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Individual, Household, Community and Country Factors Associated With Malaria in African Children

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Abstract: **Background: Malaria is a global public health problem; around 44% of the world's population lives with the risk of the disease. In 2015, there were 198 million malaria cases in the world. The prevalence of malaria varies in space; not only between countries, but also within highly endemic countries, where it is particularly influenced by socioeconomic or environmental factors.**

Objective: The objective of this study is to obtain a global view of factors influencing malaria infection in children in Africa.

Methods: A multi-level logistic regression model was used, with the national level being the highest. As a complementary tool, a classification tree provided a visual schema of sub-groups with higher malaria risk. Finally, we used geographically weighted regression (GWR) to assess the spatial heterogeneity of the relationship between the significant community factors and malaria prevalence.

Results: Using multilevel regression, we found that certain factors have a significant association with malaria risk in sub-Saharan countries. At individual level: the age of a child, maternal education level, febrile status, anaemic status and the possession of a bed net for sleeping. At household level: economic status, the availability of electricity in the house and place of residence (i.e. urban or rural). At community level: quantity of precipitation, population density and conflict events. Globally, we found a positive relationship between malaria risk and both population density and quantity of precipitation. However, geographically weighted regression showed that in some African areas the association is negative. The association between conflict events and malaria is positive across the 16 sub-Saharan countries studied, with a particularly strong relationship around Mali and Burkina Faso. At country level, the risk of malaria differed significantly between sub-Saharan countries; the highest malaria prevalence was found in Burkina Faso and the lowest in Rwanda.

Conclusion: Through a global vision of sub-Saharan Africa, this study has identified factors, operating at a number of levels, influencing malaria infection in children. The study has also demonstrated spatial heterogeneity in some of these factors and their influence. This indicates that, when implementing health policies for the eradication of malaria within a country, regional characteristics must be taken into account.

Keywords: **Malaria, spatial heterogeneity.**

1. INTRODUCTION

Malaria is a global public health problem, with around 44% of the world's population living with the risk of infection. According to a Roll Back Malaria report, there were 198 million malaria cases in the world in 2015 [1-2].

Given that transmission still occurs in 97 countries, understanding the relationship between malaria and socio-economic or environmental factors may help policy makers, health workers, social workers and other field workers to prevent infection. Despite malaria prevention efforts throughout the world (leading to a 37% reduction of malaria incidence between 2000 and 2015), the disease remains, in 2016, a major cause of morbidity and mortality in many countries. [2-4].

Our study has the potential to contribute to the fight against malaria and support the World Health Organization's goal to reduce the global incidence of the disease by at least 90% between 2015 and 2030, and to prevent re-establishment in all countries. [5]. As demonstrated in a study by RW Snow, it is important to take into account the epidemiology of *P. falciparum* in Africa when devising a strategy for the eradication of malaria [6].

The majority of malaria cases and deaths due to the disease occur in African countries. The number of deaths due to malaria was estimated at 438,000 (range: 236,000–635,000) in 2015, with 91% of these located in sub-Saharan countries. Deaths occurred often among children under five, with malaria killing a child every 60 seconds [2].

According to many studies carried out in African countries, malaria prevalence varies spatially, depending on several factors. Socio-economic or environmental factors can have a strong association with malaria. In DR Congo, researchers have mapped the prevalence of malaria in geographically defined household groups (clusters) and identified the individual and community factors associated with malaria prevalence: age, wealth and gender, proximity to a city, the number of conflict events, average wealth, the use of bed nets and altitude [7]. One study in Angola, Tanzania and Uganda found that children from poor households were at significantly higher risk of malaria infection than those from richer households [8]. A study by Stephan Ehrhardt et al. has demonstrated that there is a significant association between malaria and anaemia in African children [9]. Studies performed in Ethiopia have found that proximity to vector breeding site(s), characteristics of dwellings, age, the climate and altitude all influence the incidence of malaria [10, 11]. In Tanzania and Ivory Coast, studies found that age, gender and the use of a bed net influence the risk of malaria [12, 13]. In Senegal, a study by Karina Laneri et al. indicated the crucial influence of climate on malaria risk in moderate transmission areas [14]. Studies by E Cairns et al. and Adrian M. Tompkins et al. have found that seasonality or climate strongly influence the malaria burden in sub-Saharan countries [15, 16].

In our study, analysis was extended to several countries in order to obtain a global view of what influences malaria infection in African children. Estimates of socioeconomic and environmental determinants of malaria among sub-Saharan children were made based on analysis of 16 African countries. A classification tree was created to provide a visual schema of sub-groups at higher risk of malaria. A multi-level regression model was applied, with the national level being the highest; allowing the socio-economic and environmental context of the country to be taken into account. The advantage of a multilevel study is that it can explain both inter and intragroup variation (when data on individuals in groups are correlated). This method will help us to identify malaria risk factors at each level considered. As demonstrated in a study by Marcel Tanner et al., an integrated and multifactorial analysis is essential in the fight against malaria [17]. Finally, a geographically weighted regression of malaria prevalence was applied to the significant community variables to assess homogeneity or heterogeneity in their relationship with malaria prevalence across sub-Saharan countries.

