Modelling of Malaria Risk Areas in Ghana by using Environmental and Anthropogenic Variables – A Spatial Multi-Criteria Approach*

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Abstract

Malaria is the leading cause of morbidity and mortality in Ghana, accounting for over three million cases and thousands of deaths annually. The risks of morbidity and mortality associated with malaria are characterized by spatial and temporal variation across the country. This research sought to use GIS and multi-criteria decision analysis to produce a predictive model of malaria using eight risk factors ranging from environmental to anthropogenic. Each of the risk factors was classified into three classes of malaria risk according to how it impacts malaria prevalence. The classified risk factors were finally overlaid through the use of weighted overlay after weights were determined from them using the Analytical Hierarchy Process (AHP). Results indicate that high risk areas are concentrated at the central as well as the west-southern parts of the country consisting mainly of the Ashanti, Brong Ahafo, Eastern, Central and the Western Regions. No area was classified as low risk while 53.51% and 46.49% were classified as medium and high risk respectively. The risk map created can serve not only as a predictive tool, but can be used to obtain a comprehensive understanding of the dynamics of malaria transmission.

Keywords: Malaria, GIS, Analytical Hierarchy Process, Weighted Overlay

1 Introduction

Malaria, a major public health issue in several developing countries, is a major cause of morbidity and mortality in Africa and a leading cause of death most particularly among children in several African countries (Binka, 1997; Kleinschmidt *et al.*, 2000). The risk of morbidity and mortality associated with malaria however vary both spatially and temporally, particularly in semi-arid and highland areas (Snow *et al.*, 2002; Anon., 2003a; Kiszewski *et al.*, 2004b). Malaria is quite unstable and epidemic malaria is a common public health challenge causing an estimated 12.74 million clinical episodes and 155 000–330 000 deaths annually (Worrall *et al.*, 2004; Yeshiwondim *et al.*, 2009). Malaria therefore presents a huge socio-economic problem to Africa, which is the most affected continent. There is therefore an urgent need to address this problem since good health is not only a basic human need, but also a fundamental human right and a necessity for socio-economic growth (Anon., 2003b; Basommi, 2011).

The malaria situation in Ghana continues to be a major public health problem with a current fatality rate of 1.7% (Anon., 2010) and it is similar to that of most Sub-Saharan African countries; the transmission is all year round in the southern part, while in the northern part it is seasonal (Afari *et al.*, 1995). Malaria is the leading cause of outpatient morbidity with a total recorded case of 5 041 025 in 2008 representing 47.4% of the total outpatient morbidity cases recorded in that same year (Anon., 2010). A Ministry of Health report indicates that between 3 million and 3.5 million cases of malaria are recorded annually with about 900 000 of those cases being children under five (Anon., 2010). It is the leading cause of hospital admission across all ages with a proportional morbidity rate of 32.9% as well as the leading cause of death with a proportional mortality rate of 13.4% (Anon., 2010). Apart from the human suffering caused in terms of morbidity and mortality, malaria causes huge economic losses through lost production, and through curative and preventative measures in a country that can ill afford such problems (Chikodzi, 2013).

This therefore makes the controlling of malaria a major priority in Ghana and has been recognised by Ghana Health Service (GHS) as very critical in achieving the Millennium Development Goals (Anon., 2010). The outbreak of malaria in Ghana just like other Sub-Sahara African countries is unstable and fluctuates in intensity both temporally and spatially (Kiszewski *et al.*, 2004b; Snow *et al.*, 2005), thus there is the need to spread resources for control in time and space to be prepared for outbreaks, which have occurred in the past despite aggressive and effective malaria control operations (Mabaso *et al.*, 2005; Chikodzi, 2013). Additionally, the levels of malaria risk and transmission intensity exhibit significant spatial and temporal variability related to variations in

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climate, altitude, topography and human settlement pattern (Gebremariam, 1988; Tulu, 1993; Abeku *et al.*, 2004; Yeshiwondim *et al.*, 2009).

