Bayesian Analysis of the Joint Risk of Malaria and Anemia Among Under-age Ve Children in Nigeria

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Research Article

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Bayesian analysis of the joint risk of malaria and anemia among under-age five children in Nigeria

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Abstract

-Background

A life-threatening malaria parasites are known to have a substantial causative effect with the occurrences of frequent episodes of other diseases causing rapid progression to death. The parasites feed on iron molecules present in the red blood cells, therefore, resulting in low functional hemoglobin concentration causing anemia in children, and preventing rapid recovery. This study quantifies the impact of malaria on under-age five anemic children in Nigeria.

-Method

The joint risk and disease specific risks factors of malaria and anemia were estimated using a generalized linear mixed model in a Bayesian framework and a Besag-York-Mollié spatial prior model to account for spatial heterogeneity. Data were sourced from the Demographic and Health Survey conducted by the National Population Commission.

-Results

Malaria significantly places anemic children at a higher risk, which signifies a significant correlation between these diseases with regards to risk factors such as the place or region of residence, family wealth index, and use of a mosquito-preventive net.

-Conclusion

A high proportion of parents that live in the rural region is non-educated and low-income earners engaging in subsistence farming places children at severe risk of malaria and anemia.

Keywords: Malaria, Anemia, Joint risk, Besag-York-Mollié prior, Spatial model

1 Introduction

Malaria has been known to be the most frequent and severe public health problems contributing to the severity of other diseases such as diarrhea and anemia (White, 2018). It is a life-threatening mosquito-borne disease in humans and animals caused by the plasmodium parasite, spread to humans through infected mosquito bites, usually Anopheles mosquitoes. Falciparum malaria is the most severe type of malaria disease and can possibly lead to death within few days of disease onset. However, anemia in the presence of malaria is a health risk for under-age five children. Anemia was identified as the main cause of morbidity and mortality among under age five children in most developing countries, especially in Africa (Muhammad et al., 2017; Gayawan et al., 2014; U. S. Embassy, 2015). It is believed to be the most common low nutrition illness among preschool children. Anemia in children threatens the quality of life, causing symptoms such as increased heart rate, poor wound and tissue healing, and slow or delayed growth and development (Oladeinde et al., 2012), which eventually lead to a poor cognitive performance of children and possibly death. It is usually a result of low concentration of functional hemoglobin (Hb) level in the body, a condition in which the amount of red blood cells decreases below normal. Iron deficiency is the most common causes of anemia (Gayawan et al., 2014), it occurs when there is insufficient amount of iron in the red blood cells. 70% of iron in the bloodstream is found in the red blood cells, which carry oxygen through the entire body. Malaria parasites attack these red blood cells by feeding on iron in blood cells for development during the liver stage and causes a shortage in Hb concentration level resulting in frequent episodes of anemia (Spottiswoode et al., 2014). Moreover, life-threatening malaria-anemia disease is a severe health problem in developing countries that is further compromised in the presence of infections in the body. Malaria parasites play a major causative role in anemia, especially on children less than 59 months, placed at higher risk due to the amount of iron needed for development (Clark, 2008; Sadrzadeh and Saffari, 2004).

In 2017, an estimate of 219 million cases of malaria occurred worldwide, of which 92% of the case were in African Region. Fifteen countries in sub-Sahara Africa and India carried about 80% of the global malaria burden, and Nigeria accounted for about 25% of malaria cases worldwide (Adigun et al., 2018; WHO, 2018). Reports from World Health Organization (WHO) shows that among under-age five children in the high-burden countries in Africa, the prevalence of anemia was 61%; of children who tested positive for malaria, the prevalence of anemia is 79%. An under-age five children are said to have anemia if the mean blood Hb concentration is less than 110g/l (11/dl) (Gayawan et al., 2014). The estimate of Hb concentration of an average preschool child in Nigeria is 100d/l (97,104 CI) such that the level of public health significance was classified as severe (WHO, 2015).

The distribution of the key risk factors of malaria and anemia, such as mother's education, family wealth index, access to health care delivery, place of settlement, among preschool children in Nigeria have only being reported nationally, and a concrete study of the relationship between both diseases have not been adequately considered. Moreover, studies have focused on spatial modeling of single illness in a univariate framework or multivariate approaches for two or more diseases. A multivariate model was used to identify the risk factors of malaria and anemia for pregnant women in Mali (Dicko et al., 2003). Kateera et al. (2015) utilized bivariate and multivariate models to measure the prevalence of malaria, anemia, and under-nutrition among under age five children in rural Rwanda. Ehrhardt et al. (2006) employed a multivariate approach to investigate the interactions between malaria, anemia, and malnutrition among African children. However, most diseases share common risk factors such as environmental in cases of anemia and malaria. Possible identification of geographical patterns in a joint analysis of disease will provide proof of underlying risk surface on subsets within a population than when a single or multivariate disease analysis are considered (Leonhard and Nicola, 2000).

This analysis aims to quantify the risk relationship shared between malaria and anemia among under age-five children in Nigeria. A generalized linear mixed model was utilized , within a Bayesian framework to account for the different risk factors considered. The Baseg-York-Mollié (BYM) spatial prior model (Besag et al., 1991) was used to account for the spatial heterogeneity.

2 Method

Nigeria has 36 states, and the Federal Capital Territory (FCT), grouped into Six geopolitical zones (Figure 1). Efforts have been put in place to eradicate malaria and anemia in Nigeria, however, malaria and anemia remain endemic in Nigeria and remain a major health burden, threatening children development less than 59 months old. In combination with the Democratic Republic of Congo, Nigeria contributes up to 40% of the global malaria burden (NMIS, 2016). It also accounts for 11% maternal mortality, 25% infant mortality, and 30% under-five mortality (NMIS, 2016). The disease overburdens the health system of the country. Nigeria implemented strategic plans to eradicate malaria and control anemia, moreover, beginning from the year 2014, Nigeria embarked on the implementation of National Malaria Strategic Plans (NMSP), ended in the year 2020 to achieve pre-elimination status. This study made use of data collected before and after NMSP was initiated.

