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Effect of Insecticide-Treated Nets on Anemia in Nigerian Children

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Walden University
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Abstract

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by

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MS, Epidemiology & Biostatistics, Northwestern University, 2011

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Dissertation Submitted in Partial Fulfillment

of the Requirements for the Degree of

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Public Health

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Abstract

Childhood anemia is a significant public health problem in Nigeria and frequently coexists with malaria. The mortality associated with malaria increases when anemia is present. Insecticide-treated nets (ITNs) are a cheap and effective malaria preventive measure that can provide a protective barrier from insects. There are conflicting results from several studies on the effect of ITNs on anemia in children, with fewer studies on the effect of ITNs on anemia in Nigerian children. This study aimed to measure the effect of ITN use on anemia among children aged 6–59 months in Nigeria. The social ecological model was used as the theoretical framework. In this cross-sectional study, secondary data from the 2010 and 2015 Malaria Indicator Surveys and the 2018 Demographic Health Survey were analyzed using Bayesian multilevel regression. The results did not provide sufficient evidence of the protective effect of ITN use against anemia. Additionally, it was found that malaria, fever within the past 2 weeks, rural residence, and improved water source were risk factors for anemia. Older children, female children, children with older mothers, children with more educated mothers, and those residing in wealthier households had a lowered risk of anemia. Specific to malaria, rural residence, older children, children with older mothers, and recent fever increased malaria risk. ITN use, female children, children with more educated mothers, wealthier households, and access to an improved source of drinking water lowered the risk of contracting malaria. This study contributes to positive social change by providing evidence for the development of public health policies and interventions to reduce childhood anemia in Nigeria.

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Dedication

To my parents, Peninnah and Isaac Onu, for you have borne me aloft on the wings of your love and prayers.

Acknowledgments

In so many ways, studying at Walden University has been like a journey, a journey with many exciting sights and detours. It recalls to mind the words of J.R.R. Tolkien in *The Fellowship of the Ring*, "He [Bilbo] used often to say there was only one Road; that it was like a great river: its springs were at every doorstep, and every path was its tributary." I have enjoyed every bit of this journey, much like Bilbo Baggins.

So, I am thankful to God Almighty for seeing me through the period of my Walden studies. I want to thank Dr. Namgyal Kyulo, my dissertation committee chair, for his calm advice and encouragement. To my committee member, Dr. German Gonzalez: thank you for all your time and effort to guide me on this dissertation and research journey.

The completion of the Ph.D. journey would not have been possible without the love, encouragement, and support of my dear wife, Ojone Ocheja. I am grateful for her support and prayers. I am also thankful to my children: Umaojo, Uluojo, Iḿiojo, Ibeojo, and Ejuojo, and their regular reminders to study. I am grateful to Dr. Emmanuel Adegbe for his timely interventions and Dr. Michael Egwu for access to his library.

Ultimately, this dissertation would not have been possible without the example and motivation provided by my teachers and mentors. I acknowledge, and I am grateful for their influence on me. I am but a dwarf standing on the shoulders of giants.

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Chapter 1: Introduction

Children have a high risk of being affected by both anemia and malaria, especially if they live in sub-Saharan Africa (White, 2018). Malaria is one of the leading causes of anemia (White, 2018). Concurrent anemia and malaria increase the risk of death in children, killing an estimated 2,000 people daily, mostly children in Africa (White, 2018; White et al., 2014). There is a high disease burden of anemia and malaria in Nigeria. The prevalence of anemia in Nigerian children less than 5 years old was 68.3% in 2017 (World Health Organization [WHO], 2017). In Nigeria, malaria incidence was 281.2 cases per 1,000 population at risk (WHO, 2019). The use of insecticide-treated nets (ITNs) prevents malaria by killing the Anopheles mosquitoes, which are the vectors of malaria (Tokponnon et al., 2014; White, 2018). Preventing malaria reduces the incidence of anemia (Florey, 2012; Tokponnon et al., 2014), leading to the hypothesis that the use of nets impacts the prevalence of anemia.

There is low coverage of ITNs and long-lasting insecticide nets (LLINs) in Nigeria, with less than 50% of households owning at least one ITN for every two persons (Federal Republic of Nigeria, 2014; Gething et al., 2016). Studies in other countries examined the relationship between mosquito nets and anemia (Florey, 2012; Tokponnon et al., 2014). However, similar studies in Nigerian children have been few and limited in scope (Adah et al., 2009; Oladeinde et al., 2012). The main focus of this study was the association between ITN use and hemoglobin levels in Nigerian children. This study will provide a better understanding of the association between ITN use and anemia in Nigeria. The study findings may contribute to positive social change by influencing policy to

reduce child mortality through increasing awareness about the burden of anemia in Nigerian children. The findings can also guide the design of appropriate preventive interventions to address childhood anemia in Nigeria.

