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Spatially Adjusted Determinants of Malaria and Anaemia Morbidity among Children Under age 5 years in Ghana, 2014



By

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A Research Report Submitted to the Faculty of Health Sciences, University of the Witwatersrand in partial fulfilment of the requirements for the Degree of

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Dedication

This work is devoted to my lovely father and mother, Mr Blam Gilbert Nuertey and Juliana Tetteh, my extraordinary mother, Janet Ofusu. It is with your love, support and prayers that I have come this far.

Preface

This research is made as an accomplishment of the Master of Science in Epidemiology and Biostatistics. In truth, I could not have achieved my current level of success without a strong support group. Numerous persons contributed intellectually, practically and with support to this master thesis. I would therefore firstly like to thank my supervisor Professor Eustasius Musenge for his time, precious input and support throughout the complete master's period. Furthermore I want to thank Dr. Daniel Maduku Kofi for his immense help and constructive comments throughout the entire process. To end with, I want to thank my family and friends for their help and support during my time studying Epidemiology and Biostatistics at University of Witwatersrand.

University of Witwatersrand, May 2018

Declaration

I, **Stephen Nuerteye Blam** hereby declare that except where specific reference is made to the work of others, the contents of this research report are original and have not been submitted in whole or in part for consideration for any other degree or qualification in this, or any other University. This research report is the result of my own work and includes nothing which is the outcome of work done in collaboration, except where specifically indicated in the text.



Blam Stephen Nuerteye

02-May-2018

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I am most grateful to my dear supervisor, Professor Eustasius Musenge who has been of great support, encouragement and guide throughout this thesis work. Your vast experience in research during this study has made me better equipped in research than ever. Learning STATA, WINBUGS (Bayesian statistics) and R, would not have been a success without your expertise at all times.

Thanks to the noble lecturers and staff of the School of public health. To my colleagues at the masters level who assisted in one way or the other, may God richly bless you.

My sincere thanks goes to Dr. Daniel Maduku Kofi, for your immence support, constructive critisms and countless encouragement, without which I would not have come this far.

To my close family, Charles Adjei, Eric Maduku, Ernestina Appiah and Roberta Obeng, thank you so much for your unflinching support, dedication, love and encouragement. To my kid brother Vincent Nartue Blam for your timely support to aid me complete my study. Evelyn Nuerki Blam, your appearance in the scene brought me joy.

Finally, I dedicate this work to my family and friends. To my father Mr Blam Gilbert Nuertey, words cannot express my gratitude to you. To my mother who always prayed and cared for me. To you mum Janet Ofosu, I forever remain indebted to you.

This thesis is a celebration of success for team work.

Abstract

Background: Malaria and anaemia pose significant public health challenges to most developing countries. Sub-Saharan Africa continues to carry a disproportionately high share of the global malaria burden. Recent WHO (2015) global estimates on disease burden shows the African region accounted for 88% of the 214 million new malaria cases in 2015. This statistic further highlighted that the region accounted for 90% of malaria deaths in 2015. Similarly, anaemia, defined as low hemoglobin concentration, is estimated to globally affect 43% of children under five years of age. Anemia prevalence is very high among Ghanaian children under 5 years of age. The objectives of this study were to determine the prevalence and spatial distribution of malaria morbidity in children under age 5 years in Ghana in 2014, to ascertain the prevalence and spatial distribution of childhood anaemia morbidity in Ghanaian children under age 5 years in 2014, to determine the spatial distribution of factors associated with malaria morbidity in Ghana in 2014, and to determine the spatial distribution of factors associated with anaemia morbidity in Ghana in 2014.

Objectives: The aim of the study is to determine spatial distribution and factors associated with malaria and anaemia morbidity among Ghanaian children under 5 years of age in 2014.

Methods: This study analysed malaria and anaemia morbidity and prevalence using data from the Ghana 2014 Demographic and Health Survey. These data captured malaria related information on children under 5 years. Survey logistic and ordered logistic multivariable regression was done to determine associations between the singular outcomes malaria and anaemia and several explanatory variables. The regression models were employed and results thereof were used to produce maps illustrating the predicted risk of malaria and anaemia occurrence. The generalized linear mixed model was used to simultaneously identify the risk factors of malaria and anaemia of children under five years and how these are spatially distributed. Multilevel survey adjusted logistic and ordinal logistic regression models with non-spatial random effects were fitted for malaria and anaemia respectively. A Bayesian approach was employed to further adjust for spatial random effects on the convolution models for the two main outcomes.

Results: The sample in this study was made up of 2727 children under age 5 years, of which 783 tested positive for malaria and 1873 had anaemia, resulting in an observed malaria and anaemia prevalence of 28.71% and 68.68% respectively. Spatially adjusted significant variables were: Child's age; type of place of residence; mother's highest education level, wealth index; child's altitude adjusted haemoglobin level; cluster altitude; severe anaemia vomiting; severe anaemia extreme weakness. Children from the Western, Central, Greater Accra, Eastern, and Brong Ahafo regions were more likely to have malaria compared to northern region. Malaria was 1.46 times more likely to occur among children residing in rural than urban areas [OR=1.46, (95% CI: 1.02-2.16); p=0.05]. Vomiting as well as extreme weakness were 6.37 [OR=6.37 (95% CI: 2.16-

18.75); p<0.001] and 7.63 [OR=7.63 (95% CI: 3.02-19.22); p<0.001] times more likely to have anaemia than those without these symptoms. Children residing at higher altitude were 0.98 times less likely to have anaemia compared to those at lower altitude [OR=0.98 (95% CI: 0.97-0.99); p=0.01].

Conclusion: Recent reports in Ghana indicate that malaria and anaemia related deaths in children under age 5 years are on the ascendancy. In spite of this, there is a dearth of empirical research that establishes our understanding on the prevalence of malaria and anaemia in the endemic regions of Ghana. Understanding the prevalence of malaria and anaemia in terms of spatial risk factors, will provide more insight and practical guidelines to the formulation of policies aimed at fighting the spread of malaria and anaemia. Hence, directing health interventions to higher risk areas and ensuring nationwide coverage are promising strategies for promoting equity and reducing risk of malaria and anaemia. This study showed that Brong Ahafo, Eastern, Northern, Western, Volta and Upper East regions were the hotspot zones with greatest disease burden.

Keywords: Ghana, Anaemia morbidity, Malaria morbidity, Malaria Indicator Survey (MIS), Demographic and Health Survey (DHS), spatial mapping, West Africa.

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Nomenclature

Anemia: A condition in which the blood is deficient in red blood cells, in hemoglobin, or a lowered ability of the blood to carry oxygen.

Choropleth map: This is a thematic map in which areas are shaded or patterned in proportion to the measurement of the statistical variable being displayed on the map, such as disease prevalence. The map provides an easy way to visualize how a measurement varies across a geographic area or it shows the level of variability within a region.

Convolution model: It is a mathematical operation in statistics and other fields, applied on two functions which produces a third function, that is classically viewed as a improved version of one of the original functions, giving the integral of the pointwise multiplication of the two functions as a function of the amount that one of the original functions is transformed.

Disease mapping: describing the underlying geographical distribution and pattern in a disease as part of general health surveillance (epidemics, increasing rates, identification of elevation in risk, etc).

Geographic information system (GIS): it is an information system created specifically for maps

Global Moran's I and Geary's I: These are two statistics that estimate the overall degree of spatial autocorrelation. That is, they measure the tendency of events to cluster or the extent to which points close together have similar values on average than those farther apart.

Malaria: This is a mosquito-borne infectious disease affecting mostly humans and caused by parasitic protozoans belonging to the *Plasmodium* type. Malaria causes symptoms that typically include fever, tiredness, vomiting, and headaches.

Malaria morbidity rate: This is the number of recorded clinical cases (illness) of malaria per unit of population over a certain period.

Mixed effects model: It is a statistical model containing both fixed effects and random effects. These models are useful in a wide variety of disciplines in the physical, biological and social sciences.

Spatial Conditional autoregressive (CAR) models: This are Bayesian analytical models which are often used to describe the spatial variation of quantities of interest in the form of summaries or aggregates over sub-regions, with the essential idea that the probability of values estimated at any given location are conditional on the level of neighboring values.

Spatial hot spot: It is a spatial analysis and mapping technique showing an area that has higher concentration/clustering of spatial phenomena/events such as diseases compared to the expected number given a random distribution of events. These spatial phenomena are depicted as points in a map and refer to locations of events or objects.

Unstructured random effects: These are random effects models which often use unstructured covariance matrices for the random effects. In these models, one or more random effects are included in the model. Like a residual, these random effects are each a measure of unexplained variance.

Abbreviations

DHS	Demographic Health Survey
DIC	Deviation Information Criteria
GHS	Ghana Health Service
GDHS	Ghana Demographic Health Survey
GIS	Geographic Information System
GPS	Geographical Positioning System
GSS	Ghana Statistical Service
IPTp	Intermittent Preventive Treatment in Pregnancy
IRS	Indoor Residual Spraying
LLIN	Long Lasting Insecticidal Nets
MCMC	Markov Chain Monte Carlo
OR	Odds Ratio
SA	Spatial Analysis
SMA	Severe Malarial Anaemia
SES	Socio-Economic Status
SSA	Sub-Saharan Africa
UNICEF	United Nations International Children's Emergency Fund
USAID	United States Agency for International Development
WHO	World Health Organisation

Chapter 1 **Introduction**

1.1 **Global burden of Malaria and Anaemia**

Owing to their significant socio-economic impact, malaria and anaemia pose significant public health challenges to most developing countries around the world (WHO, 2016). Estimates of the WHO (2016) on the global burden of disease indicate that 214 million malaria cases were recorded in 2015. In the same period 438000 malaria mortalities were reported worldwide, of which most of the malaria mortalities were of children under age 5 years. In addition, a more recent research conducted by the World Health Organization (WHO, 2016), called the World Malaria Report 2016, reveals a 0.9% and 2.05% reduction in malaria incidence cases and deaths respectively. This means that in the year 2016, there were 212 million incidence cases and 429000 deaths as a result of malaria worldwide. As a result of the Global Malaria eradication programme instituted by WHO in the 1950s, 79 countries eradicated malaria (Caminade and Stenlund, 2014).

The global estimate for anaemia prevalence in the year 2010 was 32.9%, with East sub-Saharan Africa having the highest burden, the hardest hit age group were children under age 5 (Kassebaum et al., 2014). Even though Iron-deficiency was the top cause for anaemia globally, malaria ranked among the top three causes of anaemia. Anaemia is known to be of greater risk

in mostly pregnant women and pre-school children. Anaemia affects 1.62 billion people world wide with almost 293 million children under-5 years, the highest percentage found in Africa (Baranwal et al., 2014). Hence, WHO categorized anaemia to aid international assessments of anaemia as a public health risk. The problem is considered severe if anaemia prevalence is ≥40%, moderate from 20% to 39.9%, and mild from 5% to 19.9% (Pita et al., 2014). A 2013 study on global burden of disease (Syed et al., 2016, Wang et al., 2014) assessed that iron deficiency anaemia is the leading cause of global years lived with disability (YLDs) from 1990 to 2013, as estimated to have affecting 619 million children and adolescents in 2013.

1.2 Burden of Malaria and Anaemia on Sub-Saharan Africa

A WHO report (2015) indicates that about 80% of all malaria infections is from Sub-Saharan Africa**.** This figure makes the continent the highest spot for malaria infections globally. Future predictions by WHO, note that malaria infections will decrease to 40% in the malaria endemic countries.

Ghana is ranked among the highest countries in Sub-Saharan African with high incidence of malaria. Malaria is most common cause of illness and death in the country (WHO, 2015). In 2013, malaria constituted over 38% of hospital consultations and 17.6% of those admitted die of the disease. Furthermore, in 2013, there were 528 000 deaths from malaria, 78% of these deaths occurred in children less than 5 years of age (Pond, 2013, Stevens et al., 2015, Walker et al., 2015).

Sierra Leone is another Sub-Saharan African country with a high reported incidence rates of malaria. A study conducted by Sierra Leone Micronutrient Survey (Wirth et al., 2016) found

the malaria prevalence in children aged under 5 to be 52.6%. It is reported that malaria causes the death of 1 in every 11 children before they reach age 1. Furthermore, 1 in every 7 children does not stay alive to his or her fifth birthday due to malaria (Walker et al., 2015).

Another leading cause of deaths in children is anaemia. Globally, it is predicted that anaemia affects 43% of children less than 5 years old (Masukume et al., 2015). Thus like malaria, the occurrence of anaemia is a serious communal health concern for children in most African countries (Wirth et al., 2016). Anaemia is one of the main complications often noticed in malaria infections and augments its morbidity and mortality. On the other hand, most malaria attributed mortality is ascribed to severe anaemia, and research has revealed strong evidence to effectively show this notable interaction between the epidemiological causative pathways of malaria and anaemia (Adebayo et al., 2016). Severe anaemia due to malaria (SMA) is the most recurrent severe disease manifestation in intensely feverish children with ascetic malaria in Cameroon (Sumbele et al., 2015).

1.3 Statement of problem

Malaria and anaemia are two leading public health concerns globally, particularly among children and pregnant women in developing countries (WHO, 2016). A number of studies have emphasized the importance of understanding prevalence of malaria and anaemia (Muoneke, 2011; Semedo, 2014; Noland, 2014; Chitunhu and Musenge, 2016). Evidence of this is seen in high incidence rates reported across the globe. WHO (2016), in 2015 it was reported that was

212 million new malaria cases globally, with Africa accounting for most global cases of malaria (90%). Such understanding arguably guides policy decisions and interventions aimed at curbing the incidence rates of those epidemic diseases (Waller, 2010). Above all, an estimated 429 000 deaths was globally reported in 2015 which was as a result of malaria, again most of these deaths occurred in the African Region (92%) (WHO, 2016). The most vulnerable groups of people at risk or infected with malaria are children and pregnant women (Schicker et al., 2015).

In spite of this, there is a dearth of empirical research that establishes our understanding on the prevalence of malaria and anaemia in the endemic regions of Ghana.

1.4 Justification for the study

Understanding the spatial distribution and factors allied with the prevalence of malaria and anaemia will provide more insight and provide practical guidelines to the formulation of policies aimed at fighting the spread of malaria and anaemia. Thus policy makers are well informed of the high prevalence of malaria and anaemia. What is extensively unidentified is the prevalence within exact socio-demographic subdivisions as well as sub-regional areas with precise requirements. Hence, appreciating the spatial distribution and factors linked with malaria and anaemia morbidity among Ghanaian children less than 5 years of age will directly help in the distribution of scarce resources to the appropriate target areas. Further, identifying the specific factors associated with malaria and anaemia is important in prioritizing interventions and revealing patterns for better results.

1.5 Research Question

In an attempt to address the research problem, this study seeks to answer the following key research question:

What factors are associated with the morbidity of malaria and anaemia among Ghanaian children under 5 years and how are these spatially distributed?

1.5.1 Aim

The aim of the study is to determine spatial distribution and factors associated with malaria and anaemia morbidity among Ghanaian children under 5 years of age in 2014.

1.5.2 Study objectives

To achieve the objective mentioned above, the following definite objectives are set:

1. To determine the prevalence and spatial distribution of malaria morbidity in children under age 5 years in Ghana in 2014.
2. To ascertain the prevalence and spatial distribution of childhood anaemia morbidity in Ghanaian children under age 5 years in 2014.
3. To determine the spatial distribution of factors associated with childhood malaria morbidity in Ghana in 2014.
4. To determine the spatial distribution of factors associated with anaemia morbidity in Ghana in 2014.

1.6 Conceptual Framework

This conceptual framework represents a relationship between factors that influence the prevalence of malaria among the under-fives in Ghana. This converging radial show relationships of concepts or components to a central idea (malaria and anemia prevalence) in a cycle.

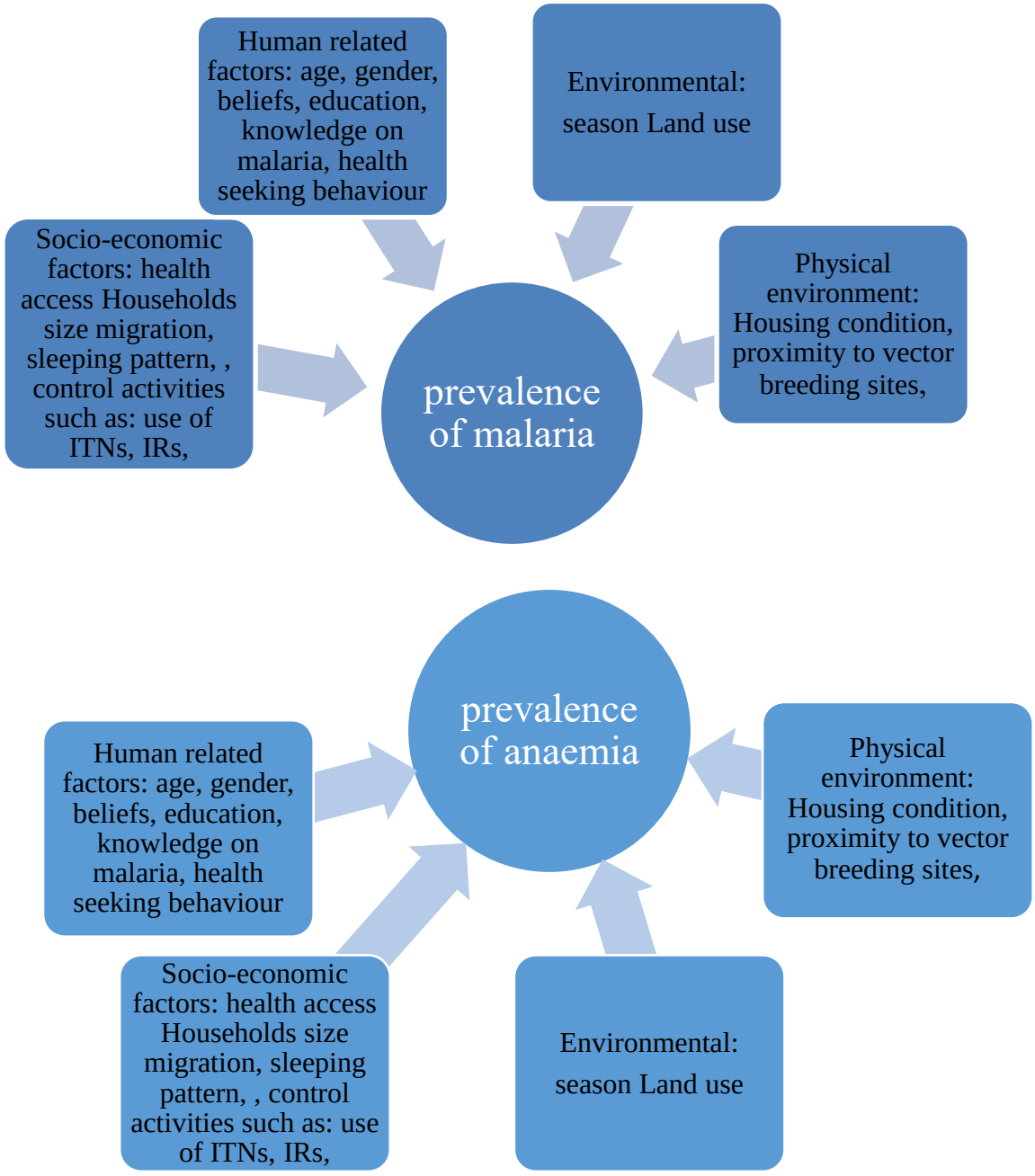

Figure 1.1 Conceptual framework of malaria and anaemia prevalence

1.7 Structure of the thesis

The second chapter reviews the relevant literature on the factors associated with the morbidity of malaria and anaemia among Ghanaian children under 5 years and how are these spatially distributed. Firstly, malaria and anaemia as diseases will be outlined and their impact globally and locally will also be assessed. The application of geographical information systems and remote sensing in disease mapping will be reviewed and how it can contribute to spatial modelling. Subsequently, Bayesian approaches will be outlined as a confirmatory analysis for unstructured random effects and the final modelling technique for the models with unstructured and structured random effects. Finally, the selected risk factors of malaria and anaemia morbidity and prevalence will be discussed to show their relevance to the study.