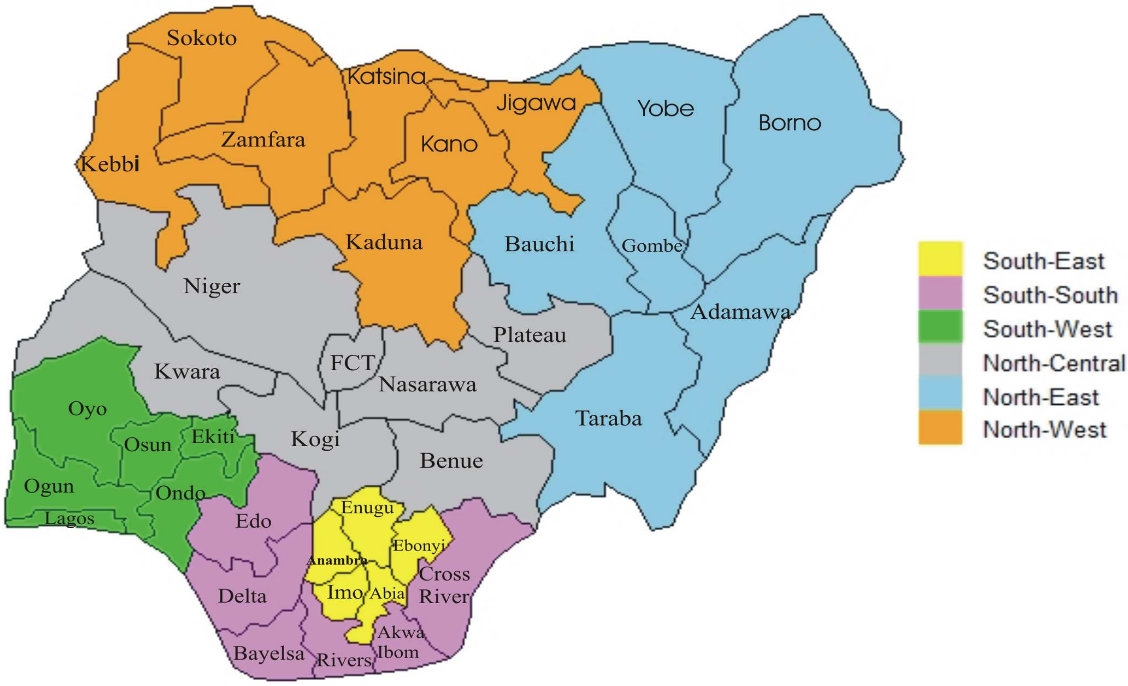


Figure 1: Map of Nigeria showing the states and geopolitical zones

2.1 Data

This research used the 2010 and 2015 Nigeria Malaria Indicator Survey (NMIS) conducted by the National Population Commission (NPC) and National Malaria Control Programme (NMCP) from October 2010 through November 2010 for NMIS 2010 and from October 2015 through November 2015 for NMIS 2015, which are available on Demographic and Health Survey (DHS) webpage. The sampling frame used for the survey came from the 2006 population census of the Federal Republic of Nigeria conducted in 2006. This study adopted a two-stage sampling technique. A stratified two-stage cluster design consisting of 240 clusters (83 in urban and 157 in rural areas) in NMIS 2010 survey, and 333 clusters (138 in urban and 195 rural areas) in NMIS 2015 across all states including FCT was conducted. In the second stage of the selection process, an average number of 26 households in NMIS2010 and 25 households in NMIS2015 were selected from each cluster by equal probability systematic sampling. Women in the selected households were administered a Women's questionnaire. Moreover, all children age 6-59 months present on survey day including visitors were eligible. Due to the strong association of malaria and anemia, tests for anemia in children aged 6-59 months were included in the survey. Finger-or-heel-prock blood samples from children were tested for malaria and anemia immediately. The data collection survey incorporated three biomarkers for testing malaria, anemia using RDT, and thick blood smear and thin blood film sample preparation on microscope slides. The NPC enumerators used a global positioning system (GPS) receiver to record coordinates where data were collected (NMIS, 2016). The extraction of variables of interest leads to a total of 3,393 households, with 73% and 27% samples from NMIS 2010 and NMIS 2015 respectively.

2.2 Statistical Analysis

A generalized linear mixed model, within a Bayesian approach, was adopted to account for the risk of a child having both malaria and anemia accounting for the socio-economic, demographic, and spatial risk factors on the prevalence of anemia and malaria among under age-five children. Four response variables were considered in this study; first, presence of anemia in children, coded as binary, second, presence of malaria with binary outcomes, third, is the Hemoglobin (Hb) level with continuous outcomes, and four, quantify the relationship of anemia and malaria with binary outcomes. For the binary outcomes, *1* indicates the presence of disease, and *0* indicates otherwise. The response variable indicating the relationship between malaria and anemia was coded as *1* if a child has both diseases and *0* otherwise.

Let y_{ijk}, $k = 1, 2, 3$, where $k = 1$ indicates presence of malaria, $k = 2$ indicates presence of anaemia, and $k = 3$ indicates presence of both diseases. The index $j = 1, 2, ..., n_i$, where n_i is the number of children in county $i \in \{1, 2, ..., 37\}$. In the binanary cases, Bernoulli distribution was assumed. That is, for each child,

$$y \sim Bernoulli\,(\pi)$$

independently with success probability $\pi = \frac{exp(\eta)}{1+exp(\eta)}$, where η is a linear predictor given as;

$$\eta = b_0 + \boldsymbol{\beta} + \mathbf{z} + \mathbf{u} + \mathbf{v}. \tag{1}$$

In addition, hemoglobin concentration assumed a Gaussian distribution with constant variance σ^2,

$$y \sim N(\mu, \sigma^2),$$

$$\mu = b_0 + \boldsymbol{\beta} + \mathbf{z} + \mathbf{u} + \mathbf{v}. \tag{2}$$

where b_0 is the global risk of a child having disease k, $\boldsymbol{\beta}$ is a vector of linear effects such as mother's level of education, family wealth index etc, modeled independently with a flat prior given as $p(\beta) \propto 1$. z is a random effect of a child's age modeled as a temporal structure using a random work with order two, given as;

$$z_t \mid z_{t-1}, z_{t-2} \sim Normal\Big(2z_{t-1} + z_{t-2}, \sigma_z^2\Big), \tag{3}$$

where $t = 2, 3, ..., 59$. A BYM is specified on the $\mathbf{u}$ and $\mathbf{v}$. That is, $\mathbf{v}$ is the spatial unstructured effects modeled as exchangeable structure given as $\mathbf{v} \sim Normal\big(0, \sigma_v^2\mathbf{I}\big)$, where $\mathbf{I}$ is an identity matrix, and $\mathbf{u}$ is the spatial structure effects jointly modeled using intrinsic conditional autoregressive (ICAR) model (Besag et al., 1991). The model was estimated using the Integrated Laplace approximation (INLA). The main advantage of approximating the joint posterior distribution with INLA over the popular Markov Chain Monte Carlo method is its computational advantage and does not suffer convergence problems. The hyper-parameters were assigned such that the priors lead to non-informative priors. R software (R Core Team, 2019) was used for the data analysis. Detail of the analytical procedures used is in Blangiardo et al. (2013).

3 Result of Analysis

Table 1 reports the average mean Hb level, the proportion of children with malaria and anemia, and the confidence intervals. Children who live in Northcentral have the highest mean Hb level of 17.7 g/dl, with Northwest having the highest proportion of children with malaria 22.9% and anemia 73.1%. However, children with parents belonging to the poorer category of wealth index have the highest Hb of 12.9g/dl and the highest proportion of 23.1% of the total children living with malaria, whereas 70.5% of children from the poorest category of wealth index were anemic. Children with mothers who only attended a primary education level have the highest average Hb level of 12.3 g/dl. As expected, children whose mothers have the highest educational level have the lowest percentage of children with malaria and anemia. A large percentage (68.4%) of children live in a rural area and has parents who, most likely, engage in subsistence farming. A larger

