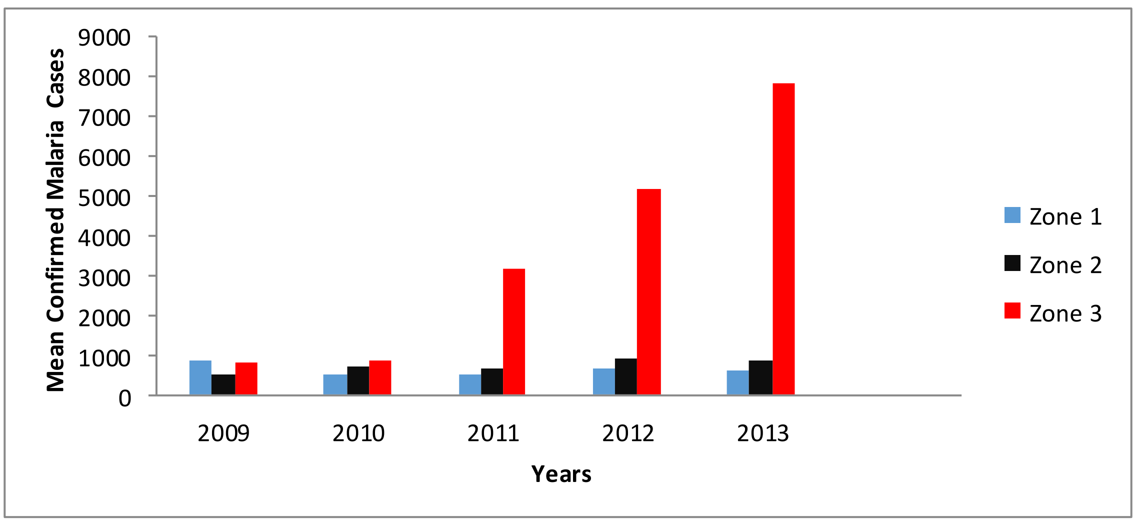


Figure 4: Annual distribution of confirmed malaria cases across the three malaria epidemiological zones from 2009-2013.

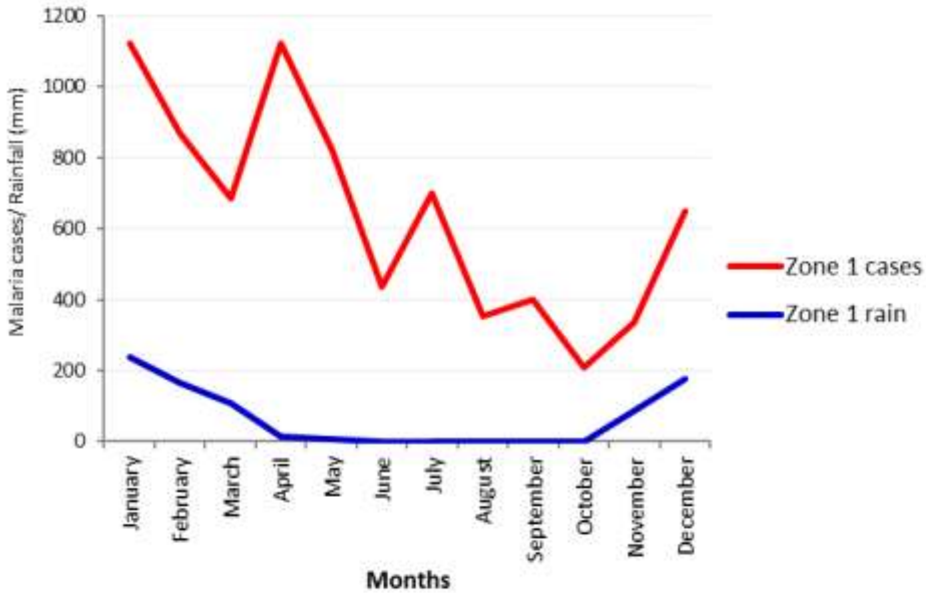


Figure 5: Zone 1 annual trend in the occurrence of malaria incident cases and rainfall (mm)

