

Influences of Rainfall and Temperature on Malaria Endemicity in Cameroon: Emphasis on Bonaberi District

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Abstract

Relating the influence of climate on the occurrence of a vector-borne disease like malaria quantitatively is quite challenging. To better understand the disease endemicity, the effects of climate variables on the distribution of malaria in Cameroon are studied over space and time, with emphasis on the Bonaberi district. Meteorological monitoring can lead to proactive control. The government of Cameroon, through the National Control Malaria Program, has put in place strategies to control and stop the spread of the disease. This study is therefore geared towards assessing the yearly parasite ratio of malaria over the ten regions of Cameroon and to work out the influence of rainfall and temperature on disease endemicity with emphasis on a district of Douala. The model used is the VECTRI model, which shows the dynamic link between climatic variables and malaria transmission. The parasite ratio observed and simulated showed a maximum correlation of 0.75 in 2015. A positive relationship between temperature, rainfall and malaria is revealed in this study but Bonaberi has malaria all year round. The West region is the least affected by malaria. We recommend that For the VECTRI model to perform better, the population could be incorporated in the model.

Keywords

Malaria, Parasite Ratio, Malaria Modeling, Climate Variables

1. Introduction

Many people worldwide are at risk with regards to climate-health relationships. Some of these reasons may include climate variation and population density (Afrane et al., 2004; Ayanlade, 2020). Malaria being a climate-health-related disease is a well-talked-about ancient vector-borne disease, and still remains a public health issue in Cameroon. It is one of the most prevalent mosquito-borne parasitic diseases throughout tropical and subtropical regions of the world (Mfon-fu, 1986; Titanji et al., 2001; Fru-Cho et al., 2013; Nyasa et al., 2021). Malaria is caused by a parasite, transmitted to humans through a bite of infected female Anopheles mosquitoes. Five Plasmodium species are currently involved in malaria transmission: *P. vivax*, *P. malariae*, *P. ovale*, *P. knowlesi* and particularly *P. Falciparum* which is the main malaria species in Cameroon (Craig et al., 1999). While there are affordable drugs to treat and stop the disease, malaria still contains a negative effect on people's health worldwide (WHO, 2015). Globally according to WHO's latest World malaria report 241 million malaria cases and 627,000 malaria deaths were recorded in 2020 (WHO, 2021).

In Endemic areas, pregnant women, children under five years old, and immune-suppressed individuals are the foremost vulnerable (WHO, 2009; Dan-wang et al., 2021). This accounts for 67% of malaria deaths in the whole world. In sub-Saharan Africa, the malaria burden is incredibly high. Accounting for over 94% of world malaria deaths, this particularly is due to the climate and hydrological conditions that favour the breeding of mosquitoes. While there are affordable drugs to treat and stop the diseased, more than 90% of the population is in danger of malaria infection in Cameroon. Annually about 41% of the population had an encounter with malaria at least once. In addition, malaria is the root explanation for 50% - 56% of morbidity and 40% of annual mortality among children (Mbenda et al., 2014). Malaria inflicts an economic burden on both the government and individuals, with an estimated cost of about US \$12 billion each year (National malaria control programme in Cameroon, 2008) in the whole world. The government of Cameroon has put in situ various intervention strategies. Among these include; free distribution of treated mosquito nets, free malaria treatment for uncomplicated malaria for youngsters from zero to five years, and indoor residual spraying. In addition, the reduction of cost of diagnosis and treatment of simple malaria in health care facilities to five thousand francs CFA (Coldiron et al., 2017). This has enabled the habitants to be treated from malaria. Also, free intermittent preventive treatment for pregnant women since 2005, seasonal malaria chemoprevention for children 3 to 59 months within the Far North and North regions during the rainy season have been implemented since 2016 (Coldiron et al., 2017). Epidemics of malaria energetics are firmly influenced by climate (Caminade et al., 2014). Drivers of malaria include rainfall, temperature, humidity, immunity, epidemiologically population (Laneri et al., 2010; Boyce et al., 2016). All these influence vector multiplication and distribution. Temperature specifically has an impact on the developmental period

with regards to the mosquito life cycle, blood-feeding rate, biting rate and also the gonotrophic cycle (Alonso et al., 2010). Rainfall provides water available for vector survival (Abiodun et al., 2016). Recently, studies have been carried out concerning climate and human health. Climate change has an effect on the occurrence of malaria in Africa and Cameroon inclusive. Temperature and rainfall are some of the main climatic variables. Most of the agents that cause climate-related diseases are sensitive to temperature and rainfall (Ameneshewa, 1995; Boakye et al., 2004). Studies carried out by Ayanlade (2020) stipulate that malaria is distributed throughout the warmer regions of the world, and Cameroon is one of such countries. Not much has been done about malaria and climate change in Cameroon and nothing in Bonaberi especially with the use of the VECTRI model. Because malaria a vector-borne disease is powerfully modulated by weather, a detailed study of the relationship between vector abundance and weather variables may enable the peaks of vector population through forecast and meteorological monitoring. Mosquitoes' life cycle is quite complex with rainfall, temperature, and temperature has an impact in all the developmental stages (Leeson, 1939; Kiszewski & Teklehaimanot, 2004; Paaijmans et al., 2007; Paaijmans et al., 2009) Land use and land cover also affect vector multiplication, so vector population does not only depend on meteorological variables (Koenraadt et al., 2003; Paaijmans et al., 2010a, 2010b). In recent times and over the last few decades mathematical (dynamical as well as static) models have been employed to study disease epidemiology (Macdonald et al., 1968; Bouma et al., 1994; Smith et al., 2012; Matsuoka & Kai, 1994). The statistical model is based on statistic relation based on passed observations or static relations between various variables under given conditions. In dynamic models, the system evolves through time variations of the variables that govern the epidemic. These models have arrived divergent conclusions. Malaria has been studied for quite a long time and is one of the first human diseases to be modeled mathematically. Sir Roland explained that plasmodium spreads across intermediary mosquitoes. He proposed a model that took into consideration the human host and the mosquito population in the 1900s, but it did not take into consideration the mosquito life cycle (Smith et al., 2012). In the 1950s George Macdonald reformulated the model by Ross and came up with an expression of the basic reproduction number R_0 . It is defined as the number of secondary case a single initial case will generate in a completely susceptible population. During the 1960s, Ross-Macdonald provided a theoretical rationale for insecticide spraying because according to Macdonald R_0 , is most sensitive to changes in adult mosquito survival probability. The Ross-Macdonald model has been quite influential to date. More comprehensive dynamical malaria models have been attempted (Wu et al., 2007; Gaudart et al., 2009). The Bomblies model takes into consideration the relationship between rainfall and temperature; it runs on a village scale of 10 m resolutions and tracks every human and mosquito. The Liverpool Malaria Model (LMM) is a dynamical mathematics biological malaria model. Both rainfall and temperature affect the growth and

