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Research Article

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The Impact of Climate Change on Malaria Incidence in Bonaberi and Tombel Districts, Cameroon

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ABSTRACT

Global warming and its impact on malaria incidence is a cause for concern. Malaria, a vector-borne disease, is sensitive to weather and climate conditions. Increased human activities in wetlands make the populations living there particularly vulnerable to climate-related diseases, including malaria.

This study examines malaria incidence and the impact of climate change on the populations living in Bonaberi and Tombel. The observed parasite ratio (PR) is obtained from the national malaria program, while precipitation data is sourced from the Famine Early Warning Systems Network. Temperature data is derived from the ECMWF ERA-Interim reanalysis data. Simulations are performed using the VECTRI model to study the observed and simulated PR in Tombel and Bonaberi and to project the PR for these areas using CORDEX projection data under two representative concentration pathway (RCP) scenarios (RCP2.6 and RCP8.5).

Results show that both Tombel and Bonaberi experienced peaks in PR, with Tombel reaching a PR of 0.8 and Bonaberi showing a slight increase to a PR of 0.9. Future projections indicate a fluctuating increase in PR for Bonaberi, reaching 0.95, and Tombel peaking at 0.9.

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Keywords: Climate Change, Tombel, Bonaberi, CORDEX, Malaria, VECTRI

Introduction

Suffering from a vector-borne disease like malaria due to global warming is quite challenging [1,2]. Being one of sub-Saharan Africa's most common poverty-related diseases [3]. Malaria transmission is favored by climate variability [4]. Some weather parameters may affect the life cycle of mosquito development and the parasite in the mosquito hence increasing the malaria incidence [5,6].

Globally, due to malaria 241 million cases and 627 000 deaths were recorded in 2020 with a percentage of 7.8 deaths [7]. There is an increase from an estimated 227 million cases and 558 000 deaths recorded in 2019. This increase in death may be due to global warming or the interruption of services caused by the Coronavirus (COVID19) disease pandemic in 2019 [8]. By 2021 in Cameroon, 4,121 deaths and 2,974,819 cases were recorded. Malaria has been proven to be one of the stumbling blocks to economic development (WHO,2023). Malaria may be influenced by future climate change depending on the distribution of infected female Anopheles mosquitoes, competent to transmit Plasmodium falciparum [6]. The biting rates, development and mortality of anopheles vectors are influenced by temperature. The breeding ground that favors larval development is enhanced by rainfall . Temperatures of 18-32°C turn to favors malaria transmission as it speeds up the life cycle of anopheles vectors

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[9]. The minimum temperature for Plasmodium falciparum to develop in the vector is 18°C [2]. Recently, studies carried out explained the relationship between the well-being of the population and the environmental management of wetlands for public health reasons. They proposed that assessments of the ecosystem services provided by wetlands should be frequent. These strategies will enable wetland managers to consider the health of the inhabitants before making a decision [9].

Tombel is one of the towns in the South West Region of Cameroon and Bonaberi is a District in the Littoral Region. They are all endemic with regards to malaria. Bonaberi has water all year round around most of the settlement areas. Therefore the link between water abundance and malaria is necessary.

limate change can influence the outbreak of vector born diseases due to global warming. However, the availability of water also favors the survival of pathogens in the environment. Also, migration may favors the spread of most vector born disease [8]. Dynamical models like; the Liverpool Malaria Model (LMM), the hydramates model of malaria, have been developed. These models are generally needed to better understand the disease endemicity and to better study climate-related diseases [10]. The malaria system of interaction is complicated since it involves the host and the environment. Therefore the use of the Vector-borne disease community model of ICTP, Trieste (VECTRI) takes into consideration population density and climate to simulate malaria transmission on a regional scale. also, the model accounts for the difference in transmission rates between urban and peri-urban areas. It is based on the use of equations and simulations done by the different climate-driven variables. It is quite difficult to eliminate malaria in Bonaberi and Tombel because it requires a complete trace of the disease progression . Intervention strategies are being put in place to reduce the disease niche. Measures taken include; children under five years old and pregnant women are given free long-lasting insecticidal net (LLIN), Subsidizing the cost of artemisinin-based combination therapy use as first-line treatment for uncomplicated malaria cases and, adequate advice to families is provided by training of the local health assistants capable of managing uncomplicated malaria cases. Seasonal Malaria Chemo prevention to maintain therapeutic drug concentrations in the blood throughout the period of greatest malarial risk [11].

