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Assessment of Patterns of Climate Variables and Malaria Cases in Two Ecological Zones of Ghana

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Abstract

Climate change is projected to impact human health, particularly incidence of water related and vector borne diseases, such as malaria. A better understanding of the relationship between rainfall patterns and malaria cases is thus required for effective climate change adaptation strategies involving planning and implementation of appropriate disease control interventions. We analyzed climatic data and reported cases of malaria spanning a period of eight years (2001 to 2008) from two ecological zones in Ghana (Ejura and Winneba in the transition and coastal savannah zones respectively) to determine the association between malaria cases, and temperature and rainfall patterns and the potential effects of climate change on malaria epidemiological trends. Monthly peaks of malaria caseloads lagged behind monthly rainfall peaks. Correlation between malaria caseloads and rainfall intensity, and minimum temperature were generally weak at both sites. Lag correlations of up to four months yielded better agreement between the variables, especially at Ejura where a two-month lag between malaria caseloads and rainfall was significantly high but negatively correlated ($r = -0.72$; p value < 0.05). Mean monthly maximum temperature and monthly malaria caseloads at Ejura showed a strong negative correlation at zero month lag ($r = -0.70$, p value < 0.05), with a similar, but weaker relationship at Winneba, ($r = -0.51$). On the other hand, a positive significant correlation ($r = 0.68$, p value < 0.05) between malaria caseloads and maximum temperature was observed for Ejura at a four-month lag, while Winneba showed a strong correlation ($r = 0.70$; p value < 0.05) between the parameters at a two-month lag. The results suggest maximum temperature as a better predictor of malaria trends than minimum temperature or precipitation, particularly in the transition zone. Climate change effects on malaria caseloads seem multi-factorial. For effective malaria control, interventions could be synchronized

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with the most important climatic predictors of the disease for greater impact.

Keywords

Malaria, Rainfall, Temperature, Climate Change, Ecological Zone

1. Introduction

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 [1]. 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 [1] [2].

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 [3] and in Africa [4]-[6]. Climatic factors that feed into the phenomenon could have a direct bearing on the number of malaria cases. A number of studies have reported association between malaria cases, rainfall and temperature [7]-[10]. For example, a study carried out in Ethiopia revealed an association of malaria with rainfall and minimum temperature, the strength of which varied with altitude [8]. In South Africa, variations in annual cases of malaria were shown to be related to patterns of rainfall and temperature [11].

Rainfall impacts on malaria through its effect on the population dynamics of the major vector of the disease in sub-Saharan Africa. Indeed the abundance of *Anopheles gambiae* s.s. in most malaria endemic regions has been shown to peak during the wetter parts of the year [7]. This could be explained by the biology of the vector where the availability of pools of water provides breeding sites and subsistence, hence directly influencing vector numbers. *Anopheles gambiae* s.s. prefers to breed in temporary pools of clean water such as potholes, foot and hoof prints and puddles that become plentiful in the rainy seasons. Immature stages of the *An. gambiae* s.s., *i.e.* eggs, larvae and pupae are aquatic forms and require suitable aquatic environments in which they develop prior to the emergence of adults from the pupae. Additionally, when water availability to the adult mosquitoes is limited, they become predisposed to dehydration leading to a direct negative effect on their population [12].

Temperature has also been reported to correlate positively with malaria caseloads. For example, combinations of maximum and minimum temperatures in association with rainfall have been used to successfully fit a biological transmission model to malaria case data in Zimbabwe [8]. On the other hand, a number of other studies failed to establish strong correlation between climatic variables and the caseloads of malaria, e.g. [13]-[15] in Sri Lanka, and [11] in South Africa.

Apart from the effect of rainfall and temperature on adult mosquito longevity, these climate parameters also influence development of the parasites within the vector. For instance at 26˚C ambient temperature, 6˚C drops can double the development time of Plasmodium falciparum within the vector [16] [17]. At relatively higher temperatures both vector and parasite development accelerate. However, the efficiency of malaria transmission varies widely and is influenced by several factors including the type of vertebrate host, parasite and vector factors [18]. Generally human ecology and activities that affect the environment, such as land use [19] and urbanization [20] have also been linked to malaria transmission.