The spatial and temporal pattern of malaria transmission at both national and local level in Ghana have not been well studied and accurately defined. Such research is therefore necessary in developing dynamic and area-specific risk maps to identify locations and populations at highest risk for appropriate planning and implementation of targeted and epidemiologically sound preventive and control measures against the disease (Yeshiwondim *et al.*, 2009). In recent times, there is a growing emphasis on the need to obtain malaria risk maps for Africa (Snow *et al.*, 1996; Anon., 2008), since such maps can assist in identifying appropriate strategies of response to disease outbreaks including vaccination (Haydon *et al.*, 2006; Chikodzi, 2013) and vector, reservoir or agent control (Caldas de Castro *et al.*, 2004). In the past, malaria risk maps have been produced by adopting several methods such as the use of reports of disease case and distribution of disease agents, reservoir or vectors and based on surveys and expert opinion (Kiszewski *et al.*, 2004a; Gemperli *et al.*, 2006; Chikodzi, 2013).

Research has indicated that the timing and intensity of malaria incidence is influenced by the annual changes in climatic conditions which subsequently affect the effectiveness of interventions (Chikodzi, 2013). Due to this, several researchers have investigated the production of climate-based malaria early warning systems (models) which have the ability to predict seasonal to inter-annual variations with a lead time that allows health authorities to respond in a timely manner with preventive measures (Caldas de Castro *et al.*, 2004; Haydon *et al.*, 2006; Chikodzi, 2013). Such models analyse malaria data against certain environmental determining factors such as altitude, vegetation, climate and land cover. A relation is established between the malaria prevalence and these environmental factors; this relation is then used to predict the level of prevalence for an entire country or region (Chikodzi, 2013).

Geographic Information System (GIS), satellite remote sensing, geospatial techniques and spatial statistics have provided new methodologies and solutions to analyse the epidemiological and ecological context of malaria and other infectious diseases (Getis *et al.*, 1992; Boulos, 2004; Yeshiwondim *et al.*, 2009). For instance, Chikozi (2013) used certain environmental and anthropogenic variables coupled with GIS techniques to model malaria risk zones in the Masvingo Province of Zimbabwe. Yeshiwondim *et al.* (2009) also carried out a spatial analysis of malaria incidence at the village level in areas with unstable transmission in Ethiopia using several spatial statistic techniques. Despite much research in identifying areas at risk to malaria, it is urgent to investigate mapping techniques in Ghana to produce malaria risk map. The present study therefore aims to model malaria risk regions in Ghana using several environmental and anthropogenic factors in a GIS environment and spatial multi-criteria approach.

2 Materials and Methods Used

2.1 Study Area

The entire country of Ghana was selected as the study area for this research. Ghana is a developing country located in Sub-Sahara Africa. The country lies in the centre of the West African coast and shares borders with three French-speaking countries of Burkina Faso to the north, Togo to the East and Côte d'Ivoire to the west. To the south lies the Gulf of Guinea and the Atlantic Ocean.

Ghana, whose size is almost that of Great Britain, has a total land area of 238 699 km^2. Its southernmost coast at Cape Three Point is 4˚30'N. From this location, the country extends inland for about 670 km to 11˚N. The widest distance measures about 560 km and lies between longitudes 3˚15'W and 1˚12'E. The Greenwich Meridian, which passes through London, also traverses the eastern part of Ghana at the industrial enclave of Tema. Fig. 1 is a map showing the study area.

Ghana has a tropical climate, warm and comparatively dry along the southeast coast, hot and humid in the southwest, and hot and dry in the north. Its terrain is mostly low plains with a plateau in the south-central area. Its highest point is Mount Afadjato, which rises to 880 meters. Lake Volta, its largest lake, is the world's largest artificial lake. Ghana has 10 regions: the Northern, Upper West, Upper East, Volta, Ashanti, Western, Eastern, Central, Brong-Ahafo and Greater Accra as shown in Fig. 1.

2.2 Materials

Several datasets, both vector and raster, covering the whole country were utilised for this research. These datasets were obtained from diverse sources based on availability (see Table 1).

Fig. 1 Map of Ghana

2.3 Methods

In this research, a spatial Multi-Criteria Decision Analysis (MCDA) incorporated into GIS was the method adopted. GIS-MCDA has the capability of transforming and combining geographic entity (criteria map) and value judgement (decision-makers' preference) to obtain relevant information for decision making (Boroushaki *et al.*, 2010). The main rationale behind integrating GIS and MCDA is that these two distinct tools of research can complement each other. While GIS is commonly recognised as a powerful and integrated tool with unique capabilities for storing, manipulating, analysing, and visualising spatial data for decision making, MCDA provides a rich collection of procedures and algorithms for structuring decision problems, designing, evaluating, and prioritising alternative decisions (Malczewski, 1999; Boroushaki *et al.*, 2010). The adopted method was implemented through three main stages viz. determination and standardisation of malaria risk factors (criteria), determination and assignment of weight (degree of influence) to risk factors and finally combination of weighted risk factors to determine the risk zones. These stages are fully outlined in the following sections.