Table 1: Descriptive Statistics

Variablel	Frequency	Hb g/dl Mean (CI)	Malaria % proportion (CI)	Anemia % proportion (CI)
Total	3393	11.6 (11.2,12.0)	15.2(14.1,16.5)	64.4 (62.8,66.0)
Region				
Northcentral	618	17.7 (15.9,19.5)	17.6 (14.7,20.9)	53.7 (49.7,57.7)
Northeast	598	11.9 (11.4,12.3)	11.9 (9.3,14.7)	59.5 (55.5,63.5)
Northwest	722	9.8 (9.6,10.1)	22.9 (19.8,26.1)	73.1 (69.7,76.3)
Southwest	411	10.7 (10.2,11.1)	12.9 (9.8,16.5)	63.1 (58.3,67.9)
Southsouth	634	10.0 (9.7,10.3)	12.6 (10.1,15.5)	74.6 (71.0,78.0)
Southeast	410	10.8 (10.2,11.5)	9.6 (7.1,13.5)	63.1 (58.3,67.9)
Wealth Index				
Poorest	610	12.5 (11.3,13.7)	22.5 (19.2,26.0)	70.5 (66.7,74.1)
Poorer	601	12.9 (11.7,14.1)	23.1 (19.8,26.7)	66.9 (63.0,70.6)
Middle	690	10.6 (10.0,11.1)	17.5 (14.8,20.6)	70.7 (67.2,74.1)
Richer	740	11.1 (10.5,11.7)	10.3 (8.2,12.7)	63.9 (60.3,67.4)
Richest	752	11.3 (10.8,11.8)	6.0 (4.4,7.9)	52.1 (48.4,55.8)
Highest Level of education				
No Education	1406	11.1 (10.5,11.6)	19.8 (17.8,22.0)	69.5 (67.0,71.9)
primary	678	12.3 (11.3,13.3)	14.2 (11.6,17.0)	64.9 (61.2,68.4)
Secondary	1082	12.1 (11.4,12.8)	12.6 (10.7, 14.7)	60.0 (57.0,63.0)
Higher	227	10.8 (10.7,11.0)	3 (1.2,6.3)	52.4 (45.7,59.1)
Residence				
Rural	2322	11.9 (11.4,12.4)	19.0 (17.4,20.6)	69.4 (67.5,71.3)
Urban	1071	11.0 (10.7,11.4)	7.2 (5.7,8.9)	53.5 (50.5,56.5)
Child's Gender				
Female	1701	11.8 (11.3,12.3)	16.5 (14.7,18.3)	62.0 (60.0,64.3)
Male	1692	11.4 (10.9,11.9)	14.1 (12.4,15.8)	66.8 (64.5,69.0)
Listened to Radio				
Yes	2295	11.9 (11.4,12.4)	13.2 (11.8,14.7)	60.5 (58.5,62.5)
No	1098	11.0 (10.4,11.5)	19.5 (17.3,22.1)	72.5 (69.8,75.1)
Source of Water				
Improved System	1343	11.0 (10.6,11.3)	11.3 (9.7,13.1)	62.0 (59.4,64.6)
Non-improved System	2050	12.1 (11.5,12.6)	17.9 (16.2,19.6)	66.0 (63.9,68.0)
Toilet				
Improved System	618	11.3 (10.8,11.9)	7.4 (5.5,9.8)	51.2 (47.3,55.5)
Non-improved System	2775	11.7 (11.3,12.1)	17.0 (15.6,18.5)	67.8 (65.5,69.0)
Fever in the last two weeks				
Yes	758	10.7 (10.2,11.2)	17.0 (14.4,19.9)	66.2 (62.7,69.6)
No	2638	11.9 (11.4,12.3)	14.8 (13.4,16.1)	63.9 (62.0,65.7)
Child's Age				
6-11	219	11.3 (9.8,12.7)	7.8 (4.6,12.1)	70.8 (64.3,76.7)
12-23	550	10.9 (10.1,11.6)	10.9 (8.4,13.8)	72.4 (68.4, 76.1)
24-35	632	11.4 (10.6,12.2)	14.6 (11.9, 27.6)	65.7 (61.8, 69.3)
36-47	938	12.6 (11.7,13.4)	15.9 (13.6,18.4)	61.3 (58.3,64.2)
48-59	1054	11.4 (10.8,11.9)	19.0 (16.7,21.5)	61.3 (58.3,64.2)

proportion of children living with malaria and anemia were from the rural region. The average Hb level of female children was 11.8g/dl, whereas, for male children, the average Hb was 11.4g/dl. While a higher percentage (16.5%) of female children had malaria, 66.8% of male children had anemia. Children between age 36-47 months had the highest Hb level of 12.6g/dl, whereas the highest proportion of children between the age of 48-59 months had malaria. The survey from 2010 had the highest mean Hb level of 11.9g/dl. While a larger percentage of children who had malaria were from the 2015 survey compared to 2010, a larger percentage of anemic children were from the 2010 survey. Children without fever in the last two weeks before the survey have a higher mean Hb level of 11.9g/dl, a lower proportion of anemia, and a higher proportion of malaria.

3.1 Estimates of linear risk factors

Table 2 shows the posterior mean, standard error (Se), and 95% confidence interval (CI) of the fixed effect for anemia (first panel), malaria (second panel), Hb level (third panel), and the joint effect (fourth panel). Statistical Significance of the risk factors were determined using the non-inclusion of zero in the confidence intervals. In the first panel, the result shows that children living in rural areas are more susceptible to anemia than children living in urban areas. It showed that children living in the rural region are 51% significantly more likely to suffer from anemia than those in the urban settlement. Female children are 23% significantly less likely to have anemia compared to male children. This result agrees with the findings from Gayawan et al. (2014); Adebayo et al. (2016). Source of water is not significantly contributing to children having anemia, however, improved toilet system significantly lowers the contribution compared to the base category, which is unimproved toilet system. Children from the richest family are significantly less likely to have anemia compared to children from the poorest category of the family wealth index. It means that parents from the richest category of wealth index would have enough resources to provide an adequate diet for their children. Other categories of wealth index are not significantly different from the poorest category. Children who the mother have a secondary level of education are significantly less likely to have anemia compared to children who the mother had no formal education. Other levels of education were not significant from the base category. The presence of fever in the last two weeks is not significantly different from the absence of fever. Children with malaria are 97.7% significantly more likely to be anemic compared to children without anemia. The result revealed that subsequent episodes of malaria significantly contribute to children having anemia. It proves the significant coexistence between malaria and anemia. Children whose parents had a radio system and use mosquito net are significantly less likely to be anemic compared to those without a radio system and mosquito net. The risk of anemia is significantly higher for all regions than the base category, except for children in the Northeast region. The result shows that there are improvements in the anemic status of children between the years 2010 and 2015, in the sense that children surveyed in 2015 are 29.7% less likely to be anemic. The reduction might be as a result of sensitization programs centered on regions with severe anemia.

