Research Article

Confirmed Malaria Cases in Children under Five Years: The Influence of Suspected Cases, Tested Cases, and Climatic Conditions

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1.Introduction

Malaria has triggered a number of health issues throughout Ghana despite attempts by the government, individuals, nongovernment organizations, and other stakeholders. The World Health Organization (WHO) emphasized that malaria is a tropical and deadly disease caused by Plasmodium spp which spreads from one person to another through the bite of infected female anopheles mosquitoes [1]. In Ghana, malaria is pervasive and perennial, with significant seasonal disparities mostly in the savanna and northern parts [2]. Malaria transmissions dynamics in Ghana vary in terms of geographical region, which is associated with the duration of dry seasons where there are often few transmissions [2].
The four main species of Plasmodium protozoa which cause malaria include *Plasmodium vivax*, *Plasmodium malariae*, *Plasmodium falciparum*, and *Plasmodium ovale* [3]. In Ghana, almost all malaria cases are a result of *Plasmodium falciparum*, which transmits through the bite of female anopheline mosquitoes. Furthermore, at least 35% of the patients admitted in health facilities are attributed to malaria in the last decade [4].

Malaria accounts for more than 40% of all outpatient cases across health facilities in Ghana and contributes to about 15% of mortalities annually [4]. About 31% of under-five mortalities in developing countries are attributed to malaria [5]. In the 2018 World Malaria Report (WMR), 220 million malaria cases were reported globally with 49% of them reported in children under five years.

Severe anaemia, hypoglycaemia, and cerebral malaria are the characteristics of severe malaria more commonly observed in children than in adults [6]. When children develop a continual malaria infection, their exposure to diseases such as diarrhoea, fever, and other illnesses increase. An estimated two percent of the children who recover from cerebral malaria such as epilepsy and spasticity develop some weakness and infirmities in their learning [6]. Malaria contributes to twenty-five percent of mortalities in children of less than five years [7, 8].

Ghana contributes about 4% and 7% of the malaria cases in the world and West Africa, respectively. This has occasioned the significant increase in laboratory testing of the number of suspected cases from 31% to 78% between 2013 and 2016 [9]. Despite the progress made in the fight against malaria, it is still endemic in Ghana and several developing countries [10]. This has called for excessive budgetary allocations to over US$ 10 billion in high burden high impact (HBHI) countries such as Ghana and several countries. These efforts have improved the number of countries endemic in malaria that recorded fewer than 10,000 cases to increase from 40 to 49 between 2010 and 2018 [11].

Moreover, MacDonald [12] revealed that malaria within the forest areas in Ghana has a complex consequence on the individuals living around there. The high social and economic financial loss of individuals on malaria treatment depicts the need to eliminate or reduce malaria incidence and death in Ghana [13]. The Ghana National Malaria Control Program focuses on the use of insecticide treated mosquito nets (ITNs), indoors residuals spraying (IRS), case management, and many preventive methods [14, 15]. According to [16], at least US 950 million dollars is needed between 2020 and 2029 to eliminate malaria completely in Ghana.

The survival period of the parasite depends on climatic factors [17, 18]. They showed that suitable temperature of 20°C to 30°C is often required for speedy mosquito vector. Similarly, findings from [19] revealed that the increase in temperature levels minimizes the array between the blood meals but increases the biting rate of female mosquitoes, which further accelerates parasites’ growth, thereby resulting in the rise in malaria infection [20–22]. Also, Ck et al. [23] conducted a study in Kumasi, Ghana, which has similar geographical characteristics as the highlands of Ethiopia, on the relationship between the incidence of malaria within a 12-week period and high temperature in broad human scale population. Their findings, however, contradicted the works of [20–22] on the influence of temperature on malaria.

Relative humidity may influence the activeness of the malaria parasite [21]. The life of the anopheline mosquito may be shortened as compared to the external incubation period if the average relative humidity is less than 60%. Under conditions in which the average relative humidity is less than twenty-five percent, the mosquitoes will stop biting [10]. Thus, the adult mosquito life span may be significantly shortened by low humidity [24], thereby reducing the rate of malaria positivity [21]. Relative humidity has been revealed to be a principal climatic predictor of malaria occurrence in unusual geographical regions [25].