2.3.1 Determination and Standardisation of Malaria Risk Factors

The selection of malaria risk factors is very essential since the reliability of the risk map would be dependent of them. As outlined in the introduction, there exists a relation between malaria prevalence and certain environmental factors. It was therefore these environmental factors that were determined and used as the malaria risk factors. After a thorough review of published work, the risk factors were determined and selected.

It has been shown that low temperatures have a limiting effect on the spread of malaria (Chikodzi, 2013). Usually, at temperatures below 18˚C, transmission of malaria is highly unlikely to occur due to the fact that the few adult mosquitoes, about 0.28%, survive the 58 days required for *sporogony* at that temperature and mosquito abundance is limited by long larval duration (Chikodzi, 2013). Temperatures between 22°C and 32°C are the best to complete *sporogony* in less than three weeks and mosquito survival is sufficiently high (15%) for the transmission cycle to be completed. Temperatures higher than 32°C have been reported to cause high vector population turnover, but also cause high mortality. Thermal death for mosquitoes occurs around 41-42°C (Jepson *et al.*, 1947; Ngxongo, 1994; Chikodzi, 2013).

Several researches have proven the relation between Potential Evapo-Transpiration (PET) and malaria exposure risk (Kazembe *et al.*, 2006; Xiao-Nong *et al.*, 2012). PET influences the vapour level in the atmosphere as well as the water temperature and humidity which advertently impact sporogony and larval growth in mosquitoes.

The President Malaria Initiative (2009) divided Ghana into three main malaria epidemiologic zones namely, the northern savannah; the tropical rainforest; and the coastal savannah and mangrove swamps, these division being influenced by the rainfall pattern of the country (Anon., 2009). Additionally, data from the GHS indicate high annual malaria incidence coincides with the rainy season where rainfall is high, while low incidence coincides with warm a atmospheric condition which is usually experienced in the dry season. The land cover of an area is also a key contributor to the occurrence of malaria and therefore significant risk factor to malaria transmission. The *gonotrophic* cycle of the female Anopheles gambiae is observed to be shortened by 2.6 days (52%) and 2.9 days (21%) during the dry and rainy seasons respectively in treeless areas as compared to forested areas (Bayoh *et al.*, 2003; Minakawa *et al.*, 2004; Kebede *et al.*, 2005). This is as a result of the warmer noon temperatures experienced at open treeless areas as compared to forested area (Chikodzi, 2013).

There exists a proven inverse relation between altitude and mosquito abundance (Hartman *et al.*, 2002; Ebi *et al.*, 2005; Ermert *et al.*, 2013). The ecology of malaria transmission through temperature is defined by altitude. At certain elevations, it is rare for malaria transmission to occur because of the extreme temperature that prevents the mosquito and parasite life cycle (Chikodzi, 2013). Research has shown that, for small areas, large scale differences in malaria risk is defined by the topography since climate variables change very little over the limited range of elevation (Crees *et al.*, 1983; Chikodzi, 2013). The spread of malaria could also be influenced by the slope of an area coupled with the amount of rainfall it receives. Flat areas are highly prone to accumulation of rain water and therefore increase the risk of malaria (Crees *et al.*, 1983; Chikodzi, 2013).

The occurrence and distribution of malaria to a large extent can be affected by the distribution of water bodies such as rivers and streams. Water bodies would serve as breeding grounds for the larvae of mosquitoes; this therefore makes the identification of water bodies a direct determinant for malaria risk zones (Crees *et al.*, 1983; Chikodzi, 2013). A straight line distance (Euclidean distance) was used to determine the distance from a fixed point to all other points on water bodies and road. Road was selected as a risk factor since the euclidean distance of a place from roads determines its accessibility as well as the effectiveness of intervention measures against malaria (Chikodzi, 2013). These risk factors were therefore selected, classified and standardised into three levels of risk namely, low, moderate and high risk. The classification and standardisation of the risk factors is shown in Table 2.