Table 2: Linear effect

	Anemia				Malaria				Hemoglobin			Joint risk			
	mean	exp (mean)	2.50%	97.50%	mean	exp (mean)	2.50%	97.50%	mean	2.50%	97.50%	mean	exp (mean)	2.50%	97.50%
(Intercept)	0.722	2.058	0.262	1.191	-2.123	0.120	-2.697	-1.558	16.065	12.623	19.474	-0.384	0.681	-0.656	-0.109
Residence															
Urban(ref)															
Rural	0.410	1.506	0.213	0.606	0.647	1.910	0.336	0.965	0.121	-0.757	0.998	0.343	1.409	0.208	0.478
Gender															
Male(ref)															
Female	-0.258	0.773	-0.409	-0.107	0.138	1.148	-0.065	0.341	0.419	-0.228	1.066	-0.070	0.932	-0.171	0.030
Source of Water															
Unimproved(ref)															
Improved	0.098	1.103	-0.085	0.281	-0.120	0.887	-0.367	0.126	-0.007	-0.796	0.781	0.024	1.024	-0.097	0.144
Toilet System															
Unimproved(ref)															
Improved	-0.301	0.740	-0.555	-0.046	-0.209	0.812	-0.633	0.206	0.154	-0.980	1.288	-0.217	0.805	-0.398	-0.038
Wealth Index															
Poorest(ref)															
Poorer	-0.061	0.941	-0.326	0.204	-0.098	0.907	-0.399	0.203	-0.429	-1.549	0.690	-0.061	0.941	-0.230	0.108
Middle	0.091	1.095	-0.189	0.371	-0.368	0.692	-0.700	-0.037	-2.012	-3.190	-0.835	-0.110	0.896	-0.289	0.068
Richer	-0.174	0.840	-0.497	0.148	-0.928	0.396	-1.355	-0.505	-2.161	-3.540	-0.783	-0.363	0.695	-0.574	-0.153
Richest	-0.444	0.641	-0.834	-0.056	-1.129	0.323	-1.700	-0.569	-2.59	-4.288	-0.894	-0.520	0.595	-0.782	-0.258
Level of Education															
No Education(ref)															
Primary	-0.234	0.791	-0.482	0.014	-0.101	0.904	-0.419	0.215	0.916	-0.156	1.987	-0.148	0.862	-0.311	0.015
Secondary	-0.307	0.736	-0.567	-0.048	0.248	1.281	-0.090	0.586	1.789	0.663	2.913	-0.101	0.904	-0.274	0.072
Higher	-0.150	0.861	-0.531	0.232	-1.084	0.338	-1.983	-0.295	0.228	-1.465	1.919	-0.239	0.787	-0.514	0.033
Fever in Last Two Weeks															
No(ref)															
Yes	0.007	1.007	-0.179	0.194	-0.024	0.977	-0.269	0.218	0.019	-0.779	0.816	0.006	1.006	-0.117	0.128
Malaria															
No(ref)															
Yes	0.681	1.977	0.443	0.925					0.003	-0.955	0.961				
Radio															
No (ref)															
Yes	-0.377	0.686	-0.559	-0.196	-0.107	0.899	-0.332	0.120	1.124	0.361	1.887	-0.194	0.824	-0.310	-0.078
Having Mosquito Net															
No(ref)															
Yes	-0.049	0.952	-0.223	0.125	-0.365	0.694	-0.597	-0.133	-0.060	-0.821	0.701	-0.120	0.887	-0.234	-0.007
Region															
Northcentral(ref)															
Northeast	-0.097	0.908	-0.611	0.406	-0.495	0.610	-1.060	0.075	-5.816	-10.449	-1.161	-0.185	0.831	-0.460	0.084
Northwest	0.686	1.985	0.188	1.181	0.307	1.359	-0.215	0.84	-6.32	-10.775	-1.846	0.414	1.513	0.155	0.676
Southeast	0.731	2.077	0.183	1.271	-0.098	0.907	-0.743	0.539	-5.428	-10.314	-0.516	0.335	1.397	0.037	0.627
Southsouth	1.127	3.088	0.609	1.641	0.123	1.131	-0.444	0.696	-6.114	-10.741	-1.461	0.554	1.740	0.281	0.824
Southwest	0.546	1.727	0.022	1.063	0.315	1.371	-0.282	0.912	-5.246	-9.902	-0.565	0.340	1.405	0.054	0.623
Year Data were collected															
2010(ref)															
2015	-0.338	0.713	-0.525	-0.151	1.302	3.678	1.070	1.535	-1.019	-1.829	-0.210	0.269	1.309	0.147	0.391

In the second panel, the expected risk of children having malaria in the rural area is 91% significantly more likely to have malaria compared to children leaving in the urban settlement, which supports Wilson et al. (2015) claim. Malaria affects children irrespective of their gender since there is no significant difference between the risk of malaria between male and female children. Sources of water and toilet system do not significantly contribute to whether a child has malaria or not. Though the poorer category of wealth index is not significantly different from the poorest category, which is the base, it can be concluded that the risk of children having malaria declines with an increase in the wealth index. Children with a Higher level of mothers education are significantly less likely to have malaria compared to the reference category, which is no education, whereas other education levels are not significantly different. Children's risk of fever in the last two weeks before the survey and children whose parents have radio systems are not significantly different from the base category. Children who sleep under treated mosquito nets are less likely to have malaria compared to those sleeping without a treated mosquito net. It can be concluded that the region where a child resides does not significantly contribute to a child having malaria. The result implies that the impact of malaria is similar in these regions. In 2015, children are more likely to have malaria compared to the base category 2010.

In the third panel, place of residence, sources of water, and the toilet system does not significantly contribute to the Hb level of a child when compared to respective base categories. In other words, residence, water source, and toilet system do not explain more information on the variation that exists in the hemoglobin level of children. Gender does not significantly contribute to the Hb level, which confirms the result obtained in Dang et al. (2003). Though the poorest category does not significantly contribute to the Hb level of children, the higher the wealth index, the lower the effect on the mean Hb level. Regarding the mother's level of education, the primary and higher category do not significantly contribute to the mean Hb level, whereas the secondary category contributes significantly higher to the mean Hb level compared to the base category. The risk of children with fever in the last two weeks before the survey does not significantly contribute to the Hb level of children. The effect of listening to radio contributes higher to the mean Hb level of children, whereas having a mosquito net does not, compared to the base category. The result shows that the risk in the Northeast, Northwest, Southeast, Southsouth, and Southwest regions on mean Hb is lower compared to the base category, which is Northcentral. The effect of 2015 on the mean Hb is significantly lower compared to the base category.

In the fourth panel, children leaving in the rural region are 41% significantly more likely that the anemic status of children is due to subsequent episodes of malaria. In other words, children living in the rural area are more likely to suffer from both malaria and anemia. Gender and source of water are not significant compared to the base categories. However, children whose parents used improved toilet systems are less likely to have a shared risk of malaria and anemia compared to the base category. Children of a richer and richest category of family wealth index have a significantly lower risk than the base category. However, as the level of wealth index increases, the risk of a child having a shared effect of malaria and anemia declines. The education level on the shared risk is not significantly different from the base category, which is no formal education. Moreover, the risk of a child having malaria and anemia declines as the level of education increases. Fever in the last two weeks before the surveys does not significantly contribute to the risk of a child having malaria and anemia. Children who sleep under a mosquito net and whose parents listen to the radio are 17.6% and 11.3% less likely to have a shared component of malaria and fever than the base category. Regarding region, children from Northwest, Southeast, Southsouth, and Southwest are significantly more likely to have malaria and anemia than the base category, whereas Northeast is not significant. In 2015, children are 30.9% more likely to have malaria and anemia than the year 2010 survey, which is the base category.

3.2 Estimates of spatial risk factors

Figure 2 showed the spatial risk (left) and the probability of excess risk (right) of anemia, malaria, and Hb level. The green parts represent the regions at low risk, whereas the red parts represent regions at higher risk, and the yellow parts signify the regions at moderate risk. Moreover, in Figure 2a and c, children residing in green regions are about 0-80% less likely to have anemia or malaria than the whole country. However, children living in the yellow parts are about 0-50% more likely, lighter red parts are about 50% to 100% more likely, and the dark red regions are above 100% more likely to have either anemia or malaria compared to the whole country. In Figure 2e, the red parts signify regions with a low level of Hb, while the green parts signify regions with a high level of Hb, and the yellow parts signify areas of moderate risk. Figure 2b,d, and f are the graphs showing the probability of excess risk. The black regions are the regions where a child has a greater than 0.8 probability of having anemia, malaria, or low Hb. Figure 3 presents the joint spatial risk of malaria and anemia. Children living in the green parts are 20-50% less likely to have both malaria and anemia, while children living in the yellow parts are between 0-20% less likely to have both diseases. Children living in the red and dark-red parts are 0-20% and above 20% more likely to have malaria and anemia respectively.