To better understand malaria and climate variability, the Coordinated Regional Climate Down scaling Experiment (CORDEX) is used in this study. Simulations data set are used in the Vector born disease community model (VECTRI) to project impacts of global warming on malaria prevalence in Cameroon in the future. The study enhances our understanding on how these regional climates are impacted under RCP2.6 and RCP8.5 emission scenarios, as well as the timings of the changes. Hence, this work aims to highlight the relationship between climate change and malaria transmission in Bonaberi and Tombel using the VECTRI malaria model and also to estimate the effect of climate change on malaria incidence in the nearest future using the VECTRI malaria model driven by CORDEX. Our results are focusing on Bonaberi (wetland) and Tombel (dry land), two endemic towns in Cameroon. The model is to run for the historical period (2017 – 2019) and a future projection period (2026 - 2060). Although the possible health impacts of climate change are quite understood, there is relatively little or no research on global warming, malaria endemicity and future projections in Bonaberi and Tombel. There is a need for more work to be done in order to better understand the connections between climate change, and malaria prevalence. Results can be used in health assessment and adaptation strategies.

Materials and methods

Study Area

The study will focus on Bonaberi and Tombel districts in Cameroon. Bonaberi is an urban area in the Littoral region, while Tombel is a rural area in the Southwest region. These districts represent different ecological zones, providing a comprehensive understanding of malaria transmission dynamics under varying climatic conditions.

Tombel a town within the Kupe Muanenguba division of Cameroon is sort of populated. Tombel has an estimated population of about 110178 inhabitants, and a complete land extent of 1007 square kilometers, it's situated between latitude 04°16' and 05°15' north and longitude 09°13' and 09°1 5' East [12]. It lies on the western side by the Kupe Muanenguba Mountain. The annual average rainfall is about 2743.5mm and therefore the average annual temperature is approximately 27.3°C [12]. Located at a height of 482.97m . Volcanic soil supports rich natural forests and a wide variety of tropical crops both for local consumption and for exportation, which form better habitats for mosquitoes. The rainy season is from March to September and the dry season is from October to February. Because of the presence of Mount Kupe, there are gentile slopes, deep valleys and streams that are seasonally originating from the mountain. Tombel has natural vegetation just like the equatorial rain forest rich in fauna and flora with their main activities being local cultivation and hunting. All this form the better breeding ground for mosquitoes [13]. Bonaberi too is a town found in the Littoral region having almost the same longitude of 9.67°C as Tombel and a latitude of 4.07°C. Bonaberi found in the littoral region has an average temperature of 29.48°C and annual precipitation of 3392.2 mm is characterized by the deep equatorial evergreen forest, the humid savanna, mangrove and dense vegetation.

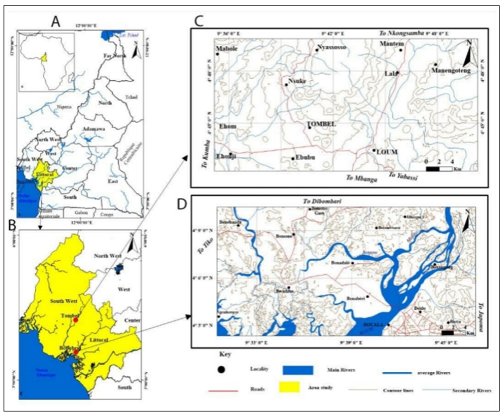


Figure 1: Map of Cameroon (A) The influence of the Atlantic Ocean on Tombel and Bonaberi (B), Tombel and geographical relief (C), Bonaberi and water bodies (D).

The VECTRI Model

The malaria dynamical model used is the VECTRI model (The Vector-Borne Disease Community Model of the International

Center for Theoretical Physics, Trieste). It is a grid cell distributed model . The model physics and associated parameters are taken from the literature on the Anopheles gambiae and the Plasmodium falciparum malaria parasite. VECTRI has as its goal to regionally forecast epidemic outbreaks in malaria-threatened areas and in endemic areas malaria transmission is represented. Delay between the rainy season onset and the malaria season is necessary to be represented. Therefore, the model explicitly resolves the growth stages of the egg-larvae-pupa cycle in addition to the gonotrophic and sporogonic cycles using arrays of bins for each process [14]. The structure of the VECTRI model is shown in 2.