Chapter three describes a detailed description of the materials and methods employed for the study by outlining the data and the techniques used in data management, model formulation and development.

Chapter four presents and discusses the results and main findings relevant to this study. The results of the spatial modelling are outlined. Spatially adjusted malaria and anaemia prevalence maps produced will be presented.

Chapter five will conclude the study. The aim and objectives presented initially are reviewed to establish if they were achieved by this study. A brief synopsis of the main findings and implications of the study will be provided. Finally, the limitations of this study are appraised and recommendations for future research in this field are suggested.

Chapter 2 Literature review

2. Literature review

2.1 Definition of Malaria and Anaemia

Malaria is a vector ailment triggered by Plasmodium parasites. These parasites are spread to individuals through the bites of septic female *Anopheles* mosquitoes . Children who have acute malaria normally develop one or more of the following symptoms: severe anaemia, respiratory distress in relation to metabolic acidosis, or cerebral malaria (http://www.who.int/malaria-terminology). In malaria endemic areas, individuals may develop partial defence, countenancing asymptomatic infections to happen.

On the other hand, WHO defines anaemia as an illness in which the quantity of red blood cells or their oxygen-carrying capacity is deficient to meet physiologic needs, which differ by sex, age, pregnancy, altitude and smoking status with iron scarcity understood to be the most mutual cause of anaemia universally (http://www.who.int/topics/anaemia). Additionally the WHO, revealed that the direct causes of anaemia are poor dietery intake; increased need for nutrient due to growth or disease; malaria; tuberculosis and genetic blood diseases. Other contributing causes are poverty; poor knowledge and behaviour; environment and lack of access to services. In its ascetic form, the symptom is concomitant with drowsiness, weakness, fatigue, and dizziness.

2.2 **Burden of Malaria and Anaemia on Ghana**

It has been acknowledged that malaria is closely linked with underdevelopment. Hence, a major threat to public health in Ghana, since the country is categorised among the malaria endemic countries. The burden of the disease is a challenge to child survival especially among children under age 5 years. Likewise, malaria is the principal cause of disease and mortality among children under 5 years in the country (GSS, 2015). Besides, 2.2 million suspected cases of malaria reported in the first quarter of 2016 among all ages, in the first quarter of 2016, representing a 3.50% increase over 2015. It is worth noting that, the total deaths attributable to malaria within the first quarter of 2016 was 379 representing a reduction of 15.2 % to the 2015 figures. Surprisingly, of these malaria deaths, 152 occurred among children under 5 years in 2016 compared to 182 in 2015. Further, there was a marginal decrease in case fatality rate amongst children under five years from 0.42% in 2015 to 0.39% in 2016 (figure 2.1). This reduction may be due to improved case management systems such as: Intermittent Preventive Treatment in Pregnancy (IPTp), Long Lasting Insecticidal Nets (LLIN) that were implemented in all 30 sentinel sites within the country (GHS, 2016). According to the WHO, granting the fact that substantial improvement has been made in the combat against malaria, the burden of the disease is still very high, especially in Africa, with 80% of the global malaria cases coming from the region in 2015 (Organisation, 2016). The WHO, reported that the economic impact of malaria on Africa is estimated to cost $12 billion per year, the reason for urgent need for further pragmatic efforts to reduce this preventable disease to its minimum (Organisation, 2015).

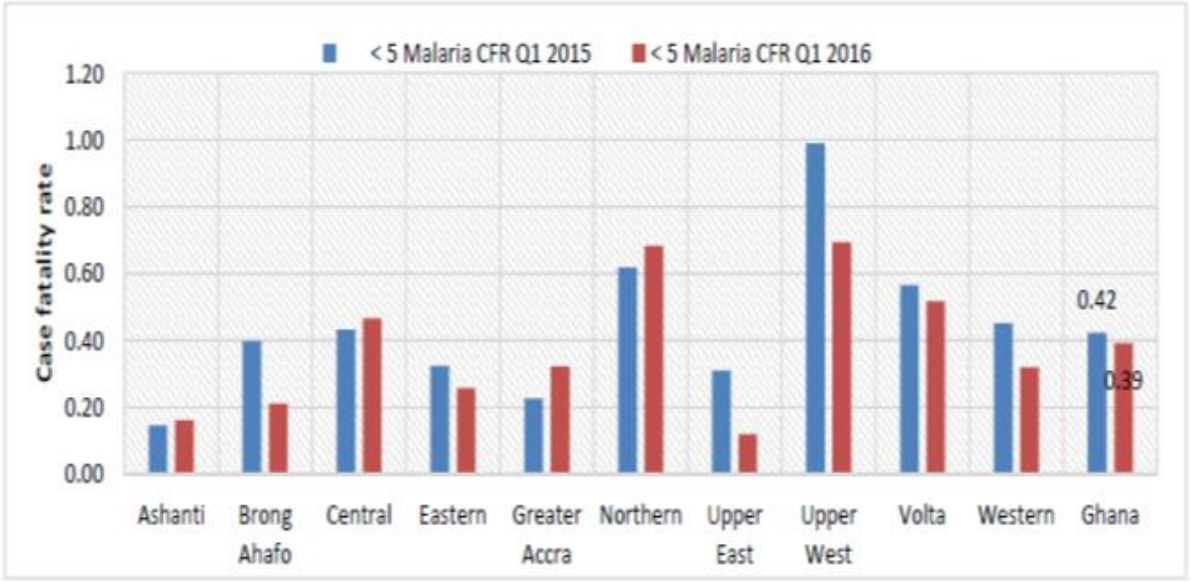

Figure 2.1– Malaria Case fatality rates for children under five years, Regions, 1st Quarter of 2016. Source: GHS quarterly report, 2016.

2.3 **Factors contributing to high incidence rate of malaria and anaemia in Sub-Saharan Africa**

According to Semedo (2014), the age of a child (below age 5 years), diarrhoea incidences, and the appalling conditions in household were the key determinants that mostly contributed to the observed anaemia prevalence. These combination factors they argued, may possibly result in anaemia in up to 80% of children (Semedo et al., 2014). In regions with high reports of severe and prolonged infection, swelling may also be a collective cause, notwithstanding the difficulty

to completely isolate from other factors (Sumbele et al., 2015). This is important in order to target the available limited resources to areas of where they are required the most for the greatest effect in malaria control (Kazembe et al., 2006). Identifying the causal factors of malaria in a low income Sub-Saharan nations is useful in supporting the advance of health agendas targeted at helping to reduce the problem of malaria with existing resources and interventions in order to ease the problem of malaria on the population (Chitunhu and Musenge, 2016). However, a recent study revealed that microscopic results yielded enormous over diagnosis of malaria cases with a mean rate of errors as high as 85%, implying that most patients who received malaria treatment had a wrong treatment. Overestimated malaria diagnosis and treatment may have severe consequences when avoided (Manguin et al., 2017).

A contrasting view was however presented by Sumbele (2015). The study noted a significantly high prevalence of malarial anaemia and anaemia in urban children under 6 years, 26.8% as compare to rural children with a prevalence of 14.8% (Sumbele et al., 2015). This explains why malaria and anaemia may show heterogeneity with the geographical location of residence or settlement. Hence separating malaria risk factors into its constituents, may provide efficient confirmation on which factors can be directed for decreasing malaria risk and exposure to the illness. Additionally, low parasite concentration is allied with malarial anaemia while negative malaria parasite and microcytosis is associated with anaemia. An anaemia study done by Simbauranga (2015), with under-five children revealed a 77.2 % prevalence among children with anaemia. It also noted that factors such as associated parent unemployment, malaria parasitaemia and iron deficiency were associated with this high anaemia (Simbauranga et al., 2015).

A comparable study by Ngesa and Mwambi (2014), found that the risk of anaemia decreased with progressive increases in the child's age, as it was observed that children less than age 1 year were at the main risk to acquire anaemia. This explains why malaria status of a child is positively associated with risk of anaemia. Additionally the study noted that, anaemia in male children was considerably greater compared to female children. Moreover, mothers who attained secondary education and beyond were much exposed to protecting anaemia risk on their children (Ngesa and Mwambi, 2014). A 54.6% and 56.3% malaria parasitemia and anaemia respectively, were found in a study aimed to ascertain malaria and anaemia prevalence among inpatient children under age 5 years (Kiggundu et al., 2013). Subsequently, a spatial study by Gayawan (2014) revealed the existence of high risk haemoglobin concentration in children among additionally risk factors such as household wealth index, sex of the child, and fever as main contributing determinants of anaemia (Gayawan et al., 2014).

Other researchers have also showed that factors such as precipitation and day temperature may determine the presence of malaria within a locality or an area (Lowe et al., 2013, Giardina et al., 2015). On the other hand, additional factors worth noting including age of both mother and child, education, haemoglobin, position in household, wealth index and socio-economic status (SES) may directly and indirectly impact malaria morbidity (Chitunhu and Musenge, 2015). Also Siri (2014), with additional evidence supported the fact that level of maternal education, household resources, were individually associated with childhood malaria risk (Siri, 2014).

2.4 **Under age 5 years malaria and anaemia prevalence in Ghana**

Epidemics of infectious disease foist a heavy burden on susceptible populations (children under age 5 years). Malaria a vector-borne disease, despite recent progress in eradication and control by the country, malaria remains the most prevalent vector-borne disease. WHO for the past decades has been providing most of the global anaemia surveillance, although the reports have concentrated on iron dearth and encompassed at most 4 age groups with diminutive description by severity or cause (WHO, 2016). A study by Aimone and Donald (2013) found a correlation between iron deficiency anaemia and protection against malaria infection, besides a correlation between iron supplementation and upsurge in risk of malaria related mortality (Ashley Mariko Aimone, 2013).

A review by Syed et al (2016) found that malaria was highly associated with anaemia compared to malnutrition (Syed et al., 2016). More so, there are concerns of the adverse impact of anaemia in children with regard to their reasoning and behavioural growth pattern as they advanced in age.

Ewusie et al (2014) noted that, Ghana's overall anaemia prevalence in 2008 among children under 5 years was 78.4%. The researchers further argued that not only is the anaemia prevalence high in children, but also that it negatively affected their reasoning and behavioural development in later years (Ewusie et al., 2014). A parallel study found that child's age, mother's age, place of residence and mother's level of education were central contributing factors of anaemia in Ghana (Frank Mawutor Borbor, 2014). Tay (2015) revealed from their

studies that most participants diagnosed of malaria infection were found to be anaemic, 93.6% (Tay et al., 2015)

According to Owusu et al (2014), climatic or weather conditions within an area coupled with inadequate protection on the part of residents against malaria infection, can negatively impact children in the community. The reason may be that it would result in some asymptomatic children with *P. falciparum* becoming symptomatic and later causing fatality in under 5 year olds (Owusu et al., 2014). A research conducted by Aimone et al (2016), further disclosed that the risk of infection amongst young children from malaria prevalent regions may have a probable spatial pattern which is related with geographical features, like altitude and distance to a health facility, since these children may have baseline symptoms of malaria parasitaemia (Aimone et al., 2016).

In addition Fobil (2012) presented solid evidence of spatial autocorrelation, that established a relationship between mortality and socioeconomic; environmental conditions. This study, suggested that both socioeconomic and the environmental covariates may be essential risk factors for urban malaria mortalities (Fobil et al., 2012). Krefis (2010) further observed that socioeconomic condition were meaningfully associated with malaria, at the rural level where economic variances were not much noticeable (Krefis et al., 2010, Krefis et al., 2011). In addition, Adu-Prah (2015) also observed that malaria prevalence may vary broadly with regards to the geographic region, year, and season of a country. He explained, two significant

factors such as humidity, temperature and marginal evidence of rainfall were associated with malaria prevalence in Ghana over that past years (Adu-Prah and Tetteh, 2015).

2.5 Spatial Analysis in Epidemiological studies

Spatial analysis involves both spatial statistical and non-statistical methods, which seeks to apply probing techniques to present good explanation of the data such as in any traditional analysis, and consequently help the definition of hypothesis as well as the choice of the suitable models. Key distinguishing feature of spatial statistical analysis, in comparison to the traditional statistical models, is that the locations where the events happened are, explicitly, offered in the analysis (Pina et al., 2010). Spatial analysis (SA) most often depends on a collection of techniques for analysing geographical events (a collection of point, line or area objects, located in geographical space, attached to which are a set of one or more attribute values), where the results of analysis depend on the spatial arrangement of the events. In contrast to other forms of analysis, therefore, SA requires information both on attribute values and the geographical locations of the objects to which the collection of attributes are attached.

In most epidemiological studies, the fundamental question of interest is to identify factors that either increase or decrease the individual risk of observed disease in at-risk populations or samples from the at-risk population. However in spatial studies, the additional view is to enhance this vital question to discover spatial variations in the risk of disease in order to detect places and most significantly, people associated with greater risk of the disease (Waller, 2010).

Chapter 3 Materials and Methods

3 Material and methods

3.1 Primary study design

The standard Demographic and Health Survey (standard DHS), 2014 survey dataset was used in this study. The Standard DHS are designed to encompass the national populace and includes a wide range of households. Individuals from household roster, were identified to conduct studies in addition to the household surveys. Here, women and men aged between 15–49 years and children aged 0–59 months were included into the survey (Corsi et al., 2012).

3.2 Study design

This study was a spatial cross sectional survey study, where secondary data from the standard DHS, of the Ghana Demographic and Health Survey programme (GDHS), 2014 were used for the statistical analysis. The 2014 GDHS provided data on health situations that were monitored in the Ghanaian population. This data were acquired from the Demographic and Health Survey programme website (measureDHS). The data were derived from a sample of households that was selected throughout the ten geographical regions (Central, Western, Northern, Greater Accra, Ashanti , Upper East, Eastern, Volta, Upper West and Brong Ahafo) in Ghana. A total sample size of 3197 children tested for malaria/anaemia from the primary study was used; it was also established whether the data had at least 80% power, thus to provide the ability of the

study to detect a difference if a difference existed. This was a secondary data analysis of all the children under five years with confirmed malaria (prompt parasitological confirmation by microscopy) and anaemia to determine the malaria and anaemia morbidity and spatial distribution and factors of malaria and anaemia in Ghanaian children below age five years.

3.3 Study population

All children under five years of age with both malaria and anaemia confirmed test results from the Ghana Demographic and Health survey (GDHS) in 2014 were included in this study.

3.4 Study sample

The primary study used stratified sampling procedure, where a two-stage cluster sampling technique was used to select the households from the sampling frame. In the initial stage, 427 enumeration areas (EAs) were chosen with probability proportionate to the EA size and with independent selection in respective sampling stratum. EAs provided the blue print for drawing 37641 clusters (16503 urban and 21138 rural), nominated with a likelihood proportional to their size. The opening stage involved selecting primary sampling units (PSUs), also called clusters, based on the list of enumeration zones created in the 2010 Population and Housing Census (PHC) provided by the Ghana Statistical Service (GSS, 2015). Each EA encompassed a geographical zone covering an average of 145 households. Politically, Ghana is divided into ten geographical regions. Stratification was achieved by further dividing each region is into a quantity of districts, cumulatively there are 170 districts. However, after the 2010 census, the

government transformed the second level administrative units by splitting some of them, which resulted in a total of 216 districts currently in Ghana.

To abate the duty of household listing for EAs with greater than 200 households, each large EA was subdivided. Only single segment was designated for the survey with likelihood proportional to the segment size. Thus, household listing was conducted only in the selected segment. So, a 2014 GDHS cluster was either an EA or a segment of an EA.

Stage two of selection, involved a static number of 30 households for each cluster selected with an equal likelihood systematic selection from the newly generated household listing. The survey questioners visited and interviewed only the chosen households. A total number of 319 households were permitted during data collection, in order to obviate bias. All women age 15-49 who were usual affiliates of the selected households or who spent the night before the study in the selected households were eligible for the female survey. In fifty percent of the selected households, all men age 15-49 who were usual members of the families or who spent the night before the survey in the households were entitled for the male survey (GSS, 2015).

3.5 Study area

Geographically, Ghana is centrally situated on the coast of West African. It's total land area is 238,537 square kilometres, and bordered: Burkina Faso on the north and northwest, Côte d'Ivoire on the west and Togo on the east. The sea (Gulf of Guinea) lies to the south and spans across the 560-kilometre shoreline.

Ghana has tropical weather with temperatures and rainfall patterns that differ according to distance from the coast and altitude. The eastern coastal area is comparatively dry, the southwestern corner is hot and humid, and the north of the country is hot and dry. The mean yearly temperature is approximately 26ºC (79ºF). The country has two distinctive rainy seasons in the middle and southern parts of the country, ranging between April to June and September to November. Conversely, the North is, characterised by one rainfall period that begins in May, crests in August, and continues until September. Yearly rainfall ranges from about 2,030 millimetres (80 inches) in the Southwest to about 1,015 millimetres (40 inches) in the North. The harmattan, a dry dusty desert wind, blows from the northeast and covers much of the country between December and March, dropping the moisture and visibility, and also creates very warm days and cool nights in the North. In the South, the effects of the harmattan are felt mainly in January.