size of vector population (Ermert et al., 2011). The model uses daily temperature and precipitation data. This model did not take into consideration humidity completely. The Vector-Borne Disease Community Model of ICTP (VECTRI) is a mathematical dynamical model that incorporates the impact of weather on malaria with reasonable surface hydrology, running at over regional scales with resolution down to 1 km. It incorporates population interactions (migration, immunity) and interventions (spraying drugs bed nets) (Tompkins & Ermert, 2013) This study is therefore geared towards assessing the yearly parasite ratio (which is the number of tested positive malaria cases divided by suspected malaria cases of malaria) over the ten regions of Cameroon, and also to work out the influence of rainfall and temperature on disease endemicity with emphasis on Bonaberi district, in Douala.

2. Materials and Methods

2.1. Ethics Statement

We declare that data on epidemiology in this study was collected and compiled by the Author from the national malaria program Cameroon based on records from the public health and analyses anonymously.

2.2. Study Area

This study is carried out in Cameroon situated within latitude 7.36°N and longitude 12.35°E; with emphasis on Bonaberi district situated in Douala latitude 4.07°N longitude 9.67°E as shown in **Figure 1**.

Cameroon has a population of about 26,545,864 inhabitants according to the World Bank report 2020. It has a total surface area of about 475,000 km² (Molua & Lambi, 2007), Cameroon has as neighbors Nigeria to the West, Chad to the North, Central Africa Republic to the East and to the South by Congo, Gabon and Equatorial Guinea as shown in **Figure 1**.

Unusual weather conditions have often precipitated deadly epidemics. Malaria being one of them, has always been understood as a climate-sensitive disease, and transmission associated with summer months in temperate zones and humid lowlands in tropical regions in the past. (Nissan et al., 2021)

Recent work done by Efon et al. (2013) has described Cameroon as Africa in miniature. The country shows all major vegetation and climate within the continent. The natural milieu adds to the geographical diversity of the country across the 10 regions.

The Far North region belongs to the Sudano-Sahelian North tropical climate. It has hot and dry weather with an annual rainfall of about 700 mm/year (Dhiman et al., 2011), and a rainy season that lasts just for two (2) to three (3) months (Molua & Lambi, 2007), and eight (8) to nine (9) months of the dry season. The North region belongs to the Sudanese tropical climate within the Benue basin around Garoua, with six (6) months of the dry season. Precipitation is irregular with an annual rainfall of about 1000 mm/year, three (3) to five (5)