2.3.2 Determination and Assignment of Weight

Since each risk factor has a certain degree of influence on the determination of the risk zone, there was the need to determine the weight of each of the malaria risk factors chosen. This was relevant because all of the risk factors were not of the same significance. In this research weights were determined using the Analytical Hierarchical Process (AHP). AHP being a multi-criteria decision method adopts hierarchical structure to represent a problem and makes judgement based on expert opinion to derive priority scale (Saaty, 2001).

In this research, AHP was implemented through three main stages: first of all, pairwise comparison matrix was formulated for all the risk factors; secondly, relative importance of each of the malaria risk factors was established and finally, consistency in the pairing process was checked. Saaty's pairwise comparison table (shown in Table 3) was used in the weighting process of the pairwise matrix in the first step. Decision makers and experts were consulted to help fill the comparison matrix, after which the level of consistency was checked using a measure of consistency as shown in Equation 1 (Saaty, 2001). The weights were subsequently derived by normalising the eigenvector of the square reciprocal matrix of pairwise comparison between risk factors.

$$CR = \frac{\lambda \max - n}{n - 1} \qquad (1)$$

where CR is the consistency ratio, n is the dimension of the matrix (which is 8 by 8 in this case) and λmax is the maximum eigenvalue of the comparison matrix. CR is a measure that provides a departure from consistency, and Saaty (1980) suggests that for a CR greater than 0.1, the matrix should be re-evaluated. Adopting the procedure described by Malczewski (1999), the weight of each of the eight malaria risk factors were determined as depicted in Table 4. Following the calculation of weight, CR was estimated and found to be 5.70% which is less than 10% as proposed by Saaty (1990) and therefore found to be accepted. Therefore, there was no need to re-evaluate the matrix.

Table 1 Datasets Used for the Research

No.	Datasets	Source
1	Rainfall	Ghana Meteorological Agency
2	Temperature	Ghana Meteorological Agency
3	Potential Evapotranspiration	Ghana Meteorological Agency
4	Highway (Roads)	Ghana Highway Authority
5	Water Bodies (Rivers and Streams)	Africa Data Sampler
6	Land Cover	Forestry Commission of Ghana
7	Digital Elevation Model	United State Geological Survey

Table 2 Malaria Risk Factors Used for the Research

Risk Factor	Low Risk	Medium Risk	High Risk
Temperature	< 22˚C	22˚C - 32˚C	>32˚C
Rainfall	< 850 mm	850 mm - 1200 mm	> 1200 mm
Potential Evapotranspiration	<1400 mm	1400 mm - 1800 mm	> 1800 mm
Altitude	> 600 m	300 m - 600 m	< 300 m
Slope	> 10˚	5˚ - 10˚	< 5˚
Land Cover	Forest	Shrub, Mosaic Vegetation	Agricultural Land, Grassland, Bare Land, Urban Areas, Water Bodies
Distance to Road	< 5 km	6 km - 20 km	> 20 km
Distance from Water Bodies	> 4 km	1.5 km - 4 km	< 1.5 km

Table 3. Relative Importance in Pairwise Comparison

Criteria	Degree of Importance
1	Equally important
2	Equal to moderately important
3	Moderately important
4	Moderately to strongly important
5	Strongly important
6	Strongly to very strongly important
7	Very strongly important
8	Very to extremely strongly important
9	Extremely important

Source (Malczewski, 1999)

Table 4. Weights Determined for the Risk Factors (CR = 0.057)

Malaria Risk Factors	1	2	3	4	5	6	7	8	Weight
1) Rainfall	1	1	1/3	1/7	1	1/3	1/4	1/3	0.23
2) Temperature	1	1	1	1/7	1/2	1/4	1/4	1/3	0.22
3) PET	3	1	1	1/3	1	1/3	1/3	1	0.14
4) Distance to Road	7	7	3	1	3	2	1	4	0.04
5) Distance to Water Bodies	1	2	1	1/3	1	1/2	1/2	1	0.12
6) Land cover	3	4	3	1/2	2	1	1	3	0.06
7) Slope	4	4	3	1	2	1	1	3	0.05
8) Altitude	3	3	1	1/2	1	1/3	1/3	1	0.14