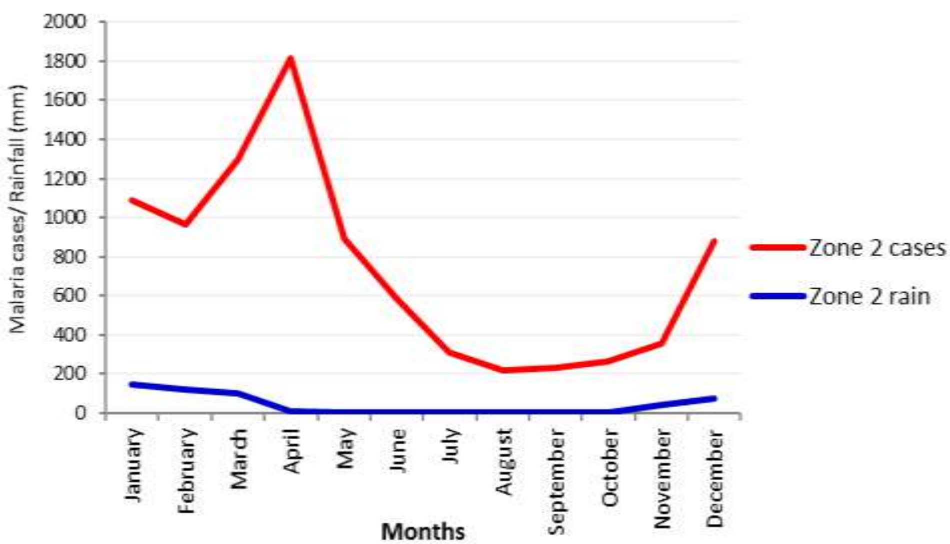


Figure 6: Zone 2 annual trend in the occurrence of malaria incident cases and rainfall (mm)

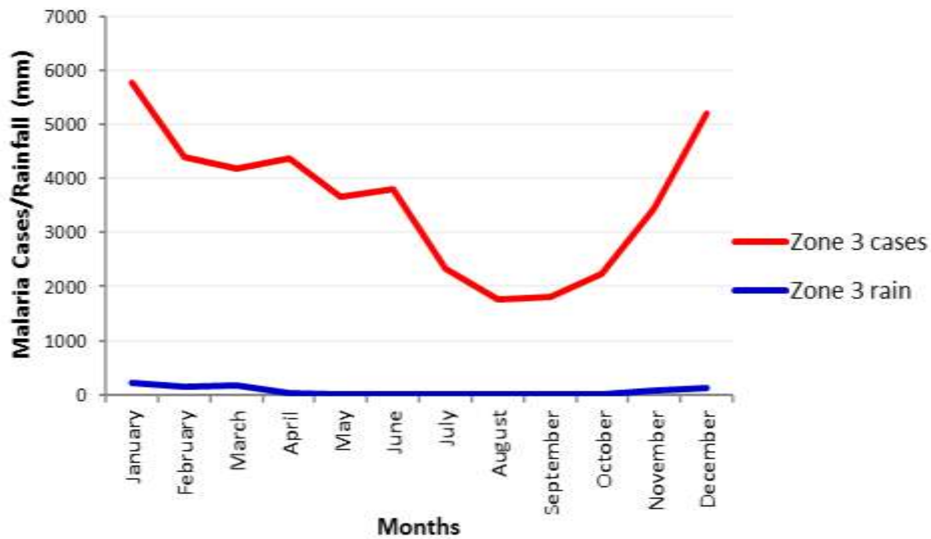


Figure 7: Zone 3 annual trend in the occurrence of malaria incident cases and rainfall (mm)

Figures 5, 6 and 7 illustrates a constant relationship between malaria cases and rainfall patterns in the different zones. Figure 7 shows constantly high cases even in dry season. The disease trend for the 3 zones (low, medium and high) for the period 2009 to 2013 is also illustrated.