High rainfall may have a significant impact on the increase of malaria cases [26]. There may exist a direct positive correlation between malaria cases and rainfall patterns when the temperature is not restricted or when waste in geographical areas becomes a stock site for anopheline mosquitoes’ breeding [26]. The association between rainfall and the malaria harm is not well known [27, 28]. Furthermore, Danuor et al. [28] agreed that the relationship between malaria and rainfall patterns is not uniformly contemporary. The eventual relation between rainfall and malaria occurs at the start of the rainfall season [29]. According to Craig et al. [18], continuous transmission of malaria happens during rainfall seasons. Moreover, Craig et al. [18] further argued that a monthly rainfall of more than 80 mm is not enough for any substantial spread in malaria case irrespective of the temperature levels. Elsewhere in Ouagadougou, Bhargavan et al. [30] equally observed that a minimum rainfall pattern around 2.3 mm as well as maximum rainfall around 200 mm stimulated the spread of malaria throughout the year.

Studies have revealed that, although both the use of indoors residuals spraying (IRS) with dichlorodiphenyltrichloroethane (DDT) and ITNs provide personal protection, the use of ITNs is better than only IRS in providing protection to humans and advised that high coverage of IRS may interrupt transmission, as the combination of high coverage of ITNs and IRS with DDT significantly reduces mosquito populations [31]. Bremen et al. [32] disclosed that malaria control measures such as IRS (with DDT) and ITNs both results in substantial reduction in malaria infection; however, the use of ITNs only without IRS may not be very efficient in reducing the malaria incidence. Findings in [33] observed that indoor residual spraying may be more effective and cost-effective than ITNs in areas with low seasonal risk of malaria. Also, Kleinschmidt et al. [34] showed that a protective effect of IRS combined with ITNs is relative to IRS alone.

Inability to consider malaria in the differential diagnosis of a febrile illness in a patient who has moved in from a malaria endemic can lead to significant morbidity as well as mortality, most particularly in pregnant women and children younger than five years old [35]. According to public health perspective, the treatment of a disease is aimed at minimizing the transmission of the infection to others in the
population through the reduction in their infection reservoir and to prevent future outbreak and spread of resistance to antimalaria drugs. It is therefore important for suspected malaria patients to have a laboratory test to confirm the diagnosis either through the rapid diagnostic test or microscopy before commencing antimalaria treatment [36].

Malaria infection occurs when there is more influx of merozoites into the bloodstream, which subsequently results in red blood cells being destroyed. The first symptoms of malaria will usually occur as early as ten days or as longer. The most significant symptoms of malaria infection among children under five years include headaches, chills, fever, nausea, body aches, vomiting, and sweating coupled with general body fatigue [36]. The above symptoms may at times be misdiagnosed as other infections. According to Mbuli et al. [37], diagnosis of malaria infections over the years in under resourced settings has mostly been based on signs and symptoms. These signs and symptoms of malaria, mostly fever and headache, have resulted in antimalaria drug overdose, sufferings of patients, and waste of resources. The WHO [38] initiative recommends the full implementation of the test, treat, and track (T3) strategy to fast track malaria control and elimination measures under various malaria risk regions particularly in sub-Saharan Africa. In line with the T3 initiative rational of testing to confirm all malaria cases before treatment with quality-assured antimalaria drugs and further tracking through appropriate surveillance systems, it is very important for the majority of suspected cases of malaria to be tested through either the microscopy or the rapid diagnostic test (RDT) by well-trained personnel in well-equipped and resourced health facilities to end the era of presumptive malaria treatment which results in waste of resources and under-treatment of other serious fever-like illnesses and development of drug resistance [38]. Malaria infection diagnosis is confirmed under a microscope provided that the parasites causing malaria are present in the blood sampled viewed. In recent times, the most effective and reliable means of diagnosing malaria is the use of microscopes to investigate blood samples by well trained technicians in well-equipped and resourced laboratories [39].

Ghana signed to the Abuja Agreement which aimed at attaining sixty percent coverage of malaria interventions such as strengthening health systems for adequate surveillance, prompt access to treatment of at least 60% of people suffering from malaria, promote community participation in malaria control programs among others by the year 2010, with particular focus on children under five years as well as women [15]. Significant successes were chopped in Ghana in this regard as a result of efforts by individuals, government, and nongovernment organizations (NGO) in fulfilling the agreement. However, malaria continues to be a major public health concern affecting several millions of people in Ghana, especially children under five years [40]. Asante et al. [41] studied malaria epidemiology in the Brong Ahafo Region, while Osei and Yibile [42] studied the geographic pattern of malaria in the Brong Ahafo Region of Ghana. However, in this study, we seek to determine the effect of tested malaria cases and climatic factors on confirmed malaria cases in the Sunyani Municipal Assembly of the Bono Region of Ghana.

Our results can help the government in its quest to achieve the sustainable development goal three as well as enhance the survival of children under five years.