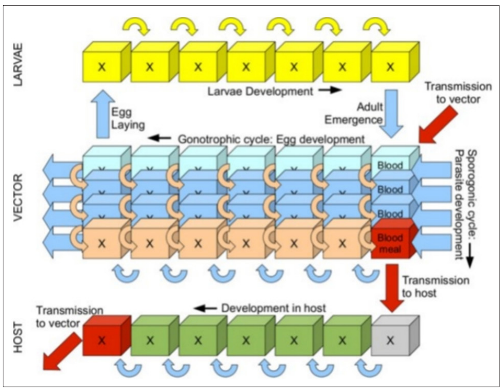


Figure 2: Structure of the VECTRI model [14]

The larva status is partitioned into bins on the first row. X represents larva density in each bin and its growth stage. A two-dimensional representation of the vector state is found in the middle block. The bottom row is used to model the infective state of the host. The growth direction of the larva, vector and host is represented by the curved arrows. The direction of transmission between the vector and host is indicated by the red arrow. A degree day concept is followed by the larva growth rate [14]. VECTRI model allows the interaction between vector and host population on a district and regional scale. This model specifies the population density H. The number of bites B that any individual receives in any given time the human biting rate (*hbr*) is considered to be a random process and is distributed following a Poisons process with a mean biting rate of

$$hbr = (1 - e^{-H_{TZOO}}) \frac{\sum_{j=1}^{N\,sporo} V(1,J)}{H} \quad (1)$$

When considering w_{perm} and converting land used as terrain information into a fractional coverage of breeding areas provided by permanent water bodies, wave actions that can drown larvae and the presence of predators in large bodies . This means that larvae exist only in sub fractions of such water bodies, in pooling that occurs on the edge of lakes and rivers, and can actually confound the classical relationship between rainfall and vector density by actually providing more breeding sites during droughts period when the flow stops altogether. Therefore, the volume of water vpond in the ponds per unit area thus evolves as:

$$\frac{dv_{pond}}{dt} = w_{\max} P\left(1 - \frac{w_{pond}}{w_{\max}}\right) - w_{pond}(E + I) \quad (2)$$

Where E is the evaporation, I is infiltration and P the precipitation rate. It is possible to derive evaporation losses from water temperature, and atmospheric wind speed and relative humidity, a simple evaporation rate is fixed and infiltration is set to a reasonable value. Relating the pond fractional coverage to volume the power law approximation is neglected and the coverage is simply linearly related to pond coverage introducing a tunable factor k_w.

$$\frac{dw_{pond}}{dt} = k_w\left(P\left(w_{\max} - w_{pond}\right)\right) - w_{pond}(E + I) \quad (3)$$

The methodology employed in this study involves several key steps. Initially, The VECTRI model is evaluated using these two data sets. With this, the parasiteratio is calculated as the number of confirmed malaria cases divided by the number of suspected malaria cases. and an observation dataset is collected. The simulation is then validated against historical results In Bonaberi and Tombel. Following this, the simulation is run for the projection period, and the results from both the historical and projection periods are analyzed. Specifically, the VECTRI model is run for a historical periods as the first step.

This study begins by running the VECTRI model for historical periods using forcing datasets. The next step involves collecting observation datasets to validate the model results. The Parasite Ratio(PR) is then gathered for validation purposes, and a comparison is made between the PR model results and the observed PR data. Subsequently, malaria transmission is simulated for the projection period. Finally, both historical and future periods are analyzed to examine changes in malaria transmission over time.

To execute the model, certain forcing datasets are required as input data.Several forcing datasets are utilized in this study to perform the simulation. Precipitation: a.Mean daily rainfall data is obtained from Famine Early Warning Systems Network ARC version 2 (FEWS/ARC2). 0.1x0.1 degree resolution. precipitation data are obtained from Climate Hazards Group Infra-Red Precipitation with Station data (CHIRPS).with 0.1 x 0.1 degree resolution).Temperature: ERA-interim with 0.1x0.1 degree resolution. Population densityfrom AfriPop.

The Climate Models

Regional climate models used in this work were developed by the Swedish Meteorological Institute. (Coordinated Regional Climate Downscaling Experiment the model considers the physical, chemical, and biological processes by which ecosystems affect climate through various spatial and temporal scales. In the evaluation run, the ERA-Interim data were used as boundary conditions for the RCA4 model to evaluate the ability of the model to simulate .These simulations are available on a daily time scale for the period 2017–2019 (historical) and 2026–2060 (projections). Climate data used for future projections are found in 1.

Data

In this study, the observed PR used were collected from the Tombel and Bonaberi health districts in Cameroon for the period 2017–2019. Where we could obtain fields data These malaria data were recorded for two health districts to derive a monthly time series for more than 10 villages in Tombel and Bonaberi. These endemic sites provide a good representation of malaria transmission in the different climatic zones of the two districts.