This chapter includes the background of the study, the problem statement, the purpose of the study, research questions and hypotheses, and the nature of the study. There will be a brief discussion of the theoretical framework, the delimitations, assumptions, limitations of the study, and the significance of the study. I then end the chapter with a summary and transition to the next.

Background

Anemia and malaria frequently coexist because malaria is a significant cause of anemia (White, 2018; White et al., 2014). The causes of anemia in children living in sub-Saharan Africa are iron and other micronutrient deficiencies, malaria, sickle cell anemia, hookworm infestation, and schistosomiasis (Petry et al., 2016). These different causes often occur together. There is a complex interplay between malaria, anemia, and nutritional deficiencies (Teh et al., 2018). Abdulkareem et al. (2017) found a positive correlation between the severity of anemia and *Plasmodium falciparum* parasite density. They also found that anemia in the presence of malaria was worse with deficiencies of iron, zinc, and copper. Malaria was a more significant cause of anemia in children than undernutrition in malaria-endemic regions (McCuskee et al., 2014).

Anemia and malaria have long-term public health consequences with increased morbidity and mortality with coexistent anemia and malaria (Allali et al., 2017). Repeated exposure to episodes of malaria infection worsens anemia (Chen et al., 2016).

Bangirana et al. (2014) found an association between severe malarial anemia (defined as Plasmodium parasitemia with hemoglobin ≤ 50 g/l) and long-term cognitive impairment in a cohort of children followed over 12 months old. The *z* scores for cognitive ability tests were lower (−0.52) in children with severe malarial anemia. This reduction in z scores corresponded to a difference of 8 IQ points (Bangirana et al., 2014). A similar study by Boivin et al. (2016) provided evidence of the mediating influence of anemia on the negative relationship between the number of malaria episodes and scores on cognitive performance tests in children aged 6–24 months.

The implication of the preceding evidence is that preventing malaria will reduce the prevalence of anemia. ITNs are a cheap and effective strategy to prevent malaria and anemia (Florey, 2012; Tokponnon et al., 2014). Several factors influence the use of mosquito nets, even when they are available (Olapeju et al., 2018; Ricotta et al., 2019). Using a qualitative study design, Abdullahi et al. (2013) found that limited access and sparse distribution networks of ITNs might explain negative attitudes towards the use of treated nets for children under 5 years old in selected rural and urban communities of Kwara State, Nigeria. In comparison, Russell et al. (2015) found that social support, exposure to a social behavior change home visit intervention, and higher social support from friends and family significantly influenced the use of ITNs. They also found that decreased ITN use was related to increased education level, increased malaria knowledge level, and any perceived disadvantage of ITNs. However, Russell et al.'s was limited to the small and mostly rural Nigerian State of Ebonyi, so the results are not generalizable.

There is a paucity of research literature on the effect of ITNs on anemia in Nigerian children, with the few available articles either reporting no protective effect of ITNs on anemia or using unrepresentative samples. Florey (2012) examined the relationship between ITN use and moderate-to-severe anemia in last-born children aged 6–23 months using survey data from malaria-endemic countries in sub-Saharan Africa between 2001 and 2011. The investigator used multivariate logistic regression models with pooled data from multiple countries, including Nigeria. The overall pooled estimates Florey's study did not show a protective effect of ITN use against anemia (adjusted *OR* [AOR] = 0.84, 95% CI [0.70, 1.02], $p = .08$). These results were similar to the findings of Pryce et al. (2018), who conducted a meta-analysis of randomized clinical trials of ITNs versus no nets or untreated nets. Pryce et al. found that ITNs probably did not protect against anemia (*OR* = 1.29, 95% [CI 0.42, 2.16]). In studies on ITN use and anemia in Nigeria, Adah et al. (2009) and Oladeinde et al. (2012) found a protective effect of ITN use against anemia. However, their studies were limited in scope, and the findings were not generalizable to the subnational or national levels due to flawed sampling designs. More recent data from nationally representative surveys are now available.

This gap in the literature, coupled with the burden of anemia and malaria in Nigerian children, provided the rationale for this dissertation. This research will contribute to positive social change by providing a better understanding of the association between ITN use and anemia in Nigerian children. The findings will inform the design of preventive and health promotion strategies targeting childhood anemia in Nigeria.