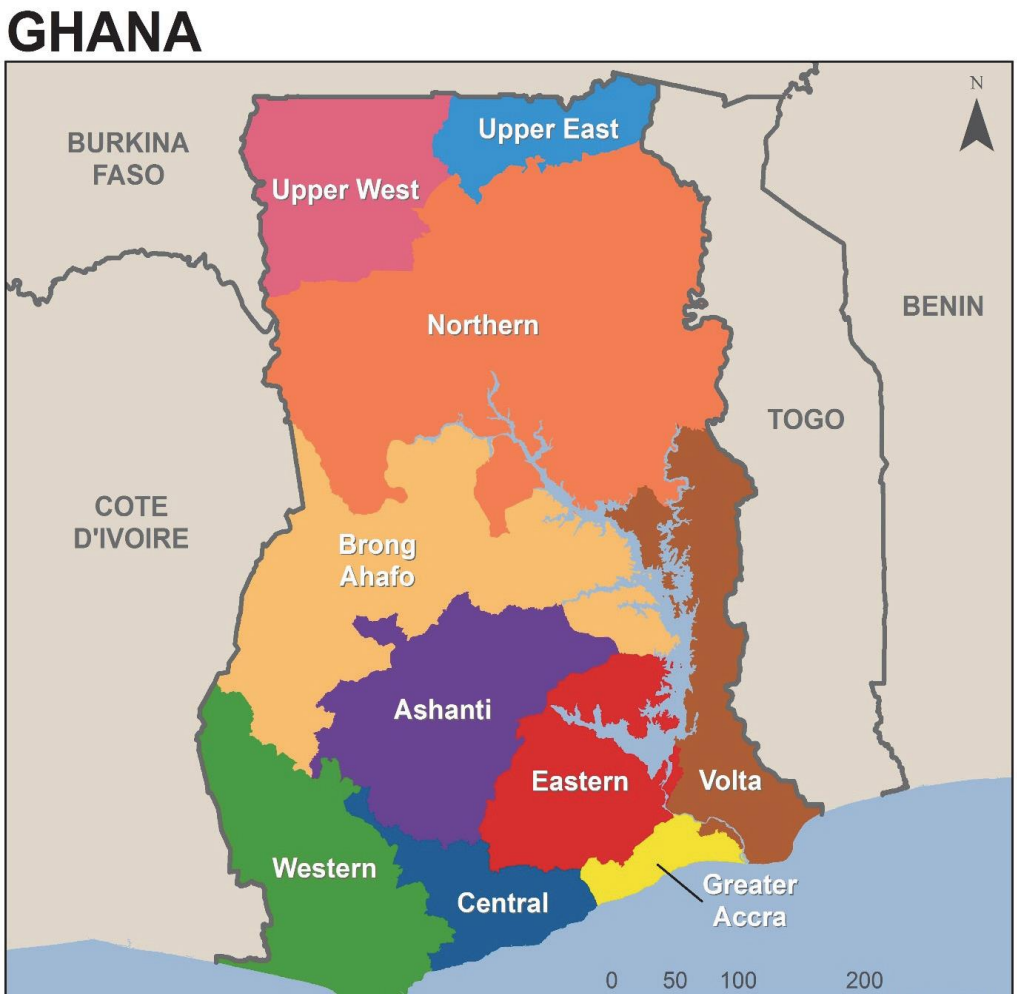

Figure 3.1– Map showing the ten administrative regions of Ghana. Source (2014 Ghana Demographic and Health Survey).

3.6 Data Analysis

A total of 11835 households were designated for the data collection. Data was collected using a questionnaire that collected the household features, identified all household members and their basic characteristics. Data about children younger than 5 years of age were collected from their guardians. Malaria and anaemia in children under age 5 years were confirmed at the household level using a rapid diagnostic test kits. It was established that data used in this study had a greater than 80% power, during the sample size calculation in the primary study.

3.6.1 Predictor (Independent) variables

The predictor covariates comprised geographic and demographic variables that included sex of the child, age of the child, use of mosquito bed net, region, cluster altitude, child's altitude adjusted haemoglobin level, time taken to collect water, type of place of residence (urban; rural), and variables in the household: mother's education, the wealth index and mother's knowledge of malaria. Statistics on household assets (example, source of water, electricity, television, radio, refrigerator, owns cattle, house construction materials, owns goat, and owns chickens) were collected and used to create a wealth index.

The wealth index is a quantity the DHS include in their studies, and is based on principal component analysis designed by Prittchett and Filmer (Corsi et al., 2012). The index is an gauge of family wealth and takes into account asset property of the household. In this regard, the index is planned to be comparative measure, and the factor marks are comparable within a study, but not across studies. To relate across surveys, the wealth quintiles could be a valuable

quantity to estimate fluctuating wealth gradients or patterns for varied quintiles, however it does not account for the change in absolute wealth across or within the quintiles. Child's age in months, is a continuous individual level variable in the analysis ranging from (0-59) including (males and females children); use of mosquito bed net, is a variable describing the health seeking behaviour of mothers in relation to their of the children; region, describes the geographical position of the household. Ghana has ten regions (Ashanti; Brong Ahafo; Greater Accra; Upper West; Eastern; Western; Central; Northern ; Volta; Upper East); cluster altitude in meters, is a continuous variable that explains the cluster altitude of the household in meters above sea level; mother's highest education level, is also an individual level continuous variable in the analysis which is categorized into four (no education; primary; secondary; higher), which explains the years of education acquired by the mothers of individual children.

3.6.2 Response (outcome) variables

Twofold response variables were used in this study: one binary, specifying whether or not a child has malaria, and a four category variable (for measuring factors correlated to anaemia sternness). The first outcome is malaria blood smear result (malaria microscopy test). Microscopic analysis remains the "gold standard" for laboratory validation of malaria because it is a moderately simple method that is conversant to most laboratories. Most laboratories that perform routine haematology examinations are equipped to perform a thin and thick malaria smear. The technique used is to smear blood specimen collected from the children and then spread as a thick or thin blood smear, stained most often with Giemsa, and studied with a 100X

oil immersion objective. The thin and thick smears of the microscopy test can provide valuable evidence. Firstly, it can determine that malaria parasites are present in the child's blood typically by identifying parasites in the thick smear. Secondly, laboratories can inspect the thin smear to examine the malaria species and the parasitemia. These vital pieces of information guide the physician in the initial cure decisions that need to be made intensely. As a result, the response variable is binary, specifying whether or not a child was positive or negative for malaria.

Blood specimens for anaemia testing were collected from all children age 6-59 months, for whom approval was obtained from their guardians. Samples of blood were drawn from a drop of blood taken from a heel prick in the case of children age 6-11 months or finger prick and collected in a microcuvette. Analysis of haemoglobin was carried out on-site by means of a battery-operated handy HemoCue analyser. The second outcome variable is anaemia which has four categories: namely severe anaemia (Hb levels <7 • 0 g/dl); moderate anaemia (Hb levels 7 • 0 g/dl-9 • 9 g/dl); mild anemia (Hb levels 10 • 0 g/dl-10 • 9 g/dl) and not anaemic (Hb levels > 10 • 9 g/dl), determined based on the child's Hemoglobin (Hb) levels using the HemoCue test kit. The WHO reference cut-off values to diagnose anaemia in children are as follows: children 6–59 months of age 109 g/l or less, children 5–11 years of age 114 g/l or less and children 12–14 years of age 119 g/l or less. Altitude modifications were carried out, as not all the districts are located at sea level.

3.6.3 Data Management

Initial, data cleaning processes included: checking for duplicates, missing values, deleting or imputing values, renaming, recoding and categorizing variables for easy identification and usage during the statistical analysis process. Data received from the measureDHS website on the GDHS for 2014 is in Stata format. Hence, data were extracted for analysis using Stata®14 (Copyright 1985–2015, StataCorp LP).

3.7 Statistical analysis methods

Based on their complex nature, Demographic and Health Survey data, takes into cognizance the variances in sample sizes through the use of sample weights. In that respect, survey setting was done by using the regions (, Ashanti, Brong Ahafo, Western, Central, Greater Accra, Eastern, Northern, Volta, Upper East, and Upper West) and place of residence (urban or rural). Each region included both urban and rural areas so the design effect yielded 20 in total. The sample weight was calculated by multiplying household sample weight (hv005) with 573 and divided by 100, 0000. In effect, the primary sampling unit (PSU) was generated and was equal to the cluster number. The Stata command that was used to create survey setting is as below;

3.7.1 Survey setting Ghana DHS data

Survey setting Ghana DHS data:

```
egen strata = group (hv024 hv025)

gen sampwt = hv005/1000000

gen psu=hv001

svyset psu[pw = sampwt],

svyset psu[pweight=sampwt], strata(strata) vce(linearized) singleunit(missing)
```

Figure 3.2–Stata command showing how the Ghana data was survey set.

3.7.2 Descriptive and bivariate analysis

Means and percentages were used to describe demographic information of respondents (shown on maps similar to figure 3.1) by means of survey adjusted summary measures for categorical variables and well as continuous variables. With regards to categorical variables weighted percentages (proportion) were used. However, for continuous variables means and standard errors were reported as shown in Tables 4.1 and 4.2. As noted earlier, the outcome variable is individual level analysis, a binary variable on whether a given child belonging to a household is positive or negative after testing for malaria and also a categorical variable on whether a child was having severe anaemia; moderate anaemia; mild anaemia or no anaemia after testing for haemoglobin level. In the bivariate analysis, survey adjusted two-way cross tabulation was performed to identify percentage dispersal of malaria and anaemia in each district and each

covariate categories. The two-way cross tables were analysed using the Pearson's Chi-square (X^2) test, which compared groups of categorical variables. Percentages were weighted using the survey sampling weight to ensure a descriptive sample. This analysis resulted in the *F*-statistic and was later on reported as seen in Table 4.1 and 4.2. Additionally, for the continuous explanatory variables such as child's age, cluster altitude, survey univariate analysis was performed. A correlation was measured to be significant if it had a p- value of less than 0.05. Univariate and multiple variable analyses were conducted to institute the associations between positive malaria blood smear and selected factors and how they impact malaria in children under age 5 years.

In order to assess probable clustering of children with malaria and anaemia morbidity, spatial analysis was performed. A spatial scan indicator was attained using SaTScan software (Coulibaly et al., 2013). This software applied several spherical windows, these are plastic in both location and magnitude, throughout the study area. Individual discrete circle represented a likely group. For every circle, the quantity of expected and observed infected individuals was calculated, with estimated numbers calculated assuming an even dispersal of infections across the children with malaria morbidity (Price et al., 2010). Survey weighting was carried out to adjust for the differences in the sampling of clusters. Spatial clustering measures such as the global indexes for spatial autocorrelation was used to recap the degree to which analogous observations tend to occur nearby each cluster, hence determined if there was evidence of spatial association/pattern between variables. Moran's Index and Geary's Index statistics were applied to measure whether the pattern expressed was random, clustered, or dispersed. A

probability ratio test was used to match the occurrence of infection within the circle to that external it to ascertain substantial groups of greater than expected or lesser than expected occurrence.

3.7.3 Univariate and multivariable analysis

Burden of malaria and anaemia morbidity was analysed per child living in a household. Individual level malaria and anaemia associated factors in the study area were determined from literature and its availability confirmed on the questionnaire. Survey adjusted two-way cross tabulation was performed to identify percentage dispersal of malaria and anaemia in each district and each covariate categories. The two-way cross tables were analysed using the Pearson's Chi-square (X^2) test, which compared groups of categorical variables. Percentages were weighted using the survey sampling weight to ensure a descriptive sample. Univariate survey logistic regression was performed to select potential factors of malaria because the malaria outcome is binary and univariate survey ordinal logistics regression for anaemia since this outcome has four categories. Covariates that were linked with malaria and anaemia at a 10% level of significance was incorporated into the multivariable regression models. The 10% significant level rather than 5% was used in selecting covariates for multivariable survey regression analysis with the reason to permit more potential covariates to be selected.

3.7.4 Analysis for spatial models

Data on the health events (malaria and aneamia) and related measures averaged to the level of of administrative regions/districts (such as counts of cases and population at risk grouped in

areas along with corresponding socio-economic descriptors and exposure measures for these groups) can be modelled at a group level within geographical areas using Markov Chain Monte Carlo (MCMC) and Bayesian modelling methods. Risk factors were categorized into three groups: demographic (includes age and sex), environmental (region, place of residence etc.) and spatial (subject to the housing material like iron sheets, wooden furniture and animal ownership etc.) variables to describe malaria and anaemia morbidity causes in the study area and the outcome variables depends on household levels of the amount of established cases of children with malaria and anaemia. For household level analysis on morbidity of malaria and anaemia, univariate survey Poisson regression model will be used adjusted for spatial random effects.

3.7.4.1 Implementing the models in WinBUGS

Winbugs is a public domain software package for Bayesia modelling which also has a link with another public domain statistical package called R. Initially we made use of ArcMap to merge the “sharp file” with the “coordinate files” and utilised a maptools package for R (codes in appendix A.3) which allowed for the importation of maps from the ArcGIS software and the plotting of such maps in conjunction with results from the WinBUGS interface.

The final model obtained from Stata (codes in appendix A.2) was updated to fit the WinBugs models (codes in appendix A.4). The Stata data was bugsdat to obtain a data (Splus) that is usable to run a further Bayesian analysis in WinBUGS.

This Bayesian models were confirmatory for unstructured random effects modelled in Stata and was the final modelling technique for the models comprising the structured and unstructured random effects. The WinBUGS models considered a fully Bayesian approach, convolution model which includes Conditional autoregressive (CAR) priors distribution for spatial random effects. Thus, required a prior distribution on regression factors and alteration parameters of random effects distribution. Hence , the fitted models included spatially unstructured (or exchangeable) log relative risk of adjacency areas compared to the map as a whole, and a corresponding spatially structured (non-exchangeable) random effect.

Using WinBUGS, we opened the models, load the data and compiled the model with two chains. We run the iterative algorithm for 25,000 iterations, discarded the first 4,000 as “burn-in", thinning 10 and monitoring the parameters of interest. The models run to generate samples from the posterior distribution and collected summary statistics from those samples. We then extracted the results from the summary statistics into excel/tableau and returned the results to Stata for plotting the spatial disease prevalence maps (codes provided in appendix A.2.4).

3.8 Ethics approval

The research involved secondary data analysis. Data collection was done in the primary study, where unwritten informed approval for testing of children was obtained from the caregivers of selected children at the households. Consent regarding the use of GDHS data was acquired from the measureDHS website. More so in protecting the confidentially of participants, the data set was sent in an anonymised format, thereby making it difficult to identify any participant. Ethics approval for the study protocol of this secondary data analysis was presented

to the University of the Witwatersrand's Human Research Ethics Committee for Ethical approval prior to the commencement of the data analysis, which was granted. The clearance certificate number is M170207 and a copy of ethical approval certificate is attached in (Appendix A).

3.9 Possible limitations

The under listed are the possible limitations of the study:

1. The primary study collected data via a questionnaire. It registered all household members and their basic characteristics. By simply use of leading close ended questions with multiple answers such as: Education; Morbidity status; SES and Income level, to select from may lead to information bias as respondents will speculate some answers. Additionally, they may be reluctant to choose answers that reflect their cultural belief system.

2. The use of secondary data will limit the probability of exploring other factors such as detailed socio-cultural factors and closeness to health amenities, which may lead to measurement bias in the study.

3. The researchers were not involved in the detailed data collection, hence familiarity with the background to the study and the data collection may be of concern.

4. Other limitaions include social desirability bias and missing data.

Chapter 4 Results

4. Results

This fourth chapter presented a summary of factors that were correlated with malaria and anaemia prevalence among under age 5 children in Ghana in the study. The first section (4.1) provided an account of the socio-demographic and behavioural features of these children. More so the non-spatial and spatial factors associated with malaria and anaemia prevalence were discussed in the second (4.2) and third (4.3) sections respectively. Subsequently, the results of the prediction are presented in the form of risk maps and they were discussed.

4.1 Descriptive statistics

The analysis for this study covered subjects that are children under age 5 years chosen from the ten regions of Ghana. The main source of data are the measure DHS database which provides good quality data for these malaria and anaemia related morbidity and prevalence data by regions and year of survey. We analysed descriptive statistics for malaria and anaemia morbidity and prevalence.

4.1.1 Malaria and anaemia reported cases and prevalence rate

A total of 2727 children under age 5 years with both malaria laboratory-based test and anaemia test results were included in the study and were distributed as follows; malaria microscopy results presented as binary outcome were 1944 (71.29%) and 783 (28.71%) for negative results

and positive respectively. Also anaemia with ordinal categories were 854 (31.32%), 732 (26.84%), 1067 (39.13%) and 74 (2.71%) for non-anemic, mild anaemia, moderate anaemia and severe anaemia respectively in children.

Table 4.1 displays the descriptive figures for both unweighted and survey weighted data that were selected for analysis considering the relationship between the selected covariates and affirmative blood smear for malaria. Table 4.2 displays the descriptive statistics regarding the proportion of covariates that are associated with the categories of anaemia. The occurrence of mild, moderate, severe anaemia were observed as 26.84%, 39.13%, and 2.71%, respectively. Thus the prevalence of moderate anemia was high in comparison to the other grades of anaemia.

4.1.2 **Malaria and anaemia according to age and gender**

A significant relationship was established between malaria and child's age ($p< 0.001$). The mean and standard error (SE) age was 31.48 (0.35) and 35.49 (0.53) months for malaria negative and positive respectively. Likewise, significant correlation was established between anaemia and child's age. The mean and SE age presented was 32.96 (0.56), 29.79 (0.46), and 25.57 (1.65) for mild, moderate and severe anaemia in that sequence.

4.1.3 **Malaria and anaemia according to wealth index and mother's educational level**

A significant relationship was apparent between malaria and wealth index (WI) (χ^2 = 205.44, p< 0.001). Children from the poorest wealth category were more probable to have high malaria prevalence compared to those in the other four categories. Mother's highest educational level show a significant association (χ^2 = 103.87, p< 0.001). A larger proportion of children with malaria episodes were more likely to have had mothers who had no education, 333 (42.53%) at all, compared to children who had mothers that are likely to have attained primary, 173 (22.09%) secondary, 194 (24.78%) and higher, 2 (0.26%) school education.

The percentage of children under 5 years of age suffering from moderate anaemia in the poorest and poorer were high (40.11% and 23.90%, respectively) as compared with the wealth index status (19.12%, 11.43%, and 5.44% in the middle, richer and richest categories, respectively). It was observed generally that as the wealth index status increased, anaemia prevalence decreased. Risk of anaemia as compared with the poorest wealth index was 0.82 times protection in poorer, 0.57 times protection in middle, 0.36 times protection in richer and 0.22 times protection in richest. Thus, lower wealth index status was allied with the increase in the danger of development of anaemia in children. This association between the wealth index status of the family and anaemia among children under 5 years was found to be statistically significant (p< 0.001).

Table 4.2 revealed that proportions of children under age 5 years suffering from severe anaemia were 50.0%, 21.62%, 22.97%, and 0.0% among mother's who had no education, those educated up to primary, secondary school, and higher education level, respectively. It was

found that the lower the level of education of the mother, the higher the probability of the child suffering from anaemia. This relationship was found to be statistically significant ($p< 0.05$). Among the children whose mothers had no education, the percentage of moderate anaemia was found to be 40.96% which was twice as compared with mothers who attained at least basic primary education. It was found that the proportion of the children who suffered from mild anaemia decreased in those whose mother's had primary, secondary and higher education, progressively. The risk of anaemia was 0.64 times protection in children with mothers with no education, whereas it was 0.4 times protection in children whose mothers had secondary education and 0.17 times protection in children with mothers with higher level of education as compared with the children whose mothers had no education. This association between the mothers educational status and anaemia in the offsprings was found to be significant statistically ($p< 0.05$).