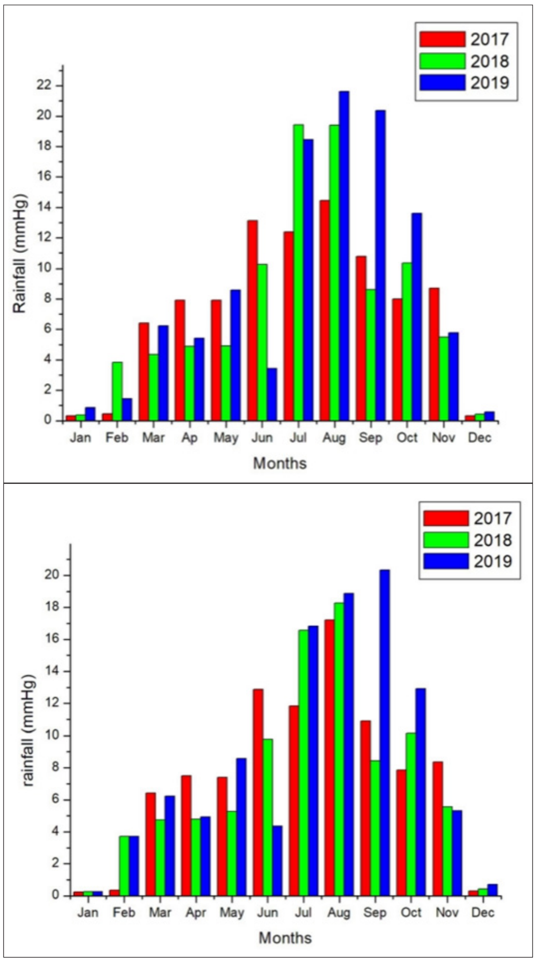
Mean Monthly Rainfall Variations for Bonaberi and Tombel

Here we present the monthly rainfall and temperature variation for Bonaberi and Tombel as simulated by VECTRI is shown in 3

Table 1: Details of CORDEX used to force VECTRI in this study

CODEX Climate Models				
Model name	Institution and Country	Resolution	Future Scenarios	Reference
EC-EARTH-	ESEarth-SystemModelConsortiumResolution,Germany1.125	⁰x 1.125	RCP2.6,RCP8.5	[Wamba et al .,2011)
MPI-ESM-LR	MaxPlanckInstituteforMeteorologyA1.9	⁰x 1.9	RCP2.6,RCP8.5	(Filling et al., 2009)
MIROC-5	Atmosphere and Ocean Research Institute (University of Tokyo)1.40	⁰x 1.40	RCP2.6,RCP8.5	(Wamba et
NorESM1-M	NorwegianClimateCentre2.5	⁰x 1.9	RCP2.6,RCP8.5	(Filing et al.,2009)
HadGEM2-ES	MetOfficeHadleyCentre1.875	⁰x 1.25	RCP2.6,RCP8.5	(Popke &Voigt,20

(a)



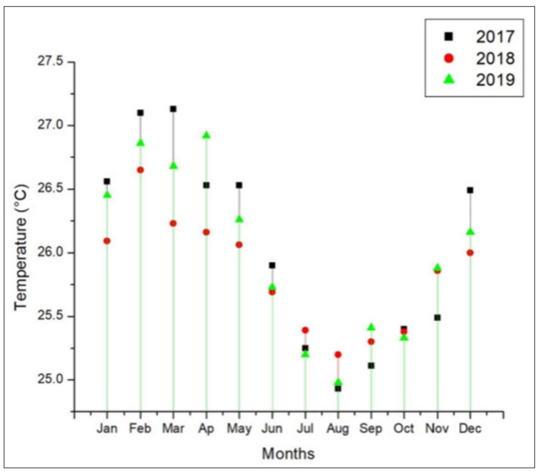
(b)

Figure 3: Rainfall (Red) 2017, green) 2018, and (black) 2019 in Bonaberi and Tombel.

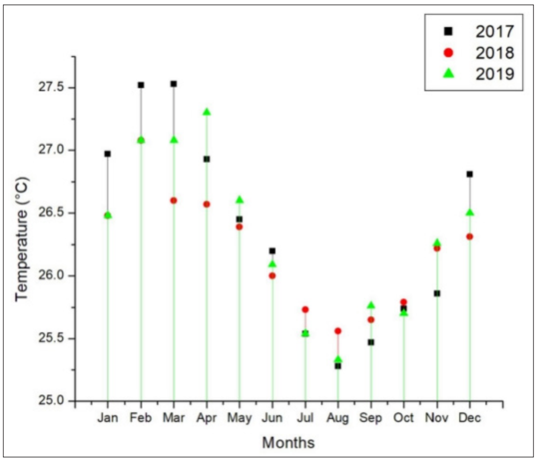
In Bonaberi, peaks of rainfall in 2017 were in the months of June, July and August and rainfall of about 23mm/day in the months of December, January and February. And in 2018 peaks of rainfall was in the months of July August with rainfall of about 21mm/day of rain the months of December and January. However in 2019 peaks of rainfall is in the months of August and September the months of December, January and February.

