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ARAŞTIRMA / RESEARCH ARTICLE

Effects of Climate Change on Malaria Incidence Rates in Selected Districts of Zambia, Over A Seven-Year Period: A Retrospective Study

Mwenya Silombe[1] **Rosemary Ndonyo Likwa**[2]

1 School of Veterinary Medicine, The University of Zambia

2 University of Zambia School of Public Health Department of Population Studies and Global Health

Abstract

Climate change has been projected to have a serious human health impact negatively, in particular the incidences of water related and vector borne diseases, such as malaria. A better understanding of the relationship between atmospheric air temperature, seasonal rainfall patterns and the incidence of malaria cases is thus required for developing effective climate change adaptation strategies involving planning and implementation of appropriate disease control interventions. The objective of the study was to determine the effects of Climate change on malaria incidence rates in selected Ecological District Zones of Zambia, over a six years period. Retrospective analytical comparative study design was used in this research, which employed the use of mixed methods for validation of data on the effect of climate change on occurrence of malaria incidence rates in three Ecological Zones in Zambia. A Linear regression model was used to analysed the data and determine the effect of the atmospheric air temperature, seasonal rainfall pattern and manmade economic activities on malaria incidence rates. The mean annual distribution for confirmed malaria cases over a six year period 2014-2020 Ecological zone 1 was 64.35, Ecological Zone 2 was 180.48 and Ecological Zone 3 was 581.06. The mean annual distribution for rainfall pattern for Ecological Zone 1 was 550.55 mm, Ecological Zone 2 was 835.39 mm and Ecological Zone 3 was 1072.05 mm. The mean annual distribution for atmospheric air temperature for Ecological Zone 1 was 22.74 oC, Ecological Zone 2 was 19.51 oC and Ecological Zone 3 was 21.57 oC. Seasonal rainfall has a positive effect on malaria incidences ($r = 0.418$, $p = 0.007$), and positive correlation. Average atmospheric air temperature have the positive effect on the malaria incidence ($p = 0.001$). Ecological human economic activities such mining, agriculture, urbanization and charcoal burning has effect on climate change and malaria.

Keywords: Climate change, Malaria, Ecological human activity, Rainfall, Temperature.

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Sorumlu Yazar / Corresponding Author:
Mwenya Silombe, School of Veterinary Medicine, The University of Zambia
E-Mail: silombe@gmail.com

INTRODUCTION

Recent publications about climate change as a result of anthropogenic activities predict a warming of the earth from 2.5 to 4°C in the next century and dramatic variations in the intensities of precipitation with large differences between geographic areas (Watson, Zinyowera and Moss 1998). Apart from creating numerous effects on the environment, these changes are likely to affect human health as well. It has been suggested that vector-borne diseases may be one of the major health impact factors that will be affected (Patz and Balbus 1996; McMichael and Beaglehole 2000; Haines and Patz 2004). Among these, malaria has been singled out as a particularly vulnerable target, as both vectors (mosquitoes of the genus Anopheles) and parasites may be affected, and also because thousands of people are currently living in areas where the malaria vectors are present but the parasites are absent or circumstances are unsuitable for parasite development (Martens et al. 1999). Malaria continues to be a major cause of death among people living in the tropics, in spite of recent gains in the fight against the disease. In Africa, it accounts for over five hundred thousand deaths annually, which is about 90% of the worldwide annual mortality (WHO, 2013). Malaria contributes significantly to the high rates of child and maternal mortality, maternal anaemia, low birth-weight, miscarriage and stillbirth. It also creates significant economic burden on families due to household expenditure on malaria treatment and reduced productivity, thereby intensifying poverty and making populations more vulnerable to malaria transmission (WHO, 2013) (Sachs and Malaney, 2002). The situation could be exacerbated by the challenges posed by climate change. Although the impact of the climate on human health is uncertain, an increase in the incidence of malaria has been identified as a potential impact of climate change in South America (Van Lieshout et al, 2004) and in Africa (Tanser et al, 2003) (Thomas et al, 2004). Current epidemiological models predict malaria risk based on generalized climate data, using average annual temperatures and rainfall, with little regard for local variation. As the climate changes will affect regions differently, it is of critical importance to be able to study the effects of the changes on local malaria risk, taking into consideration the topography, land use, habitat structure and demography of each area. Other changes may also affect malaria risk, such as rapid changes in land use, industrialization, deforestation, urbanization and human migration. As the predicted climate change may affect these entities differently, the study of environmental change and malaria becomes complex and challenging.