Table 4.1 – Socio-demographic characteristics as well as prevalence of malaria in children under age 5 years in 2014

MALARIA							
	Unweighted				Survey weighted		
variables	category	Blood smear negative (n = 1,944 (71.29%))	Blood smear positive (n = 783 (28.71%))	test statistics (p-value)	blood smear negative (n = 1,944 (73.49 %))	blood smear positive (n = 783 (26.51%))	F statistics (p-value)
Child's age in months	mean ± SE	31.48±0.35	35.49±0 .53	0.0000	31.63±0.37	35.15±0.65	F = 21.64 0.0000
Child's altitude adjusted haemoglobin level	mean ± SE	104.73±0.32	93.01±0.56	0.0000	105.59±0.49	93.65±0.89	F = 162.04 0.0000
Children under 5 slept under mosquito bed net last night	no	953 (49.02)	329 (42.02)	χ^2= 16.54 (<0.000)	953 (51.75)	329 (42.98)	F= 9.21 (<)0.0001
	yes	960 (49.38)	449 (57.34)		960 (46.46)	449 (56.41)	
Region	Western	170 (8.74)	112 (14.30)	χ^2 = 128.63 (0.000)	170 (8.97)	112 (15.6)	F=7.19 (<0.0000)
	Central	185 (9.52)	112 (14.30)		185 (10.03)	112 (16.9)	
	Greater Accra	185 (9.52)	27 (3.45)		185 (18.47)	27 (6.21)	
	Volta	153 (7.87)	57 (7.28)		153 (7.53)	57 (6.89)	
	Eastern	170 (8.74)	170 (9.58)		170 (8.73)	170 (10.14)	
	Ashanti	218 (11.21)	44 (5.62)		218 (19.09)	44 (10.65)	
	Brong Ahafo	237 (12.19)	94 (12.01)		237 (10.01)	94 (9.96)	
	Northern	265 (13.63)	153 (19.54)		265 (10.19)	153 (18.27)	
	Upper East	218 (11.21)	28 (3.58)		218 (4.83)	28 (1.77)	
	Upper West	143 (7.36)	81 (10.34)		143 (2.15)	81 (3.61)	
Type of place of residence	urban	941 (48.41)	169 (21.58)	χ^2 = 166.37 (< 0.000)	941 (54.15)	169 (23.37)	F=76.76 (<0.0000)
	rural	1003 (51.59)	614 (78.42)		1003 (45.85)	614 (76.63)	

Cluster altitude	Mean ±SE	172.83±2.45	164.43±3.24	0.0561	157.17±5.53	152.25±6.27	F= 0.57 (0.0004)
Mother's highest education level	no education	567 (29.17)	333 (42.53)	χ^2 = 103.87 (0.000)	567 (22.66)	333 (37.9)	F= 20.46 (<0.0000)
	primary	330 (16.98)	173 (22.09)		330 (16.17)	173 (22.53)	
	secondary	795 (40.9)	194 (24.78)		795 (47.98)	194 (29.52)	
	higher	74 (3.81)	2 (0.26)		74 (3.91)	2 (0.27)	
Mother knowledge of malaria	no	1877 (96.55)	753 (96.17)	χ^2 = 0.103 (0.748)	1877 (95.2)	753 (94.81)	F=0.12 (0.73)
	yes	67 (3.45)	30 (3.83)		67 (4.8)	30 (5.19)	
Wealth index	poorest	528 (27.16)	345 (44.06)	χ^2 = 205.44 (0.000)	528 (18.03)	345 (35.78)	F=27.86 (<0.0000)
	poorer	362 (18.62)	233 (29.76)		362 (17.13)	233 (30.58)	
	middle	395 (20.32)	126 (16.09)		395 (21)	126 (18.95)	
	richer	358 (18.42)	52 (6.64)		358 (22.03)	52 (9.86)	
	richest	301 (15.48)	27 (3.45)		301 (21.81)	27 (4.84)	
Time to get to water source	<10	475 (24.43)	121 (15.45)	χ^2 = 129.34 (0.000)	475 (31.99)	121 (18.31)	F = 13.19 (0.000)
	10 to <20	526 (27.06)	251 (32.06)		526 (25.16)	251 (32.44)	
	20 to <30	273 (14.04)	119 (15.20)		273 (11.87)	119 (13.72)	
	30 to <40	172 (8.85)	106 (13.54)		172 (8.04)	106 (13.26)	
	40 to <50	71 (3.65)	61 (7.79)		71 (2.64)	61 (6.14)	
	50 to <60	18 (0.93)	15 (1.92)		18 (0.85)	15 (1.89)	
	60 to 180	93 (4.78)	69 (8.81)		93 (3.56)	69 (8.01)	

	Unknown time	316 (16.26)	41 (5.24)		316 (15.89)	41 (6.23)	
sex	male	932 (52.06)	405 (51.72)	$\chi2 = 0.03$ (<0.875)	932 (52.87)	405 (51.92)	F = 0.11 (0.75)
	female	932 (47.94)	378 (48.28)		932 (47.13)	378 (48.08)	

Table 4.2 – Socio-demographic characteristics as well as prevalence of anaemia in children under age 5 years in 2014

ANAEMIA											
		Unweighted					survey weighted				
variable	category	Not anemic (n= 854 (31.32%))	Mild (n= 732 (26.84%))	Moderate (n= 1,067 (39.13%))	Severe (n=74 (2.71%))	test statistic (p-value)	Not anemic (n= 854 (33.98%))	Mild (n= 732 (26.51%))	Moderate (n= 1,067 (37.27%))	Severe (n= 74 (2.24%))	F-statistics (p-value)
Child's age in months	mean ± SE	36.51± 0.51	32.96± 0.56	29.79± 0.46	25.57±1.65	<0.000	36.58±0.58	32.69± 0.73	29.29± 0.51	24.83± 1.88)	F= 29.65 (<0.000)
Severe anemia vomiting	no	849 (99.41)	731 (99.86)	1045 (97.94)	63 (85.14)	χ2= 117.92 (<0.000)	849 (99.52)	731 (99.88)	1045 (97.75)	63 (83.41)	F= 17.7 (<0.000)
	yes	4 (0.47)	1 (0.14)	21 (1.97)	11 (14.86)		4 (0.38)	1 (0.12)	21 (2.09)	11 (16.59)	
Region	Western	98 (11.48)	79 (10.79)	95 (8.90)	10(13.51)	χ2=128.09 (< 0.000)	98 (11.1)	79 (11.35)	95 (9.75)	10 (13.92)	F= 3.3194 (<0.000)
	Central	86 (10.07)	76 (10.38)	126 (11.81)	9 (12.16)		86 (10.32)	76 (11.05)	126 (13.86)	9 (11.1)	
	Greater Accra	80 (9.37)	62 (8.47)	67 (6.28)	3 (4.05)		80 (17.63)	62 (16.2)	67 (12.72)	3 (8.66)	
	Volta	67 (7.85)	58 (7.92)	80 (7.50)	5 (6.76)		67 (6.74)	58 (7.60)	80 (7.73)	5 (7.65)	
	Eastern	78 (9.13)	74 (10.11)	91 (8.53)	2 (2.70)		78 (9.01)	74 (9.88)	91 (8.99)	2 (3.14)	
	Ashanti	123 (14.40)	65 (8.88)	69 (6.47)	5 (6.76)		123 (22.62)	65 (15.74)	69 (12.59)	5 (13.48)	
	Brong Ahafo	119 (13.93)	96 (13.11)	108 (10.12)	8 (10.81)		119 (11.01)	96 (10.93)	108 (8.43)	8 (9.18)	

	Northern	72 (8.43)	100 (13.66)	232 (21.74)	14 (18.92)		72 (6.51)	100 (10.64)	232 (18.49)	14 (18.21)	
	Upper East	69 (8.08)	72 (9.84)	100 (9.37)	5 (6.76)		69 (3.1)	72 (4.65)	100 (4.37)	5 (4.68)	
	Upper West	62 (7.26)	50 (6.83)	99 (9.28)	13 (17.57)		62 (1.96)	50 (1.96)	99 (3.07)	13 (9.34)	
Type of place of residence	urban	426 (49.88)	306 (41.80)	361 (33.83)	17 (22.97)	χ2 =60.69 (< 0.000)	426 (55.69)	306 (47.82)	361 (37.08)	17 (25.72)	F=14.31 (<0.0000)
	rural	428 (50.12)	426 (58.20)	706 (66.17)	57 (77.03)		428 (44.31)	426 (52.18)	706 (62.92)	57 (74.28)	
Cluster altitude	mean± SE	176.13±3.82	168.69± 3.90	167.57± 2.92	163.12± 10.67	0.0613	162.20± 7.07	154.94± 6.27	151.13± 6.05	149.50± 16.03	F = 2.09 0.15
Mother's highest education level	No education	181 (21.19)	245 (33.47)	437 (40.96)	37 (50.00)	χ2= 149.13 (<0.000)	181 (15.51)	245 (26.91)	437 (35.73)	37 (43.73)	F=8.87 (<0.0000)
	primary	148 (17.33)	120 (16.39)	219 (20.52)	16 (21.62)		148 (16.32)	120 (16.46)	219 (19.7)	16 (26.78)	
	secondary	375 (43.91)	288 (39.34)	309 (28.96)	17 (22.97)		375 (50.71)	288 (45.29)	309 (35.59)	17 (26.07)	
	higher	43 (5.04)	24 (3.28)	9 (0.84)	0 (0.00)		43 (5.03)	24 (3.51)	9 (0.81)	0 (0.00)	
Severe anemia extreme weakness	no	849 (99.41)	729 (99.41)	1042 (97.66)	61 (82.43)	χ2=135.97 (<0.000)	849 (99.67)	729 (99.6)	1042 (97.49)	61 (83.6)	F= 18.92 (<0.000)
	yes	4 (0.47)	3 (0.41)	24 (2.25)	13 (17.57)		4 (0.24)	3 (0.39)	24 (2.36)	13 (16.4)	
Wealth index	poorest	185 (21.66)	224 (30.60)	428 (40.11)	36 (48.65)	χ2=195.59 (<0.000)	185 (13.81)	224 (22.11)	428 (29.88)	36 (46.25)	F=12.95 (<0.0000)
	poorer	154 (18.03)	166 (22.68)	255 (23.90)	20 (27.03)		154 (15.19)	166 (20.43)	255 (25.62)	8527 (25.53)	
	middle	181 (21.19)	122 (16.67)	204 (19.12)	14 (18.92)		181 (21.54)	122 (16.06)	204 (22.51)	14 (21.67)	
	richer	156 (18.27)	129 (17.62)	122 (11.43)	3 (4.05)		156 (22.53)	129 (22.18)	122 (13.88)	3 (4.45)	
	richest	178 (20.84)	91 (12.43)	58 (5.44)	1 (1.35)		178 (26.94)	91 (19.22)	58 (8.10)	1 (2.12)	

Severe anemia no symptoms	no	698 (81.73)	480 (65.57)	471 (44.14)	39 (52.70)	χ2 = 293.27 (<0.000)	698 (85.56)	480 (70.09)	471 (46.14)	39 (55.18)	F= 43.33 (0.0000)
	yes	155 (18.15)	252 (34.43)	595 (55.76)	35 (47.30)		155 (14.35)	252 (29.91)	595 (53.72)	35 (44.82)	
sex	Male	432 (50.59)	385 (52.60)	552 (51.73)	48 (64.86)	χ2=5.72 (0.126)	432 (53.5)	385 (53.36)	552 (50.92)	48 (58.51)	F=0.56 (0.64)
	Female	422 (49.41)	347 (47.40)	515 (48.27)	26 (35.14)		422 (46.5)	347 (46.64)	515 (49.08)	26 (41.49)	

4.1.4 **Malaria and anaemia according to place of residence and region**

A total of 169 (21.58%) children were from urban areas and 614 (78.42%) were from the rural parts. A significant association was found between malaria and place of residence (χ^2 = 166.37, p<0.001). The likelihood of having malaria is about three times lower, among urban children as compared to their rural counterparts. Region was also found to be significantly associated (χ^2 = 128.63, p<.001), with the percentage of children who had malaria ranging from 3% to 20%. As mentioned earlier, the total number of children under age 5 years who confirmed for malaria using the laboratory test and had their microscopy results recorded were 2,727. The Western region had 14.3%; the Central region had 14.3% of the total cases; the Greater Accra region had 3.45%; the Volta region had 7.28%; the Eastern region had 9.58%; the Ashanti region had 5.62%; the Brong Ahafo region had 12.01%; the Northern region had 19.54%; the Upper East region had 3.58% and the Upper West region had 10.34% of total cases. The degree of severity was also examined throughout the regions (figure 2). Majority of the children under-five in all ten regions had moderate echelons of anaemia, except for the Greater Accra region, where most children, 50.3% (N=157, 95% CI: 42.3-58.3) had mild anaemia. More so, Upper East region recorded the highest prevalence of anaemia: 59.3% (N=91, 95% CI: 48.5-69.3) of the children were moderately anaemic, 34.4% (N=91, 95% CI: 25.0-45.2) were mildly anaemic and 6.3% (N=91, 95% CI: 2.5-14.0) had severe anaemia. Northern region recorded the maximum prevalence of severe anaemia, 15.1% (N=259, 95% CI: 11.1-20.2), with Eastern region reporting the lowest, 2.8% (N=134, 95% CI: 0.9-7.7).

4.2 Univariate and multivariate unconditional and ordinal logistic regression analyses

4.2.1 Survey Logistic regression results

Table 4.3, displays results of the univariate survey unconditional logistic regression and multiple variable survey logistic regression for the malaria outcome. Table 4.4, displays results of the univariate survey ordered logistic regression and multiple variable survey ordered logistic regression for the anaemia outcome.

These results from survey logistic regression model show that wealth index (OR = 0.48, CI = 0.29, 0.78); region (OR = 0.27, CI = 0.16, 0.47), time to water source (OR = 1.70, CI = 1.13, 2.57), mother's highest level of education (OR = 0.64, CI = 0.46, 0.89), child haemoglobin level (OR = 0.94, CI = 0.93, 0.96) as well as child's age (OR = 1.03, CI = 1.02; 1.04) were significant elements of malaria occurrences in children aged under 5 years in Ghana in the year 2014.

In this current study, nature of place of residence (urban or rural) similarly revealed a marginal substantial effect on malaria. Children who reside in the rural parts of the country were more prone to have malaria as compared to their urban colleagues (OR = 3.87, CI = 2.82; 5.31). Region of residence as observed was another important factor in the study with p-value< 0.001. The Western region of Ghana was the most affected with a 39% higher probabilities of malaria morbidity compared to the Northern region (OR=3.39, CI = 1.91, 6.03).

Table 4.3 – Logistic regression results of Univariable, Multivariable analysis

MALARIA			
variables	category	Univariable analysis; odds ratio (95% CI), p-value	Multivariable analysis (non-random effect); odds ratio (95% CI), p-value
Child's age in months		1.01 (1.00, 1.02), 0.00	1.03 (1.02, 1.04), 0.00
Child's altitude adjusted haemoglobin level		0.95 (0.94, 0.96), 0.00	0.94 (0.93, 0.96), 0.00
Children under 5 slept under mosquito bed net last night	no	1.00	1.00
	yes	1.46 (1.17, 1.81), 0.00	0.99 (0.78, 1.25), 0.95
Region	Western	0.97 (0.56, 1.67), 0.92	3.39 (1.91, 6.03), 0.00
	Central	0.94 (0.49, 1.78), 0.85	3.02 (1.43, 6.38), 0.00
	Greater Accra	0.19 (0.09, 0.36), 0.00	1.11 (0.49, 2.51), 0.79
	Volta	0.51 (0.23, 1.12), 0.09	1.24 (0.59, 2.63), 0.55
	Eastern	0.65 (0.36, 1.16), 0.14	2.15 (1.14, 4.04), 0.02
	Ashanti	0.31 (0.18, 0.55), 0.00	1.54 (0.76, 3.09), 0.22
	Brong Ahafo	0.55 (0.30, 1.02), 0.15	1.70 (0.91, 3.18), 0.09
	Northern	1.00	1.00
	Upper East	0.20 (0.11, 0.37), 0.00	0.27 (0.16, 0.47), 0.00
	Upper West	0.94 (0.50, 1.75), 0.83	1.31 (0.67, 2.55), 0.43
Type of place of residence	urban	1.00	1.00
	rural	3.87 (2.82, 5.31), 0.00	1.54 (0.97, 2.46), 0.06
Cluster altitude		0.99 (0.99, 1.00), 0.45	0.99 (0.99, 1.00), 0.51

Mother's highest education level	no education	1.00	1.00
	primary	0.83 (0.61, 1.14), 0.25	1.02 (0.74, 1.43), 0.86
	secondary	0.37 (0.27, 0.49), 0.00	0.64 (0.46, 0.89), 0.01
	higher	0.04 (0.01, 0.19), 0.00	0.18 (0.03, 0.99), 0.04
Mother knowledge of malaria	no	1.00	1.00
	yes	1.08 (0.68, 1.1.71), 0.73	1.36 (0.76, 2.45), 0.29
Wealth index	poorest	1.00	1.00
	poorer	0.89 (0.68, 1.23), 0.51	0.66 (0.45, 0.96), 0.03
	middle	0.46 (0.29, 0.61), 0.00	0.48 (0.29, 0.78), 0.00
	richer	0.23 (0.13, 0.33), 0.00	0.38 (0.19, 0.75), 0.01
	richest	0.11 (0.08, 0.21), 0.00	0.42 (0.19, 0.96), 0.04
Time to get to water source	<10	1.00	1.00
	10 to <20	2.25 (1.64, 3.08), 0.00	1.70 (1.13, 2.57), 0.01
	20 to <30	2.01 (1.39, 2.92), 0.00	1.32 (0.82, 2.14), 0.24
	30 to <40	2.88 (1.98, 4.18), 0.00	1.40 (0.87, 2.25), 0.15
	40 to <50	4.06 (2.34, 7.05), 0.00	1.95 (1.09, 3.47), 0.02
	50 to <60	3.86 (1.60, 9.33), 0.00	2.23 (1.01 4.89), 0.04
	60 to 180	3.93 (2.43, 6.35), 0.00	1.78 (1.06, 2.98), 0.03
	Unknown time	0.68 (0.37, 1.26), 0.22	0.82 (0.41, 1.67), 0.60
sex	male	1.00	1.00
	female	1.04 (0.82, 1.31), 0.74	1.01 (0.77, 1.34), 0.90

Table 4.4 – Ordered logistic regression results of Univariate, Multivariable analysis

ANAEMIA			
variables	category	Univariable analysis; odds ratio (95% CI), p-value	Multivariable analysis (non-random effect); odds ratio (95% CI), p-value
Child's age in months		0.96 (0.96, 0.98) 0.00	0.96 (0.95, 0.97), 0.00
Severe anemia vomiting	no	1.00	1.00
	yes	10.50 (2.83, 39.06), 0.00	6.21 (1.25, 30.77), 0.02
Region	Western	0.40 (0.26, 0.61), 0.00	0.64 (0.41, 1.01), 0.05
	Central	0.55 (0.35, 0.86), 0.01	0.80 (0.48, 1.34), 0.40
	Greater Accra	0.33 (0.21, 0.54), 0.00	0.96 (0.55, 1.69), 0.89
	Volta	0.48 (0.31, 0.76), 0.00	0.71 (0.45, 1.11), 0.13
	Eastern	0.42 (0.27, 0.66), 0.00	0.72 (0.44, 1.17), 0.18
	Ashanti	0.27 (0.17, 0.44), 0.00	0.79 (0.47, 1.35), 0.40
	Brong Ahafo	0.35 (0.23, 0.55), 0.00	0.53 (0.33, 0.83), 0.01
	Northern	1.00	1.00
	Upper East	0.55 (0.35, 0.89), 0.02	1.01 (0.65, 1.56), 0.95
	Upper West	0.73 (0.45, 1.15), 0.18	0.90 (0.57, 1.43), 0.67
Type of place of residence	urban	1.00	1.00
	rural	1.86 (1.49, 2.32), 0.00	0.67 (0.51, 0.89), 0.01
Cluster altitude		0.99 (0.99, 1.00), 0.15	0.98 (0.97, 0.99), 0.02
	no education	1.00	1.00