Although climatic indices influence malaria epidemiology, the relationship between climatic variability and malaria case intensity in Ghana is poorly understood and scarcely documented. A few studies have reported the relationship between climate variability and malaria caseloads in Ghana but information obtained from the studies spanned over relatively shorter periods, e.g., 18 months [21] and 22 months [22]. Additionally these studies were carried out in a single ecological zone (forest zone). This paper examines the relationship between climate variables and malaria cases in two different ecological zones (the transition and the coastal savannah zones) in Ghana over an eight-year period, with the aim of better elucidating the effects of climate variability on malaria caseloads. This could help to inform planning and decision making for the control of malaria in the face of changing climatic conditions.

2. Study Sites

The study was conducted in two communities in two ecological zones in Ghana: Ejura, situated in the transition zone in the Ashanti Region (7.23˚N, 1.22˚W) and Winneba, a coastal savannah location in the Central Region (5.33˚N, 0.62˚W).

Ejura is a farming community 240 km northeast of Accra the capital of Ghana and it is the district capital of the Ejura/Sekyedumase district. The district has a total land area of about 6500 km^2 and is the 24th most populous settlement in Ghana. Ejura has a population of 33,907. The transition zone is an expanding zone along forest fringes where grassland is gradually replacing the forest vegetation. The zone coincides with the Ghana Meteorological Agency (GMet) Zone C ecological zone (**Figure 1**) and enjoys a double rainfall maximum, which gives rise to a major and a minor growing season. The major rainy season occurs from March to June, with the minor occurring in September or October. In a good year however, the total volume of rainfall in the two seasons are about the same. The mean annual rainfall measures 1200 mm and decreases from south to north of the zone, in line with rainfall distribution patterns in the country.

Winneba on the other hand, is fishing and educational community located 50 km west of Accra with a population of 40,754. The total land area of the coastal savannah ecological zone that coincides with the GMet Zone A (**Figure 1**) is estimated to be 20,000 km^2. Here also the rainfall is bimodal, with the major season falling between March and June and the minor in September and October. The mean annual rainfall of the dry coastal savannah is relatively low, with an annual rainfall averaging 800 mm.

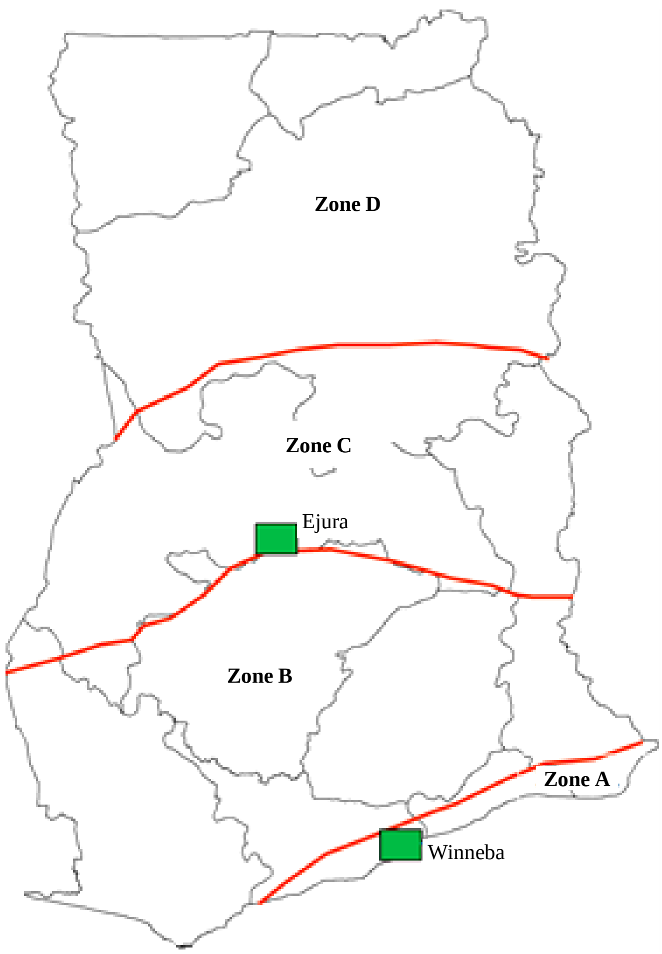

Figure 1. A map of Ghana showing the ecological zones (Source: the Ghana Meteorological Agency). The locations of the study sites, Ejura (Zone C, Transition Zone) and Winneba (Zone A, Coastal Savannah Zone) are indicated with a green box.

3. Data Collection and Methods

3.1. Malaria Data

Records of monthly malaria cases for the study sites were obtained from hospital archives and consulting room record books. At Ejura, the records were obtained from the St. Luke Hospital in Kissei, a suburb of the town. This health facility had the most complete data set, dating from 2001 to 2008 within the Ejura/Sekyedumase district. Malaria case data for the Winneba area were acquired from the Winneba Hospital, where the most complete data set spanned from 2001 to 2006.