Objective

The main research objective was to determine the effects of Climate change on malaria incidence rates in selected Ecological District Zones of Zambia**,** over a seven year period.

In order to archive the main objective the study had the following specific objectives:

1. To determine the effect of seasonal rainfall on malaria incidence rates in the selected districts.
2. To examine the effects of minimum and maximum climate atmospheric air temperature on malaria incidence rates in the selected districts.
3. To identify the effects of manmade ecological activity on influencing malaria incidences and climate change.

METHODOLOGY

Study design

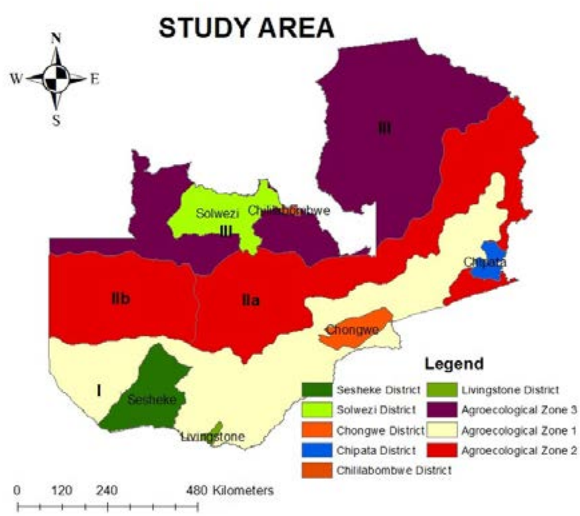
Retrospective analytical comparative study design was used in this research, which employed the use of mixed methods for validation of data on the effect of climate change on occurrence of malaria incidence rates in three Ecological Zones in Zambia.

A mixed method involved two sources of data: the first one being quantitative data yielded from the trend analysis of Malaria incidence rates alongside the Seasonal rainfall patterns and the climatic atmospheric air temperature from the selected Ecological Zones over a period of six (6) years. The second one was qualitative in nature that involved conducting in-depth interviews with relevant key informants on human activities assumed to have great influence on the climatic atmospheric air temperature change and consequently on human health to result in malaria incidences.

Study Site

The study was conducted in six districts selected from three Ecological Zones of Zambia that is Ecological Zones I, II and III. The districts selected in Zone I were Sesheke and Livingstone, Zone II included Chipata and Chongwe. In Zone III district selected were Chililabombwe and Solwezi.

Figure 1: Study area



Quantitative Approach:

Variables

Dependent Variable

The dependent variable was Malaria incidence rate

Independent variables

There were four (4) independent variables measured in this study as:

a) Climatic atmospheric air temperature,

b) Seasonal rainfall pattern

c) Manmade ecological activity

d) Socio-economic Status

e) Demographic characteristics

Study population for the Quantitative part

Health facility Malaria Case Records, 2014-2020

Seasonal rainfall

The seasonal rainfall data from 2014 to 2020 in all the six selected districts of Zambia was considered as the study population. The seasonal rainfall was in millimetres (mm).

Climatic air Temperature

The atmospheric air temperature data from 2014 to 2020 in all the six selected districts of Zambia was considered as the study population. The temperature was in degree Celsius (°C).

Data collection

Retrospective malaria case data

All malaria incidence data from 2014 to 2020 for the six selected districts was collected from the Ministry of Health (MoH) at respective district offices from all the health facilities in the district. The data collected was annually incidences.