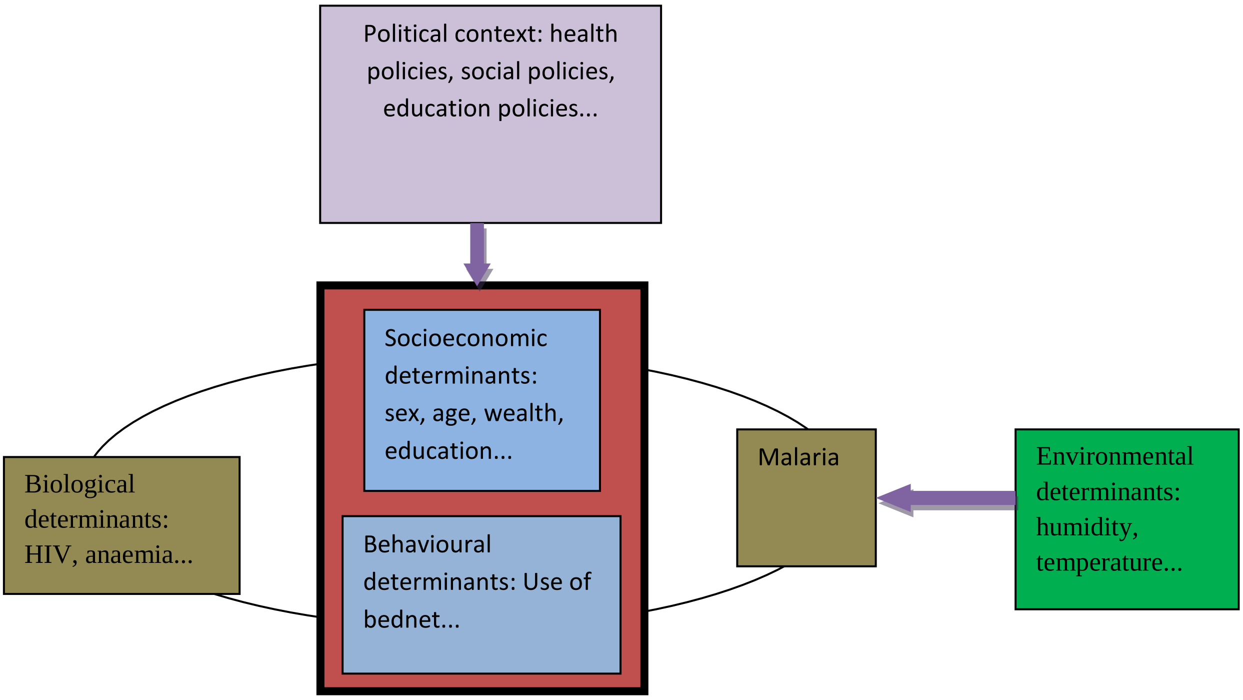

Figure1. Conceptual framework of malaria determinants

Our conceptual framework of malaria determinants was adapted from the model of health determinants published by the WHO and the Canadian Council on Social Determinants of Health [18, 19].

2. MATERIAL AND METHODS

2.1. Population and study area

Children under five in 16 sub-Saharan countries (Angola, Benin, Burkina Faso, Burundi, DR Congo, Ivory Coast, Liberia, Madagascar, Malawi, Mali, Mozambique, Nigeria, Rwanda, Senegal, Tanzania, Uganda) were included in this study. The analysis focuses on African countries in which surveys incorporating malaria tests have recently been conducted. Surveys sourced from the Demographic Health Survey (DHS) website, conducted between 2010 and 2015 which contained results of malaria tests and GPS (Global Positioning System) data, were considered.

2.2. Data

Data used in this study are taken from DHS and Malaria Indicator Surveys (MIS). DHS surveys aim to produce representative results for whole countries, for urban and rural areas, and for each province. Each country was divided into areas of study, for each of which, three strata were created: towns, cities and rural areas. In the second degree, households were selected from the complete list of all city neighbourhoods or cities. Households selected for the survey were grouped into clusters, of which the geographic references (longitude and latitude) were recorded. These geographic references were collected during the survey with a GPS device or from paper maps where GPS data was unavailable. To preserve the confidentiality of the households surveyed, urban clusters were randomly displaced by 0-2 kilometres, and rural clusters by 0-5 kilometres.

Results from rapid diagnostic tests (RDTs) for malaria were used for the multilevel regression. Different types of RDTs were used according to the country surveyed. We did not use results from microscopy for the outcome of our regression because of the many problems with this type of testing in some national African surveys (thick versus thin films, lack of skilled microscopists and quality of slides; poor staining, preparation and storage) [20].

Blood samples from a finger-prick were used to determine if a child was infected or not. Children for whom informed consent was given by their guardians were tested for malaria. The confidentiality of the children included in these surveys was assured. Data on potentially identifiable children were removed and malaria treatment was given to children in the field whose rapid diagnostic test results were positive [21].

Independent variables were separated into four levels. Level 1 consisted of individual factors: age of the child in months, maternal education level, sex of the child, availability of a bed net for sleeping, anaemia status of the child and the presence or absence of fever during the two weeks prior to the survey. Level 2 consisted of household factors: economic status (calculated on the basis of factors such as: possession of a television or bicycle, type of water access, etc.), number of household members, availability of electricity and place of residence (rural or urban). Level 3 consisted of community factors: altitude of cluster, average temperature during the month(s) of the survey, average rainfall during the month(s) of the survey, proximity to a river or other body of water (within 5 km), proximity of dwelling to conflict areas (within 100 km) and population density. Finally, Level 4 comprised the country where the survey was conducted.

Geographically weighted regression (GWR) was applied, in order to verify the direction of the relationship between malaria prevalence and the significant community factors.

The longitude and latitude of each cluster were used to extract data on temperature, precipitation, population density, and the distance of houses from cities where conflicts were taking place (within 100km) and rivers or bodies of water (within 5 km).

Temperature and rainfall data used in our study were extracted from the WorldClim website (a set of free global climate layers) for the recent period (from 2000), with a resolution of 2.5 arc-minutes. The mean temperature and mean precipitation in each country for the month(s) during which the survey was conducted were considered.

Data on population density used in our study come from the Gridded Population of the World version 3, from the Center for International Earth Science Information Network (CIESIN), Columbia University and Centro International de Agricultura Tropical (CIAT), with a resolution of 2.5 arc-minutes, using the unit ‘persons per square kilometre. Water bodies' data come from vector layer (VMAP) of National Imagery and Mapping Agency. We used data from ACLED (the Armed Conflict Location & Event Data Project) to select clusters within 100 km of conflict territories. A comma-separated value (csv) file containing geographical references of conflict locations was used. For the purposes of this study, a conflict event is taken to refer to any type of battle, violence to civilians since the year 2000, or the presence of hostile or threatening forces.

Table 1: Malaria prevalence in children by country surveyed

Countries	Year of survey	Months of surveys	Number of children under five included in our study	RDT used	Prevalence of malaria (%)
Angola	2011	January-June	2900	SD Biolone Malaria AG	12.2
Benin	2011-2012	December-April	3302	Parcheck *Pf*	25.9
Burkina Faso	2010	May-December	5706	Parcheck *Pf*	75.5
Burundi	2012-2013	November-January	2367	SD Bioline Malaria Ag *Pf*/pan	11.7
Ivory Coast	2011-2012	December-May	2766	SD Bioline Malaria Ag *Pf*	44.5
DR Congo	2013-2014	August-February	2805	SD Bioline Malaria Ag Pf	32.1
Liberia	2011	September-December	2350	First Response Malaria Ag HRP2	50.3
Madagascar	2013	April-June	4480	CareStart Malaria HRP2/pLDH (pf/pan) Combo	7.1
Malawi	2014	April-May	1741	SD Bioline Malaria Ag *Pf*	29.2
Mali	2012-2013	October-February	4146	Paracheck *Pf*	43.4
Mozambique	2011	May-December	4341	SD Bioline Malaria Ag *Pf/Pv*	33.9
Nigeria	2010	October-December	5908	Paracheck *Pf*	47.2
Rwanda	2010-2011	September-April	3737	First Response *Pf*	2.2
Senegal	2011-2012	January, March-June, September-December	5319	Paracheck *Pf*	4.2
Tanzania	2011-2012	December-May	6522	SD Bioline Malaria Ag *Pf*/pan	9.5
Uganda	2014-2015	December-February	4172	Paracheck *Pf???*	32.2