3.2. Climate Data

The climate data for the two communities (Ejura and Winneba) were obtained from the GMet headquarters in Accra. Weather variables obtained were daily rainfall volumes and minimum and maximum temperatures for the period of January 2001 to December 2008. Selection of the study period was informed by the availability of complete records of confirmed malaria cases. Data for monthly volume of rainfall were subsequently derived from the daily rainfall figures for the purposes of computing lag correlations with confirmed malaria cases in the two study sites.

3.3. Analyses

The data obtained were first entered into Microsoft Office Excel version 2010 spreadsheets, cleaned, collated and analysed using SPSS version 20. All data were assessed for normality following which the appropriate parametric or nonparametric tests were applied at an alpha (α) of 0.05. Differences in the overall annual mean values of the malaria and climate variables under investigation between the two ecological zones were tested for significance using Mann-Whitney U test. Year by year differences in the number of malaria cases, rainfall and temperature for the study sites were also assessed using Kruskal-Wallis test for within site differences. The relationship between the climatic parameters and malaria cases was assessed by the application of lag correlation analysis for 1 month, 2 months, 3 months and 4 months.

3.4. Ethical Considerations

Since the data sets were obtained in a non-invasive manner and all records were kept anonymous, there were no obvious ethical concerns regarding the work. Nonetheless, informed consents from the chief executive officers of the health facilities were obtained prior to the extraction of the malaria data from the hospital records.

4. Results

4.1. Malaria Cases

The trend of mean annual cases of malaria in the transition zone (Ejura) showed a gradual increase from 2002, peaking in 2008 at 464 cases while the lowest number of 146 cases was recorded in 2002 (**Figure 2**). A mean annual total of 2914.75 and 23905.50 cases were reported in Ejura and Winneba respectively. In the coastal savannah ecological zone (Winneba), mean annual malaria caseloads were generally low at the start of the period under review but showed two sharp peaks in 2003 and 2004. A sharp drop and a gradual increase in cases followed the peaks. The highest mean annual caseload of 5980 cases was recorded in 2003 and the least of 317 cases in 2001 (**Figure 2**).

At Ejura, the peaks of monthly average malaria cases occurred in June (318 cases) and October (293 cases), with the lowest mean of 162 malaria cases recorded in March (**Figure 3**). An overall monthly mean of malaria cases of 1999 was recorded at Winneba (**Figure 3**) during the entire study period. At this site, two peaks of mean monthly malaria caseloads were observed in January (2590 cases) and July (2567 cases). Between the peaks, monthly average caseloads were less than 2000, with the least of about 1200 cases recorded in November.

4.2. Relationships between Rainfall and Malaria Cases in the Study Areas

Mean annual rainfall values showed no clear patterns for both ecological zones for the period of study (**Figure 4**).

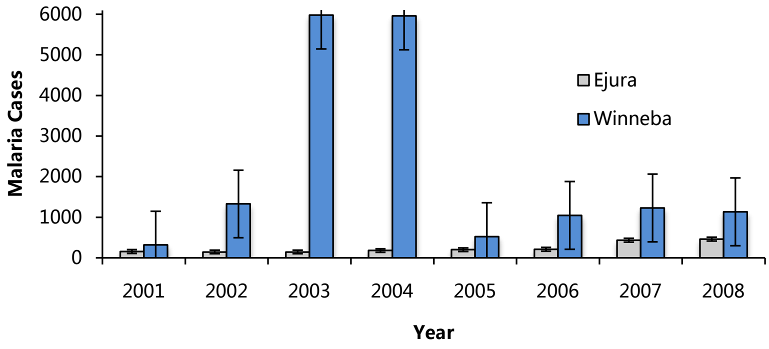

Figure 2. Annual means of malaria caseloads spanning an eight-year period in Ejura (Transition Zone) and Winneba (Coastal Savannah).