Table 3: Results of the Regression model measuring the effect of rainfall, humidity, and temperature on malaria incidence

	Measure of effect of covariates on malaria incidence	
	Incidence Rate Ratio (IRR)	*p* value
Rainfall	1.002	0.005
Humidity	1.002	0.294
Min Temp	0.983	0.116
Max Temp	1.002	0.721

Table 3 results shows an Incidence Rate Ratio (IRR) of 1.002 (95 % CI 1.001 - 1.003) for rainfall which indicates that after adjustment for confounding effects of humidity, minimum temperature and maximum temperatures, the incidence of confirmed malaria cases in Zambia increased by approximately 0.2 % with every 1 mm increase in rainfall or Malaria cases in Zambia increase by 2 % for every 10 mm increase in rainfall. This relationship (IRR) was statistically significant with a p value of less than 0.05 (0.028. 2).

An IRR of 1.002 (95 % CI 0.998 - 1.007, p = 0.028) for humidity suggests that after adjustment for confounding effects of rainfall, minimum temperature and maximum temperatures, the incidence of confirmed malaria cases in Zambia would also increase by approximately 0.2 % with every 1 mm increase in humidity or malaria cases in Zambia increase by 2 % for every 10 % increase in Humidity. However, this relationship was not statistically significant (p = 0.294).

The effect of minimum temperatures, IRR of 0.983 (95 % CI 0.962 - 1.004) suggested that incidence of confirmed malaria cases reduced by 1.7 % for every 1 ^{o}C increase in minimum temperatures after adjustment for confounding effects of rainfall, humidity, and minimum temperature and maximum temperatures, However, this relationship was not statistically significant (p = 0.116).

While the effect of maximum temperatures, IRR of 1.002 (95 % CI 0.991 - 1.013) indicates that the incidence of confirmed malaria cases increased by 0.2 % for every 10 ^{o}C increase in maximum temperatures after adjustment for confounding effects of rainfall, humidity, and minimum temperatures. However, this relationship was not statistically significant (p = 0.721).

Table 4: Pearson's correlation matrix for pairwise correlation coefficients between climatic and malaria cases

Climatic & Malaria variables	Statistics	Humidity	Min Temp	Max Temp	Confirmed Malaria	Lab diagnosed Malaria	All Malaria	Rain
Humidity		1						
Min Temp	Pearson's Coef	0.1471*	1.0000					
	p value	0.0108						
Max Temp	Pearson's Coef	0.0819	0.7201*	1.0000				
	p value	0.1568	<0.001					
Confirmed Malaria	Pearson's Coef	0.2227*	0.3714*	0.2713*	1.0000			
	p value	<0.001	<0.001	<0.001				
Lab diagnosed Malaria	Pearson's Coef	-0.0093	0.0777	0.1321*	0.1094	1.0000		
	p value	0.8732	0.1793	0.0221	0.0583			
All Malaria	Pearson's Coef	0.1810*	0.3456*	0.2880*	0.8837*	0.5619*	1.0000	
	p value	0.0016	<0.001	<0.001	<0.001	<0.001		
Rain	Pearson's Coef	0.1394*	0.4436*	0.3113*	0.1864*	0.0881	0.1967*	1.0000
	p value	0.0157	<0.001	<0.001	0.0012	0.1277	0.0006	

Key: Significance level = 0.05.

Absolute Values of r ≤ 0.35 represent weak correlations; 0.36 to 0.67 moderate correlations; 0.68 to 0.9 high correlations with r coefficients; and values ≥0.90 very high correlations. A correlation coefficient of zero indicates that no association exists between the measured variables. Table 4 illustrates the relationship of malaria and climatic variables (temperature, rainfall and humidity). The correlation coefficients between Rainfall versus Lab diagnosed Malaria was 0.881 which represents a weak correlation and it was not statistically significant with a P-value of 0.1277. The correlation between rain and lab diagnosed malaria was no different from zero which means there was no correlation.