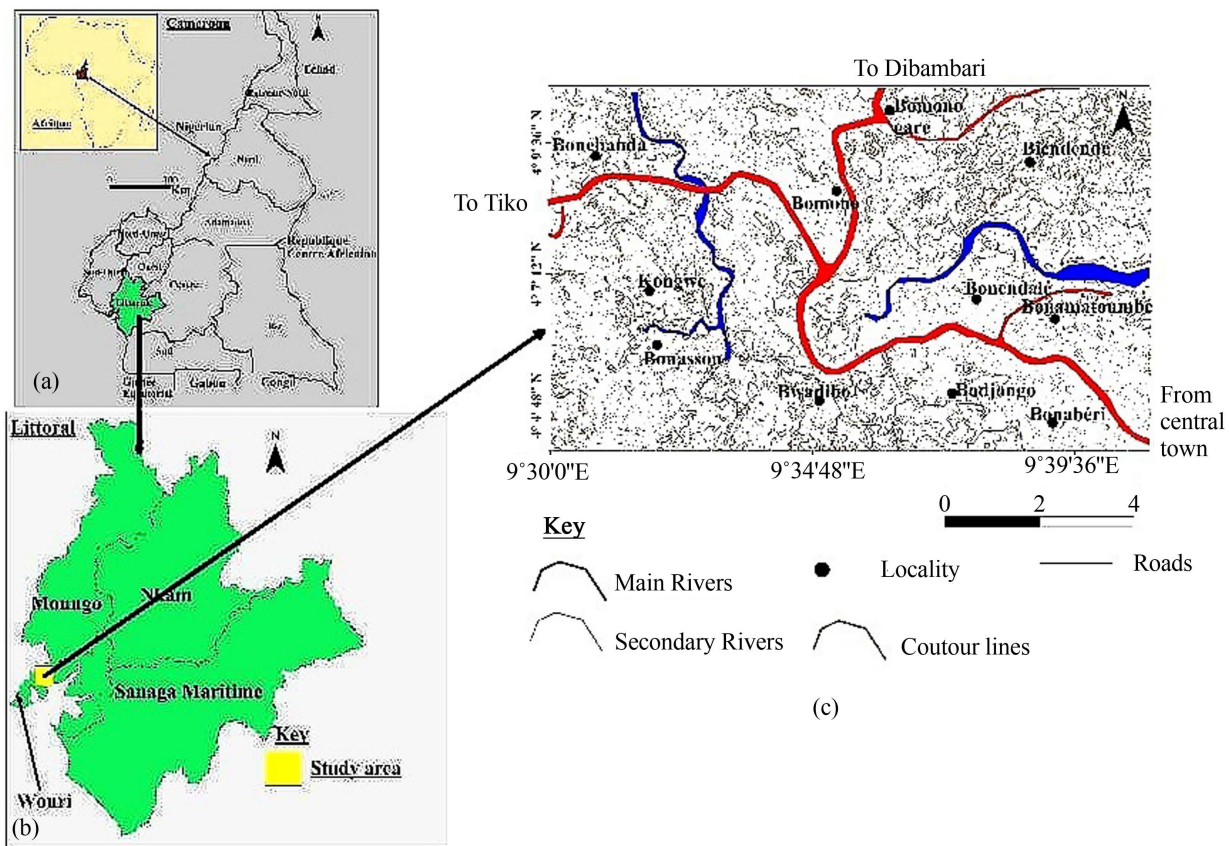


Figure 1. Study location, the figure presents (a) Cameroon map, (b) Littoral and (c) Bonaberi district with roads and rivers.

months rainy season (Dhiman et al., 2011). A mean annual temperature is 28°C (Bertrand & Banye, 2012). The Adamawa region (humid-savannah highland area) found between the Norths and therefore the Center region encompasses a moderate climate and differs from that of the Northern Savannah zone. Its lowest temperature is 20°C and annual rainfall of 1500 mm/year. The West and also the Northwest regions have an annual rainfall estimated to be 1800 mm/year, mean temperature of 22°C, a population of 1.9 million inhabitants and a long rainy season (March-October) (BUCREP, 2014).

The climate within the littoral, Center, South Regions, is made up of two rainy and two dry seasons, rainfall between 1500 mm/year to 4000 mm/year on the seacoast. It belongs to the southern forest region With a protracted dry season (December-February), followed by a long rainy season (September-November), then a short dry season (July-August) and the short rainy season (March-June), with the mean annual temperature of 25°C. This region is characterized by the deep equatorial evergreen forest, the humid savanna, mangrove and dense vegetation.

The diversity of the climate of Cameroon makes it suitable for vector multiplication. Bonaberi found within the Littoral region is made up of the following districts: Nkomba, Bonamatoumbe, Bonamikano, Bonassama, Bonendale I, Bonendale II, Djebali I, Djebali II, Mambanda and Bojong. Having a population of

about 8091 inhabitants per the world's population review, Bonaberi is located at an elevation of 3.44 meters above sea level, and has a Tropical monsoon climate. The district's yearly temperature average is about 29.48°C, which is about 2.67% higher than Cameroon's average temperature. Bonaberi typically receives about 3392.2 millimeters of precipitation annually (Norbet et al., 2018) from the monthly weather forecast Cameroon.

2.3. Data

Both observed data from the national malaria program Cameroon and simulated data from satellite climatology data are used. Climatology data include rainfall and temperature from January 2012 to December 2017 for the whole of Cameroon and January 2017 to December 2019 respectively are employed in the study.

2.3.1. Epidemiological Data

Mean yearly malaria morbidity data is compiled from the national malaria control program between 2012 and 2017. Mean monthly confirmed malaria cases are obtained from the Bonasama district hospital (Bonaberi) from 2017 to 2019. The VECTRI model is evaluated using these two data sets. With this, the parasite ratio is calculated as the number of confirmed malaria cases divided by the number of suspected malaria cases.

2.3.2. Meteorological Data

Mean daily rainfall data is obtained from Famine Early Warning Systems Network ARC version 2 (FEWS/ARC2). The daily gridded 2 m temperature data was taken from the ECMWF ERA-Interim (Dee et al., 2011) reanalysis data. These values are used as input to drive the VECTRI model to simulate climate-driven malaria transmission over the ten regions of Cameroon. Secondly, other precipitation data are obtained from Climate Hazards Group Infra-Red Precipitation with Station data (CHIRPS). Temperature again is obtained from ECMWF ERA-Interim reanalysis data.

2.4. The Model

Simulations are done using The Vector-Borne Disease Community Model of ICTP (VECTRI) (Tompkins & Ermert, 2013). VECTRI uses a flexible spatial resolution that ranges from a single location to a regional scale (10 - 100 km). VECTRI is a mathematical model for malaria transmission and takes into consideration the effects of temperature and rainfall on the parasites and their developmental stages.

$$\frac{dL}{dt} = R_L \frac{dL}{df} \quad (1)$$

VECTRI uses a time step of one day, and the larva growth rate follows a degree day concept. It is based on a linear function of water temperature above a threshold min Value $T_{L.min}$ below which larva growth ceases

$$R_L = \frac{T_{wat} - T_{Lmin}}{K_L} \quad (2)$$

The limit with this equation is surely link to temperature as we use air temperature instead of water temperature.

Mortality rate of the larva is an important factor for transmission and depends on temperature (Samé-Ekobo et al., 2001; Tompkins & Ermert, 2013).

The model sets a base daily survival rate $PL_{surv} = 0.825$. This value is Incorporated in the model by reducing survival rate proportionally by a factor related to resource constrain.

$$PL_{surv} = \left(1 - \frac{M_L}{wM_{L,max}}\right) K_{flush} P_{L,survo} \quad (3)$$

M_L is the total larva biomass per unit surface area of a water pond and w the fractional coverage of a grid cell by potential breeding site .it is given by the surface hydrology composition. Larva flushing by heavy rainfall is also an important cause of larva morality (Tompkins & Ermert, 2013).

$$K_{flush} = L_f + (1 - L_f) \left((1 - K_{flush,\infty}) e^{-R_d \tau_{flush}} + K_{flush,\infty} \right) \quad (4)$$

R_d Is the rain fall rate in mm-day⁻¹, τ_{flush} describes how quickly the effects as a function of R_d and $K_{flush,\infty}$ is the maximum value of K_{flush} for newly hatched first stage larva at extremely high rain rates. The equation is rainfall dependent; its limit is linked to rainfall amount in the area.