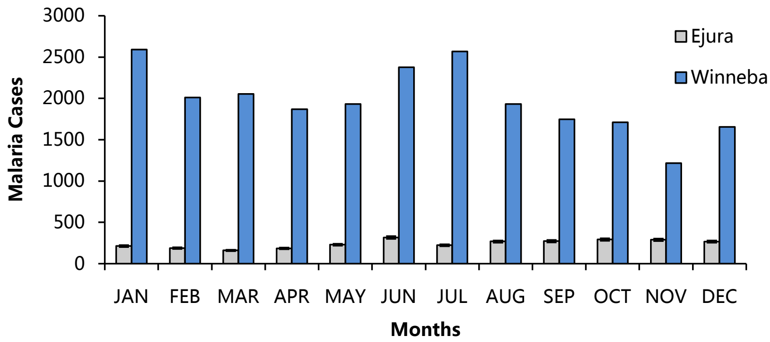

Figure 3. Mean monthly malaria cases reported at Ejura (Transition Zone) and Winneba (Coastal Savannah) over an 8-year period (2001-2008).

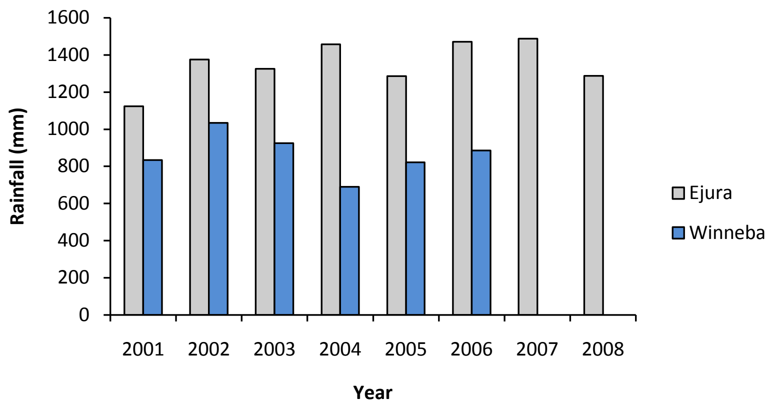

Figure 4. Total annual rainfall figures (mm) recorded over the study period for Ejura (Transition Zone) and Winneba (Coastal Savannah).

While the highest mean annual rainfall (1487.50 mm) recorded at Ejura occurred in 2007 that of Winneba (1033.80 mm) occurred in 2001. At Ejura, the lowest mean annual rainfall (1123.80 mm) was recorded in 2001, with that of Winneba (822.70 mm) occurring in 2005.

Monthly average rainfall values for Ejura and Winneba for the period studied are shown in **Figure 5**. In both the transition zone and coastal savannah zone, two monthly rainfall maxima were recorded, with the lowest overall mean monthly rainfall figure recorded at Winneba (72.12 mm). Also, in the minor rainy season the highest peak of 242 mm for Ejura was recorded in September, while the peak for Winneba occurred in the major rainy season (209.77 mm in June). The major rainy season for both ecological zones started in March, generally peaked in May/June and ended in July. In both zones, the dry season spanned from November to February with an average of less than 20 mm of monthly rainfall.

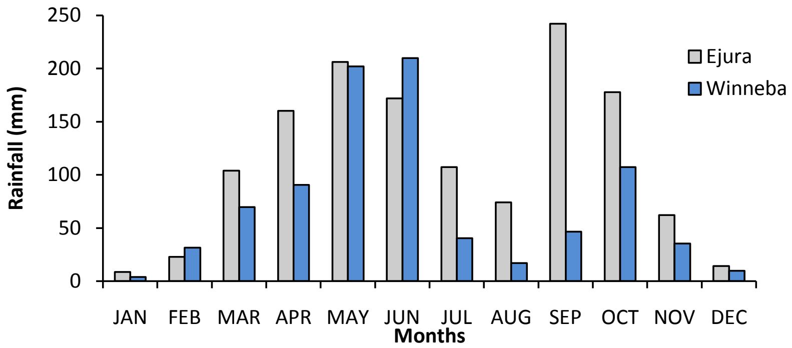

Figure 5. Monthly total rainfall figures (mm) recorded over the study period for Ejura (Transition Zone) and Winneba (Coastal Savannah).

Pearson correlation analyses between mean monthly rainfall values and mean monthly reported malaria cases at both Winneba and Ejura revealed low correlations (**Table 1**). Lag correlations of up to four months yielded better agreement between the variables, especially at Ejura where a two-month lag between malaria caseloads and rainfall was significantly high but negatively correlated ($r = -0.72$; p value < 0.05) (**Table 1**).

4.3. Relationship between Temperature and Malaria Cases in the Study Areas

At Winneba, a difference of less than 1˚C between the highest of 24.2˚C (2006) and the lowest of 23.38˚C (2001) values were observed for the minimum temperatures (**Figure 6**). Ejura recorded the highest of 22.4˚C and the lowest of 15.9˚C in minimum temperature.