2.3 Statistical Analysis

The focus of this study is the *P. falcipiarum* infection risk (odds ratio (OR)) for children under five. Before entering independent variables in multilevel models, absence of collinearity was verified using a covariance matrix. A classification tree was created using IBM SPSS statistics software. Models were used firstly in univariate analysis and secondly in multivariate analysis, which enabled study of the association between socio-economic and environmental determinants and malaria in children in Africa. In order to select the best model, assessment of models was conducted using the AIC criterion (Akaike information criterion) and BIC criterion (Bayesian information criterion). The model with the lowest AIC and lowest BIC was selected.

For mapping malaria prevalence and extracting environmental data, QGIS 2.12.0- Lyon was used, in the EPSG: 4326 (WGS 84) coordinate reference system.

SAGA GIS 2.1.2 (System for Automated Geoscientific Analysis) software was used for performing geographically weighted regression. The inverse distance was used when describing the strength of the relationship between the risk of malaria and the independent variables considered.

3. RESULTS

61,286 children under five with results from RDT tests for malaria were included. In total, 29.1% were infected with *P. falciparum*. 50.4% of these children were male and 24.8% of them lived in urban areas. Maternal illiteracy was present in around half of these cases, and 80.3% had a bed net for sleeping. (Table 1).

Table1. Description of sample (N=61286)

	Frequency (%) Or mean ± DS	[min; max]
Sex of children		
-Male	50.4	
-Female	49.6	
Age of children (in months):		
-1 to 11	12.4	
-12 to 23	23.0	
-24 to 35	22.0	
-36 to 47	21.9	
-48 to 59	20.7	
Residence		
-Urban	24.8	
-Rural	75.2	
Education level of mother:		
-Illiterate	47.1	
-Primary	38.3	
-Secondary and higher	14.7	
Household economic level:		
-Poorest	23.3	
-Poorer	21.1	
-Middle	20.0	
-Richer	19.0	
-Richest	16.7	
Number of household members	7.5±4.6	[2- 52]
Number of children who have a bed net for sleeping	80.3	
Children with fever during two weeks prior to survey	24.8	

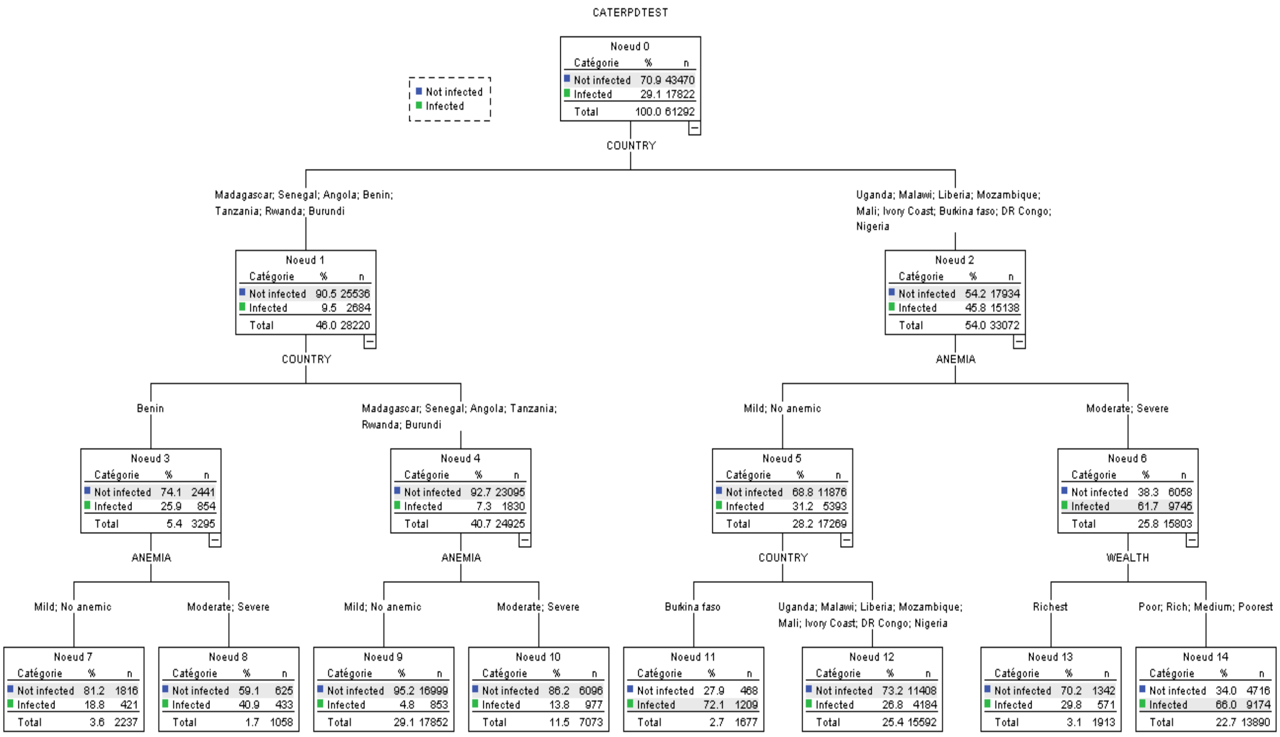

Figure2. Sub-groups with more malaria risk for African children

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The classification tree clearly shows that the country a child lives in, his anaemic status and the economic level of his household are strongly associated with infection with *Plasmodium falciparum*.

A far greater number of children living in Uganda, Liberia, Mozambique, Mali, Ivory Coast, Burkina Faso, DR Congo and Nigeria are infected than in Madagascar, Senegal, Rwanda, Benin, Angola, Burundi and Tanzania (45.8% vs 9.5%).

Anaemia also has a strong association with malaria. Among children who have moderate to severe anaemia and live in countries with a high risk of malaria, 61.7% of children were infected. In this subgroup, 70% of the richest children were not infected; whereas among rich, poor and the poorest children, just 34% are not infected.