The mobility rates of the vector, the sporogonic and gonotrophic developmental cycle rates are affected by temperature (Samé-Ekobo et al., 2001; Tompkins & Ermert, 2013). The egg develops at a rate determine by a 2-meter air temperature T_{2m} .

$$R_{gono} = \frac{T_{2m} - T_{gono}}{K_{gono}} \quad (5)$$

and the sporogonic rate

$$R_{sporo} = \frac{T_{2m} - T_{sporo}}{K_{sporo}} \quad (6)$$

VECTRI considers human population density within the calculation of human biting rates (HBR) and makes it possible to differentiate between urban, peri-urban and rural transmission rates (Tompkins & Ermert, 2013).

$$\overline{hbr} = \left(1 - e^{\frac{-H}{T_{zoo}}}\right) \frac{\sum_{j=1}^{N_{sporo}} V(1, J)}{H} \quad (7)$$

The factor $1 - e^{\frac{-H}{T_{zoo}}}$ represents the level of vector zoophily.

Surface hydrology is included in the VECTRI model and in each time step, it estimates fractional water coverage, which is formed from temporal water body W_{pond} and permanent water bodies W_{perm} as.

$$W = W_{pond} + W_{perm} \quad (8)$$

A Simple surface hydrology scheme is included in VECTRI. In each grid cell, it estimates at each time step the fractional water coverage area as shown in equation two below.

$$\frac{dW_{pond}}{dt} = kW(P(W_{max} - W_{pond}) - W_{pond}) - W_{pond}(E + I) \quad (9)$$

Is the maximum fractional coverage of temporal ponds, E and I , evaporation and infiltration rate while P is precipitation rate, is a linear constant (Leedale et al., 2016).

The VECTRI model has as goals to forecast malaria epidemic outbreaks in endemic zones and to represent malaria transmission in endemic areas (Quakyi et al., 2000).

3. Results

In the present work, we present the mean annual observed and simulated PR (parasite ratio) that is, the number of positive malaria cases divided by suspected malaria cases, monthly daily variations of rainfall, mean surface temperature and PR with an objective to understand malaria prevalence in Cameroon in general and Bonaberi in particular.

Table 1 shows Pearson's correlation coefficients between the observed PR (OPR) and simulated PR (SPR) from 2012 to 2017. All year round we had a

Table 1. Mean correlation calculated using reliability test in spss.

	OPR12	SPR12	OPR13	SPR13	OPR14	SPR14	OPR15	SPR15	OPR16	SPR16	OPR17	SPR17
OPR12	1.00	0.52	-0.64	-0.15	0.50	-0.11	-0.07	0.00	-0.45	-0.13	-0.23	-0.06
SPR12	0.52	1.00	-0.15	0.59	0.34	0.48	0.66	0.53	0.13	0.56	0.28	0.16
OPR13	-0.63	-0.15	1.00	0.38	-0.18	0.40	0.43	0.59	0.68	0.59	0.62	0.42
SPR13	-0.15	-0.59	0.38	1.00	0.35	0.64	0.60	0.47	0.57	0.55	0.54	0.18
OPR14	0.50	0.34	-0.18	0.35	1.00	0.31	-0.09	0.03	0.15	-0.14	-0.09	0.07
SPR14	-0.12	0.49	0.41	0.64	0.31	1.00	0.76	0.63	0.67	0.56	0.38	0.62
OPR15	-0.08	0.66	0.44	0.60	-0.94	0.76	1.00	0.72	0.46	0.91	0.71	0.41
SPR15	0.01	0.53	0.47	0.47	0.03	0.63	0.72	1.00	0.60	0.67	0.60	0.65
OPR16	-0.45	0.13	0.57	0.57	0.15	0.67	0.46	0.60	1.00	0.43	0.46	0.79
SPR16	-0.13	0.56	0.56	0.55	-0.14	0.56	0.91	0.67	0.43	1.00	0.76	0.31
OPR17	-0.23	0.28	0.55	0.54	-0.09	0.38	0.71	0.60	0.46	0.76	1.00	0.27
SPR17	-0.64	0.16	0.18	0.18	0.78	0.60	0.41	0.65	0.79	0.31	0.27	1.00

positive correlation throughout the study period. The highest degree of positive correlation 0.75 was observed in 2015. This could be because of reduced rainfall intensity that year, which favored breeding grounds for vector multiplication.

3.1. Annual PR Variations over the Regions

Figure 2 shows variation trends in the simulated and observed PR within the period 2012-2017. In this case, all the data points PR for the whole of Cameroon are used. Results from the annual trends show that the PR varies according to regions, during the study period. Simulated PR shows a maximum value of around 0.8 in the Center and South West regions and a minimum in the west region. Observed PR also show a maximum in the South West, Center, and