At Ejura, the overall mean monthly minimum temperatures increased steadily from 17˚C in January to 19.5˚C in April (**Figure 6**). It then decreased by 0.3˚C and 1˚C respectively in May and June. Winneba experienced mean monthly minimum temperatures that ranged between 22.5˚C and 22.7˚C (**Figure 7**). No appreciable correlation was observed between minimum temperature and cases of malaria in both study sites except for a two-month lag correlation at Ejura ($r = 0.46$, p value > 0.05) and Winneba ($r = 0.53$, p value > 0.05), albeit weak (**Table 2**).

At Ejura, average annual maximum temperature values recorded for the period under study showed a range of 32.77˚C in 2001 and 33.36˚C in 2008 (**Figure 8**). Although annual maximum temperature means were significantly lower at Winneba (p value < 0.05), a similar pattern of mean annual maximum temperatures was observed but with smaller margins of fluctuations (**Figure 8**). The mean annual maximum temperature ranged between 31.15˚C in 2001 and 31.77˚C in 2006 at Winneba (**Figure 9**).

Average monthly maximum temperature at Ejura peaked in February at 36.5˚C and gradually decreased to a minimum of 30.5˚C in August (**Figure 9**). This then increased gradually to 33.5˚C in November, with a second peak of 34.5˚C recorded in January. Relatively lower mean monthly maximum temperature values ranging between 27.8˚C in January and 28.1˚C in August were recorded at Winneba (**Figure 9**).

A strong negative correlation at zero month lag was revealed between mean monthly malaria caseloads and mean monthly maximum temperature at Ejura ($r = -0.70$; p value < 0.05). At Winneba, a similar relationship ($r = -0.51$) was found, although weaker (**Table 3**). At a four-month lag however, a significantly (p value < 0.05) positive correlation ($r = 0.68$) between malaria caseloads and maximum temperature was revealed in Ejura. The strongest correlation ($r = 0.70$; p value < 0.05) obtained between the parameters at Winneba occurred at a two-month lag. **Figure 10** and **Figure 11** show the relationship between the mean monthly reported malaria cases and mean monthly maximum temperatures at two sites.

5. Discussion

Climatic parameters have been severally reported to play a major role in the epidemiology of malaria [4]-[6] [21] [22]. Although several factors impact on malaria disease trends in a complex manner, climate variables are seen to have more direct effects on the disease through their effect on the vector biology, parasite development and human activity and behaviour. These variables are mainly temperature and rainfall [3] [21]-[23] and their effects on malaria may vary spatiotemporally, requiring an understanding of what pertains in different ecological zones

Table 1. Cross correlation coefficient values, with p values in brackets, of mean monthly malaria caseloads and mean monthly rainfall figures for the study period at Ejura and Winneba.

Rainfall	0-month lag	1-month lag	2-month lag	3-month lag	4-month lag
Ejura	0.25 (0.43)	−0.26 (0.41)	−0.72 (0.01)	−0.37 (0.24)	−0.20 (0.53)
Winneba	0.12 (0.71)	−0.05 (0.88)	0.16 (0.62)	0.36 (0.25)	0.35 (0.26)

Table 2. Cross correlation coefficient values, with p values in brackets, of mean monthly malaria caseloads and mean monthly minimum temperatures for the study period at Ejura and Winneba.

Rainfall	0-month lag	1-month lag	2-month lag	3-month lag	4-month lag
Ejura	0.09 (0.78)	−0.27 (0.40)	−0.46 (0.13)	−0.43 (0.16)	−0.15 (0.64)
Winneba	−0.35 (0.26)	0.21 (0.51)	0.53 (0.08)	0.36 (0.25)	−0.14 (0.66)

Table 3. Cross correlation coefficient values, with p values in brackets, of mean monthly malaria caseloads and mean monthly maximum temperatures for the study period at Ejura and Winneba.