Also in Tombel there was about 20mm/day of rainfall in the months of November, December and January in 2107 and highest rainfall in August, then July. In 2018 peaks of rainfall were in the months of July and August and in December a rainfall of about 19 mm/day. In 2019, the value of rainfall were highest in the months of July, August and September and 21mm/day in December and January.

Mean Monthly Temperature Variations for Bonaberi and Tombel District



(a)



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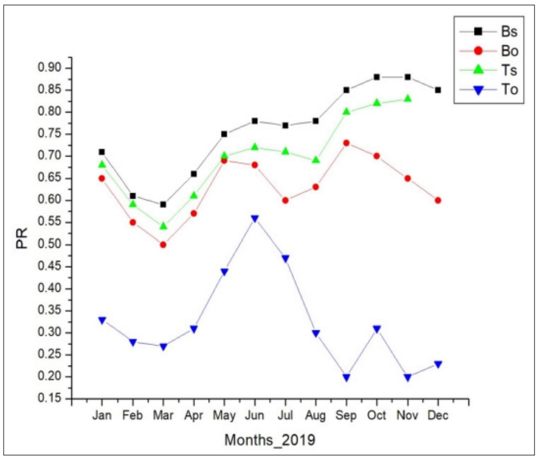
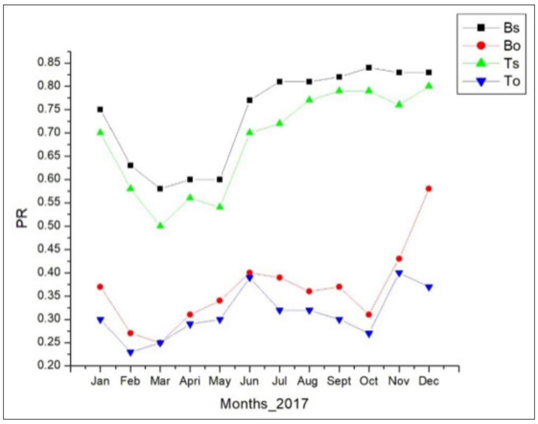


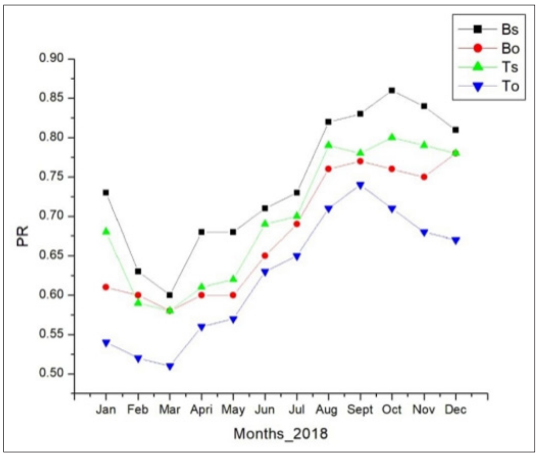
[c]

Figure 4: Mean monthly Temperature (Red) 2017, (green) 2018, and (black) 2019 for Bonaberi (a) and Tombel (b)

Figure 4 represents mean monthly temperatures in Bonaberi and Tombel. Peaks in Bonaberi were in the months of December, January, February and march while peaks in Tombel were in the months of February and March with a mean monthly temperature of about 27.5°C and quite low in the month of August about 25°C in 2017.



[a]



[b]

Figure 5: Observed and Simulated PR Bonaberi and Tombel Bo: Bonaberi Observed Bs: Bonaberi simulated, To: Tombel Observed To: Tombel simulated

Results

Observed and Simulated PR for Bonaberi and Tombel 2017 to 2019

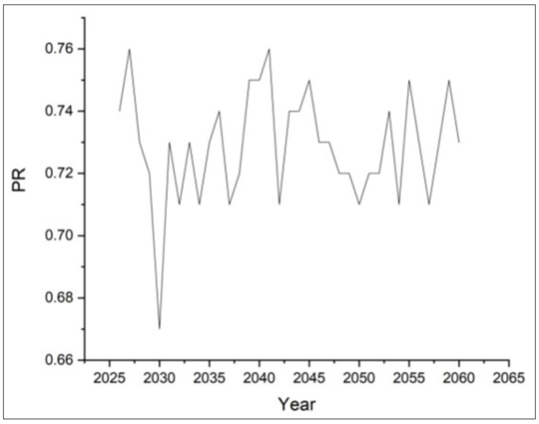
Monthly PR both simulated and observed are presented. Simulated values obtained using the mean of all five CORDEX models used for historical period 2017-2019 where we could get fields data.