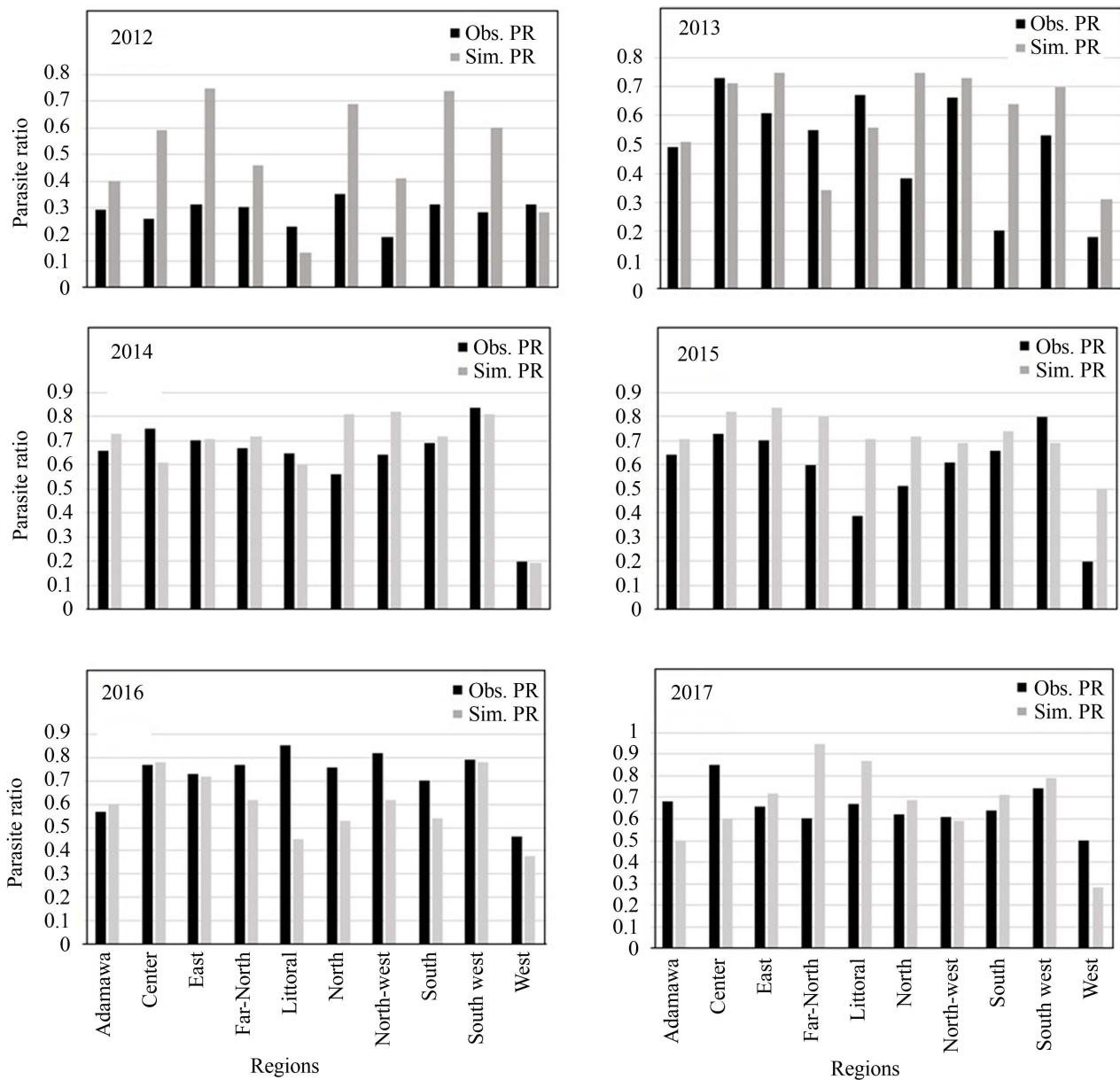


Figure 2. Trends in observed and simulated PR for 2012-2017.

South regions, and a minimum in the west region. During 2012-2013, observed values were higher than simulated values with a peak of 0.8 in the South West region and a minimum of 0.3 in the littoral region. This could be due to the fact that free distribution of mosquito nets and other intervention strategies had just started.

In **Figure 2** simulated mean annual and observed PR over the ten regions of Cameroon follows the same trend. In the regions of Adamawa, southwest and the west, both observed and simulated PR fits and follows the same trends. The simulated and the observed PR value are quite close to the East, North West North South, littoral regions and Center region.

The table below shows Pearson correlations between each observed PR (OPR) and each simulated PR (SPR) data from 2012-2017. Using inter-item correlation details, the mean correlation is then calculated using reliability test in SPSS

These yearly variations of PR can be surmised in **Figure 3**.

Globally the model is able to simulate the observed PR over the ten regions of the Country, but still overestimating it comparatively to the observed value.

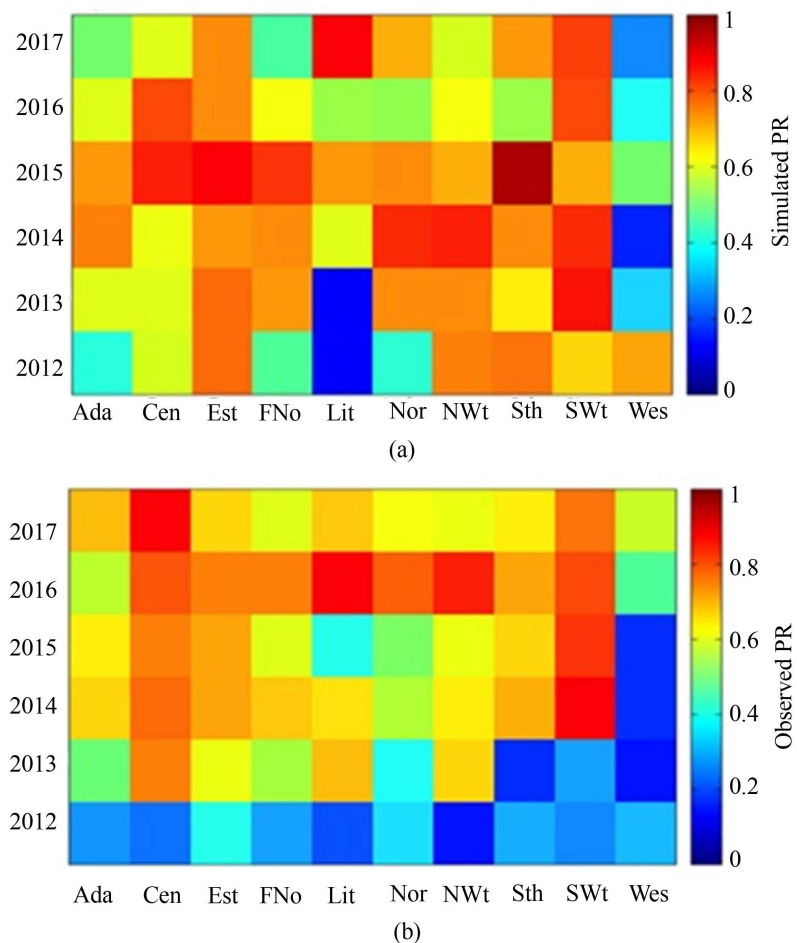


Figure 3. Summary of simulated (a) and observed (b) PR over Cameroon regions between 2012 and 2017. (Adamawa (Ada), Center (Cen), East (Est), FarNorth (FNo), Littoral (Lit), North (Nor), North West (NWt), South (Sth), South West (Swt), West (Wes).