Rainfall	0-month lag	1-month lag	2-month lag	3-month lag	4-month lag
Ejura	−0.70 (0.01)	−0.49 (0.11)	−0.16 (0.62)	0.30 (0.34)	0.68 (0.01)
Winneba	−0.51 (0.09)	0.37 (0.24)	0.70 (0.01)	0.31 (0.32)	−0.00 (1.0)

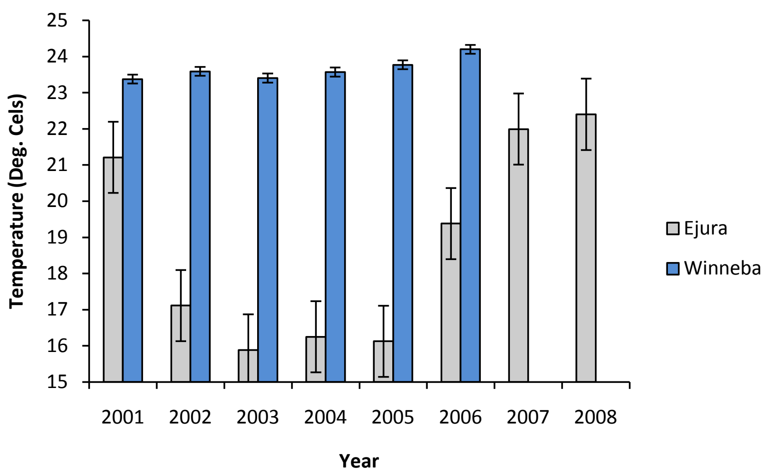

Figure 6. Annual averages of minimum temperature (˚C) recorded from 2001 to 2008 for Ejura (Transition Zone) and Winneba (Coastal Savannah Zone).

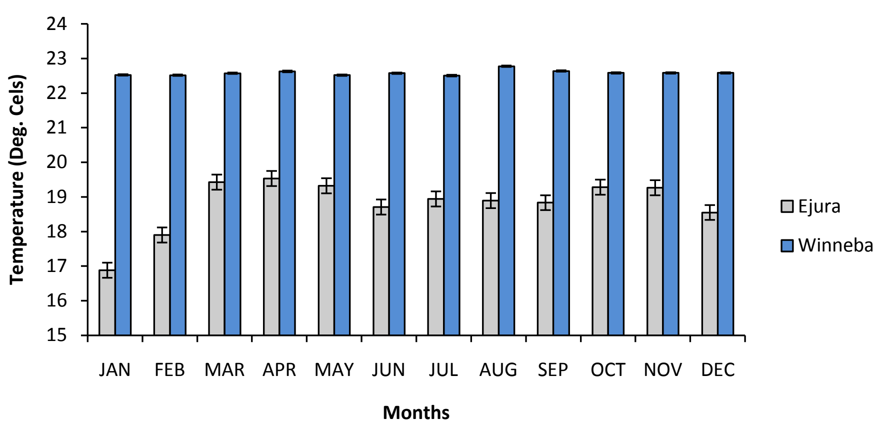

Figure 7. Monthly averages of minimum temperature (˚C) recorded from 2001 to 2008 for Ejura (Transition Zone) and Winneba (Coastal Savannah Zone).

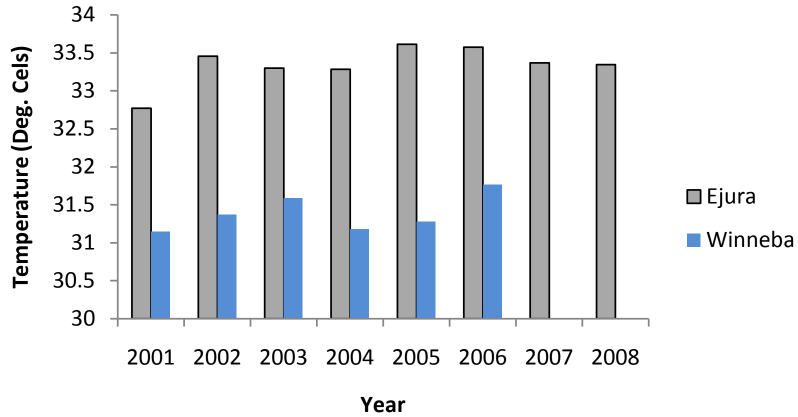

Figure 8. Annual averages of maximum temperature (˚C) recorded from 2001 to 2008 for Ejura (Transition Zone) and Winneba (Coastal Savannah Zone).