3.3 Multilevel analysis

Table2. Characteristics of children and their association with malaria risk in univariate and in multivariate analysis (N= $\sum$ n $_{countries}$)

Characteristics	n Positive (17822 cases)	(%)	Univariate		Multivariate	
Countries			OR	P-Value	OR	P-Value
Angola	355	2.0	Ref	Ref	Ref	Ref
Benin	854	4.8	8.04	<0.001	8.44	<0.001
Burkina Faso	4309	24.2	1569.35	<0.001	-	<0.001
Burundi	248	1.4	0.78	0.25	1.09	0.74
Ivory Coast	1230	6.9	59.73	<0.001	40.80	<0.001
DR Congo	896	5.0	16.77	<0.001	12.37	<0.001
Liberia	1175	6.6	107.21	<0.001	36.35	<0.001
Madagascar	318	1.8	0.22	<0.001	0.14	<0.001
Malawi	1797	10.1	12.15	<0.001	22.97	<0.001
Mali	503	2.8	53.90	<0.001	18.05	<0.001
Mozambique	1496	8.2	20.42	<0.001	23.89	<0.001
Nigeria	2428	13.6	78.03	<0.001	67.30	<0.001
Rwanda	81	0.5	0.01	<0.001	0.03	<0.001
Senegal	221	1.2	0.06	<0.001	0.04	<0.001
Tanzania	607	3.4	0.46	<0.001	0.39	<0.001
Uganda	1331	7.5	16.86	<0.001	18.50	<0.001
Individual factors						
Female gender	8540	49.0	0.92	0.06	1.01	0.08
Child age in months (%)						
<12	1555	8.7	Ref	Ref	Ref	Ref
-12-23	3630	20.4	2.03	<0.001	3.56	<0.001
-24-35	4001	22.4	3.24	<0.001	10.32	<0.001
-36-47	4367	24.5	4.49	<0.001	24.07	<0.001
-48-59	4269	24.0	5.01	<0.001	38.00	<0.001
Education level of mother (%)						
-Illiterate	10976	63.1	Ref	Ref	Ref	Ref
-Primary	4964	28.5	0.13	<0.001	0.20	<0.001
-Secondary	1388	8.0	0.07	<0.001	O.10	<0.001
-Higher	78	0.4	0.02	<0.001	0.05	<0.001
Has bed net for sleeping	13163	73.9	0.45	<0.001	0.69	<0.001
Anaemia:						
-Severely anaemic children	1564	8.9	Ref	Ref	Ref	Ref
-Moderately Anaemic children	9478	53.7	0.10	<0.001	0.08	<0.001
-Mildly anaemic children	3561	20.2	0.01	<0.001	0.01	<0.001
-No anaemia	3045	17.3	0.00	<0.001	0.00	<0.001
Had fever within 2 weeks prior to	11678	67.3	3.90	<0.001	4.29	<0.001

interview						
Household factors						
With electricity	1954	11.3	0.1	<0.001	0.47	<0.001
Household size:						
≤ 5persons	6278	36.0	Ref	Ref	Ref	Ref
6 - 12 persons	9619	55.2	1.43	<0.001	1.18	<0.001
> 12 persons	1531	8.8	0.91	0.40	1.82	<0.001
Economic level						
-Poorest	5161	29.6	Ref	Ref	Ref	Ref
-Poor	4414	25.3	0.80	<0.001	0.90	<0.001
-Medium	3911	22.4	0.63	<0.001	0.56	0.27
-Rich	2772	15.9	0.24	<0.001	0.21	<0.001
-Richest	1170	6.7	0.03	<0.001	0.07	<0.001
Rural residence	14809	85.0	7.2	<0.001	2.41	<0.001
Community factors						
Altitude >300 Km	7737	58.2	0.460	<0.001	0.94	0.53
Average accumulated rainfall during months of survey						
≥50mm	8189	52.6	Ref	Ref	Ref	Ref
51 - 200 mm	5316	34.1	0.28	<0.001	0.59	<0.001
>200mm	2069	13.3	1.80	<0.001	1.35	<0.001
Average air temperature during months of survey						
<15°C	18	0.1	Ref	Ref	Ref	Ref
15-25°C	6517	41.9	18.68	<0.001	4.15	0.03
25 -28.5°C	7984	51.3	160.29	0.09	5.08	0.01
28.5°C-30°C	965	6.2	37.65	<0.001	3.34	0.08
>30°C	84	0.5	2.98	<0.001	3.56	0.32
Cluster house within 100 km of conflict territory	11427	64.1	1.37	<0.001	1.36	<0.001
Cluster house within 5km of river or body of water	2215	12.4	0.51	<0.001	0.91	0.33
Population density (average) :						
<100 Persons/km^2	10818	67.6	Ref	Ref	Ref	Ref
100 -500 Persons/km^2	4176	26.1	0.26	<0.001	0.56	<0.001
>500 Persons/km^2	998	6.2	0.05	<0.001	0.31	<0.001

Individual level: The sex of a child is not a significant factor in the model. A univariate analysis indicates that the risk of malaria for female children is lower (OR=0.92; P-value=0.06) than that for male children; whereas after adjustment, risk is the same for both sexes. However, there are certain sub-Saharan countries (e.g. Ivory Coast), where there is a significant association between sex and the risk of malaria [13].

Significantly the malaria risk for children increases with age. Children aged 48-59 months are at higher risk of malaria (OR=38.0; p-value<0.001) than children under 12 months old.

The education of a child's mother also has a significant association with malaria risk in sub-Saharan children. Children whose mother has any level of education are at lower risk than children whose mothers are illiterate: primary level (OR=0.20; p-value<0.001), secondary level (OR=0.10; p-value<0.001) and higher level of education (OR=0.05; p-value<0.001). A mother with a higher level of education may decrease the risk of malaria for her children due to her awareness of behaviours likely to prevent infection (the use of a bed net or insecticide); or the lower risk could be attributed to the higher wealth status of households which is often associated with a high level of education.

In sub-Saharan children, we found that, generally, children who have a bed net for sleeping have a significantly lower risk of malaria (0.69; p-value<0.001) than children who do not.

The risk of a child being infected with *P. falciparum* increases with the severity of the anaemic status. This could be due to the fact that anaemia is a common consequence of malaria [22, 23], or perhaps because of the low economic level of a child's household.