3.2. Monthly PR Variations for Bonaberi District from 2017 to 2019

To better understand malaria endemicity and to predict the transmission of malaria outbreak period across the Bonaberi locality, the monthly observed and simulated PR values are correlated with rainfall and temperature, as shown in **Figure 4**.

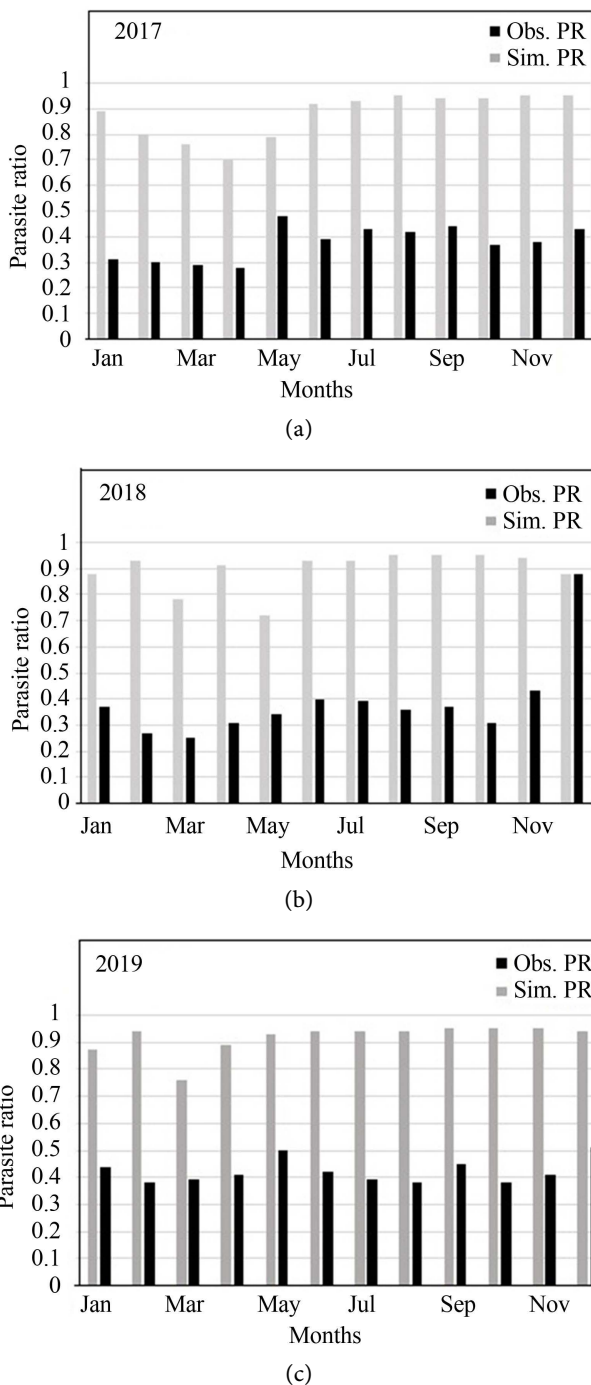


Figure 4. Simulated and observed monthly PR for Bonaberi district corrected with rainfall and temperature for the years (a) 2017, (b) 2018, and (c) 2019.

As mentioned before there is a noticed gap between observed and simulated PR values but both of them follow the same trend during the year. But PR values do not appear to be well correlated with the monthly rainfall and temperature fluctuations. In 2017, the peak of rainfall was in the month of August, and peaks of temperature in the months of December but simulated PR was at its peak from July to January observed PR had a slight peak in the month of May. Also in 2018, simulated PR had peaks all around the year but for the month of March with a slight decrease. Peaks of rainfall are in the months of July and August; peaks of temperature in the months of December and January. More so in 2019, peaks of temperatures are in the months of December and February, peaks of rainfall in the months July, August, September, and a little drop in the parasite ratio in the months of March. It is realized that the monthly rainfall accumulates over Bonaberi. During the rainy seasons' peaks of rainfall are the months of July and August 2017 to 21.7 mm, and in the dry seasons with the least values in the months of January 0.37 mm. Again, the monthly mean surface temperature is found to be above 30°C during October to February and within 26°C - 29°C during other months. In addition, the maximum PR simulated in the months of May to February was 0.87 to 0.95 and observed maximum in the months of May to January. Transmission is high year-round in Bonaberi just for a little drop in the month of March.

Simulated and observed mean seasonal PR for Bonaberi district is shown in **Figure 5**.

Generally, the seasonal simulated PR is higher than observed PR all the years. SON and JJA seasons show great disparity in observed and simulated PR in all the years. Here the rains are too high most of the larva is washed by the heavy rains and floods, the mosquito population is reduced and so fewer malaria cases registered. In DJF and MAM has a slight difference in that rainfall is moderate and sufficient for vector survivor.

4. Discussions

Observed and simulated PR in Cameroon had its peaks mostly in the South West region with a PR of 0.84 observed and 0.81 simulated. Probably because it is a characteristic ecological region and has undergone some environmental modifications recently, this situation is probably because of urbanization, rapid population growth, immigration and the presence of the Cameroon Development Cooperation (Bigoga et al., 2012). This may affect the vector population, distribution and density and probably have an impact on malaria transmission efficiency. In this region, transmission is perennial, its intensity increases with the amount of rainfall and parasitemia. This is in line with studies carried out by Bigoga et al. (2012). That the human population has developed and maintained naturally acquired immunity since the entire population is exposed to an infected mosquito bite.