Temperature and Rainfall data

The data on climate (seasonal rainfall and air temperature) for all the six selected district was collected from the Zambia Meteorological department (ZMD) offices at respective district offices and headquarters in Lusaka. Weather variables obtained were daily rainfall volumes in millimetres (mm) and minimum and maximum air temperatures (°C) for the period of January 2014 to December 2020.

Statistical analysis

Quantitative Raw data collected on malaria cases and weather were cleaned and scouted out in Microsoft Office Excel version 2010 spreadsheets. Data was entered and analysed on a computer software package program statistical package for social scientists (SPSS) version 26.0. Descriptive statistics of graphs and pie charts was used to describe the study variables. Simple linear regression was used to determine the effect of rainfall and air temperature on malaria incidences. Pearson's correlation coefficient was used to determine the relationship between variables.

Qualitative Approach

Purposive Sampling

In order to save time and resources the researcher used his judgment to select population members who were good prospects for accurate information as key informants in the society who would elicit their views on manmade ecological activities effect on climate change and malaria transmission to the community during key informant interviews. The researcher selected thirty six (six participate from each district) key informants depending on their role in society, which he would interview. These informants entail the following; Senior Agriculture Officer, District social welfare officer, forestry officer, district wildlife officer, District medical officer and Meteorology personnel.

Key informants interviews

The researcher arranged for appointments for interviews with the potential respondents after gaining their consent to participate in the study. The researcher had to adjust schedules to meet the respondents at times convenient for them. Figure 1 show the set of question guide that were used during the in-depth interviews.

Data analysis

The data was analysed in the manner that best answers the questions and addresses the objective of this study (Saunders, 2003& Mason 1997). The notes from in-depth were organised by questions. Notes records from all the participants were emerged. The findings from the key informant interviews were correlated with those from in-depth interviews and data from literature was taken into account.

RESULTS

Descriptive statistics

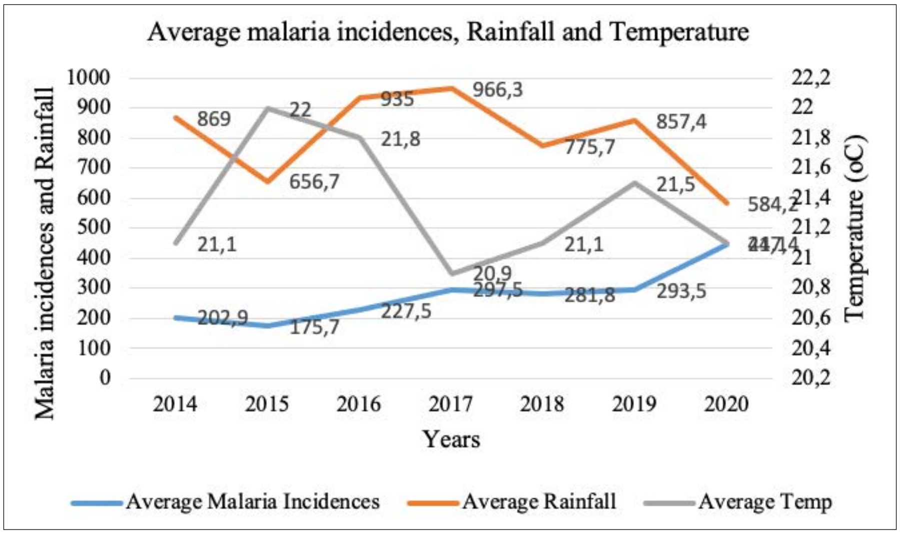
The table 1 shows the mean annual distribution for confirmed malaria cases, rainfall pattern and atmospheric air temperature for over six years period 2014- 2020 in six districts. The highest number of confirmed malaria cases of 990.2 cases were recorded in Ecological Zone 3 in 2020 and the lowest number of 14.5 cases were recorded in 2019 in Ecological Zone 1. The highest amount of rainfall of 1445.85 mm was recorded in 2017 in ecological zone 3 and lowest amount of 349.45 mm were recorded in 2019 in Ecological Zone 1. The highest temperature of 24.3^{o}C in 2015 was recorded in Ecological Zone 1 and lowest temperature of 18.2 ^{o}C recorded in 2017 in Ecological Zone 2. This means that Ecological Zone 1 is drier and hot zone with fewer cases of malaria followed by ecological zone 2 which recorded higher malaria cases. Generally, ecological zone 3 recorded the highest number of malaria cases and received more rainfall than other zones (figure 2).