Mother's highest education level	primary	0.64 (0.48, 0.85), 0.00	0.77 (0.58, 1.03), 0.08
	secondary	0.40 (0.32, 0.50), 0.00	0.71 (0.56, 0.91), 0.01
	higher	0.17 (0.84, 0.35), 0.00	0.45 (0.20, 1.02), 0.05
Severe anemia extreme weakness	no	1.00	1.00
	yes	10.38 (4.09, 26.34), 0.00	9.63 (3.33, 27.81), 0.00
	missing	1.96 (0.05, 74.03), 0.71	3.45 (0.39, 30.40), 0.26
Wealth index	poorest	1.00	1.00
	poorer	0.82 (0.61, 1.08), 0.15	0.96 (0.74, 1.26), 0.79
	middle	0.57 (0.41, 0.79), 0.00	0.79 (0.57, 1.11), 0.17
	richer	0.36 (0.26, 0.50), 0.00	0.60 (0.38, 0.95), 0.03
	richest	0.22 (0.16, 0.31), 0.00	0.33 (0.21, 0.54), 0.00
Severe anemia no symptoms	No	1.00	1.00
	Yes	4.36 (3.49, 5.45), 0.00	5.17 (3.97, 6.74), 0.00
sex	Male	1.00	1.00
	female	1.07 (0.90, 1.26), 0.41	1.06 0.88, 1.27), 0.49

4.2.2 Ordinal logistic regression results

Also results from the ordered survey logistic regression model show that wealth index (OR = 0.60, CI = 0.38; 0.95); region (OR = 0.53, CI = 0.33; 0.83), severe anaemia vomiting (OR = 6.21, CI = 1.25; 30.77), mother's highest level of education (OR = 0.71, CI: 0.56; 0.91), severe anaemia extreme weakness (OR = 9.63, CI: 3.33; 27.81), child's age (OR = 0.96, CI: 0.95; 0.97), cluster altitude (OR = 0.98, CI: 0.97; 0.99) as well as severe anaemia no symptoms (OR = 5.17, CI = 3.97; 6.74) were significant (have higher odds) causes of malaria occurrences in children aged under 5 years in Ghana in the year 2014.

4.2.3 Multivariable analysis adjusted for cluster random effect

Given the relatively small number of malaria and anaemia prevalence detected by linear models, multivariate mixed-effects logistic regression analyses were performed for only confirmed significant covariates. Table 4.5, presents multivariable analysis results of the fixed effects covariates of malaria, which displays the odds ratios, coefficients and their corresponding 95% confidence intervals. Likewise, results of the multivariable fixed effects covariates of anaemia are presented in table 4.6, which displays the odds ratios, coefficients and their corresponding 95% confidence intervals. In final models the estimates of the random-effects coefficients confirmed the effect of clustered sampled data at household level.

Our results show that the chances of having malaria was significant with respect to the child's age (OR=1.03, CI: 1.02; 1.04). The likelihoods that a child would have malaria were considerably lower for children who lived in urban areas compared with their counterparts in rural areas. The results showed that children who resided in rural areas were 46% more likely

to have malaria (OR=1.46, CI: 1.02; 2.16) compared with their urban counterparts. The odds of having malaria were not significant for children whose mothers had primary or higher education, compared with children whose mothers had no education. Those whose parents attained a secondary educational level were 42% less likely to have malaria compared with those whose mothers had no education (OR= 0.58, CI: 0.42; 0.81). Findings of cluster altitude (OR=0.99, CI: 0.99; 1.0) and mothers' knowledge of malaria (OR=1.11, CI: 0.59; 2.05) were not significant. Similarly, findings on sex of the children show that female children were less likely to have had malaria, the variation was not significant (OR=1.07, CI: 0.87; 1.33). Compared with children from the poorest households, those from the richest households were 70% (OR= 0.30, CI: 0.15; 0.63). Children within the middle-range of the wealth index were 59% (OR= 0.41, CI: 0.26; 0.63) less likely to have malaria and the richer group 75% (OR= 0.25, CI: 0.14; 0.45) less likely to have malaria. Likewise, children from the poorer households were 29% (OR= 0.71, CI: 0.50; 0.99) less likely to have malaria. With regard to use of a bed net the previous night, it is observed that the odds of having malaria was not significant for children who slept under a bed net compared with those who did not.

With regards to the multivariate regression analysis for anaemia (Table 4.6), only sex of the child was no longer a significantly increased risk with under age 5 anaemia and of the variables that remained significant the adjusted odds ratios were slightly attenuated: child's age in months (OR= 0.96, CI: 0.95; 0.97, $p < 0.05$), cluster altitude (OR= 0.98, CI: 0.97; 0.99, $p<0.05$), mother's with higher level of education (OR= 0.43 CI: 0.25; 0.75, $p<0.05$). Moreover, severe anaemia vomiting, severe anaemia extreme weakness and severe anaemia extreme weakness

(proxies predictors for anaemia) remained independently associated with anaemia disease in the multivariate model (Table 5), except for mothers with secondary education (OR= 0.74, CI: 0.59; 0.93, $p<0.05$), children who reside in rural areas (OR= 0.70, CI: 0.55; 0.88, $p< 0.001$) and children in richest wealth index category (OR= 0.38, CI: 0.25; 0.59, $p<0.001$) for which the adjusted OR increased.

4.2.4 Multivariable random effect analysis for malaria

Table 4.5 – Multivariable analysis for malaria predictor variables adjusted for random effect (reporting coefficients & odd ratios)

MALARIA			
variables	category	Multivariable analysis adjusted for random effect, coefficients (95% CI), p-value	Multivariable analysis adjusted for random effect, odds ratio (95% CI), p-value
Child's age in months		0.035 (0.03, 0.04), 0.00	1.03 (1.02, 1.04), 0.00
Child's altitude adjusted haemoglobin level		-0.05 (-0.06, -0.05), 0.00	0.94 (0.93, 0.95), 0.00
Children under 5 slept under mosquito bed net last night	no	0.00	1.00
	yes	-0.12 (-0.35, 0.12), 0.32	0.88 (0.69, 1.12), 0.32
Region	Western	1.61 (0.93, 2.28), 0.00	5.02 (2.55, 9.87), 0.00
	Central	1.22 (0.53, 1.91), 0.00	3.40 (1.71, 6.76), 0.00
	Greater Accra	0.34 (-0.51, 1.18), 0.44	1.40 (0.59, 3.28), 0.00
	Volta	0.39 (-0.32, 1.10), 0.28	1.47 (0.72, 3.01), 0.43
	Eastern	1.04 (0.39, 1.70), 0.00	2.85 (1.48, 5.47), 0.00
	Ashanti	0.67 (-0.06, 1.41), 0.07	1.95 (0.93, 4.09), 0.07
	Brong Ahafo	0.67 (0.02, 1.33), 0.04	1.96 (1.02, 3.77), 0.04
	Northern	0.00	1.00
	Upper East	-1.22 (-1.93, -0.52), 0.00	0.29 (0.14, 0.59), 0.00
	Upper West	0.36 (-0.31, 1.05), 0.29	1.44 (0.72, 2.86), 0.29

Type of place of residence	urban	0.00	1.00
	rural	0.38 (-0.00, 0.77), 0.05	1.46 (1.02, 2.16), 0.05
Cluster altitude (kilometres)		-0.00(-0.002 .001), 0.76	0.99 (0.99, 1.00), 0.76
Mother's highest education level	no education	0.00	1
	primary	-0.00 (-0.32, 0.32), 0.97	0.99 (0.72, 1.37), 0.97
	secondary	-0.52 (-0.84, -0.21), 0.00	0.58 (0.42, 0.81), 0.00
	higher	-1.45 (-3.00, 0.09), 0.06	0.23 (0.04, 1.10), 0.06
Mother knowledge of malaria	no	0.00	1.00
	yes	0.10 (-0.51, 0.71), 0.74	1.11 (0.59, 2.05), 0.74
Wealth index	poorest	0.00	1.00
	poorer	-0.34 (-0.68, -0.00), 0.04	0.71 (0.50, 0.99), 0.04
	middle	-0.88 (-1.32, -0.46), 0.00	0.41 (0.26, 0.63), 0.00
	richer	-1.36 (-1.92, -0.79), 0.00	0.25 (0.14, 0.45), 0.00
	richest	-1.17 (-1.89, -0.44), 0.00	0.30 (0.15, 0.63), 0.00
Time to get to water source	<10	0.00	1.00
	10 to <20	0.24 (-0.09, 0.58), 0.16	1.27 (0.90, 1.78), 0.16
	20 to <30	0.08 (-0.32, 0.49), 0.69	1.08 (0.72, 1.63), 0.69
	30 to <40	0.15 (-0.28, 0.59), 0.49	1.16 (0.07, 1.80), 0.49
	40 to <50	0.37 (-0.17, 0.92), 0.18	1.45 (0.83, 2.51), 0.18
	50 to <60	0.75 (-0.19, 1.71), 0.12	2.13 (0.81, 5.56), 0.12
	60 to 180	0.17 (-0.35, 0.69), 0.52	1.18 (0.70, 2.00), 0.52
	Unknown time	-0.51 (-1.02, -0.01), 0.04	0.59 (0.36, 0.98), 0.04
sex	Male	0.00	1.00
	Female	0.07 (-0.14, 0.28), 0.48	1.07 (0.87, 1.33), 0.48

4.2.5 Multivariable random effect analysis for anaemia

Table 4.6 – Multivariable analysis for anaemia predictor variables adjusted for random effect (reporting coefficients & odd ratios)

ANAEMIA			
variables	category	Multivariable analysis adjusted for random effect, coefficients (95% CI), p-value	Multivariable analysis adjusted for random effect, odds ratio (95% CI), p-value
Child's age in months		-0.03 (-0.04, -0.03), 0.00	0.96 (0.95, 0.97), 0.00
Severe anaemia vomiting	no	0.00	1.00
	yes	1.85 (0.77, 2.93), 0.00	6.37 (2.16, 18.75), 0.00
Region	Western	-0.63 (-1.02, -2.23), 0.00	0.53 (0.35, 0.79), 0.00
	Central	-0.43 (-0.83, -0.03), 0.03	0.65 (0.43, 0.97), 0.03
	Greater Accra	-0.27 (-0.73, 0.17), 0.23	0.75 (0.48, 1.18), 0.23
	Volta	-0.57 (-0.97, -1.16), 0.01	0.56 (0.39, 0.85), 0.01
	Eastern	-0.53 (-0.92, -0.15), 0.01	0.58 (0.39, 0.86), 0.01
	Ashanti	-0.54 (-0.95, -0.14), 0.01	0.57 (0.38, 0.87), 0.01
	Brong Ahafo	-0.75 (-1.12, -0.37), 0.00	0.47 (0.32, 0.68), 0.00
	Northern	0.00	1.00

	Upper East	-0.08 (-0.45, 0.28), 0.65	0.91 (0.63, 1.32), 0.65
	Upper West	-0.31 (-0.71, 0.09), 0.14	0.73 (0.49, 1.10), 0.14
Type of place of residence	urban	0.00	1.00
	rural	-0.35 (-0.58, -0.12), 0.00	0.70 (0.55, 0.88), 0.00
Cluster altitude (kilometres)		-0.00 (-0.00, -0.00), 0.01	0.98 (0.97, 0.99), 0.01
Mother's highest education level	no education	0.00	1.00
	primary	-0.13 (-0.36, 0.11), 0.29	0.88 (0.69, 1.11), 0.29
	secondary	-0.29 (-0.51, -0.07), 0.01	0.74 (0.59, 0.93), 0.01
	higher	-0.82 (-1.36, -0.29), 0.00	0.43 (0.25, 0.75), 0.00
	Missing	-0.22 (-0.52, 0.07), 0.14	0.79 (0.59, 1.07), 0.14
Severe anaemia extreme weakness	no	0.00	1.00
	yes	2.03 (1.11, 2.95), 00	7.63 (3.02, 19.22). 0.00
Wealth index	poorest	0.00	1.00
	poorer	0.01 (-0.24, 0.25), 0.96	1.00 (0.78, 1.29), 0.96
	middle	-0.13 (-0.43, 0.16), 0.36	0.87 (0.65, 1.16), 0.36
	richer	-0.27 (-0.62, 0.07), 0.12	0.75 (0.53, 1.07), 0.12
	richest	-0.94 (-1.37, -0.53), 0.00	0.38 (0.25, 0.59), 0.00
Severe anaemia no symptoms	No	0.00	1.00
	Yes	1.5 (1.33, 1.71), 0.00	4.57 (3.78, 5.53), 0.00
sex	Male	0.00	1.00
	Female	-0.09 (-0.24, 0.59), 0.23	0.91 (0.78, 1.06), 0.23

4.3 Spatial models in Stata and Winbugs

Table 4.7 (Malaria): Comparative results between stata, winbugs for the multiple variable poisson regression analysis without the spatial random effect.

Variable	category	Stata OR (CI)	Stata coefficient (CI)	WINBUGS posterior coefficient (CI 2.5,97.5)
Child's age in months		1.03 (1.02; 1.04)	0.0311 (0.115, 0.681)*	0.0312 (0.024,0.038)
Child's altitude adjusted haemoglobin level		0.94 (0.93, 0.95)	-0.0553 (-0.062, -0.048)*	-0.0552 (-0.063, -0.048)
Type of place of residence	rural	1.00	0.00	0.00
	urban	1.48 (1.12, 1.97)	0.398 (0.115, 0.681)*	0.407 (0.127, 0.685)
Cluster altitude		0.99 (0.99, 1.00)	-0.00054 (-0.002, 0.0009)	-0.00053 (-0.0019, 0.0008)
Mother's highest education level	no education	1.00	0.00	0.00
	primary	1.04 (0.79, 1.39)	0.04 (-0.23, 0.33)*	-0.41 (-0.66, -0.18)*
	secondary	0.67 (0.52, 0.89)	-0.38 (-0.66, -0.11)*	-1.57 (-3.30, -0.26)*
	higher	0.24 (0.05, 1.05)	-1.42 (-2.89, 0.05)*	-1.57 (-6.21, 6.32)*
Wealth index	poorest	1.00	0.00	0.00
	poorer	0.66 (0.49, 0.89)	-0.40 (-0.69, -0.11)	-0.39 (-0.69, -0.10)

	middle	0.43 (0.30, 0.60)	-0.84 (-1.19, -0.49)*	-0.83 (-1.18, -0.49)*
	richer	0.26 (0.16, 0.41)	-1.346 (-1.812, -0.880)*	-1.336 (-1.811, -0.862)*
	richest	0.30 (0.16, 0.55)	-1.189 (-1.786, -0.592)*	-1.185 (-1.79, -0.595)*

Stata CI = 95% confidence interval.
STATA are weighted
WINBUGS CI = 95% credibility interval.
∗Significant at 5% level.

Table 4.8 (ANAEMIA): Comparative results between STATA and WINBUGS for the multiple variable Poisson regression analysis without the spatial random effect.

Variable	category	Stata OR (CI)	Stata coefficient (CI)	WINBUGS posterior coefficient (CI 2.5,97.5)
Child's age in months		0.96 (0.95, 0.96)*	-0.0356 (-0.0408, -0.0304)*	-0.0358 (-0.0409, -0.0306)*
Type of place of residence	Rural (reference)	1.00	0.00	0.00
	urban	0.69 (0.56, 0.86)	-0.362 (-0.576, -0.148)*	-0.377 (-0.596, -0.161)*
Cluster altitude		0.99 (0.99, 0.99)	-0.0016 (-0.0025, -0.00065)*	-0.0016 (-0.0025, -0.00062)*
Mother's highest education level	no education	1.00	0.00	0.00
	primary	0.84 (0.67, 1.06)	-0.17 (-0.39, 0.06)	-0.2715 (-0.4526, -0.09104)
	secondary	0.70 (0.56, 0.86)	-0.35 (-0.56, -0.14)*	-0.75 (-1.26, -0.25)
	higher	0.43 (0.26, 0.73)	-0.81 (-1.34, -0.29)	4.32 (-1957.0, 1998.0)
Wealth index	Poorest (reference)	1.00	0.00	0.00
	Poorer	0.90 (0.71, 1.15)	-0.09 (-0.33, 0.14)	-0.12 (-0.36, 0.13)
	middle	0.78 (0.59, 1.03)	-0.24 (-0.52, 0.03)	-0.26 (-0.53, 0.02)
	richer	0.67 (0.48, 0.94)	-0.38 (-0.71, -0.05)	-0.40 (-0.74, -0.07)
	richest	0.35 (0.24, 0.52)	-1.04 (-1.43, -0.65)	-1.06 (-1.44, -0.66)
Severe anemia vomiting	No (reference)	1.00	0.00	0.00
	yes	4.10 (1.58, 10.64)*	1.41 (0.46, 2.36)	1.88 (0.86, 3.07)*
Severe anemia extreme weakness	No (reference)	1.00	0.00	0.00
	yes	5.73 (2.48, 13.25)*	1.74 (0.91, 2.58)*	2.04 (1.15, 2.98)*

Severe anemia no symptoms	no	1.00	0.00	0.00
	yes	4.25 (3.55, 5.09)*	1.45 (1.26, 1.63)*	1.48 (1.30, 1.66)*
sex	male	1.00	0.00	0.00
	female	0.91 (0.79, 1.06)	-0.084 (-0.232, 0.063)	-0.081 (-0.226, 0.069)

Stata CI = 95% confidence interval.
STATA are weighted
WINBUGS CI = 95% credibility interval.
∗Significant at 5% level

4.4 Spatial risk maps of malaria and anaemia

Maps of disease incidence are useful for purposes of production of disease; description of geographical distribution of disease; hypothesis generation; surveillance to highlight regions at allegedly high risk; placing point source (cluster) investigations in context and to assist policy development and resource distribution. Our spatial analysis of malaria and anaemia in Ghana relies on multiple analyses and visualizations to provide a broad view of the spatial variation in risk. Mapping was done using Stata 14. The Figures 4.1, 4.2 and 4.3, show posterior mean of both the random and non-random models. The average posterior estimates of the prevalence rates of malaria and anaemia are compared across districts in these figures, where the regions (districts) with highest burden of disease shown in red colour.