For febrile status, we found that children who had had fever during the two weeks prior to the survey were at significantly greater risk of malaria (OR=4.29; p-value<0.001) than children who were not febrile. Studies have found that for children in sub-Saharan Africa, malaria is one of the primary causes of fever; mainly in high endemicity areas where children with fever have been observed, more than 50% have been found to be infected with *P.falciparum* [24]. This may be due in part to the fact that the result of a rapid diagnostic test for malaria will be positive several days after parasite clearance [25].

Household level: Children who live in houses supplied with electricity are at lower risk of malaria (OR=0.47; p-value<0.001) than children who live in houses without electricity. This significant association may be due to the low economic status of the household, or because the house is in a newly inhabited or forest area.

For household size, univariate analysis indicates that those living in a household of more than 12 persons have a lower malaria risk (OR=0.91; p-value=0.40) than those in households of 6 - 12 persons (OR=1.43; p-value<0.001). However, multivariate analysis indicates that those living in a household of more than 12 persons have a significantly higher risk (OR=1.82; p-value<0.001) than those in a household of 6 - 12 persons (OR=1.18; p-value<0.001). This could be explained by the contributing factor of wealth status.

Wealth status has a significant relationship with malaria risk. We found that children who live in poor (OR=0.90; p-value<0.001), rich (OR= 0.21; p-value<0.001) or the richest households (OR=0.07; p-value<0.001) are at lower risk than children who live in the poorest households. Medium wealth status is not significant in the model (OR=0.56; p-value=0.27). Wealth status can have a significant impact on malaria risk, due to the quality of the dwelling, or parental behaviours such as the use of insecticide.

For place of residence, we found that children who live in rural areas are at higher risk of malaria than children who live in urban areas in sub-Saharan countries. This could be attributed to higher economic status and levels of education in urban areas.

Community level: In univariate analysis, the altitude of the cluster where children live appears to have a strong association with malaria risk. However, when we consider OR adjusted data, we can see that the altitude does not in fact have a significant influence on the risk of malaria; the risk of malaria may decrease in altitudes of more than 300 km, but the altitude itself is not significant if we take into account other factors such as quality of housing, maternal education level and the place of residence (urban or rural).

We found that quantity of rainfall significantly influences the risk of malaria, with a positive relationship. This means that the greater the quantity of rainfall, the greater the risk of malaria for sub-Saharan children. When the mean of monthly precipitation is between 51mm and 200 mm, the risk is lower (OR=0.59; p-value<0.001) than when the mean of monthly rainfall is more than 200mm (OR=1.35; p-value<0.001).

Peak malaria risk is observed at temperatures between 25°c and 28.5°C (OR=5.08; p-value=0.01); the lowest malaria risk is below the temperature of 15°C.

Living near areas with conflict events (all types of battles, violence to civilians or the presence of hostile or threatening forces) significantly increases the risk of malaria for sub-Saharan children (OR=1.36; p-value<0.001). This is possibly because conflict events in general bring poverty to a population, coupled with the phenomenon of migration within the country or from neighbouring countries.

Children who live in proximity to a river or body of water in sub-Saharan Africa do not have a significantly heightened risk of malaria (OR=0.91; p-value= 0.33).

We have found a significant negative association between population density and the risk of malaria; in areas where population density is low, the risk of malaria is higher than in highly populated areas. In areas with a population density of more than 500 persons/km^2, the malaria risk is lower (OR=0.31; p-value<0.001) than in areas where population density is between 100 and 500 persons/km^2 (OR=0.56; p-value<0.001).

Country level: We can see that Burkina Faso is the country with the highest malaria risk, while Rwanda has the lowest risk of malaria. All sub-Saharan countries included in this study are significant in the model, except Burundi (OR=1.09; p-value=0.74).

4. MAPPING OF MALARIA RISK

We have mapped malaria prevalence in these 16 sub-Saharan countries using community factors that were significant in the model: average monthly rainfall, population density and conflict events within 100 km. Using the inverse distance, the strength of association between malaria risk and these factors decreases when the distance increases in each radius of 500 km.

We can see clearly in figure 3 that some areas with large quantities of precipitation during the months of the survey have a higher risk of malaria. In figure 4, we observe that in the majority of areas where population density is low, there is a high prevalence of malaria. In figure 5, we can see that areas with many conflict events also have high malaria prevalence. As indicated by the multivariate analysis, Burkina Faso is the country with the highest malaria risk among the sub-Saharan countries studied (the whitest points on the map).