2. Materials and Methods

2.1. Data. Data on monthly number of laboratory-confirmed malaria cases, number of suspected malaria cases, and number of tested malaria cases in children under five years were obtained from the Departments of Health Information of the Bono Regional Hospital, Sunyani Municipal Hospital, and the Seventh Day Adventist Hospital all located in the Sunyani Municipal Assembly. We sourced our data from these hospitals because they are the major referral hospitals in the municipality. The data spanned from 2010 to 2021 (144 months). The monthly average rainfall, humidity, and temperature data from 2010 to 2021 were obtained from the Earth Observation Research and Innovation Centre (EORIC) at the University of Energy and Natural Resources, Sunyani, Bono Region, Ghana. The data were made available to us after formal letters were written to the management of the three hospitals and EORIC.

Our dependent variable is the count of laboratory-confirmed cases of malaria in children under five years where the number of suspected malaria cases and tested malaria cases in children under five years as well as the average monthly rainfall, humidity, and temperature were used as the independent variables. The data comprised of 144 monthly values for each of the variables of interest. To meet our model assumptions, we transformed all our variables by taking a natural logarithm of each data point.

The summary statistics of the transformed dependent variable is presented in Table 1. The mean and median values of 6.0, respectively, together with kurtosis and skewness values of 3.0 and 0.0, respectively, suggest our transformed dependent variable might be normally distributed.

Table 2 shows the descriptive statistics of the transformed independent variables. We can observe from the table that not all suspected cases of malaria in children below five years are laboratory tested to confirm. This must be looked into since it is against best practices, internationally.

2.2. Methods. Assume $X = \{x_1, \ldots, x_p\}$ is an $n \times 1$ matrix of the dependent variable (i.e., confirmed malaria cases). Suppose $Y = \{y_1, \ldots, y_{p-1}\}$ is an $n \times p$ matrix of independent variables (i.e., suspected malaria cases, tested malaria cases, temperature, relative humidity, and rainfall) and $\varepsilon = \{\epsilon_1, \epsilon_{p-1}\}$ be a $p \times 1$ matrix of estimates of the parameters and associated $n \times 1$ matrix of errors, $\varepsilon = \{\epsilon_1, \epsilon_{p-1}\}$. Our multiple linear regression model [43–46] can be written as follows:

$$X = \gamma Y + \varepsilon,$$

where $\varepsilon \sim N(0, \sigma^2)$, $\text{cov}(\epsilon_i, \epsilon_j) = 0$ for $i \neq j$, and $X \sim N(\gamma Y, \sigma^2)$. The fitted model is of the following form:

$$\tilde{X} = \gamma \tilde{Y}.$$
The validity of predictions from the fitted model abovementioned is ensured provided that the assumptions of linearity, normality, and homoscedastic (constant) are satisfied by examining the various residual plots [45, 46]. From the abovementioned, we have the following equation:

\[ e = X - \gamma Y. \]  

Thus,

\[ e' e' = (X - \gamma Y)' (X - \gamma Y). \]  

When we differentiate the expression abovementioned with respect to gamma, equate the result to zero, and solve for \( \gamma \), we obtain the following equation:

\[ \hat{\gamma} = \left( Y' Y \right)^{-1} Y' X, \]  

where 

\[ E(\hat{\gamma}) = \gamma, \text{ var}(\hat{\gamma}) = \sigma^2 \left( Y' Y \right)^{-1}, \text{ and } \text{se}(\hat{\gamma}) = \sqrt{\frac{\sigma^2}{n} \left( Y' Y \right)^{-1}}. \]

The measure of goodness-of-fit, the coefficient of determination, is given by the following equation:

\[ R^2 = \frac{(\hat{\theta} - \bar{X})' (\hat{\theta} - \bar{X})}{(X - \bar{X})' (X - \bar{X})}. \]

All statistical analyses in support of this study were generated in R (version 4.1.3).

3. Results and Discussion

The histogram of the transformed dependent variable is shown in Figure 1. The distribution curve of the dependent variable can be seen to be roughly bell-shaped which further affirms the normal distribution conceived in Table 1.

The near linearity of the points also further demonstrates the fact that our data is normally distributed. We concluded our normality test by conducting the Kolmogorov–Smirnov test by [46] in which they encouraged and recommended the need for all suspected malaria cases to be tested and tracked, treating the actual conditions with quality medicines to promote positive and healthy outcomes particularly among children under 5.