In the same respect all case malaria was significantly correlated with rains with a P-value of 0.0006 and the correlation was positive meaning the more rain, more malaria expected although this correlation was weak ($r = 0.1967 < 0.35$). A positive correlation coefficient indicates that an increase in the first variable would correspond to an increase in the second variable, thus implying a direct relationship between the variables.

CHAPTER FIVE: DISCUSSION

Results from this study found that there is a significant positive association between Rainfall and confirmed malaria cases. Numerous studies have also demonstrated this association (Loevinsohn, 1994; Patz and Lindsay, 2007; IPCC, 2008; Tulu, 2008). This study showed that the months of January recorded the highest number of confirmed malaria cases. This is followed by a gradual decline of cases in February then a steady increase in March. Most months within the rain season November to April recorded high malaria cases as compared to months of the dry season (August to October). Generally, malaria cases were recorded throughout the year in all the three malaria epidemiological zones of Zambia. The results in this study further illustrates that rainfall was observed from October to May, the highest recording was observed in January. Malaria cases increased at the onset of the rains. In March/April, however, the drop in rainfall led to an increase of in malaria cases from March to April.

From this study it can be concluded that monthly total rainfall was the only variable influencing incidence of confirmed malaria cases. Results from this study indicates that after adjusting for confounding effects of humidity, minimum temperature and maximum temperatures, the incidence of confirmed malaria cases in Zambia increased. This is consistent with the findings of Srinivasula who found that rainfall seems to play a more important role in the transmission of malaria (Srinivasula et al, 2013). He also found that rainfall had a greater correlation coefficient ($e=0.2695$; $p < 0.001$) for the association between malaria and rainfall.

These findings agree with those from several other studies (Gupta, 1996; Greenwood and Pickering 1993; Ramasamy et al.,1992). Pemola and Jauhari (2006), also found the highest significant correlation between rainfall and malaria incidence ($r = 0.718$, $p < 0.0001$), which is consistent with the findings of this study.

The effect of minimum temperatures, IRR of 0.983 (95 % CI 0.962 - 1.004) suggested that incidence of confirmed malaria cases reduced by 1.7% for every $1^{o}C$ drop in minimum temperatures after adjustment for confounding effects of rainfall, humidity, and minimum temperature and maximum temperatures, or Malaria cases in Zambia reduced by 17 % for every 10 ^{o}C drop in minimum temperature. However, this relationship was not statistically significant (p = 0.116).

While the effect of maximum temperatures, IRR of 1.002 (95 % CI 0.991 - 1.013) indicates that the incidence of confirmed malaria cases increased by 0.2 % for every 10 ^{o}C increase in maximum temperatures after adjustment for confounding effects of rainfall, humidity, and minimum temperatures, or Malaria cases in Zambia increased by 2 % for every 10 ^{o}C increase in maximum monthly temperature. However, this relationship was not statistically significant (p = 0.721). These findings were however, consistent with other studies that small increases in temperature will have a greater effect on malaria transmission (Peng et al., 2003). This is also consistent with the findings in the literatures (Bradley, 1993; Lindsay and Birley, 1996). This study failed to find a significant correlation between relative humidity and malaria incidence at the three malaria epidemiological zones. This can be attributed to the fact that there was paucity of humidity data.

Results of this study revealed that monthly malaria case count is influenced by climate, then it should be possible to predict malaria outbreak before its occurrence, either to strengthen control measures or to provide adequate facilities for the appropriate treatments. The advance notice provided by an early warning system could allow action to be taken earlier in the course of the epidemic, or could increase the span of time available to undertake control measures before the predicted excess cases occur (Bouma et al., 1996). Conclusively, the climatic variables that predict the presence or absence of malaria are likely to be best suited for forecasting the distribution of this disease at the edges of its range. However, the transmission of malaria is very complicated and detailed ecological and epidemiological studies are still needed to assess other local risk factors in Zambia.