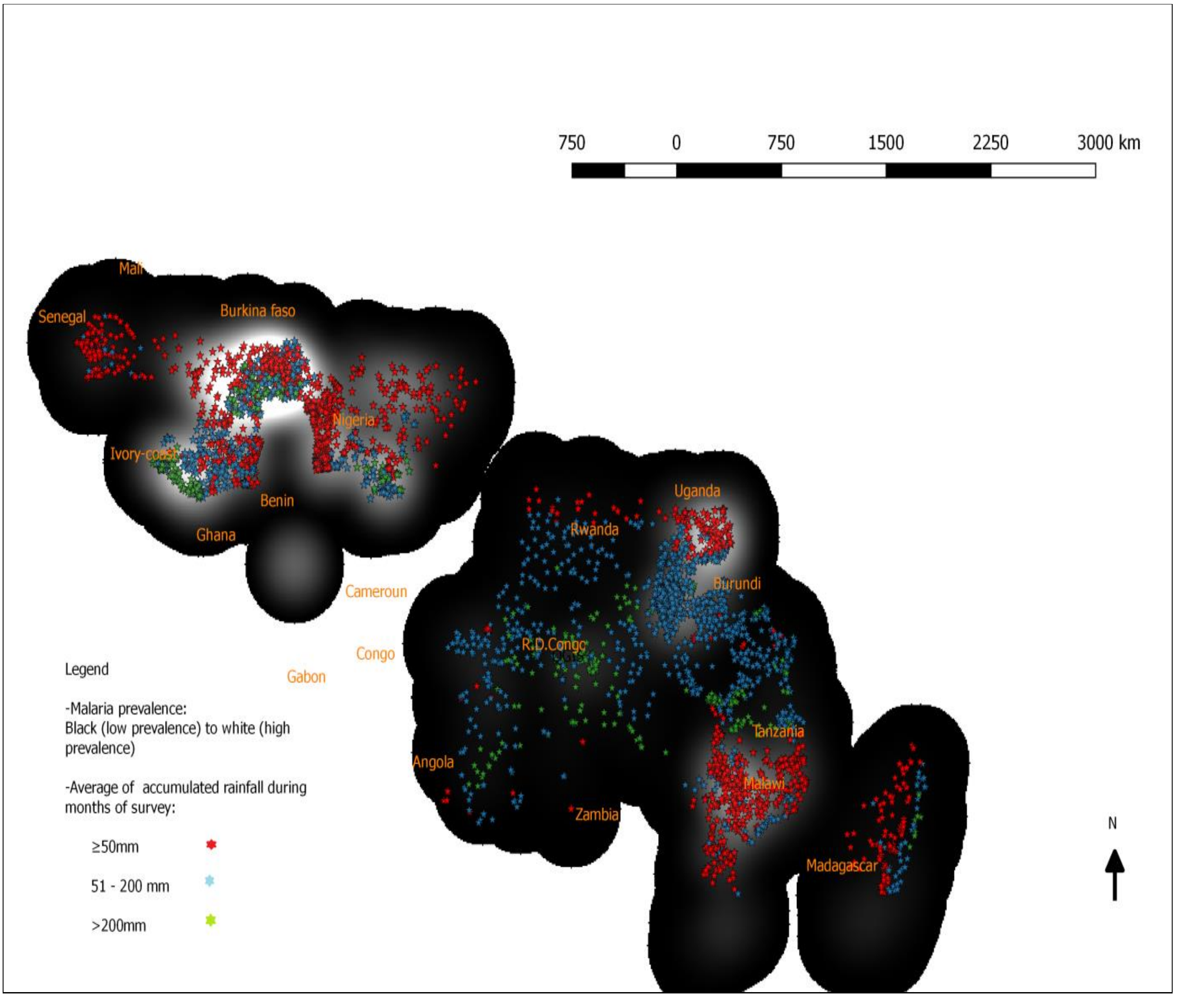

Figure 3. Average precipitation during months of survey and malaria prevalence

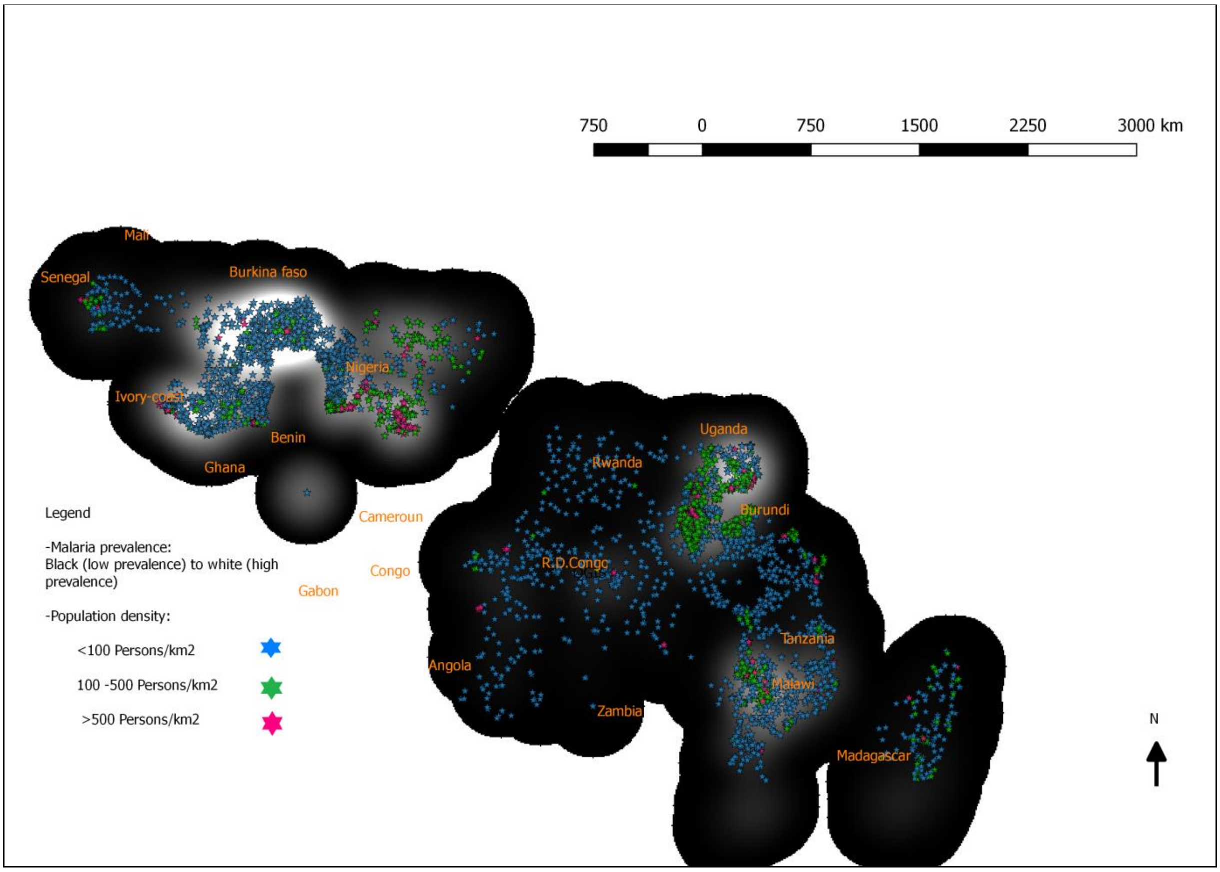

Figure 4. Population density and malaria prevalence

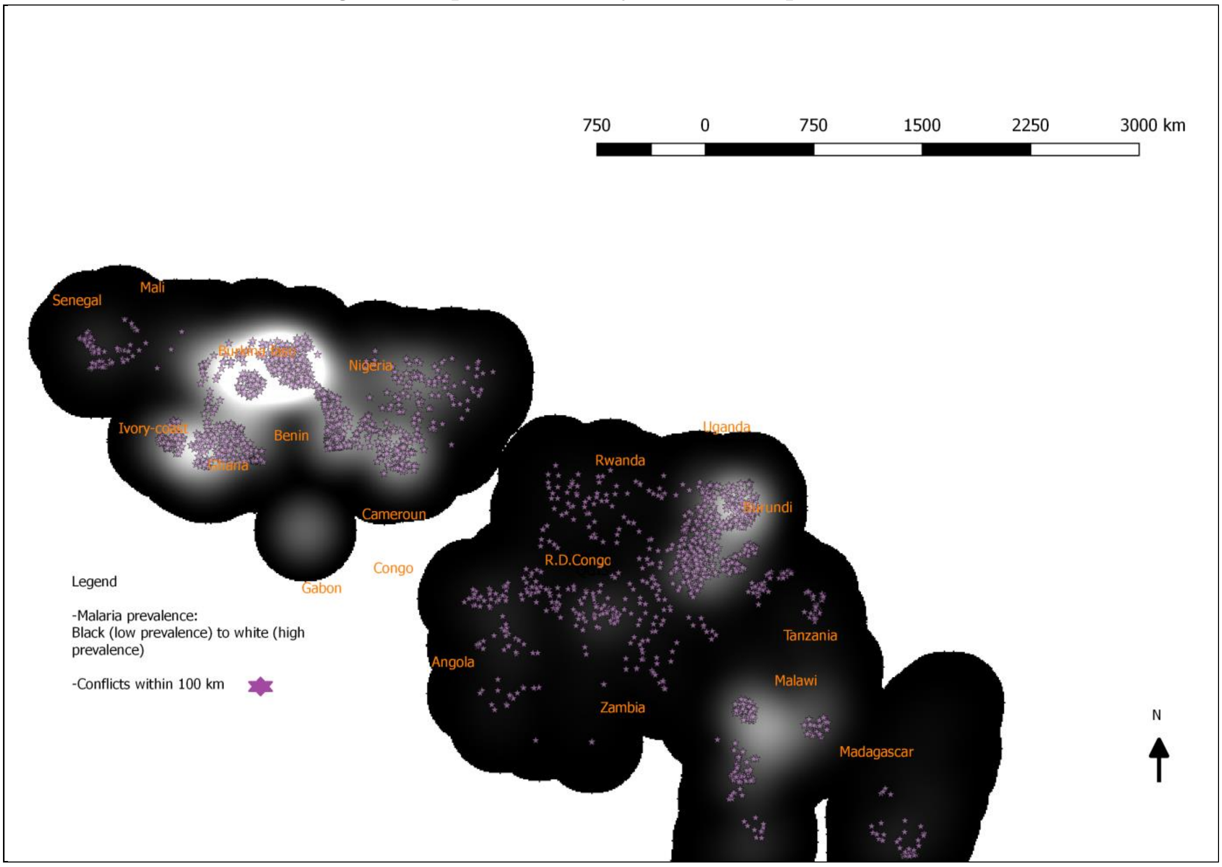

Figure 5. Conflicts within 100 km and malaria prevalence

In order to verify the homogeneity of the relationship between malaria prevalence and quantity of rainfall, population density and conflict events across these sub-Saharan countries, geographically weighted regression was applied to the data.

The results are shown in figures 6, 7 and 8. We can see that the relationship between malaria prevalence and quantity of precipitation is not the same across all countries (blue areas correspond to areas with a negative relationship with malaria). The same is true for the relationship with population density. But the relationship between malaria prevalence and conflict events is positive across all of the 16 sub-Saharan countries studied, with a notably strong association between malaria prevalence and conflict events around Mali and Burkina Faso.