Figure 5 shows both simulated and observed PR for Bonaberi follows the same trend in all three years with a peak of 0.85 in October for simulated PR and observed 0.56 in December 2017,0.75 in October 2018 and 0.50 in September 2019 .Minimum malaria incidence were observed in the month of march for both simulated and observed. In Tombel peaks of malaria simulated were noticed in the month of October (0.75) but observed in 2017 had peaked in November (0.38), in 2018 peak in September (0.68) and in 2019 July (0.50). Minimum observed incidences were recorded in March. Using Pearson correlation, in Bonaberi the average of the RCA4 climate model and the observed PR has a correlation of 0.63 in 2017, 0.93 in 2018 and 0.98 in 2019.Also in Tombel a correlation coefficient of 0.6 in 2017, 0.92 in 2018 and 0.61 in 2019.The model is capable of reproducing the historic period and fits perfectly well especially in 2018 for both locations. Therefore the five (5) ensemble mean RCA4 model are reliable to carry out future projections in both locations.

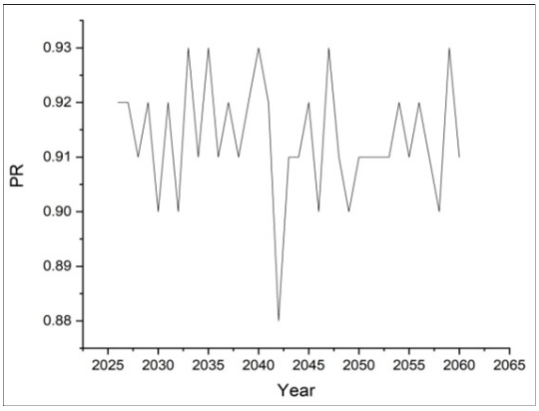
Future Projections

Here, we explore how malaria transmission in Bonaberi and Tombel is projected to change under RCP2.6 and RCP8.5 future scenarios with the use of mean of all the RCA4 climate models. An analysis is conducted for the future period 2026-2060.

Future Projections of PR for Bonaberi and Tombel using RCP 2.6 scenario



(a)

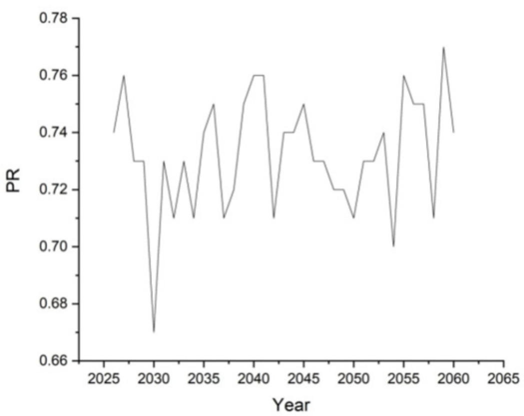


(b)

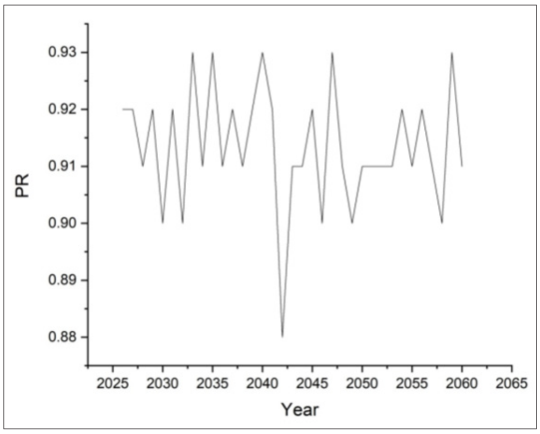
Figure 6: Future Projections RCP 2.6 Bonaberi (a) and Tombel (b).

Figure 6 represents yearly variations for the period of 2026 to 2060. It increases in a wave-like manner. The mean of the RCA4 climate model under RCP 2.6 is sensitive with a PR peak of 0.76 (2040) in Bonaberi. Also, PR has a minimum of 0.67 in 2030. As noticed in figure 6 in Tombel, PR increases and decreases with a peak of 0.93 (2050, 2060) for the climate models. The parasite ratio increases in the nearest future.

Future Projections of PR for Bonaberi and Tombel using RCP 8.5 scenario



(a)



(b)

Figure 7: Future Projections RCP 8.5 Bonaberi (a) and Tombel (b).

The 8.5 ensemble mean climate model was quite sensitive and had peaks in 2045. In Bonaberi Malaria transmission varying. In Tombel, PR increased steadily to 0.96 by 2050. Figure 6 and 7 shows the simulations of PR using the ensemble mean of the RCA4 climate models from 2026 to 2060, for the RCP2.6 and RCP8.5 scenario, illustrating the annual cycle of the PR. A fluctuating increase peaks of malaria incidence is predicted by ensemble mean RCA4 for both scenarios in the future.