5.1 Study Limitations

The data on monthly humidity and temperatures was incomplete and this could have influenced our findings that these variables had no effect on malaria case incidence. Maximum and Minimum temperature and rainfall data had a large number of missing values and was therefore used with reservations. The most important conclusions were drawn from the rainfall effects.

The study design was an ecological study which involved collection of aggregated data representing individuals. Therefore, ecological fallacy cannot be excluded when extrapolating results to individual districts. Bias might occur because the association observed between variables in malaria transmission zones does not necessarily represent association that exists districts. Furthermore, errors that occurred during the data management process from individual health facilities to district aggregates could not be controlled thereby affecting the reliability of the results. Inappropriate conclusions might be drawn on the basis of ecological data, thus it is important that results are interpreted with caution. Such ecological inferences however can provide a fruitful start for a more detailed epidemiological study on trends of climatic and malaria incidence in the low, moderate and transmission zones of Zambia.

CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS

In conclusion, this study found evidence that rainfall was positively associated with the number of confirmed malaria cases. Most months within the rain season November to April recorded high malaria cases as compared to months of the dry season (August to October). Malaria cases increased at the onset of the rains. In March/April, however, the drop in rainfall led to an increase of in malaria cases from March to April. Malaria cases were recorded throughout the year in all the three malaria epidemiological zones of Zambia. This study failed to find a significant correlation between relative humidity and malaria incidence in the three malaria epidemiological zones.

Expanding the research to include patient level variables (age, sex, socio-economic status, residential area household mosquito control measures etc.) would have added value to these findings in identifying household and individual level risk factors and not just ecological determinants. Further studies are required to confirm our findings on the correlation between humidity and malaria incidence in the three malaria epidemiological zones. Conclusively, the climatic variables that predict the presence or absence of malaria are likely to be best suited for forecasting the distribution of this disease. However, the transmission of malaria is very complicated and detailed ecological and epidemiological studies are still needed to assess the true local risk factors. The other recommendation from this study is that patient level variables such as age, sex, socio-economic status, residential area household mosquito control measures should also be added in future studies

REFERENCES

Alemu A., Abebe G., Tsegaye W, and Golassa L, (2011). Climatic variables and malaria transmission dynamics in Jimma town, South West Ethiopia. Parasites and Vectors Journal. 4: 1:30

Bouma M.J. and Van Der Kaay H.J. (1996). The EI Nino Southern Oscillation and the historic malaria epidemics on the Indian subcontinent and Sri Lanka: an early warning system for future epidemics. Tropical Medicine International Health journal, pp1: 86-96.

Briet M. N. and Lindsay S. W. (2008). Temperature-related duration of aquatic stages of the Afrotropical malaria vector mosquito Anopheles gambiae in the laboratory. *Medicine Veterinary Entomology*. 18: 174–179.

CEEZ (2006). Climate, and climate change/variability, personal communication. *Centre for Energy and Environment, Lusaka.*

Chipeta G. and Mumba Z. L. S. (2000). Rainfall indices of Zambia: State of Environment in Zambia 2000, Environmental Council of Zambia, Lusaka

Darkwah I. A. and Badu S. K. (2011**).** Knowledge of malaria prevention and control in a sub-urban community in Accra, Ghana. *International Journal of Tropical Medicine.* 2(6): 61–69.

DFID (2006). Mapping Climate Vulnerability and Poverty in Africa. *Department for International Development*. London.

Githeko A., Lindsay S., Confalonieri U. and Patz J. (2011). Climate Change and Vector-borne Diseases: A Regional Analysis. World Health Organasation. 78: 1136–1147.

Githeko A. and Ndegwa W. (2001**).** Predicting malaria epidemics in the Kenyan highlands using climate data: a tool for decision makers**.** *Global Change and Human Health*. 2: 54–63.