The correlation values show that suspected cases, tested cases, and rainfall have positive relationships with the number of confirmed malaria cases in children under five years. However, the temperature is inversely associated with the confirmed malaria cases in children under five years. This result support the call by WHO [38] in 2012 for all suspected malaria cases to be tested, treated, and tracked to ensure malaria infections in endemic regions are minimized or eradicated. Also, findings in previous studies such as [47] observed that the enhanced testing of suspected malaria infections in health facilities helps ensure timely treatment of malaria, prevents wrong treatments as well as avoiding delays in treating the actual conditions with quality medicines to promote positive and healthy outcomes particularly among children under 5.

The correlation plots also show significant high positive correlation between suspected cases and tested cases which indicate the presence of colinearity between two independent variables if both are considered in the model and could lead to redundancy of one of them.

Table 4 presents the output of the multiple linear regression model for confirmed case of malaria in children under five years with tested cases, temperature, relative humidity, and rainfall. With a significance level of 0.05, the constant term in the model is significant and its \( p \) value is less than 0.05, that is, when the natural logarithm of the number of tested malaria cases, temperature, relative humidity, and rainfall are kept constant, the natural logarithm of the number of confirmed cases will increase by 4.314 (95% CI: 0.023, 8.605). This translates into, approximately, an increase of 75 cases of confirmed malaria in children below five years when all other variables remain constant.

The number of cases tested, average monthly temperature, and average monthly rainfall were all significant in predicting the number of confirmed cases of malaria in children below five years. However, the average monthly relative humidity is insignificant to the number of confirmed malaria cases among children under five years. A unit increase in the natural logarithm of the number of tested cases increases the natural logarithm of the number of confirmed cases by 0.627 (95% CI: 0.389, 0.864) of (0.389, 0.864), translating into approximately 2 units increase in the number of confirmed cases of malaria in children younger than five years for approximate every 3 units in the number of tested malaria cases. Study results support earlier findings in [48] in which they encouraged and recommended the need for all suspected malaria cases to be tested and

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Confirmed malaria cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>4</td>
</tr>
<tr>
<td>Maximum</td>
<td>7.9</td>
</tr>
<tr>
<td>Mean</td>
<td>6</td>
</tr>
<tr>
<td>Median</td>
<td>6</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>0.9</td>
</tr>
<tr>
<td>Kurtosis</td>
<td>3</td>
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<tr>
<td>Skewness</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 1: Descriptive statistics for confirmed malaria cases.
confirmed before treatment with antimalaria medications. Again, the testing of suspected malaria cases in children under 5 helps in minimizing the misdiagnosis of diseases and further helps to identify other fatal nonmalaria conditions early to prevent complications [49].

A unit increase in the natural logarithm of the average temperature reduces the natural logarithm of confirmed cases of malaria by 1.696 (95% CI: −2.846, −0.546) translating into a 1 unit decrease in the number of confirmed malaria cases for 3 units increase in temperature. Similarly, a unit increase in the natural logarithm of the average rainfall, the natural logarithm of the number of confirmed cases of malaria increases by 0.136 (95% CI: 0.050, 0.222). The variance inflation factors (VIFs) for each of the predictors are around 1 and shows no problem with multicollinearity among predictors, which signify an adequately fitted model to the malaria incidence data in children under 5 years.

The incidence of malaria among children under five years remains a serious health threat to their survival [1]. In this study, the number of confirmed cases of malaria among children below five years is significantly associated with the number of tested cases, average monthly temperature, and average monthly rainfall in the Bono region of Ghana. The correlation and multiple regression analyses results show that the number of confirmed cases of malaria in children below five years increases with an increase in the number of tested cases and average monthly rainfall amounts. The positive correlation between rainfall and the number of confirmed malaria cases in children is similar to the findings of Oheneba-Dornyo et al. [50] in malaria prevalence in which the Ghanaian population is positively associated with rainfall. However, high amount of rainfall is destructive to breeding sites of mosquitoes which may lead to reduced mosquito populations and subsequent reduction in malaria infections. This is in agreement with the fact that rainfall contributes to the malaria spread dynamics by presenting many suitable sites for mosquito breeding. However, an increase in mean monthly temperature in the study settings results in a reduction of malaria cases in children under five. This observation is contradictory to findings of other studies where there exists positive correlation between temperature levels and malaria incidence. For instance, in [25], high mean temperature leads to a rise in malaria infections in Cameroun which is relatively cold compared to the generally warm temperature in the study setting in Ghana. Furthermore, Mafwele and Lee [51] also observed significant impact of temperature on malaria infection dynamics mostly in African countries.

Findings of the present study further highlight the important role of climatic factors such as rainfall and temperature in the spread of malaria especially as key drivers of climate change [51]. Also, Mohammadkhani [52] observed that rainfall and temperature have important impact on mosquito life and hence, contribute to the transmission of malaria.