4.4.1 Interpretation of malaria spatial maps

A measure of malaria is available in the form of posterior mean levels of cases in each district estimated from a dispersion model based upon prevalence. Mapping of such data was carried out at district levels, where numbers of cases and risk populations are relatively small and raw standardized mortality or morbidity ratio (SMRs) estimates are highly variable.

The predictive maps for malaria (figure 4.1) represent the predicted (modeled) incidence of malaria morbidity among children under age 5 years for each district (137) in Ghana. Hence, the probabilities are based on these demographic stratification (districts). The cut off mean prevalence was reported in quintiles, which gave a clear indication of all the significant

predictors of malaria in one map and also made it easy to see where there is overlap in high disease morbidity. Each quintile range (legend punnets, ordered vertically, corresponding to each class denote box with its range of numeric values) or colour represents roughly 20% of the malaria morbidity in Ghana. Each district is placed into one of five quintiles based on the estimate and where that estimate falls as compared to estimates for all of the study participants (2727). The top quintile represents the highest 20% of disease estimates and the bottom quintile represents the lowest 20% of disease estimates. The blue colour is within the bottom 20% quintile (malaria coldspots), green colour fall within the middle quintiles (40% - 60%), yellow is found within the 61%-80% quintile and the red colour fall within the top 20% quintile (malaria hotspots).

A visual inspection of the malaria risk (choropleth) map conveys the message that rates are particularly high (areas within the red colour range) in certain districts in the Earstern, Central, Upper East, Greater Accra, Weatern, Volta, Northern and Brong Ahafo Regions of the country. The lowest class interval of these malaria troubled districts have a mean risk range between 0.055 to 1.51 prevalence rate. The blue areas (indicate probabilities of 20%) were those areas where there was a little or no probability the malaria risk (range: -0.599 to -0.037) , whilst the yellow/orange areas (indicate probabilities of 61%-80%) could be regarded as areas of high uncertainty (range: 0.027 to 0.054).

The results of the spatial models (table 4.7 and 4.8) have verified that interactions of risk factors can significantly improve the prediction of spatial dynamics of malaria and anaemia. Based on these probabilities, the predicted maps have shown great level of heterogeneity in the results with respect to districts with high and low probabilities of malaria and anaemia. The significant

positive parameters (positive coefficients) estimates are the main drivers of the malaria hotspots represented by shades of red, while the significant negative parameter (negative coefficients) estimates are drivers of malaria coldspots represented by shades of blue.

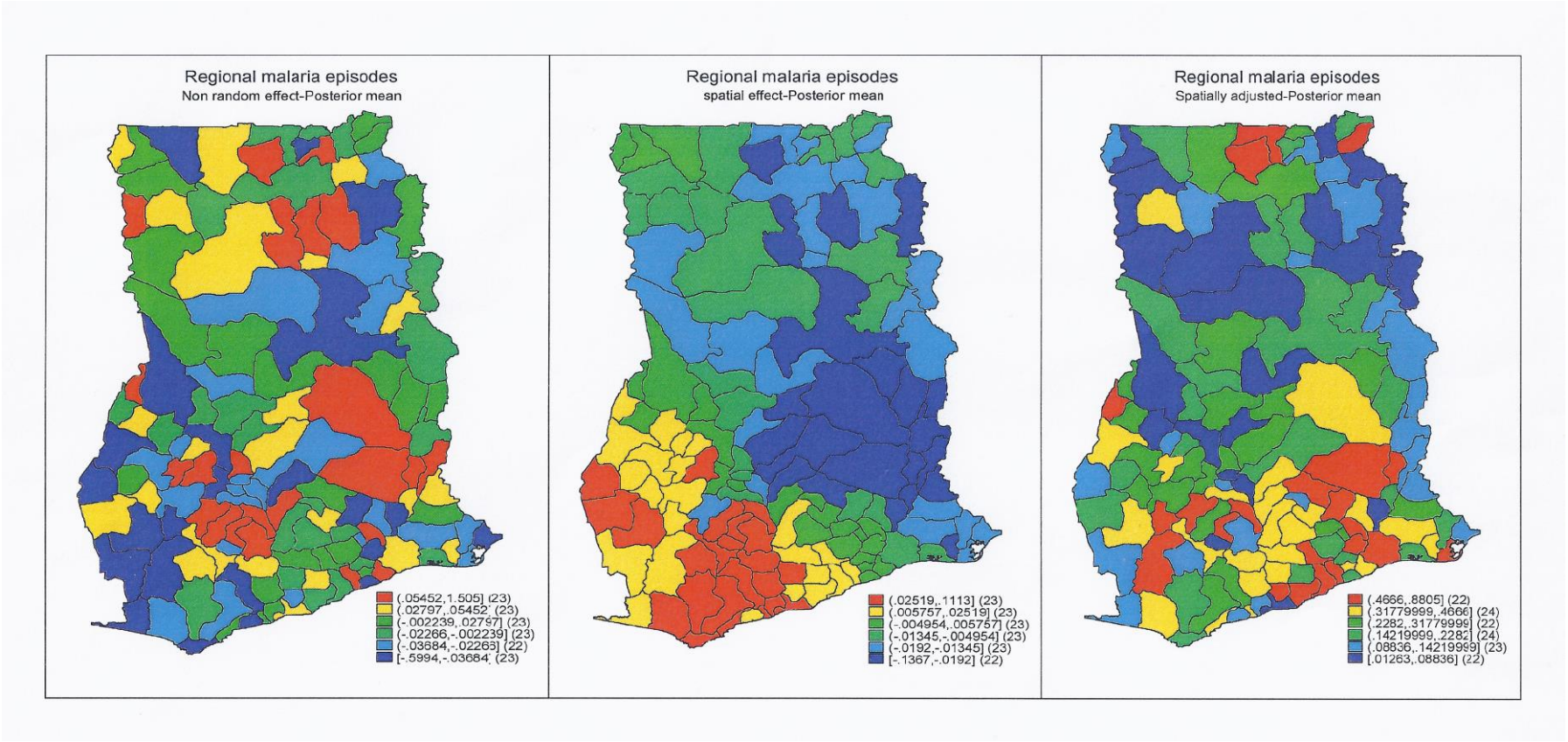

Figure 4.1– Choropleth maps that visualizes structured and unstructured spatial effects on coefficients of malaria results showing mean probabilities of malaria risk for children under age 5 years in 2014.

4.4.2 Interpretation of anaemia spatial maps and related results

Choropleth maps (figure 4.3) utilized the same administrative units (districts) with false borders to present cumulative evidence on the significant risk factors of anaemia. The dispersal map with a small mean of prediction errors equaling 0.0585 showed that the Upper-East, Upper West, Volta, Central, Asanti, Western, Brong Ahafo, Northern and Greater Accra reions of Ghana were the main epidemic areas in relation to mild anaemia episodes, between which high disease prevalent areas were scattered. Clusters of high moderate and severe anaemia prevalence were located in a similar distribution in all ten regions (compare with figure 3.1) of the country, consistent with the random effects shown in figure 4.2. Areas within the red colour range (indicate probabilities of at least 80%) were districts where there was a high odds of anaemia prevalence (range: 0.3224 to 0.3293, for mild anaemia and 0.6510 to 0.9192, for moderate to severe anaemia episodes), the blue areas (indicate probabilities of 20%) were districts where there was a low odds anaemia morbidity. Again, the yellow/orange districts indicate probabilities of high anaemia uncertainty.

This spatially adjusted maps depict an overlay of the significant risk factors mapping data with information concerning anaemia morbidity among children under age 5 years in Ghana in 2014. It shows that anaemia “hotspots” is clusterd in mostly rural districts of very high poverty and low level of educated mother’s. hence, it served as the basis for a anaemia control strategy and help to target health education messages in affected and high-risk districts.

The results from the spatial model allowed us to show and picture the parameter estimates of each explanatory variable on the map. Positive and negative associations were displayed in the result of the error maps. The positive coefficient range means that as specific explanatories

variable increase, anaemia cases correspondingly increase. Conversely, negative coefficient implies as specific explanatories variable decrease, anaemia cases correspondingly decrease. Districts with red shade signify areas where predictor variables exhibit strong influence on anaemia occurrence whereas blue shade represent districts where predictor variables exhibit lo or weak influence on anaemia prevalence.

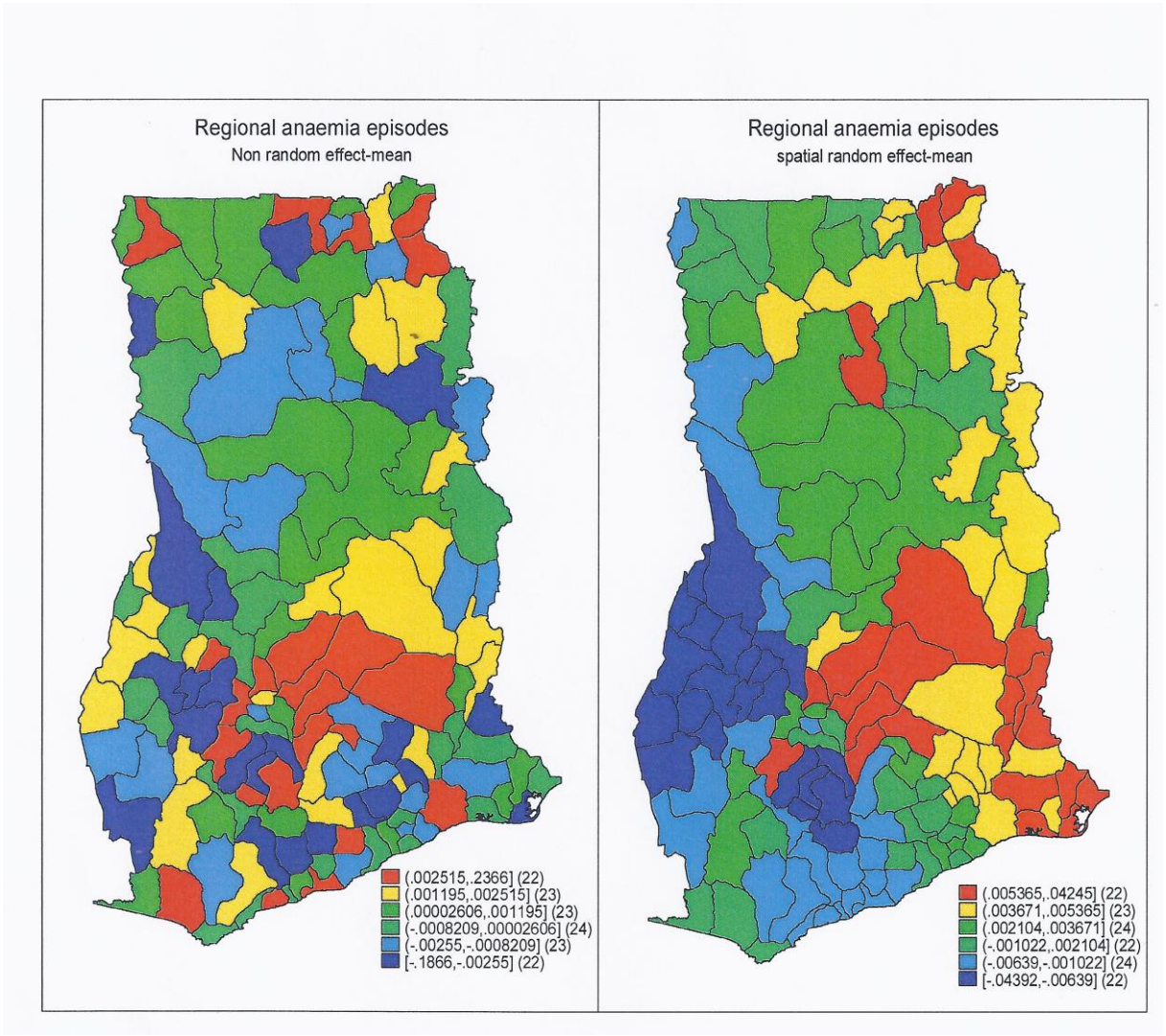

Figure 4.2– Choropleth maps that visualizes the unstructured spatial effects on coefficients of anaemia results showing mean probabilities of anaemia risk for children under age 5 years in 2014.

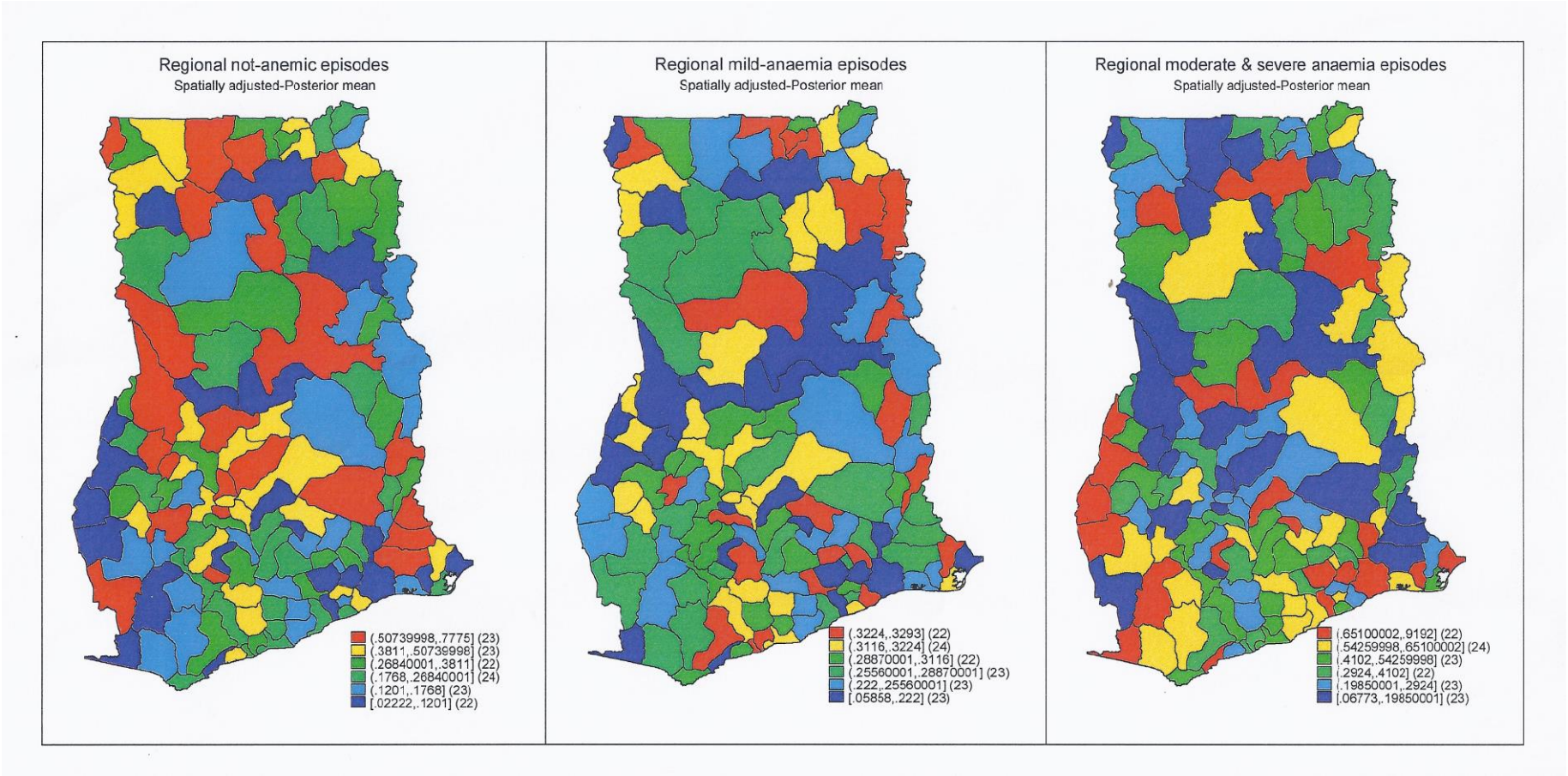

Figure 4.3– Choropleth maps that visualizes structured and unstructured spatial effects on coefficients of malaria results showing mean probabilities of malaria risk for children under age 5 years in 2014.

Chapter 5 Discussions and Conclusions

5.1 Discussions

This chapter presents the results and discussion of the aim and objectives of this study. The results on the non-spatial and spatial modelling of the prevalence data with regards to the factors associated with malaria and anaemia prevalence among children under 5 years of age in Ghana in the year 2014 are discussed. Afterwards, the results of the prediction are presented in the form of spatial risk maps and they are discussed. The aim of this study was to determine spatial distribution and factors associated with malaria and anaemia morbidity among Ghanaian children under 5 years of age in 2014. Specifically, the study analysed some of the known factors of malaria and anaemia in order to identify which factors predict morbidity in the ten regions of Ghana.

5.1.1 Significant risk factors of malaria and anaemia morbidity

The current study applied survey logistic regression models, which is a designed-based method, and involves the extension of logistic regression to complex survey designs. Our findings confirm that child's age; type of wealth index; mother's education level, and place of residence were significant determinants of both malaria and anaemia status of the child. More so our findings confirm that child's altitude adjusted haemoglobin level is also significantly related to

child's malaria status. Other factors significantly related to anaemia were cluster altitude; severe anaemia vomiting; severe anaemia extreme weakness, and severe anaemia no symptoms. The prevalence of anaemia among children under age 5 years was 68.68%, beyond the WHO country estimates of 66% for the under age 5 years in 2014 (Organization, 2015). Our percentage was slightly lower than the figure shown in a study carried out in Ghana among children below the age of five years, 78.4% (Ewusie et al., 2014). Thus, a drop of 12.4% in the country's anaemia burden six years along the line.

5.1.2 Clinical implications of malaria and anaemia risk factors

Wealth index was negatively associated with malaria and anaemia risk. Children from richer households had a significantly lower risk of malaria compared to those from poorer households. The reason being that wealthier families are more likely to meet the expense of improved health services and afford suitable housing amenities which may prevent mosquito bites resulting in reduced transmission. This finding confirms previous results that showed that malaria burden is highly associated with poverty (Ssempiira_et al., 2017). This is consistent with findings by Nyarko and Cobblah (2014), Chitunhu and Musenge (2015;2016), Clouston et al. (2015), Roberts and Matthews (2016), Oladeinde et al. (2012), which found that WI a proxy of socio-economic status is a major factor affecting risk of malaria. Likewise, Oladeinde et al. (2012), Reithinger et al. (2013), Ewusie et al. (2014), Semedo et al. (2014), Kinyoki et al. (2015), arrived at the same conclusion regarding the significant relationship that exist between WI and anaemia risk.

Furthermore, mother's highest education level was related with reduced risk of malaria and anaemia prevalence. Our findings predict that among the participants, the higher a mother's education, the lesser chance of their child being infected with malaria. It however, may not take a lot of education to teach a mother how to take simple precautions to prevent malaria in her child. All it may require is knowing the importance of using a bed net and knowing the importance of seeking care when the child has a fever. Highly educated mothers in coupled with being richer are also most likely to have the means to afford malaria and anaemia preventive measures. So educating a mother has a profound effect on childhood malaria as the findings builds upon previous studies that have shown the importance of maternal education in reducing malaria morbidity among children under-fives in other countries in Africa (Roberts and Matthews, 2016, Chitunhu and Musenge, 2016, Zgambo et al., 2017).