Judging by the probability graphs, in Figure 2b, regions such as Jigawa, FCT, Ondo, Kwara, and Yobe are the top risk states in anemia in the country, while in Figure 2d Benue, Kebbi, Sokoto, Taraba, and Zamfara, are the top risk states in malaria. In Figure 2f the regions such as Benue and

Kogi are the areas with the highest Hb compared to the whole country. In Figure 3, the regions Ebonyi, Kebbi, Kwara, Nasarawa, Ondo, Osun, Nasarawa, and Zamfara are the regions at high risk of both anemia and malaria.

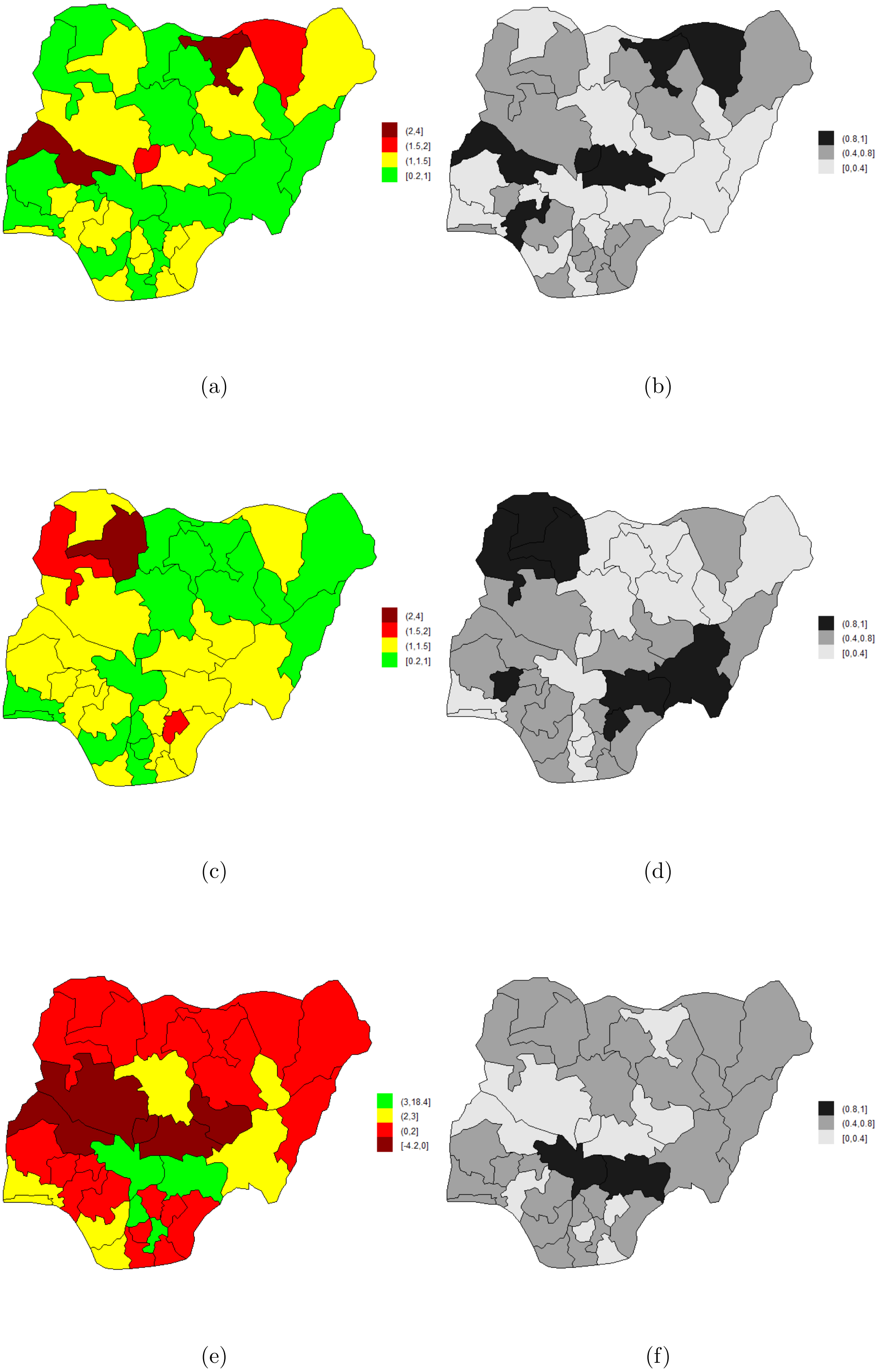
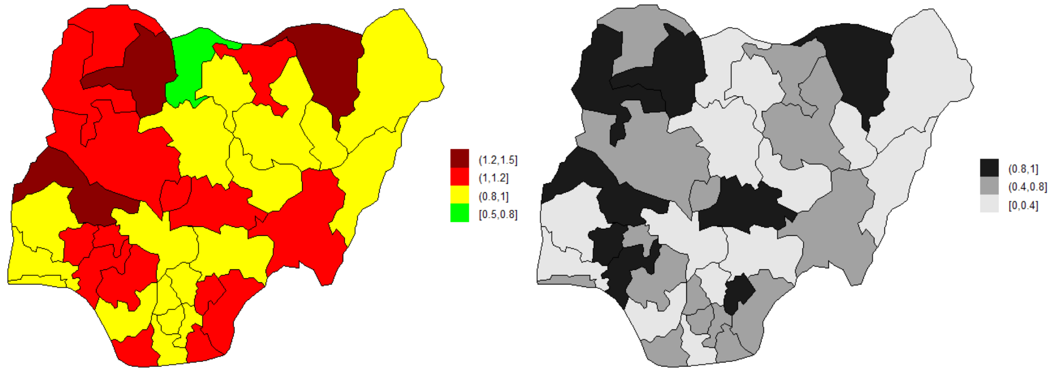


Figure 2: (a) Posterior Risk of anemia $\zeta = exp(\xi)$ compared with the whole country. (b) probability of excess risk of anemia $P(\zeta > 1|y)$ (c) posterior risk of malaria $\zeta = exp(\xi)$ compared with the whole country. (d) probability of excess risk of malaria $P(\zeta > 1|y)$. (e) posterior mean of Hb level ξ compared with the whole country. (f) probability of high Hb level $P(\xi > 0|y)$