### Table 2: Summary statistics for covariates.

<table>
<thead>
<tr>
<th></th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Standard deviation</th>
<th>First quartile</th>
<th>Median</th>
<th>Third quartile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suspected cases</td>
<td>4.9</td>
<td>8</td>
<td>7.2</td>
<td>0.7</td>
<td>7</td>
<td>7.4</td>
<td>7.6</td>
</tr>
<tr>
<td>Tested cases</td>
<td>4.5</td>
<td>7.9</td>
<td>7.1</td>
<td>0.6</td>
<td>6.9</td>
<td>7.3</td>
<td>7.5</td>
</tr>
<tr>
<td>Temperature</td>
<td>2.1</td>
<td>3.3</td>
<td>3.1</td>
<td>0.1</td>
<td>3</td>
<td>3.1</td>
<td>3.2</td>
</tr>
<tr>
<td>Relative humidity</td>
<td>3.7</td>
<td>4.8</td>
<td>4.3</td>
<td>0.2</td>
<td>3.1</td>
<td>3.2</td>
<td>3.3</td>
</tr>
<tr>
<td>Rainfall</td>
<td>0</td>
<td>5.3</td>
<td>4.1</td>
<td>1.3</td>
<td>4</td>
<td>4.5</td>
<td>4.7</td>
</tr>
</tbody>
</table>

### Table 3: Kolmogorov–Smirnov test of normality for confirmed malaria cases.

<table>
<thead>
<tr>
<th></th>
<th>Statistic</th>
<th>DF</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Confirmed case</td>
<td>0.103</td>
<td>131</td>
<td>0.06</td>
</tr>
</tbody>
</table>

### Figure 1: Histogram and normal Q-Q plot of the confirmed malaria cases in children under five years.

### Figure 2: Correlation analysis plots.
malaria across populations. Moreover, human-related activities have significantly altered climatic conditions, which have also affected the malaria spread dynamics in sub-Saharan Africa, especially due its high exposure to climatic change and the associated disease burden [25, 51].

Table 5 shows the summary of the multiple linear regression model. The $p$ value of less than 0.001 implies that the number of tested malaria cases, average temperature, and average rainfall are significant in predicting the number of confirmed malaria cases in children under five years. The adjusted R-square value of 0.398 implies that approximately 40% of the variations in the number of confirmed cases of malaria in children aged less than five years are influenced by the number of tested malaria cases, average temperature, and average rainfall.

4. Conclusion

This current study presents more insights and updates on malaria infection dynamics among children under 5 years who are at a higher risk. The study showed that the number of confirmed malaria cases in children under five years increases with increase in rainfall and the number of tested cases reduces with increase in temperature. The study findings further support and encourage the continuous implementation of the test before treatment initiative in health facilities. To reduce the incidence of malaria particularly in children under 5 years, the government and its stakeholders should encourage parents to sleep with their children under INTs, distil stagnant waters during raining seasons, spray bushes with anti-mosquito insecticides, and destroy all breeding grounds of mosquitoes at all times. We proposed that all malaria cases should be laboratory tested and properly confirmed.

Data Availability

The data used in the study are available upon request from the corresponding author. Data on monthly number of laboratory-confirmed malaria cases, number of suspected malaria cases, and number of tested malaria cases in children under five years were obtained from the Departments of Health Information of the Bono Regional Hospital, Sunyani Municipal Hospital, and the Seventh Day Adventist Hospital all located in the Sunyani Municipal Assembly. The monthly average rainfall, humidity, and temperature data from 2010 to 2021 were obtained from the Earth Observation Research and Innovation Centre (EORIC) at the University of Energy and Natural Resources, Sunyani, Bono Region, Ghana.

Disclosure

The study was performed as a part of our employment as staff and students of the University of Energy and Natural Resources.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors’ Contributions

Kassim Tawiah, Killian Asampana Asosega, Richard Kwame Ansah, Sampson Takyi Appiah, Dominic Otoo, Isaac Aganeba Aponye, Thomas Tinbil, and Isaac Mensah Addai conceptualized and visualized the study and validated the data. Kassim Tawiah, Killian Asampana Asosega, Richard Kwame Ansah, Isaac Aganeba Aponye, Thomas Tinbil, and Isaac Mensah Addai performed data curation. Kassim Tawiah, Killian Asampana Asosega, and Richard Kwame Ansah wrote the original draft. Kassim Tawiah, Killian Asampana Asosega, Richard Kwame Ansah, Sampson Takyi Appiah, and Dominic Otoo reviewed and edited the article.

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