Table 1: ***Mean annual distribution of confirmed malaria cases, rainfall and temperature from 2014-2020.***

Year	Ecological Zone 1			Ecological Zone 2			Ecological Zone 3		
	Malaria Cases	Rainfall (mm)	Temp (°C)	Malaria Cases	Rainfall (mm)	Temp (°C)	Malaria Cases	Rainfall (mm)	Temp (°C)
2014	79	597.05	22.5	178.45	1150.15	19.25	351.3	897	21.45
2015	49.8	504.65	24.3	133.1	912.55	20.15	344.35	991.45	21.6
2016	85.65	502.55	23.4	171.65	679.8	19.05	427.2	745.2	22.05
2017	56.7	672.65	22.4	207.95	590.7	18.2	627.95	1445.85	21.2
2018	64.95	723.55	22.05	169.9	898.4	19.35	610.45	1169.15	21.9
2019	14.5	349.45	21.9	150.05	956.05	20.95	716	1059.4	21.7
2020	99.85	503.95	22.65	252.25	660.1	19.65	990.2	1196.35	21.1

Source: Research data, 2022.

Figure 2: Malaria incidences, rainfall and temperature



The table 2 shows the analysis of variance performed on the rainfall, temperature and malaria cases data collected. The significant of the model shows 0.001 which is less than the significant level used of 0.05 (p- value). This mean that the model can be used to predict the malaria incidences is significant, F (2, 39) = 8.646, p = 0.001.

Table 2: The effect rainfall and atmospheric air temperature on malaria incidences

ANOVA[a]						
Model		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
1	Regression	1315998.104	2	657999.052	8.646	.001[b]
	Residual	2967985.506	39	76102.192		
	Total	4283983.610	41			
a. Dependent Variable: Malaria						
b. Predictors: (Constant), Rainfall, Temperature						

The analyses of variance (ANOVA) table 3 below shows that the model is significant with model significant of 0.007 less than the level of significant used of 0.05 (p - value). Seasonal rainfall has a positive effect of on malaria incidences (r = 0.418), the effect size is moderate and positive correlation. 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 seasonal rainfall and malaria incidences.

Table 3: The effect seasonal rainfall on malaria incidences

ANOVA[a]						
Model		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
1	Regression	1128506.789	1	1128506.789	8.243	.007[b]
	Residual	5339364.601	39	136906.785		
	Total	6467871.390	40			
a. Dependent Variable: Malaria Cases						
b. Predictors: (Constant), Seasonal Rainfall						

The ANOVA table 4 below shows the model significant figure of 0.011 which means that average temperature is a good predictor of the malaria incidences across the six districts in Zambia. Average temperature have the positive effect on the malaria incidence

Table 4: ANOVA table of average temperature and malaria incidences

ANOVA[a]						
Model		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
1	Regression	733366.085	1	733366.085	7.307	.011[b]
	Residual	3211736.545	32	100366.767		
	Total	3945102.630	33			
a. Dependent Variable: malaria						
b. Predictors: (Constant), average temp						

There was a significant correlation between maximum temperature and malaria incidence across all the six districts. The strength of the linear was negative (-0.429) with the p-value of 0.005 at alpha level of 0.05 (Table 5).

Table 5: Correlation between maximum atmospheric air temperature and malaria incidences

Correlations			
		max temp	**malaria**
max temp	Pearson Correlation	1	-.429**
	Sig. (2-tailed)		.005
	N	41	41
malaria	Pearson Correlation	-.429**	1
	Sig. (2-tailed)	.005	
	N	41	42
**. Correlation is significant at the 0.01 level (2-tailed).			

Qualitative results

The objective was to identify the ecological manmade activities and their effect on climate change and malaria transmission. The data was collected using in-depth interviews.