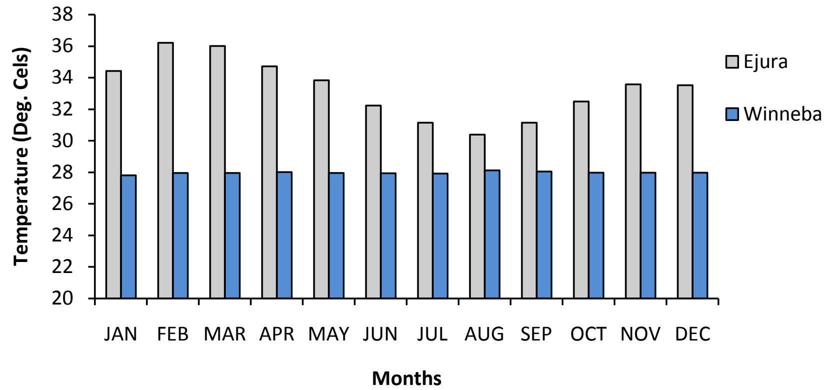

Figure 9. Monthly averages of maximum temperature (˚C) recorded from 2001 to 2008 for Ejura (Transition Zone) and Winneba (Coastal Savannah Zone).

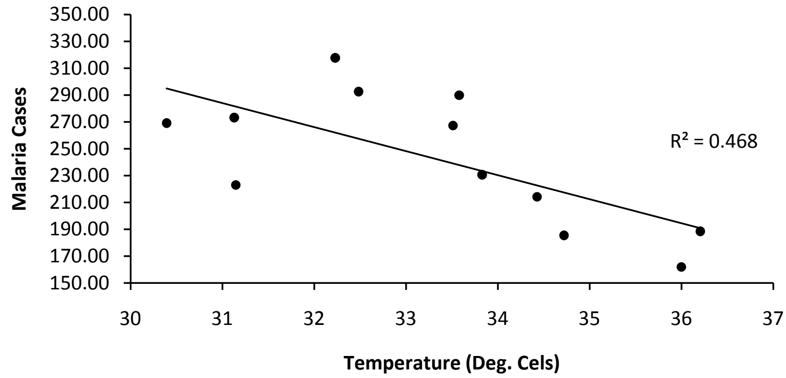

Figure 10. Scatter plot of mean monthly malaria caseloads and mean monthly maximum temperature over Ejura for the study period.

to enable effective planning and control of the disease. Here, the relationship between malaria caseloads and the climatic parameters in two different ecological zones, coastal savannah (Winneba) and transition zone (Ejura) in Ghana were investigated.

Similar to the findings of [22] in an urban setting, generally weak correlation between rainfall and malaria cases were found with a positive correlation at zero lag for both zones but negative correlations for the other month lags at Ejura. Except for the one-month lag, all other correlations between rainfall and malaria cases at Winneba were positive. The similarity in correlations between rainfall and malaria cases at Ejura and that of the

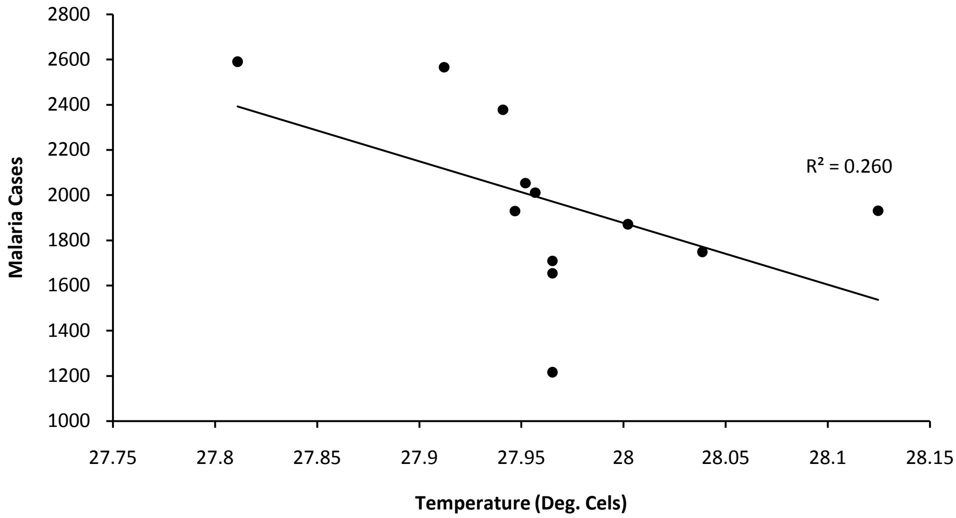

Figure 11. Scatter plot of mean monthly malaria caseloads and mean monthly maximum temperature over Winneba for the study period.

study of [22] could be due to the similarities in socio-ecological factors in the study communities. Relatively higher rainfall figures in the transition zone may suggest an abundance of Anopheles breeding sites all year round, impacting on malaria vector abundance and hence disease transmission. Nonetheless the relationship between rainfall and mosquito abundance is a complex one best studied under similar temperature regimes [3] [4] [23]-[25] also reports that ideal conditions of rainfall and temperature have to be temporally concurrent for transmission to occur.