Discussion

Initially, this work shows the variation of PR in Bonaberi and Tombel both observed and simulated. It is realized that peaks in Bonaberi PR (0.85) and Tombel PR (0.75) are noticed in October. Since the rainfall peak is in the months of July (19mm/day) and August (21mm/day) most of the larvae are flushed by heavy rain. A temperature of 25.5°C .is mild and coupled with the heavy rain does favor the developmental stages of the vector. but after one or two months, the larva regains its strength. This is in line with works carried in 2022 [15]. Also, Bonaberi is closer to the Atlantic Ocean [16]. With the presence of the River Wouri and its Estuaries, poor drainage, and floods in some areas like Mabanda are quite marshy with water always available for vector multiplication even in the dry season. This explains why the simulated value of PR may be higher than that of the Tombel district. It could also be that the town is poorly planned and there is rapid urbanization, this is in line with studies carried out in other cities of the world [17]. A few studies in Africa show the link between water abundance and elevated malaria transmission in communities closer to the water bodies [18]. Studies carried out in Ethiopia showed that children living in communities closer to small dams had malaria incidence higher than those living far away from these water bodies [19]. Ethiopia's high prevalence was recorded in a village closer to the Gilgel-Gibe Reservoir than in controlled villages. This is in line with those in Bonaberi, especially with the presence of the river Wouri. Also combining VECTRI and ensemble mean OF five (5) climate models for future The 8.5 ensemble mean climate model was quite sensitive and had peaks in 2045. In Bonaberi Malaria transmission varying. In Tombel, PR increased steadily to 0.96 by 2050. Figure 6 and 7 shows the simulations of PR using the ensemble mean of the RCA4 climate models from 2026 to 2060, for the RCP2.6 and RCP8.5 scenario, illustrating the annual cycle of the PR. A fluctuating increase peaks of malaria incidence is predicted by ensemble mean RCA4 for both scenarios in the future. Initially, this work shows the variation of PR in Bonaberi and Tombel both observed and simulated. It is realized that peaks in Bonaberi PR (0.85) and Tombel PR (0.75) are noticed in October. Since the rainfall peak is in the months of July (19mm/day) and August (21mm/day) most of the larvae are flushed by heavy rain. A temperature of 25.5°C is mild and coupled with the heavy rain does favor the developmental stages of the vector. But after one or two months, the larva regains its strength. This is in line with works carried in 2022. Also, Bonaberi is closer to the Atlantic Ocean [20].With the presence of the River Wouri and its Estuaries, poor drainage, and floods in some areas like Mabanda are quite marshy with water always available for vector multiplication even in the dry season. This explains why the simulated value of PR may be higher than that of the Tombel district . It could also be that the town is poorly planned and there is rapid urbanization, this is in line with studies carried out in other cities of the world [21].

A few studies in Africa show the link between water abundance and elevated malaria transmission in communities closer to the water bodies. Studies carried out in Ethiopia showed that children living in communities closer to small dams had malaria incidence higher than those living far away from these water bodies. Ethiopia's high prevalence was recorded in a village closer to the Gilgel-Gibe Reservoir than in controlled villages. This is in line with those in Bonaberi, especially with the presence of the river Wouri. Also combining VECTRI and ensemble mean OF five (5) climate models for future projections of PR, for Bonaberi and Tombel fluctuates its temperature also increases to 30.4°C due to global warming. To better predict the transmission of malaria outbreak period across the Bonaberi and Tombel locality, the mean Rainfall and Temperature represented. 4.1 Future Projections of temperature for Bonaberi and Tombel with RCP 2.6 scenario. Rainfall variation In both districts was similar using both climate models with a projections of PR, for Bonaberi and Tombel fluctuates its temperature also increases to 30.4°C due to global warming [22]. To better predict the transmission of malaria outbreak period across the Bonaberi and Tombel locality, the mean Rainfall and Temperature represented [23-30].

Because of increase in rainfall and temperature as shown in Figure 8&9, in both locations and both scenarios global warming has a positive effect on vector multiplication.. Because of increase in rainfall and temperature in both locations and both scenarios.

Global warming has a positive effect on vector multiplication. 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 inthe spread of vector-borne diseases. 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 [31-38].