Mothers' highest education level was found to be a significant socio-economic factor for the occurrence of anaemia among children under age five (P= 0.00). This finding is in agreement with those found in Ghana (Ewusie et al., 2014) and elsewhere (Ncogo et al., 2017), and show that anaemia was more frequent among children aged under five years old and those living in rural settings among the under-fives was related to lower maternal education. Similar results to ours were found in a cross-sectional study conducted in Cape Verde, Haiti and Yemen, which examined haemoglobin (Hb) levels in the under-5 children in the Ghanaian population, based on demographic and socio-economic risk factors. These studies found that one of the factors contributing to anaemia (low Hb levels) in the child was maternal education, highlighting the

need to educate mothers on anemia, especially before, during and after pregnancy (Ayoya et al., 2013, Ebtesam Mahdi Al-Zabedi1 et al., 2014, Semedo et al., 2014).

In the multiple survey logistic regression analysis and after adjusting for other factors, the current study found that, child's age and child's altitude adjusted haemoglobin level were significantly associated with malaria morbidity and prevalence. Child's age was also positively correlated with anaemia morbidity and prevalence in children under age five year. This association has also been found in other studies which could correlate with child's age and child's altitude adjusted haemoglobin level (Chitunhu and Musenge, 2016).

The region and type of place of residence of Ghana that a child resided in was found to be significantly associated with the risk of malaria and anaemia ($p< 0.001$), with children from rural areas having a higher burden of malaria prevalence compared to urban areas. Children living in the Ashanti, Brong Ahafo, Eastern, Western, Greater Accra, Central and Upper East regions were having the highest risk compared to those in the Northern region. Similarly the microscopy result was higher in rural areas than in urban (78.42% vs. 21.58%). This is in agreement with what was reported by GDHS. Ghana Statistical Services reported that, occurrence of malaria in children aged 6-59 months based on microscopy was higher among children residing in rural areas than in urban areas (37.9% vs. 13.5%).This is also in agreement with findings by Chitunhu and Musenge in Malawi where prevalence of Malaria in urban and rural Malawi indicated by blood smear positive (microscopy test) were significantly higher in rural (95.0%) than in urban (5.0%) (Chitunhu and Musenge, 2015). The higher malaria prevalence in the rural area than urban may be due to behavioural communication changes, as it may increase knowledge and promote positive behavioural changes among people. For

instance, publicity to malaria messages through the numerous media sources such as television (TV), radio and print media were more frequent in urban than in urban areas. From the regional perspective, Greater Accra reportedly had the greatest proportion of respondents who were exposed to malaria adverts by means of newspaper and/or magazine (20%), TV (84%), and posters (39%). Ashanti region had the greatest exposure to malaria adverts through the radio (86 percent) and through flyers (11%). More so, huge discrepancies were found regarding wealth quintile; exposure to malaria adverts by means of various media rised steadily with increased wealth; richest (91.5%) access to TV as compared to poorest (19.2%) (GSS, 2015).

5.1.3 Spatial distribution of risk factors

The region of Ghana where a child resided, was shown to be significantly correlated with the risk of malaria and anaemia. In this study, maps displaying the spatial differences in malaria and anaemia peril in children under age 5 years in Ghana was created using posterior-mean incidence of infection data. The map is the first attempt to empirically describe malaria and anaemia risk countrywide. These maps (Figures 4.1, 4.2 and 4.3) shows that malaria as well as anaemia risk differs extensively in the country and even within districts. Our map identifies regions with highest malaria risk in Ashanti (Amensie East, Amensie West and Adansi North districts), Brong Ahafo (Jama South district), Central (Awutu-Efutu-Senya, Ajumako-Enyam-Esiam and Gomoa districts), Eastern (Akwapim North, Yilo Krobo, West Akim, Akwapim South and Kwehu West districts), Greater Accra (Accra, Dangbe East and Ga West districts),

Upper East (Garu Tempane, Builsa and Kassena Nankana districts), Volta (Keta and Kpandu districts), and Western (Amenfi West and Bibiani-Anhwiaso-Bekwai districts).

Surprisingly all ten region had their own share of anaemia in children under age 5 years. However, the regions that were most affected are Brong Ahafo (Pru, Kintampo North, Jaman South and Dormaa districts), Eastern (Kwehu West, Suhum Kraboa Coaltar, Akwapim North and Asuogaman districts), Northern (Gushiegu, Saboba Chereponi, Central Gonja and Nanumba South districts), Volta (Krachi East, Hohoe, Akatsi districts) and Western (Bia, Juabeso, Jomoro, Wasa Amenfi West and Shama Ahanta East districts).

5.1.4 **Limitations and strength of study**

The limitations were that, the standard DHS was a cross-sectional study, therefore a child who tested negative may be asymptomatic for malaria and was not taken into consideration. Also it took a very long time to run the spatial models in WinBugs. Nonetheless, the study has its strengths. The present study used GDHS data collected from a national representative sample and that it had over 95% response rate, thus, the findings can be generalised to children under the age of five years in Ghana. The complex design of the study was accounted for by survey setting the data, including the effect of the clusters in the model as a random effect. Survey-adjusted multiple logistic regression, spatial modelling plus running the same models using Stata and WinBugs in analysis presented us with a solid background to make important and precise statistical inferences with regards to the significant determinants (risk factors) of both malaria and anaemia.

5.2 Concluding remarks

Malaria and anaemia morbidity are still highly prevalent and considered as serious health problems among children under age five years in Ghana. The findings showed that more than half of the study population were found to be anaemic with 66.68% prevalence rate and those who had malaria was 28.71%. Child's age in months, child's altitude adjusted haemoglobin level, type of place of residence, mother's highest education level, wealth index, cluster altitude, severe anaemia vomiting, severe anaemia extreme weakness, severe anaemia no symptoms were identified as the significant spatial risk factors of malaria and anaemia among these children. This study provides the first comprehensive risk map of malaria and anaemia at the national level among children under age five years. Children from about 46 districts were at a greater risk of acquiring malaria and anaemia, with their mean posterior estimates ranging from 0.32 to 0.88 for malaria and 0.54 to 0.91 for anaemia. Our findings, thus revealed considerable geographical differences and the maps produced can guide policy makers and other stake holders to identify specific districts and on how to pragmatically use the limited resources for designing more cost-effective interventions that will warrant optimum results. However, further studies may consider the joint modelling of the two diseases to support the findings of the present study.

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Appendix A

A.1 Ethics certificate

R14/49 Mr Blam Stephen Nuerteye

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

CLEARANCE CERTIFICATE NO. M170207

NAME: (Principal Investigator)	Mr Blam Stephen Nuerteye
DEPARTMENT:	School of Public Health
PROJECT TITLE:	Spartial Determinants of Malaria and Anaemia Morbidity among Children Under Age 5 Years in Sierra Leone, 2013
DATE CONSIDERED:	24/02/2017
DECISION:	Approved unconditionally
CONDITIONS:	
SUPERVISOR:	Dr Eustasius Musenge
APPROVED BY:	Professor P Cleaton-Jones, Chairperson, HREC (Medical)
DATE OF APPROVAL:	27/02/2017

This clearance certificate is valid for 5 years from date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Research Office Secretary in Room 301, Third Floor, Faculty of Health Sciences, Phillip Tobias Building, 29 Princess of Wales Terrace, Parktown, 2193, University of the Witwatersrand. I/we fully understand the conditions under which I am/we are authorized to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated, from the research protocol as approved, I/we undertake to resubmit the application to the Committee. **I agree to submit a yearly progress report**. The date for annual re-certification will be one year after the date of convened meeting where the study was initially reviewed. In this case, the study was initially reviewed in February and will therefore be due in the month of February each year. Unreported changes to the application may invalidate the clearance given by the HREC (Medical).

Principal Investigator Signature

Date 06-03-2017

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

A.2 Plagiarism Form

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG | FACULTY OF HEALTH SCIENCES

PLAGIARISM DECLARATION TO BE SIGNED BY ALL HIGHER DEGREE STUDENTS

SENATE PLAGIARISM POLICY:

I **Stephen Nuerteye Blam** (Student number: **847644**) am a student registered for the degree of **Master of Science in Epidemiology in the field Biostatistics and Epidemiology** in the academic year 2015.

I hereby declare the following:

- I am aware that plagiarism (the use of someone else's work without their permission and/or without acknowledging the original source) is wrong.
- I confirm that the work submitted for assessment for the above degree is my own unaided work except where I have explicitly indicated otherwise.
- I have followed the required conventions in referencing the thoughts and ideas of others.
- I understand that the University of the Witwatersrand may take disciplinary action against me if there is a belief that this is not my own unaided work or that I have failed to acknowledge the source of the ideas or words in my writing.

Signature:  Date: 02-May-2018

A.3 Stata codes

A.3.1 Multivariable analysis for malaria

A.3.1.1 binary inferential statistics

- tab malaria_microscopytest, missing
- svy linearized : tabulate malaria_microscopytest, count col obs percent
- ttest child_age, by (malaria_microscopytest)
- svy linearized: mean child_age, over(malaria_microscopytest)
- ttest heamoglobin,by(malaria_microscopytest)
- svy linearized: mean heamoglobin, over(malaria_microscopytest)
- svy:regress heamoglobin i.malaria_microscopytest
- tab use_of_bednet malaria_microscopytest,m col chi
- svy linearized: tab use_of_bednet malaria_microscopytest, count col percent obs pearson
- tab region malaria_microscopytest, col chi
- svy linearized: tab region malaria_microscopytest,count col percent obs pearson

A.3.1.2 checking for multicollinearity of significant variables

- xi:sw, pr(0.25):regress place_of_residence mother_education wealth_index use_of_bednet child_age region heamoglobin time_watersource
- regress place_of_residence mother_education wealth_index use_of_bednet child_age region heamoglobin time_watersource
- vif

A.3.1.3 step-wise regression

- stepwise, pr(0.2) hierarchical : logistic malaria_microscopytest region place_of_residence mother_knowledgeof_malaria mother_education wealth_index use_of_bednet child_age cluster_altitude time_watersource sex_of_child haemoglobin
- stepwise, pe(0.2): logistic malaria_microscopytest region place_of_residence mother_knowledgeof_malaria mother_education wealth_index use_of_bednet child_age cluster_altitude time_watersource sex_of_child haemoglobin

A.3.1.4 fitting of final model comparing coeficients

- xi: svy: logistic malaria_microscopytest place_of_residence mother_knowledgeof_malaria mother_education wealth_index use_of_bednet child_age region heamoglobin cluster_altitude time_watersource sex_of_child, or
- est store A

- xi: svy: logistic malaria_microscopytest place_of_residence mother_education wealth_index use_of_bednet child_age region heamoglobin time_watersource
- est store B

A.3.1.5 suest test for goodness of fit of final model

- suest B A

A.3.1.6 testing of models

- test [B_malaria_microscopytest=A_malaria_microscopytest], common

A.3.1.7 random effects for malaria

- melogit malaria_microscopytest i.place_of_residence i.mother_education i.wealth_index child_age heamoglobin cluster_altitude || region:
- melogit malaria_microscopytest i.place_of_residence i.mother_education i.wealth_index child_age heamoglobin cluster_altitude || region:,or

A.3.2 Multivariable analysis for anaemia

A.3.2.1 Ordinal inferential statistics

- tab child_anemia, m
- svy:tab child_anemia, count col percent obs
- tabstat child_age , by(child_anemia) stats(mean semean sd)
- regress child_age child_anemia
- svy linearized: mean child_age, over(child_anemia)
- svy:regress child_age i.child_anemia
- tab region child_anemia, col chi
- svy linearized: tab region child_anemia,count col percent obs pearson
- tab place_of_residence child_anemia, col chi
- svy linearized: tab place_of_residence child_anemia, count col percent obs pearson
- tab mother_education child_anemia,m col chi
- svy linearized: tab mother_education child_anemia,count col percent obs pearson
- tab wealth_index child_anemia,m col chi
- svy linearized: tab wealth_index child_anemia,count col percent obs pearson

A.3.2.2 random effects for anaemia

- meologit child_anemia2 severe_anemia_extreme_weakness severe_anemia_vomiting severe_anemia_nosymptoms i.place_of_residence i.mother_education i.wealth_index c.child_age c.cluster_altitude, ||region:
- meologit child_anemia2 severe_anemia_extreme_weakness severe_anemia_vomiting severe_anemia_nosymptoms i.place_of_residence i.mother_education i.wealth_index c.child_age c.cluster_altitude, ||region:,or

A.3.3 WinBUGS Splus dataset creation in Stata- bugsdat

- bugsdat region place_of_residence cluster_altitude wealth_index mother_knowledgeof_malaria child_age sex_of_child heamoglobin child_anemia malaria_microscopytest use_of_bednet time_watersource , f(ghmis2014_workdata.dat)
- bugsdat child_anemia2 severe_anemia_extreme_weakness severe_anemia_vomiting severe_anemia_nosymptoms region place_of_residence mother_education wealth_index sex_of_child child_age cluster_altitude time_watersource, file(child_anemia.dat)

A.3.4 Stata spmap tool for graphing data onto maps

* download and instal the following Stata commands:

- ssc install shp2dta
- ssc install spmap

- ssc install spgrid
- ssc install vincenty
- ssc install sppack
- shp2dta using "GHA_adm2", database("GH_districts") /// coordinates("GH_coords") gencentroids("centroid") genid("id")replace
- use "GH_districts", clear // Country names and map boundary information from shape file
- use "GH_coords", clear // Coordinates that describe the boundaries of the Countries
- use"C:\Users\BLAM\Desktop\GH_graph\collapse_ordmeanp1p2p3.dta" ,clear
- merge 1:1 id using"C:\Users\BLAM\Desktop\GH_graph\GH_districts.dta"
- save "C:\Users\BLAM\Desktop\GH_graph\malaria_post_estfinal.dta",replac
- use "C:\Users\BLAM\Desktop\GH_graph\malaria_post_estfinal.dta",clear
- rename id _ID

  ****Spatially adjusted-Posterior mean maps for malaria***
- spmap malariamean_pi using "GH_coords.dta", id(_ID) clnumber(6)clmethod(quantile) fcolor(Rainbow) ndfcolor(gs8) ndlab("Missing") legend(size(*1.4)) legcount title("Regional malaria episodes", size(*0.8)) subtitle("Spatially adjusted-Posterior mean", size(*0.8))
- spmap malariamean_pi using "GH_coords.dta", id(_ID) clnumber(6)clmethod(quantile) fcolor(Blues) ndfcolor(gs8) ndlab("Missing") legend(size(*1.4)) legcount title("Regional malaria

episodes", size(*0.8)) subtitle("Spatially adjusted-Posterior mean", size(*0.8))

- spmap malariamean_pi using "GH_coords.dta", id(_ID) clnumber(6)clmethod(quantile) fcolor(Greys) ndfcolor(gs8) ndlab("Missing") legend(size(*1.4)) legcount title("Regional malaria episodes", size(*0.8)) subtitle("Spatially adjusted-Posterior mean", size(*0.8))

A.4 R codes

```
#read ghana shape file----GHA_adm2

install.packages("maptools")

install.packages("R2WinBUGS")

install.packages("mcmc")

install.packages("shapefiles")

install.packages("R2BayesX")

install.packages("spdep")

library(maptools)

library(R2WinBUGS)

library(mcmc)

library(shapefiles)

library("R2BayesX")

library(spdep)
```

```
setwd("C:/Users/BLAM/Desktop/GHA_adm_shp/GHA_adm_shp")

##get.adjacency(graph.edgelist(as.matrix(GHA_adm2.shp), directed=FALSE))

ghanaSHP <- maptools::readShapeSpatial("GHA_adm2.shp")

ghanaSHP2 <- maptools::readShapePoly ( "GHA_adm2.shp",IDvar="ID_2",
proj4string=CRS("+proj=longlat +ellps=clrk66"))

plot(ghanaSHP2, border="red", axes=TRUE, las=1 )

##export to Splus

##then open wibug as a text file import the map

maptools::sp2WB(map =as(ghanaSHP2, "SpatialPolygons"),filename="ghanaWinbug" )
```

A.5 WinBUGS codes

A.5.1 Logistic Regression Model (Malaria)

Logistic Regression Model with spatial and non spatial random effects #This code fits a modified version of the the following stata model

#melogit malaria_microscopytest i.place_of_residence i.mother_education i.wealth_index child_age heamoglobin cluster_altitude || region:

#Model Specification

```
model{
for (i in 1:N){
malaria_microscopytest[i]~dbern(p[i])        # Malaria main outcome variable
            logit(p[i])<-
b[1]+b[2]*child_age[i]+b[3]*equals(place_of_residence[i],2)+b[4]*equals(mother_education
[i],2)+b[5]*equals(mother_education[i],3)+b[6]*equals(mother_education[i],4)+b[7]*equals(
```

```
mother_education[i],5)+b[8]*equals(wealth_index[i],2)+b[9]*equals(wealth_index[i],3)+b[1
0]*equals(wealth_index[i],4)+b[11]*equals(wealth_index[i],5)+b[12]*heamoglobin[i]+b[13]
*cluster_altitude[i]+re[region[i]] +sp[region[i]]

}
for (k in 1:137)  {
# Exchangeable prior on unstructured random effects
re[k] ~ dnorm(0, tau.h)
}
# CAR prior distribution for spatial random effects:
sp[1:137] ~ car.normal(adj[], weights[], num[], tau.b)
for (k in 1:sumNumNeigh) {
weights[k] <- 1
}
# All priors and hyperpriors:
#Priors for beta coefficients
for (i in 1:13)  {
b[i]~dnorm(0,0.1)
 }
#Priors for the unstructured and structured random effects
tau.b ~ dgamma(0.5, 0.0005)
sigma.b <- sqrt(1 / tau.b)
tau.h ~ dgamma(0.5, 0.0005)
sigma.h <- sqrt(1 / tau.h)
            }
}
```

A.5.2 Ordinal Logistic Regression (Anaemia)

Ordinal Logistic Regression Model with spatial and non spatial random effects #This code fits the following stata model