2.3.3 Combination of Risk Factors to Determine Risk Zones

After the determination of the weights, the weighted malaria risk factors were combined to obtain malaria risk zones for the study area. There are several techniques that could be used to combine the risk factors and determine the risk zone (Rafiee *et al.*, 2011). Boolean Intersection (BI), Weighted Linear Combination (WLC) and Ordered Weighting Average (OWA) are the most common procedures. In this research, the WLC method, which is based on a weighted average that can easily be implemented in a raster GIS environment, was applied. By obtaining the summation of the product of the relative importance weight (percentage of influence) of each risk factor with its standard risk score, risk zone was determined using Equation 2:

$$S=\sum W_i S_{ij} \qquad (2)$$

where S is the spatial unit value in output map (Malaria Risk Zone), Wi is the weight of i_{th} factor map (Malaria Risk Factor map) and S_{ij} is the i_{th} spatial class (Malaria Risk Score) of the j_{th} factor map (Malaria Risk Factor Map). Several spatial analyses were carried out on the malaria risk zone map to determine which of the ten regions in the study is most vulnerable to malaria. In order to do these analyses, the high risk zones were extracted from the malaria risk zone map. The area and percentage of high risk zones in each of the regions were then computed and compared with data obtained from the Ghana Ministry of Health.

3 Results and Discussion

3.1 Results

3.1.1 Standardisation of Malaria Risk Factors

Fig. 2 depicts the malaria transmission risk associated with each of the eight malaria risk factors that were considered in this research. The figure reveals that apart from the temperature risk factor, all the risk factors had three levels of risk classification namely low, medium and high risk.

The temperature risk factor had no area classified as medium risk and additionally more than 99% of the study was classified as high risk. This means that the whole country is very susceptible to mosquito breeding with regard to temperature. The area in both kilometre squares and percentages occupied by each of the risk classes were computed for each of the malaria risk factors and shown in Table 5.

It can be observed from the table that all the risk factors, apart from PET, distance from road and distance from water bodies, had more than 50% of the study area classified as high risk.

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3.1.2 Combination of Risk Factors to Determine Risk Zone

Fig. 3 shows the final malaria risk map of the study area after combining all the risk factor by using the weighted overlay function in a GIS environment. It can be observed from the figure that no area was classified as low risk after overlaying all the risk factors. The high risk areas are concentrated at the central as well as the west-southern parts of the country consisting mainly of the Ashanti, Brong Ahafo, Eastern, Central and the Western Regions. The area occupied by each of the malaria risks was computed, as shown in Table 6.

3.2 Discussion

The spatial maps developed for malaria risk zones in Ghana show that the Upper East, Upper West, Northern, Greater Accra, Central and Volta Regions have medium risk of malaria. The Ashanti, Brong Ahafo, Eastern and Western Regions were observed to have high risk. It can be observed that, malaria risk generally increases from north to south with the high risk areas concentrated at the south-western and north-eastern parts of the country. Historical clinical data on incidence of malaria collected by the Ghana Health Services on regional level reveals a similar pattern (Anon., 2010). During the literature review stage of this research, it was clearly observed and stated that climatic factors such as rainfall and temperature do influence the spread of malaria. This research has demonstrated this influence and has shown that there exists a strong relation between rainfall, potential evapotranspiration and temperature, and the spread of malaria. These three malaria risk factors had the highest influence on the final malaria risk. Several studies have also concluded that malaria outbreaks have strong discernible relation with climatic conditions (Mabaso *et al.*, 2005; Chikodzi, 2013).

In this research, a novel model has been produced to consider climatic and environmental factors, anthropogenic (human-induced) variables such as land use/land cover changes and distance to road. These variables were considered due to their impact on the conditions that affect mosquito proliferation. In order to establish the propensity of natural variables to influence the conditions that impact mosquito breeding and their subsequent proliferation, geomorphological data was also incorporated into the model. These considerations make this model unique from other models that consider only environmental and climatic factors.

4 Conclusions

The study has demonstrated the novel integrated use of GIS and multi-criteria decision analysis to model malaria epidemic in Ghana using low to medium resolution data. It is concluded from this study that high malaria risk areas are concentrated at the central as well as the west-southern parts of the country consisting mainly of the Ashanti, Brong Ahafo, Eastern, Central and the Western Regions. No area was classified as low risk while 53.51% and 46.49% were classified as medium and high risk respectively. The risk map created can serve not only as a predictive tool, but can be used to obtain a comprehensive understanding of the dynamics of malaria.There is the need however to test this model during a significant nationwide malaria outbreak and its outputs compared with case studies and field observations.