Future Projections of temperature for Bonaberi and Tombel with RCP 2.6 scenario

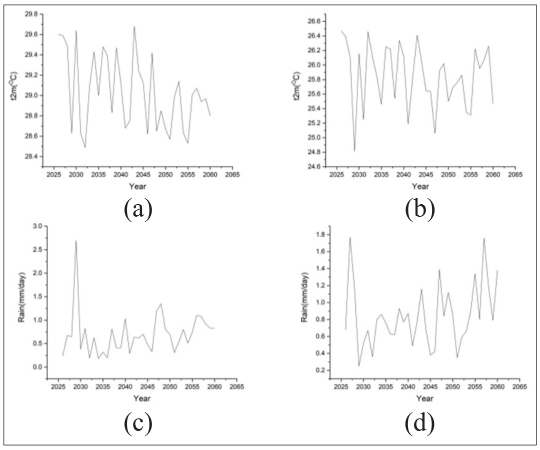


Figure 8: Rainfall and Temperature for Bonaberi and Tombel 2026 to 2060 using RCP 2.6 scenario Temperature Bonaberi(a), Temperature Tombel (b) Rainfall Bonaberi, (c) Rainfall Tombel(d).

Future Projections of rainfall and Temperature for Bonaberi and Tombel with RCP 8.5 scenario

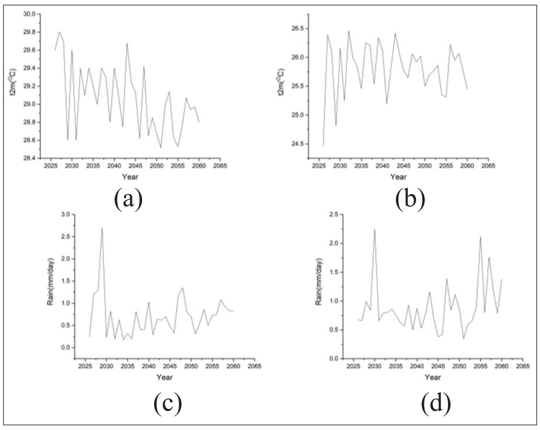


Figure 9: Rainfall and Temperature for Bonaberi and Tombel 2026 to 2060 using RCP 8.5 scenario Temperature Bonaberi(a), Temperature Tombel(b) Rainfall Tombel(d)

Conclusion and Recommendations

Rainfall is a principal climatic variable associated with malaria transmission and involves a one to two months lag in Tombel and Bonaberi. Peaks of rainfall are in the months of July–August, and many malaria cases are in the months of September–October–November. Temperature too is another climatic variable that plays an important role in larva multiplication. The VECTRI model was able to simulate malaria transmission. The dynamical model showed the two months lag and PR in Tombel and Bonaberi (October–November) and rainfall in (July–August–September). However, the monthly variation showed a coherence in months of high and low malaria transmission between PR and observed and simulated.

However, in Tombel, malaria increases up to 2050 probably due to global warming. Nevertheless, there may be some discrepancies, the model displayed malaria's spatial and temporal distribution in Bonaberi and Tombel. The VECTRI, a simulation tool for climate-modulated malaria transmission, can help improve early health warning systems related to vector-borne epidemics.

This work also strengthens evidence of the link between climate change and malaria transmission patterns. Knowledge of the impact of climate and environment on vector biology, transmission intensity, clinical disease and mortality risks have been widely informed. The outcome also supports previous works describing clinical patterns of malaria infection and morbidity that will help stakeholders establish a robust framework for monitoring, forecasting and control. PR can, therefore, be used as the gold-standard metric for evaluating seasonal malaria outcomes of weather-driven dynamical mathematical malaria models as a function of climate and environment. Following the impact of climate change on temperature suitability for malaria transmission at highland areas. Temperature surveillance and monitoring at elevated areas are necessary to curb the proliferation of malaria vectors.

The inclusion of immune processes of the vector into models is very useful. While the conventional use of mean temperatures by the models to simulate PR might be appropriate under certain conditions, it may likely over- or under-estimate. Future developments should, therefore, focus on the use of diurnal daily temperature ranges rather than mean. This is important since the biology of the malaria vectors and parasites is influenced by both average temperature and the extent of the diurnal temperature variation that occurs throughout the day. There are some difficulties in considering this procedure. Firstly, rainfall and temperature were the only climatic factors taken into consideration in analyzing the risk of malaria in this study. Like any other vector-borne disease, malaria typically was driven by climatic, ecological and human factors. Factors. Other factors, the use of treated mosquito nets, and migration were not included in analyzing this work Secondly, the malaria data were from the national malaria program and under-reporting bias is possible. Not everybody went to the hospital for treatment, Auto-medication is very common as well as traditional medicine and most inhabitants may not seek medical assistance. This could probably explain the wide gap between observed and simulated PR for both regions.

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

Data Availability Statement: The CORDEX-Africa data from the Earth System Grid Federation server are gotten free online. Data are downloaded using a wget script. Malaria data was gotten from the Cameroon national Malaria program, the Bonasama district hospital and the Tombel district hospital.

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