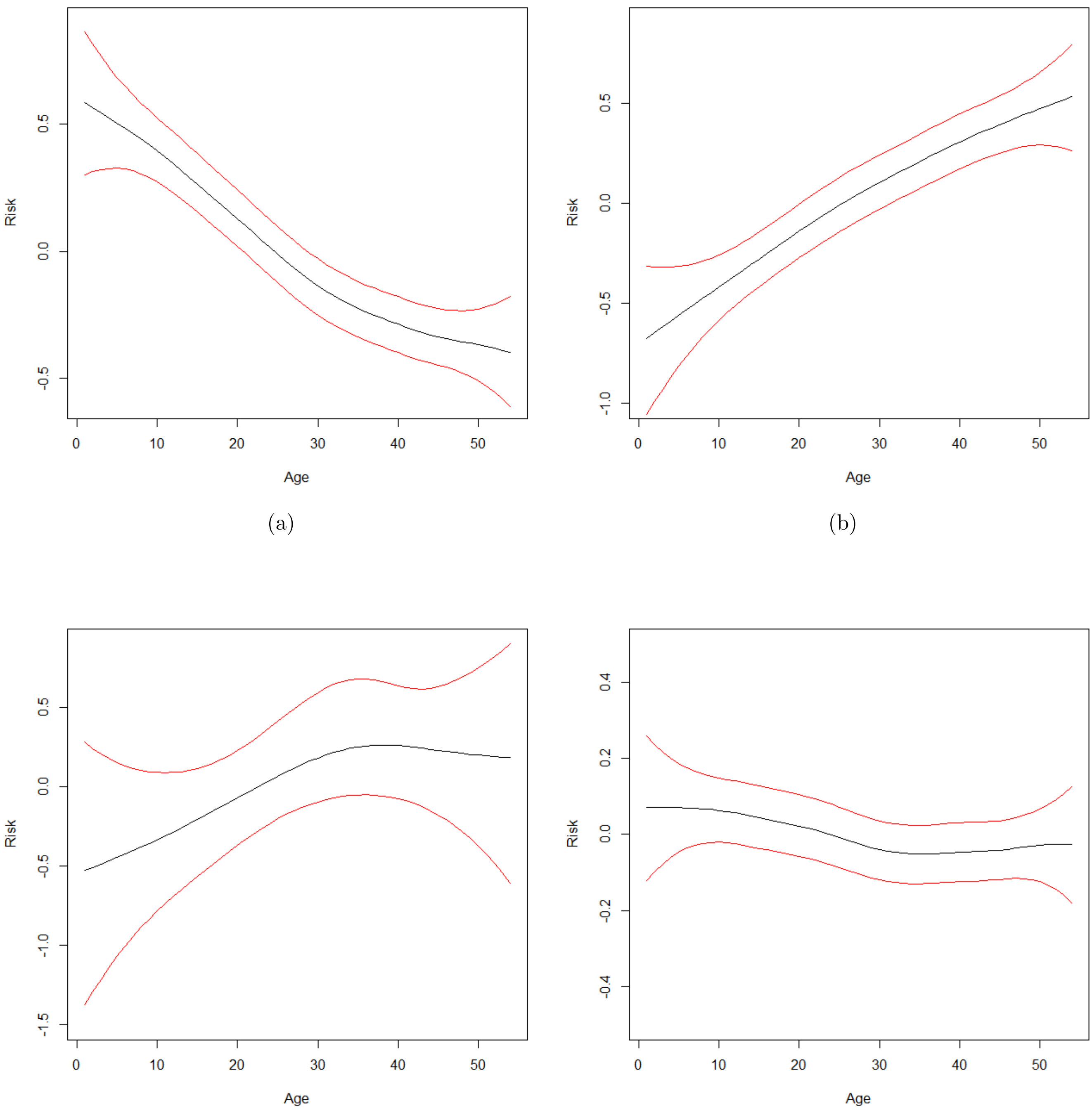
(a) (b)

Figure 3: (a): posterior mean of shared risk of malaria and anemia $\zeta = exp(\xi)$ compared with the whole country (b) probability of excess risk of malaria and anemia $P(\zeta > 1|y)$

3.3 Estimates of non-linear risk factors

Figure 4 showed a nonlinear relationship between children's age and the associated risk factors. The middle-black line represents the point estimates, and the red lines represent the 95% upper and lower confidence interval estimates for each age. As the age increases, the risk of a child having anemia reduces at a constant rate until age 35 months, where it had a slight distortion (Figure 4a). The result agrees with the findings that younger children suffer more from the disease (Mulenga et al., 2005). In Figure 4b, a child's risk of malaria increases with age. It confirms the result obtained by Adebayo et al. (2016) that children are more exposed to mosquito bites as they gradually rely less on the parents to meet all their immediate needs. Additionally, this may be due to a strong immune system associated with breastfeeding, which favors the younger children. Negligence on the parents' part to prevent their children from infected mosquito bites, as they grow older, worsen malaria cases, which make the children more vulnerable to malaria. In Figure 4c, as the age increases, the hemoglobin level of children increases until age 40 months and became slightly constant till age 59 months. In Figure 4d, as the age increases, there is a gradual decrease in the shared risk factor of malaria and anemia until age 32 months where it appreciates slightly.

While anemia decreases with age, malaria increases with age. As expected the Hb level increases with age, and the shared risk, which is a combination of both risks, decreases slightly with age.



(a) (b) (c) (d)

Figure 4: Risk of anemia (a), risk of malaria (b), Hb concentration (c), risk of malaria and anemia (d), with children's age

4 Discussion

Under-five age children living in rural areas are one of the most vulnerable groups to these diseases. That is, the risk of malaria and anemia in rural settlements is higher than in urban settlements. It agrees with the recent findings that a higher percentage of diseases in the urban areas were transported from the rural, tagging rural settlements a high transmission and endemic regions. It could be associated with a high ratio of less-informed parents and their negative attitude towards the control measures and programs to mitigate these diseases, thus, causing high incidence and low child recovery rates. Moreover, the lack of vital education on frequent environmental sanitization against mosquito, and cases where children consume inappropriate diets weakens the immune system and causes frequent episodes of the diseases and slow recovery. Thus, sustainable strategic intervention programs, formal and informal education should be targeted and maintained in rural areas. Female children are less likely to have anemia, which confirms the result obtained in Gayawan et al. (2014), while (Koukounari et al., 2008) concluded otherwise for children between 10-21 months in Kenya. In other words, rapid progression to death is frequently found for male children. It could be associated with higher Hb concentration found among female children. As expected, use of an improved toilet system lowers the risk of anemia and shared risk of having both diseases compared with unimproved systems. The rate of children having both diseases is higher for families with a low wealth index. Hence, programs to mitigate the impact on children should be targeted at low-income earners. Parents' education plays an essential role in children's development and health. Highly educated parents are more informed and would promote programs to mitigate the impact of diseases in children, such as the distribution and use of mosquito nets and environment sanitization. The use of mosquito nets prevents malaria and reduces the anemic nature in children since children will be free of malaria parasites, thus, the irons within the red blood cells are unaltered. The risk of a child having malaria is higher in 2015 compared to 2013, whereas it is significantly lower in anemia. It revealed that the NMSP program initiated in 2014 is gradually reducing malaria impact on anemic children. With time and consistency, the risk of children having malaria may substantially drop. The spatial result shows that states with large rural landmass, such as the northern part of Nigeria, are endemic regions. The Northwest and Northcentral Nigeria are at high risk of malaria, whereas the shared risk of both diseases is more severe in the Northwest region of Nigeria.

5 Conclusion

This article focused on the modeling of the joint risks associated with malaria and anemia among children using a generalized linear mixed model within a Bayesian framework. Four response variables were considered to estimate diseases specific and joint risk factors. Integrated Nested Laplace approximation in Bayesian framework was used in the estimation procedure. Result showed that Malaria has severe adverse causative effect on anemia, especially among infants between 0-10 months, and thus worsen anemia impact. The rural regions are malaria endemic, thus intervention strategies and policies should be directed towards rural region to tackle issues related to malaria and other causatives effects, such as iron deficiency to control its adverse effects on children. The population of parents with no education and low wealth index are usually located in the rural settlements engaging in subsistence farming; therefore, social intervention program should focus attention on rural settlements. In Nigeria, the Northwest region through FCT, down to Eastern region of Nigeria should be of most priority to mitigate the impact on children development.

-List of Abbreviations

BYM : Besag-York-Molliée

DHS : Demographic and Health Survey

Hb : Hemoglobin

NMIS :Nigeria Malaria Indicator Survey

NPC : National Population Commission

6 Declarations

-Ethics approval and consent to participate

Not applicable

-Consent for publication

Not applicable

-Availability of data and materials

The datasets analysed during the current study are available in the DHS website repository upon registration.

-Competing interests

The authors declared that they have no competing interests

-Funding

No funding received

-Authors' contributions

Osafu Augustine Egbon contributed to the data analysis, manuscript writing, and final manuscript revision.