One of the important points in multilevel regression analysis is the choice of the model (table 5) which best represents possible factors that can explain differences in risk in a target population. In our study, we considered the model with low AIC and low BIC to be the best model for understanding the relationship between malaria prevalence and its determinants. We observe that model M15 (Model including Individual factors + HH factors + community factors + country factor) is the most effective for understanding malaria risk in sub-Saharan children. We can also observe that, compared to factors at other levels, community factors contribute strongly to malaria risk in sub-Saharan children.

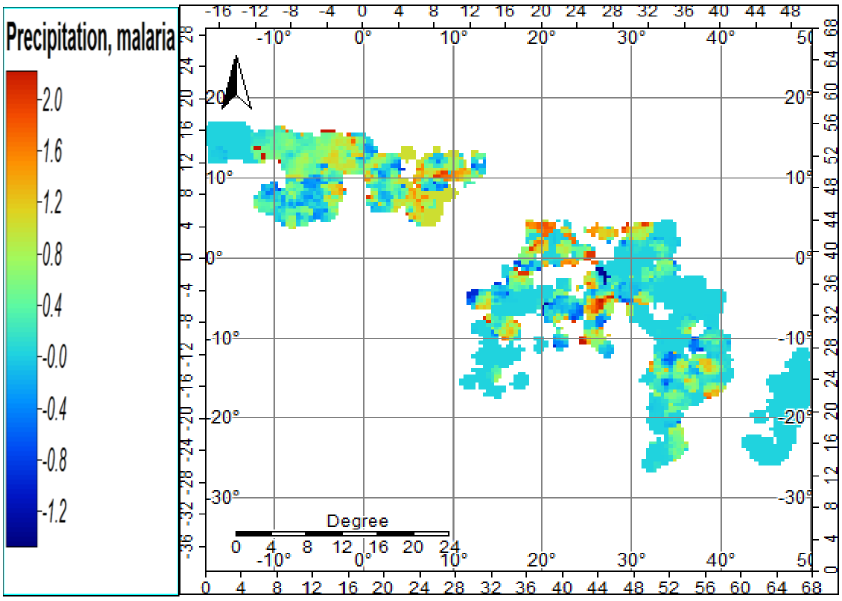

Figure 6. Direction of relationship between malaria prevalence and quantity of monthly mean rainfall over African countries

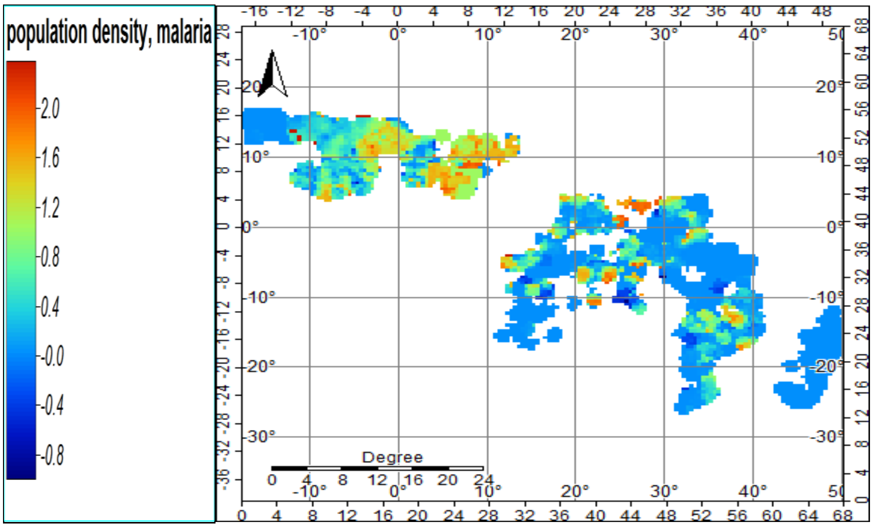

Figure 7. Direction of relationship between malaria prevalence and density of population over African countries