The North and Far North regions are closer to the peaks in both observed and simulated PR. perhaps because of the presence of the Lagdo dam and the

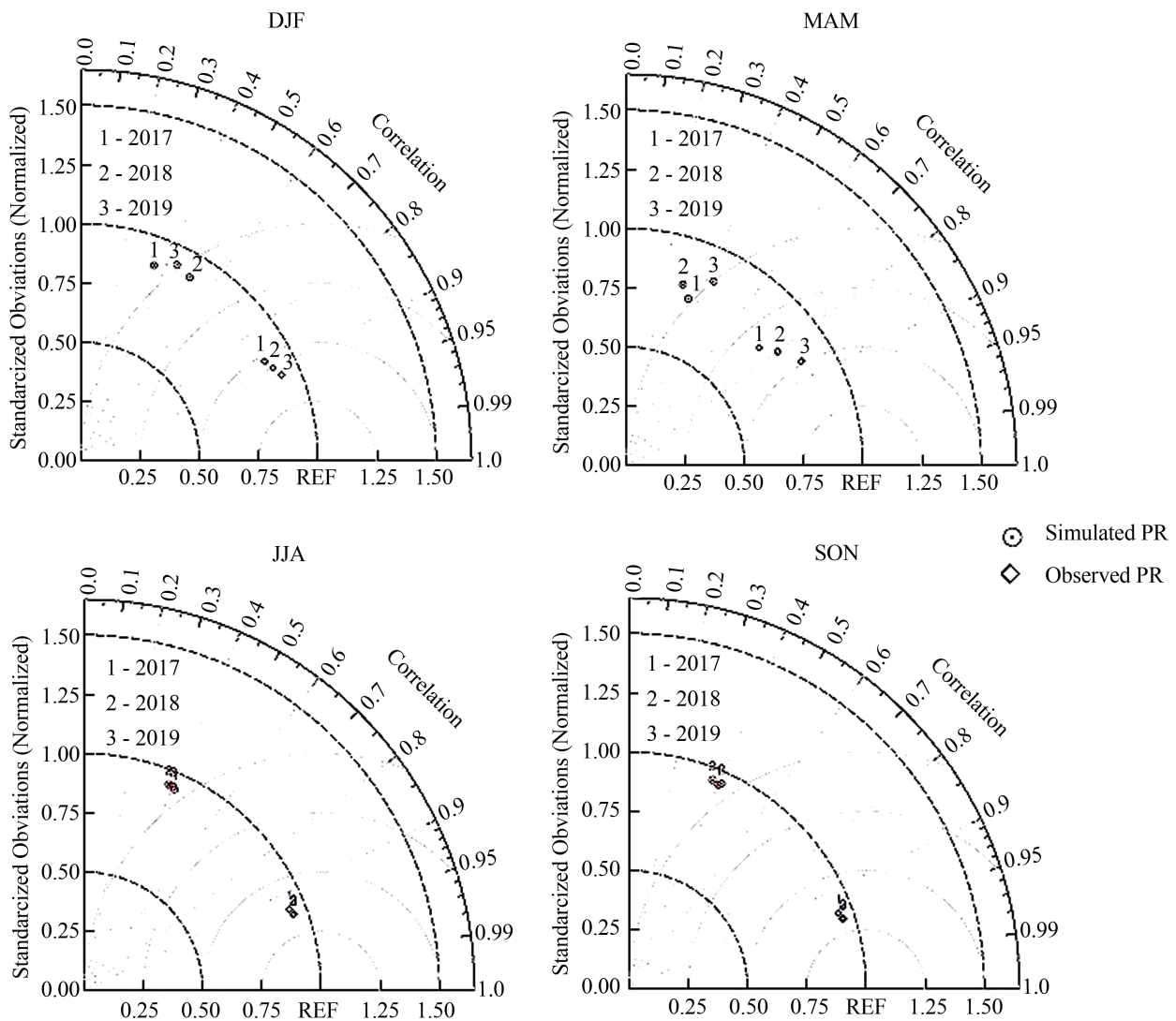


Figure 5. Taylor diagrams showing seasonal simulated and observed PR for Bonaberi.

expansion of irrigated land surface, which provides enough breeding ground for larva multiplication. This is in line with studies previously carried out by [Wanji et al. \(2003\)](#), which shows that after the construction of the Lagdo dam and the irrigated rice farm, there has been an increase migration, thus human malaria cases and transmission.

Also, the South region has a high PR, with a maximum simulated PR of 0.74 and observed PR of 0.69 the seasonal transmission increases may be due to the presence of the river Sanaga that provides a leave lock pool available for vector multiplication. Similarly in Congo according to [Carnevale et al. \(1992\)](#) and [Manga et al. \(1997\)](#) also in agreement with the fact that permanent rivers, increases malaria transmission rates.

Extremely low PR is observed in the west region. there is the availability of permanent breeding sites in Dschang such as lakes and swamps, the suppressing effects of altitudes and climate on mosquito biodiversity and may limit siblings

species (Manga et al., 1997). Due to altitude, climate variation reduces vector survivor and multiplication this is true as around Mount Kilimanjaro (Manga et al., 1997). Despite the fact that the river Nkam and its tributaries meander around Sancho, the PR is quite low compared to the south region with large water bodies, probably because of the absence of the forest ecosystem. In sub-Saharan Africa, the *Anopheles Gambiae* and *Anopheles funestus* species were in most locations. In the dry season, *Anopheles Funestus* is resistant with a low transmission rate caused by micro climatic conditions of highland regions (Fontenille et al., 2000). This is similar to what is happening around Mount Cameroon as transmission intensity decreases gradually with altitude and also in Tanzania (Bødker et al., 2003; Maxwell et al., 2003; Wanji et al., 2003).