Greenwood B. and Mutabingwa T. (2012). Malaria in 2008. *Journal of Nature*. 415: 670-74

Greenwood B.M. and Pickering H.A. (1993). A malaria control trial using insecticide-treated bed nets and targeted chemoprophylaxis in a rural area of the Gambia, West Africa. *Journal of Tropical Medicine* 87: 2- 10

Gupta R. (1996). Correlation of rainfall with upsurge of malaria in Rajasthan. *Journal of Physics. India.* 44: 385-9.

Hunter P. R (2003). *Climate change and waterborne and vector-borne disease*. Application Microbiology 94: 37–46.

Hui F., Xu B. and Chen Z. (2009). Spatio-temporal distribution of malaria in Yunnan Province, China. *American Journal of Tropical Medicine and Hygiene*. p. 503–509.

Intergovernmental Panel on Climate Change. (2001). Climate Change: Impacts, Adaptation and Vulnerability: Working Group II of the IPCC. A Fourth Assessment Report for WMO and UNEP.

Jones V., Macintyre K., Keating J., (2007). Malaria transmission in urban sub-Saharan Africa. *American Journal of Tropical Medicine Hygiene*. 68: 169–176

Kasali G. (2008). Climate Change in Zambia: Capacity Strengthening in the Least Developed Countries for Adaptation to Climate Change, working paper II.

Kigotho A.W. (2009). Services Stretched as Malaria Kenyan Highlands Increases. *Lancet Series*. 212: 350-422

Loevinsohn M.E. (1994). Climatic Warming and Increased Malaria Incidence in Rwanda. *Lancet Series*. 343: 714-720

Masaninga F., Chanda E., Kapata., Hamainza B., Masendu T., et al. (2013). Review of the Malaria Epidemiology and Trends in Zambia. *Asian Pacific Journal of Tropic Biomedicine*. 3 (2): 89-94

Mathers C. D., Bernard C., Moesgaard I. C,. Inoue M., Shibuya K., et al. (2003). Global Burden of Disease in 2002: Data Sources, Methods and Results. World Health Organization.

McSweeney C., New M., Lizcano G. (2008). Zambia United Nations Development Program Climate Change Country Profile. Available from: http://country-profiles.geog.ox.ac.uk (Accessed: 14th July, 2014).

Ministry of Health (2014). Health Management Information System. Lusaka, Zambia.

Ministry of Health (2006). The National Health Strategic Plan 2006-2010. Lusaka, Zambia

Murray J. L., Vos, T., Lozano R., Naghavi M. (2013). Disability-adjusted life years (DALYs) for 291 diseases and injuries in 21 regions, 1990–2010: A systematic analysis for the global burden of disease study 2010. *Lancet* series. 380. p. 2197–2223.

Musawenkoi L.H., Vounahsou P., Midzi S. (2006). Spatio-temporal Analysis of the Role of Cliamte in Inter-Annual Variation of Malaria Incidence in Zimbabwe. *International Journal of Health Geographics.* 5: 1-20

National Malaria Control Centre (2011), *National Malaria Action Plan for 2010-2011*. Ministry of Health, Zambia.

Paaijmans K. P., Wandago M. O., Githeko A. K., and Takken ,W. (2007). Unexpected high losses of Anopheles gambiae larvae due to rainfall**.** PLoS One

Partz J.A and Lindasay S.W. (2007). New Challenges, New Tools: The Impact of Climate of Change on Infectious Diseases. *International Journal of microbiology*. 2: 445-451

Pemola N.D. and Jauhari R.K. (2006). Climatic variables and malaria incidence in Dehradun, Uttaranchal, India. *Journal of Vector Borne Disease*.43:21-28.