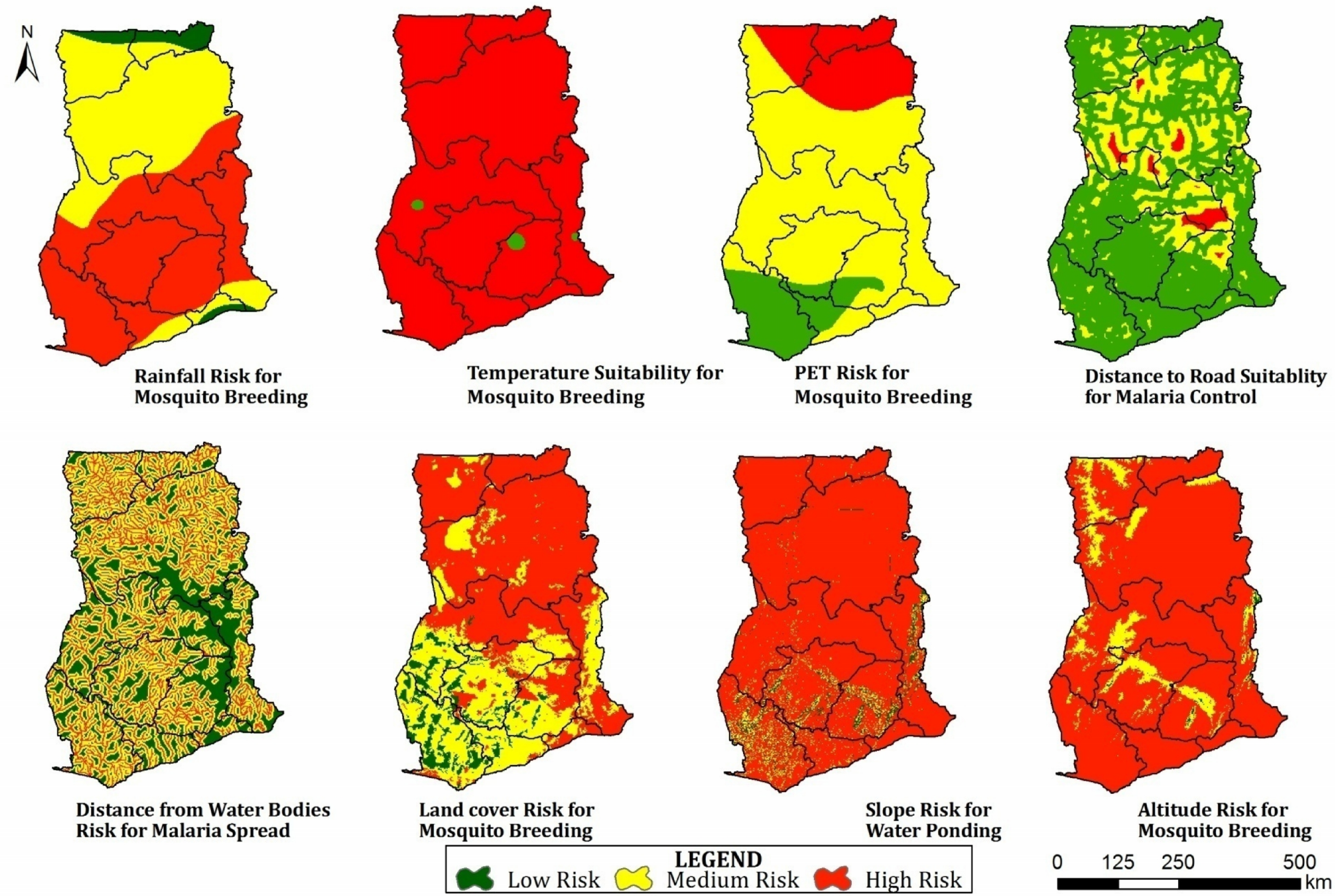

Fig. 2 Malaria Transmission Risk associated with the Malaria Risk Factors

Table 5 Risk Factor Classes with their Areas

Risk Factor	Low Risk		Medium Risk		High Risk	
	km^2	%	km^2	%	km^2	%
Rainfall	9764	4.09	100780	42.21	128228	53.70
Temperature	1668	0.70	0.00	0.00	237104	99.30
PET	32672	13.68	163136	68.32	42964	17.99
Distance to Road	173868	72.82	59076	24.74	5828	2.44
Distance from Water Bodies	65748	27.54	117388	49.16	55636	23.30
Land cover	14824	6.21	83304	34.89	140644	58.90
Altitude	748	0.31	23572	9.87	214452	89.81
Slope	6136	2.57	12112	5.07	220524	92.36