Indeed the temperature profiles for the two zones were not similar, thus complicating the influence of rainfall on transmission patterns. The generally higher rainfall at Ejura could be impacting negatively on malaria cases since flooding events associated with the heavier rainfall temporarily reduce vector abundance as breeding sites are destroyed [26], although a residual vector population may persist [3].

Temperature effects on malaria disease trends are numerous with the most important being the duration of parasite development within the vector, larval development time and vector survival [24] [27] [28]. A significant negative correlation between maximum temperature and malaria cases were observed at both zones. Maximum temperatures seem to be the major driver for malaria cases, particularly at Ejura where cross correlation analyses revealed a significant correlation at a four-month lag. This time lag between malaria cases and maximum temperature probably allowed for a bounce back of vector populations after the first few heavy rains had destroyed larval habitats through flooding. Additionally, such a time lag may have facilitated the concurrence of ideal temperature and rainfall conditions necessary for optimum disease transmission to occur in this zone. At Winneba temperatures ranged between 22.5˚C and 28.1˚C while that of Ejura ranged between 15.9˚C and 36.2˚C. Although temperatures of not less than 16˚C may sustain the development of parasites within the vector, the long developmental period of about 56 days at such higher temperatures may not be suitable for effective transmission, since very few adult mosquitoes can survive for that long [23]. Optimum temperatures for parasite development, larval development and adult mosquito survival, range between 28˚C and 32˚C [23] [24] akin to temperature ranges experienced at Winneba, likely leading to higher levels of transmission and hence higher caseloads.

Another important factor that has been reported to influence malaria epidemiology is population growth [3]. Differences in the demographics and use of the health facilities in the two communities made it rather challenging for a direct comparison of malaria caseloads between the two study zones. In the current study the requisite historical data with sufficient spatial coverage were not available, thus limiting the possibility for comparative analysis of the population dynamics. Differences in population growth rates, emigration and migration could account for the differences in malaria caseloads between the two different ecological zones. Nonetheless, economic growth and urbanisation are reported to decrease population vulnerability to malaria. Indeed reduction in malaria risk with urbanization is well documented [29]. In contrast, higher malaria cases were recorded at the more urbanized coastal savannah zone, further underscoring the multifaceted nature of malaria disease trends.

6. Conclusions

Determining the precise trends in malaria transmission is daunting due to the difficulty in accounting for the micro-ecological variability and temporal changes in the risk of transmission [23]. The study examined the relationship between climate variables and malaria cases in two different ecological zones in two districts in Ghana over an eight-year period (2001 to 2008). Lag correlation analyses carried out to determine the level of association between malaria cases, temperature and rainfall patterns revealed weak correlations between malaria caseloads and climatic variables, except for maximum temperature and an instance for rainfall. Such an effect of maximum temperature on the incidence of malaria was more prominent in the transition zone than the coastal savannah, further emphasizing the need for factoring in micro-ecological differences in determining disease patterns across diverse ecological profiles. Although climatic factors are measureable and offer some degree of predicting malaria disease trends, the present study suggests maximum temperature as the most important parameter that affects malaria caseloads. Generally, the results suggest a minimal direct or linear relationship between malaria incidence and climate variables, and underscore the complex and multifaceted nature of malaria transmission trends. Hence a larger study that incorporates other factors such as human behaviour, ecology of disease vectors and parasites, and the role of vector-parasite-host genetic makeup in malaria transmission is required to better understand the spatial and temporal disease transmission dynamics.

Based on the monthly patterns of climatic variables, it is recommended that for effective malaria control, interventions could be intensified and focused on the peak rainy months and the immediate subsequent months.

In conducting this study, a major challenge faced was the unavailability of long term records of health data across most districts of Ghana. In the case of Ejura, health records in the main state hospital were not available, thus compelling the study to fall on a private hospital where the records were better kept. This highlights the urgent need for strengthening record keeping within the relevant institutions mandated for keeping such important data intact and complete.

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Authors' Contributions

YNB conceptualized the study, participated in defining the data collection instruments, provided input into the preparation of the manuscript and critically reviewed the paper for intellectual content; NABK participated in the data collection, performed the data treatment and analysis, and prepared the first draft of the manuscript. FAA participated in the data collection, critically revised the manuscript. KO participated in the development of the data collection instrument and revision of the manuscript. All authors were involved in the definition of the scope of the paper. All authors read and approved of the manuscript before submission.

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