The East region is one of the most affected regions in Cameroon, with PR between 0.6 - 0.8 simulated and 0.3 - 0.5 observed. Maybe because of the poor road network that makes it difficult for the movement intervention team, also constant immigration from the center African republic could increase the spread of the disease. This is in line with a report from the ministry of public health (Minsante, 2018).

The Center region is rapidly urbanized and is surrounded by many hills irrigated by several permanent rivers (Knudsen & Slooff, 1992). Its PR ranges between 0.6 - 0.8 both simulated and observed. Its transmission is the all-around year in agreement with other studies (Ndo et al., 2011). During the rainy season, permanent habitats for mosquitoes could arise from inundations and in the dry season. Urban agriculture as a result of the exploitation of the flood plains may lead to the spread of malaria. In addition, rapid unplanned urbanization, poor drainage especially by other human activities for example public and private construction sites, water from car wash points may also provide available breeding grounds. This is in conformity with studies carried out in Libreville in Gabon, Daresalaam, Tanzania (Antonio-Nkondjio et al., 2019).

The northwest region has stable and high malaria prevalence, with the *Anopheles gambiae* species dominating (Mourou et al., 2012) this stability may vary with altitude moderation effects. Contrary to studies carried by (Antonio-Nkondjio et al., 2019) that highland areas with cooler weather conditions may discourage vector multiplication thus lowering prevalence. (Mourou et al., 2012; Machault et al., 2009) according to Klinkenberg et al. (2008). In recent times the climate of the North West region has drastically changed from cool and dry to a fertile ground for vector survivors that may account for a high parasite ratio 0.6 - 0.7.

The littoral region is close to the Atlantic Ocean, this region constantly has malaria as mentioned by (Klinkenberg et al., 2005; Klinkenberg et al., 2008; Machault et al., 2009; Mourou et al., 2012). Part of this region is found in the marshy area and always has breeding sites for vector transmission all this may be due to poor waste disposal, unplanned urbanization, and poor drainage facilities. This is similar to other urban cities like Accra in Ghana, Dakar Senegal and Lilongwe Malawi (Nimpaye et al., 2001; Afrane et al., 2004; Asare & Amekudzi, 2017; Mohamed & François, 2020). The *Anopheles gambiae* species happen to be

more productive in the littoral region and thus have high parasite transmission.

Figure 4 represents observed and Simulated PR correlated with rainfall and temperature, with peaks of rainfall from July to September and minimum rainfall from November to February, temperatures of peak 30°C to 34°C in the months of minimum rainfall the months of November, December, January and February. In the months of July August and September, the temperatures were quite low to about 28°C, which is favorable for vector multiplication (Moukam Kakmeni et al., 2018).

Also, the PR simulated ranges from 0.8 - 0.9 and observed from peaks 0.4 - 0.5 in almost all the months and a little drop in March. The peaks in rainfall follow peaks in PR according to Kamgang et al. (2010). Recent studies confirm the fact that with rapid urbanization, increased population growth, poor housing conditions, lack of proper housing and sanitation, poor drainage facilities, frequent flooding during the rainy season especially in areas like Mabanda all this help in the spread of vector-borne diseases (Okiro et al., 2007; O'Meara et al., 2008). With two dry seasons and two rainy seasons, most of the time Bonaberi always has small pools of water, the river Wouri estuaries probably provide permanent water bodies that may sustain vector multiplication in the dry season and may lead to permanent reliable breeding sites. This difference in PR observed and simulated probably is due to the fact that there are increased interventions including widespread of insecticide-treated nets (ITNs) (Antonio-Nkondjio et al., 2019) which leads to decreased parasite ratio and fewer hospital admissions most of the inhabitants are now educated on preventive measures with regards to malaria transmission and eradication also, private health facilities may treat patients, both orthodox and traditional medicines, increase the widespread of malaria drugs for prophylaxis are not taken into consideration by the VECTRI model (Antonio-Nkondjio et al., 2019). Vector survival is incorporated as a user parameter for surface hydrology in which VECTRI turns to underestimate. Its growth rate, vector multiplication, and the adult population is reduced immediately the temporal ponds dry off. When the rains are quite heavy the larva are being flushed. But the surface hydrology scheme accounts for this negative effect (Tompkins & Ermert, 2013).

5. Conclusion

This present work compares and assesses the yearly PR of malaria over the ten regions of Cameroon, and correlates monthly rainfall and temperature with PR both simulated and observed on disease endemicity in Bonaberi district, in Douala. Results from simulated and observed PR value imply the whole of Cameroon is endemic with regards to malaria; the level of endemicity varies from one region to the other depending on its climatic variables. The areas with the highest transmission are mostly in the southwest region, followed by the Center, and south regions and Bonaberi Douala and the western region is the least. The model used shows the dynamic link between climatic variables and malaria transmission. Rainfall and temperature predominantly control malaria transmission and

intensity as revealed by both simulated and observed results. However, in Bonaberi malaria transmission is high all year round but for a little drop in the month of March. Because of this, the VECTRI model possesses the potential to provide malaria early warning information for Cameroon and Bonaberi and should be considered by the national malaria program. Moreover, the model was able to discriminate between regions of low and high malaria transmission, months of peaks of malaria in Bonaberi due to differences in rainfall and temperature. From the population and mosquito infection status from the national malaria program and the Bonasama district, one may conclude that malaria is influenced by temperature and rainfall. The parasite ratio from the model when compared with observed data is reliable to monitor malaria transmission and control. Thus, results from the study will be useful at various levels of decision making, for example, in setting up an early warning and sustainable strategies for climate change and adaptation for malaria vector control program in Cameroon. For the VECTRI model to be more performant parameterization for permanent water bodies, topography, soil characteristics, habitat water temperature, and immunity level of the population could be incorporated in the model.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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