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Figures

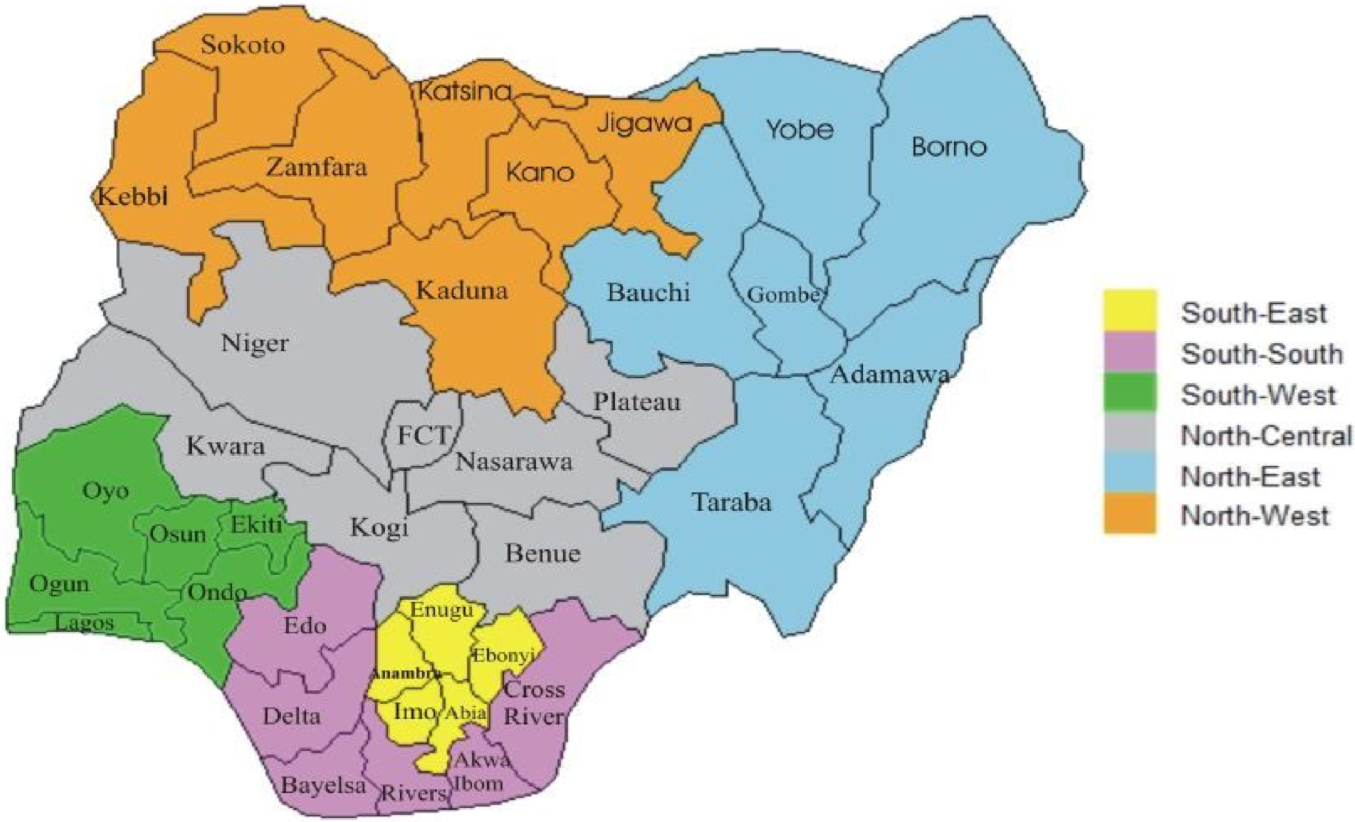

Figure 1

Map of Nigeria showing the states and geopolitical zones Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

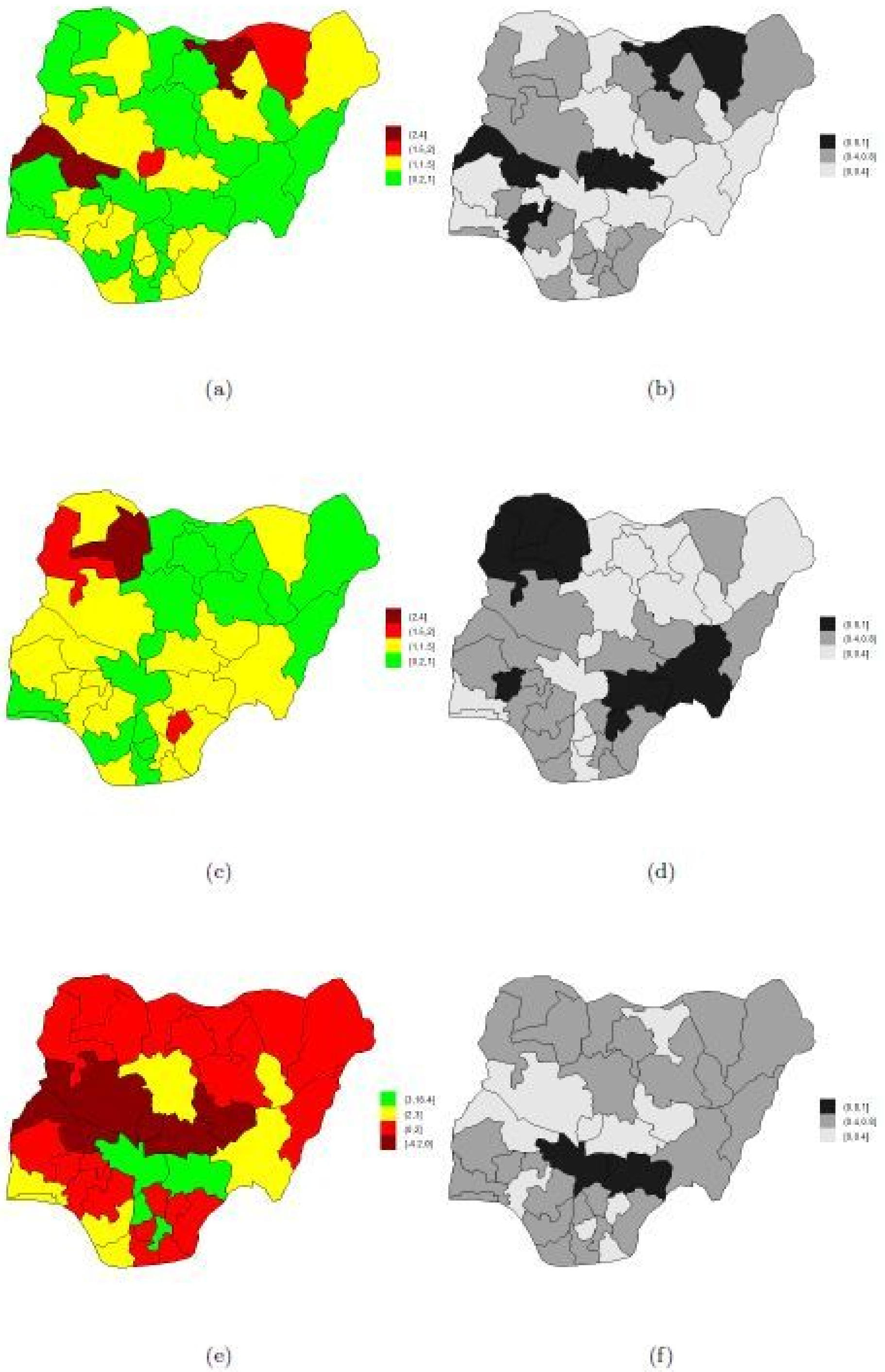

Figure 2

(a) Posterior Risk of anemia □ = exp(□) compared with the whole country. (b) probability of excess risk of anemia P(□ > 1jy) (c) posterior risk of malaria □ = exp(□) compared with the whole country. (d) probability of excess risk of malaria P(□ > 1jy). (e) posterior mean of Hb level □ compared with the whole country. (f) probability of high Hb level P(□ > 0jy) Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research