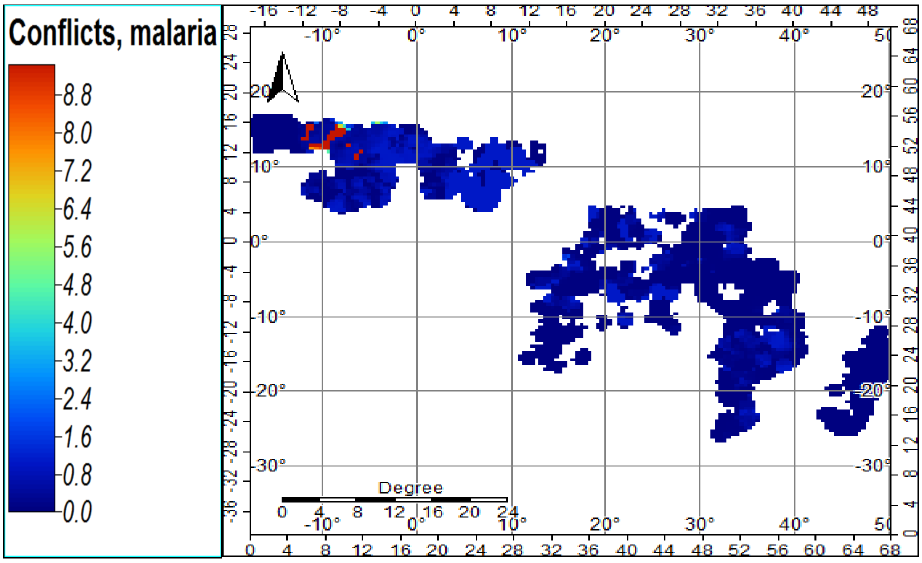

Figure 8. Direction of relationship between malaria prevalence and conflict events within 100 km over African countries

Table 5. Most effective model for an understanding of malaria risk in sub-Saharan countries

Models	AIC	BIC
M0: Empty model	73882.8	73900.9
M1: Model including Individual factors	60772.7	60916.6
M2: Model HH factors	68824.6	68923.6
M3: Model including community factors	46311.9	46424.7
M4: Model including country factor	58901.5	59054.9
M5: Model including Individual factors + household with electricity	59003.7	59156.4
M6: Model including Individual factors + household with electricity + number of household member	58787.5	58967.1
M7: Model including Individual factors + household with electricity+ number of household member+ household economic level	58354.0	58569.5
M8: Model including Individual factors and HH factors	58267.2	58491.7
M9: Model including Individual factors + HH factors + altitude of cluster	45232.7	45434.8
M10: Model including Individual factors + HH factors + altitude of cluster + mean temperature of survey month	38352.7	38585.8
M11: Model including Individual factors + HH factors+ altitude of cluster + mean temperature of survey month + rainfall during month of survey	37409.7	37660.0
M12: Model including Individual factors + HH factors + altitude of cluster + mean temperature of survey month + rainfall during month of survey + location within 100 km from conflicts events	37288.1	37547.1
M13: Model including Individual factors + HH factors + altitude of cluster + mean temperature of survey	37283.3	37550.9

month + rainfall during month of survey + location within 100 km from conflicts events+ location within 5km from river or water body		
M14: Model including Individual factors + HH factors + community factors	37113.9	37398.8
M15: Model including Individual factors + HH factors + community factors + country factor	34418.2	34815.3

5. DISCUSSION

Using a classification tree, we have identified sub-groups with the highest malaria risk in the sub-Saharan countries in our study. The first 3 sub-groups having a strong association with malaria risk are: children who live in Uganda, Liberia, Mozambique, Mali, Ivory Coast, Burkina Faso, DR Congo and Nigeria; children with severe or moderate anaemia; and children in households where the economic status is anything other than the richest.

We performed a multilevel analysis, estimating the risk of malaria for children in sub-Saharan countries using univariate and multivariate analysis. For individual factors we found that the age of a child, maternal education level, febrile status, anaemic status and the possession of a bed net for sleeping all have a significant association with the risk of malaria. At household level, we found that wealth status, the presence or absence of electricity in the house and finally place of residence (urban or rural) were significantly associated with malaria risk. At community level, we observed a significant association between malaria risk and quantity of precipitation, population density and conflict events. GWR enabled us to verify whether there was no change of relationship direction between malaria prevalence and the risk factors considered, throughout the sub-Saharan communities. Globally, using multilevel regression, we have found positive relationships between malaria risk and population density, as well as between malaria risk and quantity of precipitation. However, GWR shows us that there are some African areas with negative associations. For conflict events, there is a positive association across all of these 16 sub-Saharan countries, noting that the relationship between malaria risk and conflict events is very strong around Mali and Burkina Faso. At country level, we have found that the risk of malaria differs significantly between sub-Saharan countries. Burkina Faso is the country with the highest malaria risk and Rwanda has the lowest malaria risk of any country in this study. Our objective was a better understanding of malaria risk; and the model with the lowest values of AIC and BIC and which includes factors at individual level, household level, community level and country level (M15), is the model that best explains the differences in malaria risk among children under five in sub-Saharan countries.

Strength and Weakness

This study of 16 sub-Saharan countries has allowed us to calculate estimates, using multilevel modelling, for malaria risk factors in Africa and to obtain a global view of significant malaria risk factors. This study also has the merit of presenting the spatial relationship between malaria risk and certain community variables, highlighting the particularity of each region in sub-Saharan Africa. It should be noted that, due to concerns about the privacy of children included in the DHS survey, geographic references were displaced by 0-2 kilometres for urban clusters, and by 0-5 kilometres for rural clusters. The results of our study may, therefore, contain some inaccuracy. Because of the limitations of microscopy and the absence of gold standard tests for use during national surveys in some developing countries, results from RDT alone were preferred for our analysis.

6. CONCLUSION

Through a global vision of sub-Saharan Africa, the study identified factors, operating at a number of levels, influencing malaria infection in children. The study also demonstrated spatial heterogeneity in some of these factors and their influence. This indicates that, when implementing health policies aimed at the eradication of malaria within a country, regional characteristics must be taken into account.

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