Descriptive of key informants

The total sample size was 36 informants which included District medical officers, District senior agriculture officers, Environmental officers, Social welfare officers, Forestry and Wildlife officers as shown in table 6 and 7.

Table 6: Sample Characteristics by Ecological Zones

Ecological Zone	Key Informants by Gender		Sample
	Male	Female	
Eco Zone 1	8	4	12
Eco Zone 2	10	2	12
Eco Zone 3	7	5	12
Total	25	11	36

Table 7: Key informants by Community role

	Key informant community role
	Wildlife officer
	Forestry officer
	Social welfare officer
	District medical officer
	Environmental officer
	District senior agriculture officer

Perception of Land Use and Climate Change

The results in the table 4 shows the reasons for land use such deforestation, agricultural expansion, socio- demographic changes, and socioeconomic status have influence on climate change.

Table 4: Reasons for land use and climate alternation

Environmental changes	Effect on climate change
Deforestation	1. Much of that stored carbon is released into the atmosphere again as CO_2 contributing to global warming. 2. The cooling effect disappears
Agricultural expansion	1. Release greenhouse gases into the atmosphere e.g. methane and nitrous oxide. 2. Massive cutting of trees and grasses increase CO_2 in the atmosphere.
Socio-demographic changes	Environment at risk 1. Increased size in human population leads to more land clearing for settlements. 2. Low education level among the rural people make them to be engaged in activities that affect climate change such as cutting trees, bush burning.
Socioeconomic status	1. Low income causes people to be engaged in illegal activities such as cutting reserved hard wood for timber, charcoal burning and forest clearing. 2. People with high socioeconomic status disproportionally affect energy-driven greenhouse gas emissions directly through their consumption and indirectly through their financial and social resource. E.g. mining activities. 3. Increased risk and uncertainty of forest or agricultural production, alteration in productivity for crops and forest products, reduction in supply of ecosystem goods and services, increased cost of utilities and services, and altered energy needs.

Perception of Land Use and Malaria transmission

The results in the table 5 shows that land use such deforestation, agricultural expansion, socio- demographic changes, and socioeconomic status and wildlife reservoirs have influence on malaria transmission from the in-depth interviews

Table 5: Reasons for land use and malaria transmission

Environmental changes	Effect on malaria
Deforestation	1. Increases in anopheline larval breeding sites in response to forest clearing. 2. Initial decreases in vector densities followed by colonization by more efficient malaria vectors. 3. Changes in vector habitat suitability linked with forest disturbance. 4. Changes in ecological structure and biodiversity increasing or decreasing vector densities, availability of blood meals and resulting disease risks
Agricultural expansion	1. Effects of irrigation systems, aquaculture and plantations 2. Expansion of rubber and rice paddies associated with increases in anopheline densities
Socio-demographic changes	Population at risk 1. Influx of susceptible populations into endemic areas in response to increased economic opportunity 2. Increase and movement of migrant worker populations 3. Occupational changes, such as forestry and extraction activities bringing people into vector habitats
Socioeconomic status	1. Increased income following agricultural development leading to decrease in malaria risk 2. Improved housing structure due to development reducing malaria risks
Wildlife reservoirs	Origin of malaria 1. P. falciparum originated from non-human primates Spatial overlap with wildlife hosts. 2. Increased contact between people and non-human primates hypothesized as main driver of human infections.