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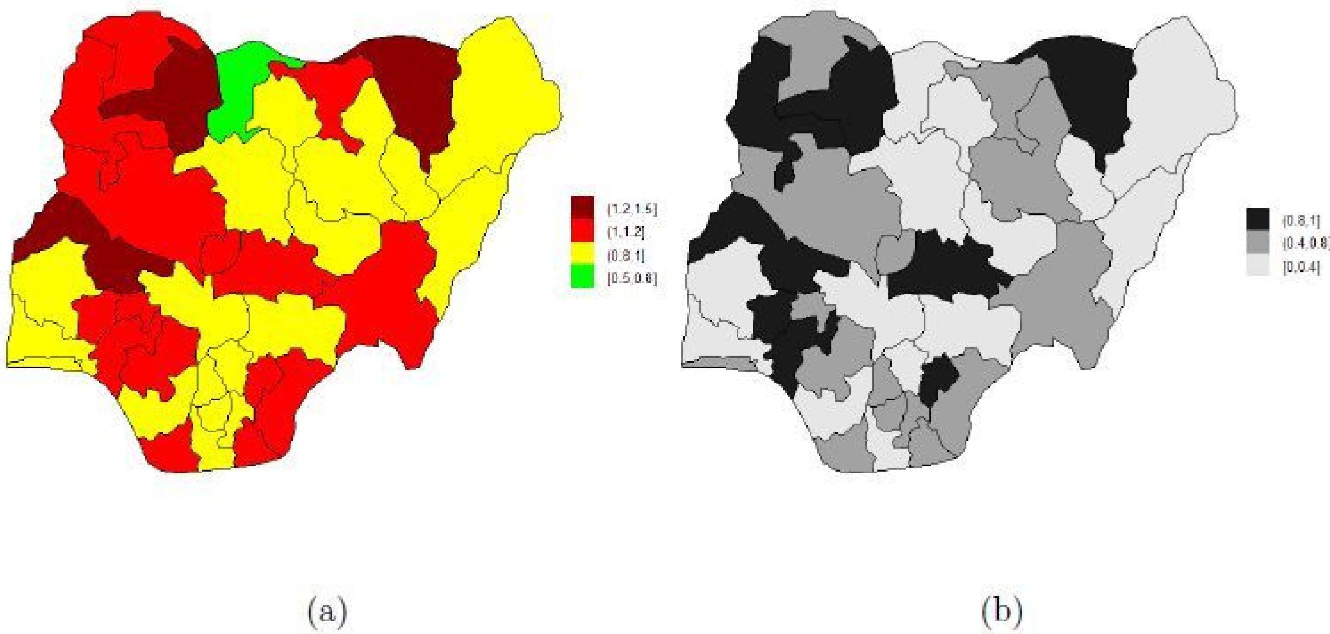

Figure 3

(a): posterior mean of shared risk of malaria and anemia = exp() compared with the whole country (b) probability of excess risk of malaria and anemia P(> 1jy) Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

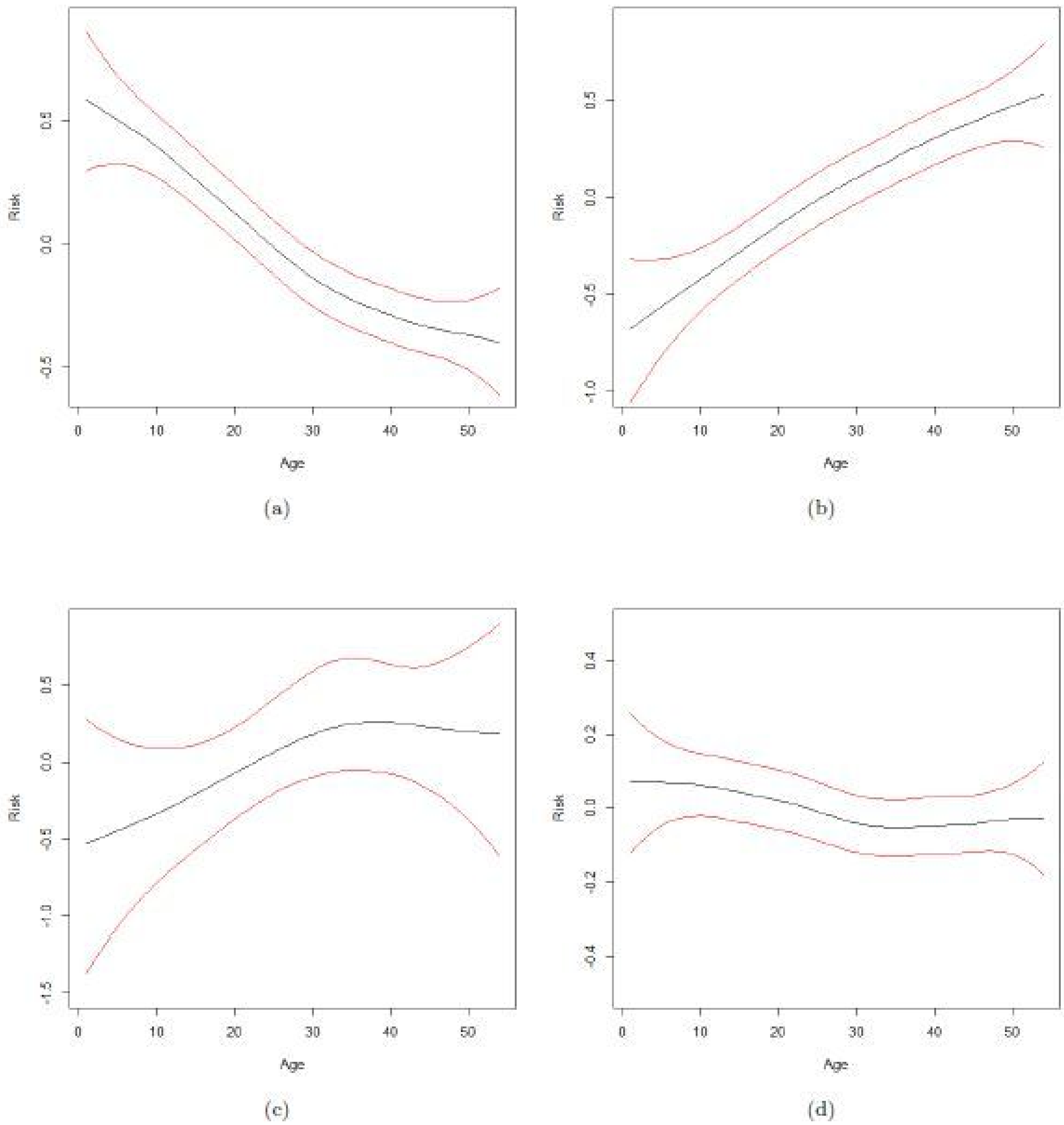

Figure 4

Risk of anemia (a), risk of malaria (b), Hb concentration (c), risk of malaria and anemia (d), with children's age