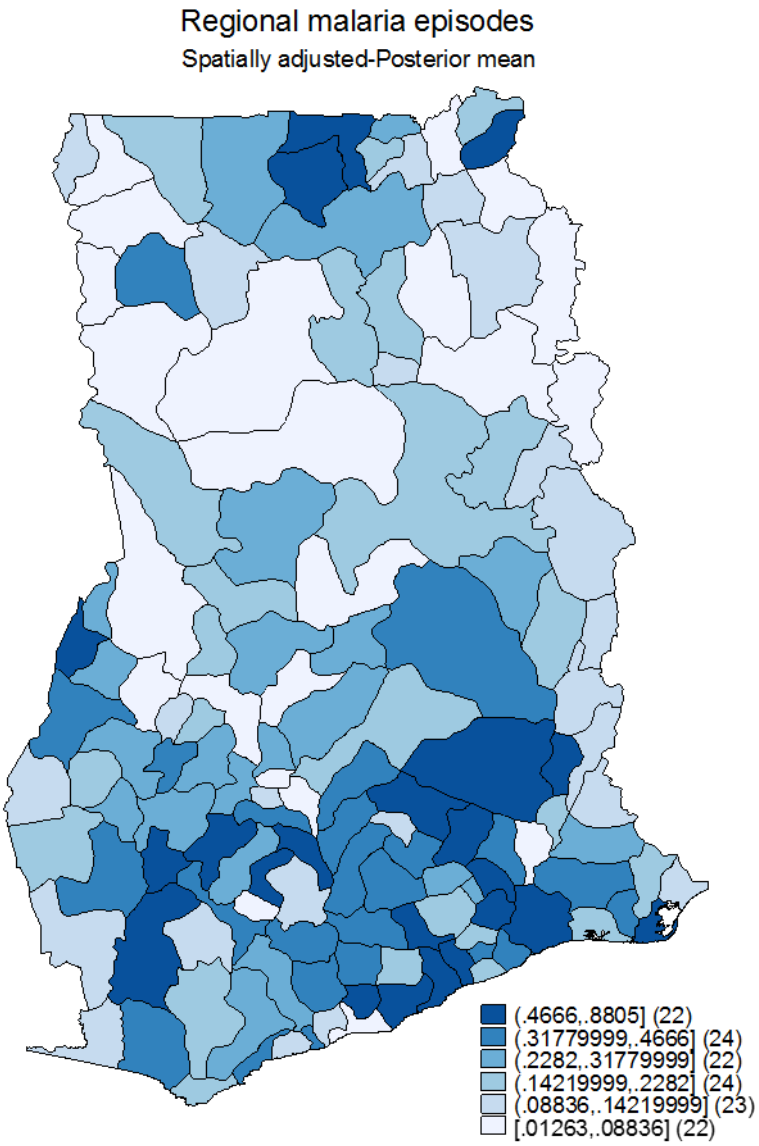
#meologit child_anemia2 severe_anemia_extreme_weakness severe_anemia_vomiting severe_anemia_nosymptoms i.place_of_residence i.mother_education i.wealth_index c.child_age c.cluster_altitude, ||region:

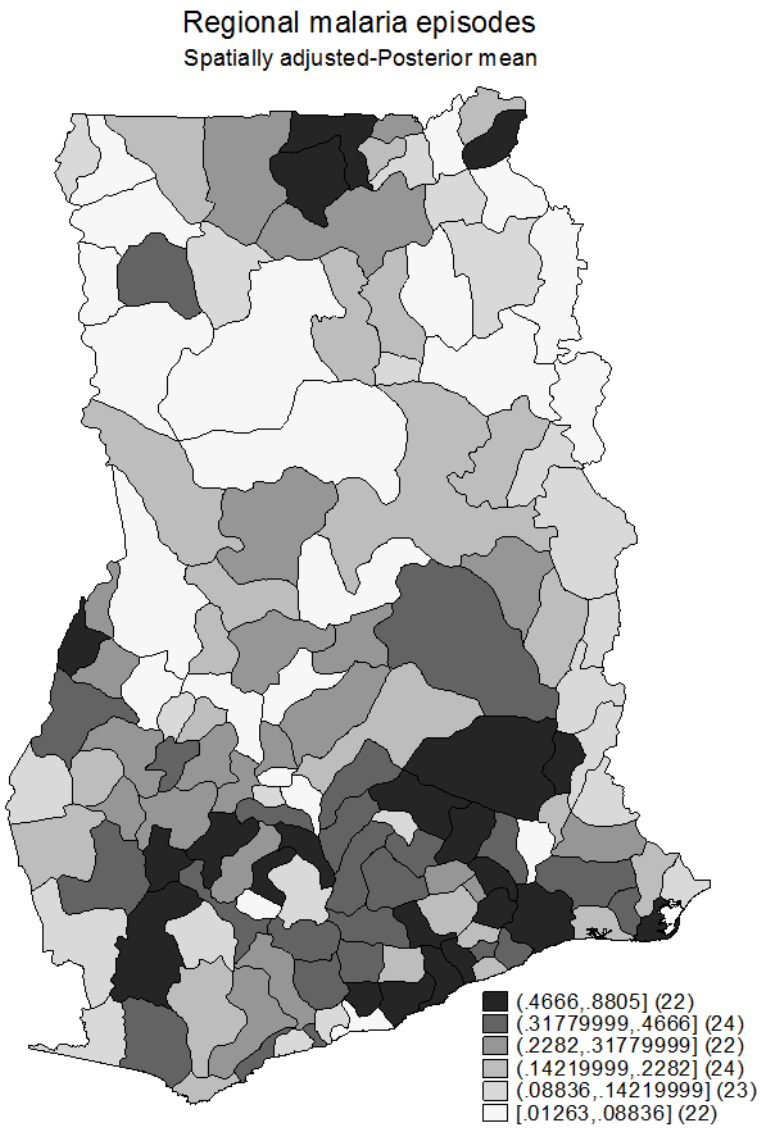
```
model{
  for( i in 1:N)
   {
   child_anemia2[i] ~ dcat( p[i,] )
   p[i, 1] <- 1/( 1 + exp( -c[1] + mu[i] ) )
   p[i, 2] <- 1/( 1 + exp( -c[2] + mu[i] ) ) - 1/( 1 + exp( -c[1] + mu[i] ) )
p[i, 3] <- 1- 1/( 1 + exp( -c[2] + mu[i] ) )

mu[i]  <-
beta[1]+beta[2]*child_age[i]+beta[3]*equals(place_of_residence[i],2)+beta[4]*equals(mother_education[i],2)+beta[5]*equals(mother_education[i],3)+beta[6]*equals(mother_education[i],4)+beta[7]*equals(mother_education[i],5)+beta[8]*equals(wealth_index[i],2)+beta[9]*equals(wealth_index[i],3)+beta[10]*equals(wealth_index[i],4)+beta[11]*equals(wealth_index[i],5)+beta[12]*cluster_altitude[i]+beta[13]*severe_anemia_extreme_weakness[i]+beta[14]*severe_anemia_vomiting[i]+beta[15]*severe_anemia_nosymptoms[i]+beta[16]*equals(sex_of_child[i],2)+re[region[i]] +sp[region[i]]

}
### All priors and hyperpriors:
c[1] <- g[1]
c[2] <- g[1] + g[2]
```

```
#Priors for adjusting coefficient for ordinal
g[1] ~ dnorm(0, 1.0E-6)
g[2] ~ dgamma(0.5, 0.005)
 for (k in 1:137)  {
# Exchangeable prior on unstructured random effects
re[k] ~ dnorm(0, tau.h)
}
# CAR prior distribution for spatial random effects:
sp[1:137] ~ car.normal(adj[], weights[], num[], tau.b)
for (k in 1:sumNumNeigh) {
weights[k] <- 1
}
#Priors for beta coefficients
for (i in 1:16)  {
beta[i]~dnorm(0,1.0E-6)
}
#Priors for the unstructured and structured random effects
tau.b ~ dgamma(0.5, 0.0005)
sigma.b <- sqrt(1 / tau.b)
tau.h ~ dgamma(0.5, 0.0005)
sigma.h <- sqrt(1 / tau.h)
}
```

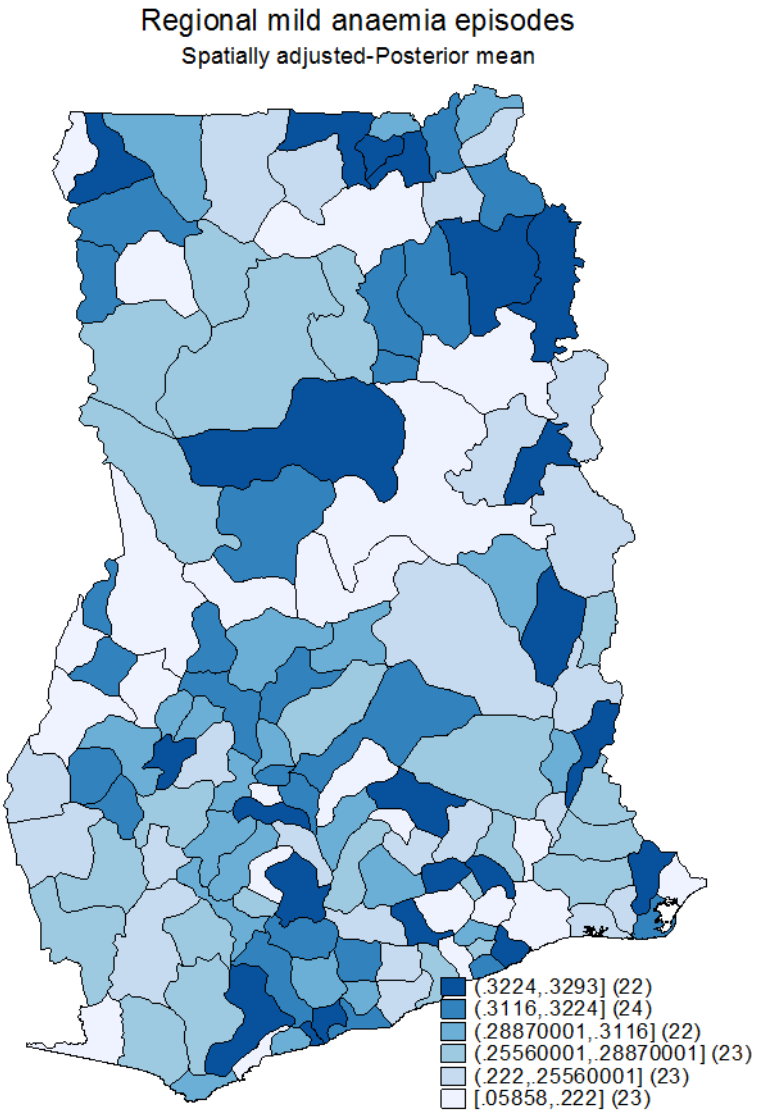
Appendix B Malaria and anaemia risk maps

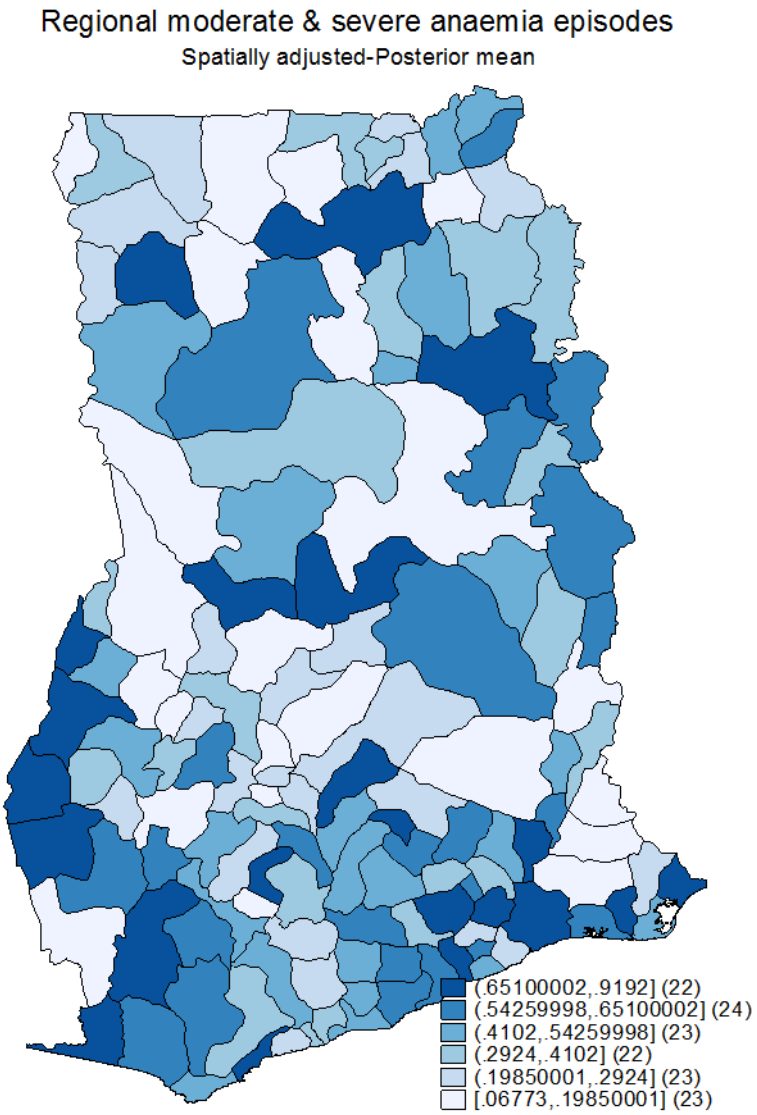
B.1 Spatially adjusted posterior mean maps for malaria

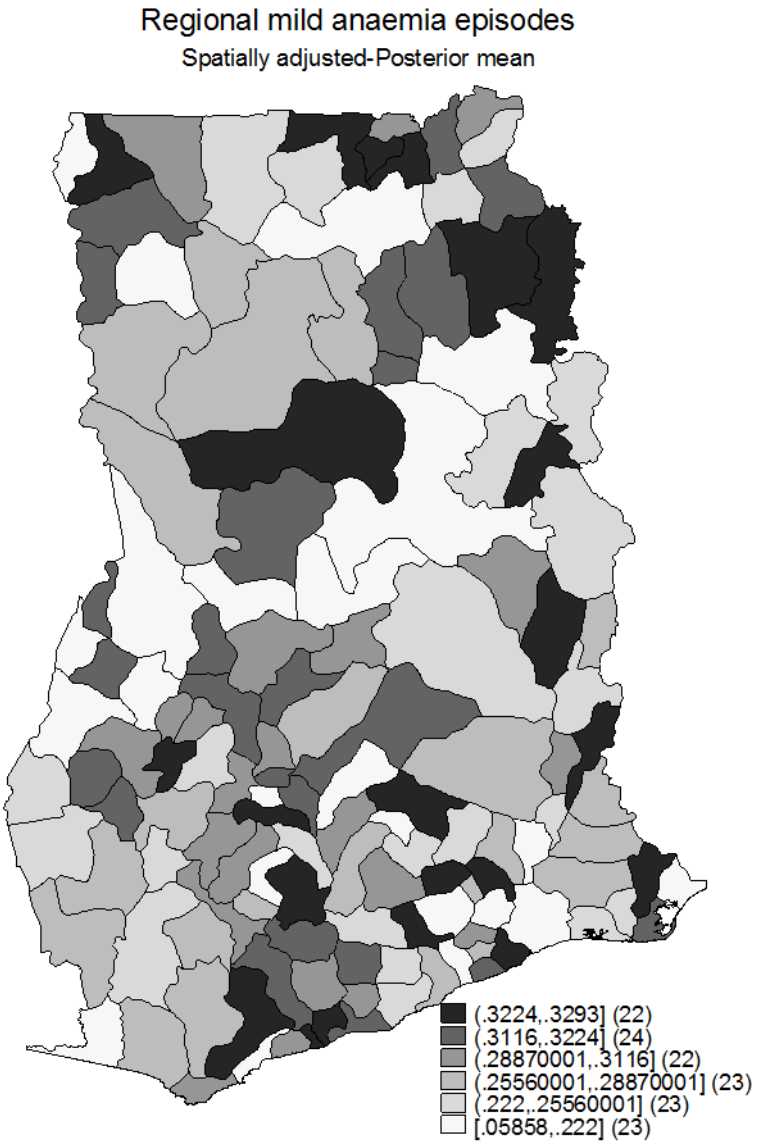


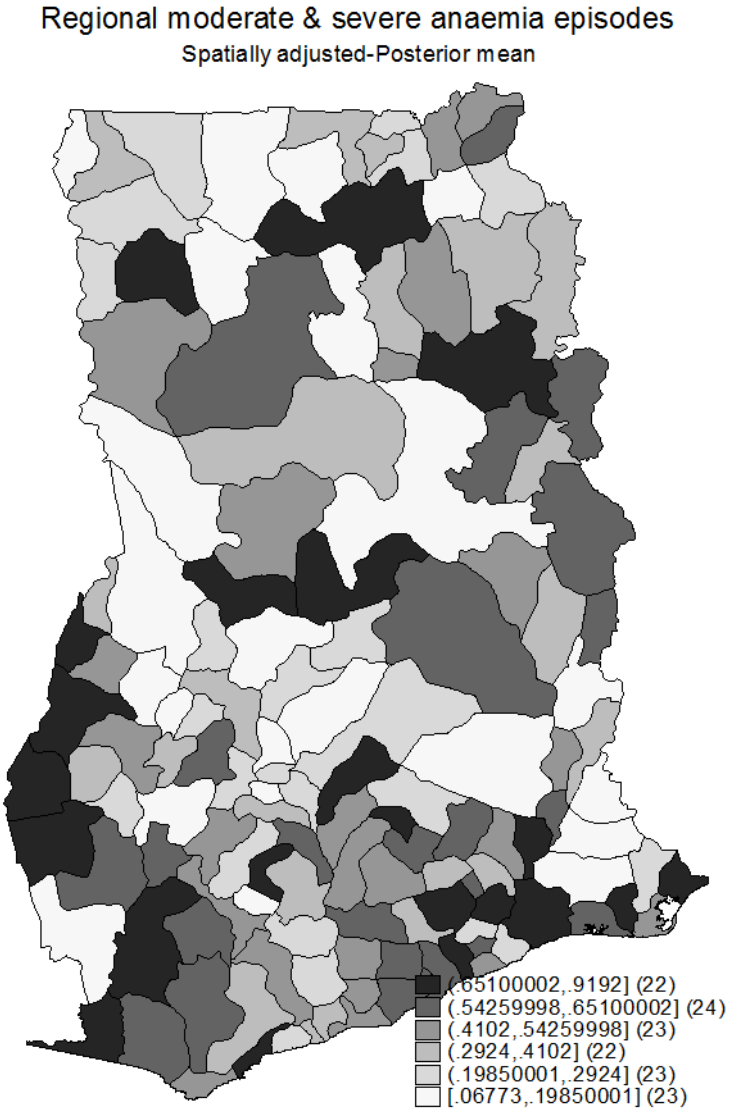

Regional malaria episodes
Spatially adjusted-Posterior mean
(.4666,.8805] (22)
(.31779999,.4666] (24)
(.2282,.31779999] (22)
(.14219999,.2282] (24)
(.08836,.14219999] (23)
[.01263,.08836] (22)

B.2 Spatially adjusted posterior mean maps for anaemia




Regional moderate & severe anaemia episodes
Spatially adjusted-Posterior mean
(.65100002,.9192] (22)
(.54259998,.65100002] (24)
(.4102,.54259998] (23)
(.2924,.4102] (22)
(.19850001,.2924] (23)
[.06773,.19850001] (23)


Regional mild anaemia episodes
Spatially adjusted-Posterior mean
(.3224,.3293] (22)
(.3116,.3224] (24)
(.28870001,.3116] (22)
(.25560001,.28870001] (23)
(.222,.25560001] (23)
[.05858,.222] (23)


Regional moderate & severe anaemia episodes
Spatially adjusted-Posterior mean
(.65100002,.9192] (22)
(.54259998,.65100002] (24)
(.4102,.54259998] (23)
(.2924,.4102] (22)
(.19850001,.2924] (23)
[.06773,.19850001] (23)