Peng B., Shilu T., Donald K., Parton K. A. and Ni J. (2003). Climatic variables and transmission of malaria: A 12 year data analysis in Shuchen County. China-Public Health Report. pp118:69

Ramasamy R., Vickie J. L., Jones S. (1992). High seasonal malaria transmission rates in the intermediate rainfall zone of Sri Lanka. *Annual Tropical Medicine of Parasitology*. 86: 591 600.

Reiter P. (2001). Climate Change and Mosquitoe-borne Disease: Knowing the Horse before Hitching the Cart. *Scientific Review Journal*. 27: 383-398.

Sachs J. and Malaney P. (2008). The Economic and Social Burden of Malaria. *Nature*. 415: 680 – 685.

Srinivasula T. P., Kumar P., and Reddy N.N. (2014). Factors affecting Malaria Disease Transmission and incidence: a special focus on Visakhapatnam District. *International Journal of Recent Scientific Research.* 5:312-317

Tulu A.N, (2008). Determinants of Malaria of Malaria Transmission in the Highlands of Ethiopia: The Impact of Global Warming on Morbidity and Mortality Ascribed to Malaria. *International Journal of Environmental Research and Public Health.* 56: 346-30

Lieshout V. Kovats R. S. and Livermore M. T. (2004). Climate change and malaria: analysis of the SRES climate and socio-economic scenarios. *Global Environmental Change*. 14: 87–99
WHO/WMO/UNEP (2009). Climate Change and Human Health: An Assessment Prepared by a Task. Geneva, Switzerland: World Health Organisation

World Health Organisation (2008). World Malaria Report: Global Malaria Programme. Geneva, Switzerland: World Health Organisation.

World Health Organisation (2012). World Malaria Report: WHO Global Malaria Programme. Geneva, Switzerland: World Health Organisation.

World Health Organization (2014). *World Malaria Report*. (Online) Available from: http://www.who.int/malaria/world_malaria_report (Accessed on 16th December 2015).

Zambia briefings (2010). *Poverty, Food and Energy in a Changing Climate*. (Online) Available from: http://uk.oneworld.net/guides/zambia/climate-change (Accessed on 10th August, 2014)

Zambia National Malaria Indicator Survey (2010). *Ministry of Health Report*. Government Printers, Lusaka, Zambia.

Appendix 1: Budget

B**elow is an estimated budget for the study**

S/N	Item	Quantity	Unit cost ZMK	Total cost
1.	Communication	1	1,500	1,500
2.	Toner	1	800	800
3.	External hard disc	1	650	650
5.	Transport-	1	1,000	1,000
6.	Bond paper	5	50	250
7.	Research Ethics Committee fees	1	500	500
8	Flash Disk	1	250	250
8.	Publication	1	2,500	2,500
9.	Other stationary	1	500	500
11.	Binding of final report	5	350	1,850
12.	poster printing	1	1,000	1,000
13.	**Sub total**			14,800
14.	**Contingency (10%)**	-	-	1,480
Grand Total				**12,280**

Appendix 2: Work Plan

Task to be performed	**April-14**				**May-14**				**June-14**				**July-15**				**Oct-2015**				**Dec-2015**				**Jun-2016**				**Oct-16**
	Week				**Week**				**Week**				**Week**				**Week**				**Week**				**Week**				**Week**
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	
Finalize research proposal and submit to ERES for approval																													
Clearance from school																													
Development of data collection tools, pretesting and revision																													
Data collection																													
Data entry																													
Data analysis																													
Draft report writing																													
Finalization of report writing																													
Dissemination of results and discussion with stakeholders																													
Binding and submission of final dissertation																													
Graduation																													

Appendix 3: Data Collection Form

	2009				2013			
District Name	**Average Monthly Temp(oC)**	**Average Monthly Rainfall (mm)**	**Average Monthly Humidity (%)**	**Recorded Malaria cases**	**Average Monthly Temp(oC)**	**Average Monthly Rainfall (mm)**	**Average Monthly Humidity (%)**	**Recorded Malaria cases**
Lusaka								
Choma								
Lundazi								
Mbala								
Kalabo								