DISCUSSION

Effect of temperature on malaria incidences

Climate change represents a potential environmental factor affecting disease emergence, shift in the geographic ranges of hosts and vector, effect reproduction, development, and mortality rates on hosts, vectors, and pathogens. Effects of the increased climate variability, floods and droughts all have the potential to affect disease incidence and emergence either positively or negatively. Climate factors i.e. atmospheric temperature and rainfall affect malaria incidences (Desalegn et al., 2021). Published research generally agrees that rainfall and temperature are important drivers of malaria. Temperature fluctuations have been shown to have profound impacts on predictions of mosquito and malaria parasite development time (Paaijmans et al., 2009: Paaijmans et al., 2010). Mosquitoes are sensitive to temperature throughout their life cycle and, because temperature dependencies are nonlinear and differ between life-history traits and life stages, it is difficult to predict the population level responses to temperature fluctuations. In a study by Zhang et al. (2010) in a temperate region in China the maximum and minimum temperature had the highest positive relation with monthly incidence and this relation was also seen with one month lag and 1 °C increase in minimum temperature resulted in 12 to 16% increase in incidence and minimum temperature was more effective than maximum temperature (Zhang et al., 2010). Blanford *et al.,* (2013) explained temperature as an important determinant of malaria transmission. Maximum and minimum temperatures affect the life cycle of malaria parasite

Effect of rainfall on malaria

The results showed a positive correlation coefficient between rainfall and malaria incidences. This means that an increase in the first variable would correspond to an increase in the second variable, thus implying a direct relationship between the variables seasonal rainfall and malaria incidences. 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. Most of the analysis of the research results supported the hypothesis that rainfall has an impact on malaria incidence. Higher rainfall has a significant impact on increasing the number of malaria cases. In years with high rainfall, a significant increase in malaria cases is immediately followed (Sena et al., 2015; Adeola et al., 2019, and Mihreteab et al., 2020). According to the study done by Adeola et al (2019), they estimated that the transmission of malaria cases occurs when the rainfall intensity is estimated at 40–55 mm. In Indonesia, using the data set for 2005 - 2014, rainfall ranges from 178 mm – 251 mm per year. An increase in rainfall of 1 mm was associated with a 0.08% increase in malaria cases after months of rains (Rejeki et al., 2018).

Effect of land use change on the potential malaria incidences and climate change

Malaria is a particular problem in agricultural areas, as land use practices implemented often result in increased presence of breeding sites (Randell et al. 2010 and Okyere et al. 2009). The influence of agricultural systems on health is particularly notable via the intermediary process of land use change. Agricultural production systems including farming practices, location of farms, and farming technologies could lead to land use change that create suitable ecological and climatic conditions for the breeding and survival of the Anopheline mosquitoes, which transmit the malaria (Okyere et al. 2009). Previous study links land use with microclimate variables such as temperature, rainfall and humidity, which in turn influence the development of the malaria vector and parasite, thereby shaping local mosquito population dynamics and malaria transmission (Lindblade et al. 2000; Patz and Olson 2006; Patz et al. 1998; Pascual et al. 2006). Warmer temperatures have been clearly associated with specific types of land use such as cultivated swamps verses natural swamps (Lindblade et al. 2000), farmland habitats (Munga et al. 2006), and deforestation (Afrane et al. 2008; Yasuoko and Levins 2007; Minakawa et al. 2005; Olson et al. 2010). Variable amounts of shading, temperature, and evaporation are mechanisms by which land use affects the surface microclimates that can influence malaria transmission. Results of this study indicate that not only land use type, but also spatial relations between land use and breeding habitats, may be an important influence on runoff reaching malaria vector breeding habitats in water-limited environments. In the rural areas, deforestation is one of the most potent factors in emerging and re-emerging infectious diseases (Yasuoka and Levins, 2007). Deforestation is driven by a wide variety of human activities, including agricultural development, logging, transmigration programmes, road construction, mining, and hydropower development (FAO, 2011). These processes alter the various elements of local ecosystems such as microclimate, soil, and aquatic conditions, and most significantly, the ecology of local flora and fauna, including human disease vectors like Anopheles mosquitoes. As reported by Yasuoka and Levins (2007), mosquitoes are very sensitive to environmental changes.

CONCLUSIONS

The purpose of this study was to determine the effect of climate change on malaria incidence rates in six selected districts of Zambia. The results showed that climate variables (atmospheric air temperature and rainfall pattern) effect the malaria transmission in all the districts. There is a positive correlation between the climate variables and malaria transmission. Manmade ecological activities have impact on the transmission of malaria and climate change. It was observed that land use change is the driving force for climate change in all the districts.

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