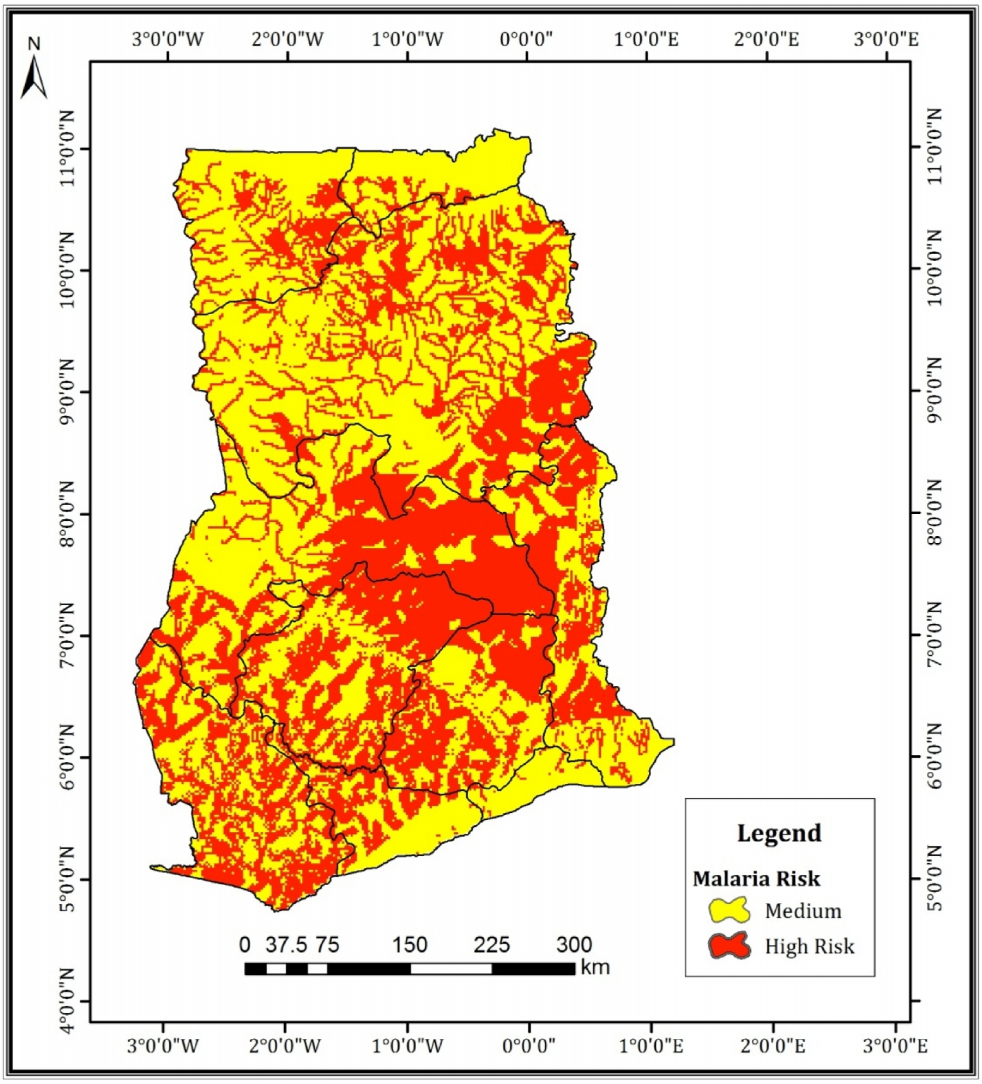

Fig. 3 Malaria Risk Map of Ghana

Table 6 Area Covered by Different Malaria Risk in Ghana

Malaria Risk	Area (km^2)	Area (%)
Low	0.00	0.00
Medium	127757.40	53.51
High	111014.63	46.49

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