Problem Statement

Malaria and childhood anemia are significant public health problems that often occur together. Twenty-five percent of the estimated 219 million malaria cases worldwide in 2017 were in Nigeria (WHO, 2018). In 2017, the prevalence of anemia in African children under 5 years old was 61%, rising to 79% in the presence of malaria (WHO, 2018). Nineteen percent of global malaria deaths in 2017 were in Nigeria, with the majority of these malaria deaths in children younger than 5 years old (WHO, 2018). Concurrent anemia and malaria increase the risk of death and worsen health outcomes (Scott et al., 2014; White, 2018), which include long-term neurocognitive impairment in children (Bangirana et al., 2014; Ssenkusu et al., 2016).

As malaria is a leading cause of childhood anemia in endemic malaria regions like Nigeria, preventing malaria can contribute to reducing the incidence of anemia (Athuman et al., 2015). ITNs prevent malaria by killing the *Anopheles* mosquito, which is the vector for malaria and also acting as a physical barrier preventing mosquito bites (L. Choi et al., 2019; Pryce et al., 2018; Tokponnon et al., 2014, 2019; White, 2018). Since 2001, several ITN distribution campaigns in Nigeria have provided free ITNs to pregnant women and children under 5 years old (Noland et al., 2014). The National Malaria Strategic Plan 2014–2020 aimed to achieve 100% coverage of ITNs and an 80% ITN use rate by 2020. ITN coverage is measured as the proportion of households with at least one ITN per every two persons (Federal Republic of Nigeria, 2014). This target has not been met as there was a decline in ITN coverage from 2015 to 2018. About 36% of households reported having at least one net for every two persons in the household in 2015 compared

to 29.8% in 2018 (National Malaria Elimination Programme [NMEP] et al., 2016; National Population Commission [NPC] & ICF, 2019).

The specific problem is the lack of data on how the rate of ITN use following the campaigns of net distribution has affected the prevalence of anemia in Nigeria. Only a few studies previously sought to measure the effect of ITN use on anemia in Nigerian children (Adah et al., 2009; Florey, 2012; Oladeinde et al., 2012). Adah et al. (2009) assessed the effect of ITN usage on parasitemia and anemia in 1,580 children (790 ITN users and 790 non-ITN users) between the ages of 6 months and 2 years old in Ogun state. They found that the mean hemoglobin level of children who used an ITN was statistically significantly higher than for those who did not use an ITN. However, they did not adjust for the effects of sociodemographic variables, and they did not report the prevalence of ITN use. Oladeinde et al. (2012), on the other hand, found the prevalence of ITN use was low (4.9%) and that ITN use did not protect against malaria. Their results suggested some effect modification because among malaria parasite-infected children, ITN use significantly reduced the prevalence of anemia. Florey's (2012) study was limited to only last-born children 6–23 months of age. The data used for the study excluded other children below the age of 5 years old. Only data from the baseline 2010 Malaria Indicator Survey was available for Nigeria in that study (Florey, 2012). The exclusion of children aged 24–59 months limited the generalizability of Florey's findings. In this study, I sought to fill the literature gap concerning the effect of ITN use on anemia in Nigerian children since the onset of mass ITN distribution.

Purpose

The purpose of this study was to measure the effect of ITN use on anemia among children aged 6–59 months in Nigeria. In this study, I used a quantitative approach and a cross-sectional design to examine secondary survey data for a correlation between the use of ITNs and hemoglobin levels in these children. I also evaluated the influence of other sociodemographic variables on the relationship between ITN use and hemoglobin levels in these children.

Research Questions and Hypotheses

The following research questions and corresponding null and alternative hypotheses provided the focus for this study:

RQ1: Is there an association between malaria infection status and hemoglobin level in children aged 6 to 59 months?

$H_0$1: There is no statistically significant association between malaria infection status and hemoglobin level in children aged 6 to 59 months.

H_A1: There is a statistically significant association between malaria infection status and hemoglobin level in children aged 6 to 59 months.

RQ2: Is there an association between the use of ITNs and malaria infection status in children aged 6 to 59 months?

$H_0$2: There is no statistically significant association between the use of ITNs and malaria infection status in children aged 6 to 59 months.

H_A2: There is a statistically significant association between the use of ITNs and malaria infection status in children aged 6 to 59 months.

RQ3: Is there an association between the use of ITNs and hemoglobin level in children aged 6 to 59 months?

$H_0$3: There is no statistically significant association between the use of ITNs and hemoglobin level in children aged 6 to 59 months.

H_A3: There is a statistically significant association between the use of ITNs and hemoglobin level in children aged 6 to 59 months.

Theoretical Framework

The theoretical framework for this study was the social ecological model. Bronfenbrenner (1979) initially proposed the social ecological model as nested but interacting levels of influence. These interacting levels of influence were the microsystem, the mesosystem, the exosystem, and the macrosystem. The microsystem is made up of the interactions within family and group members. The mesosystem consists of the interactions among family, school, and peer groups. The exosystem is the social system of institutions and social interactions. The macrosystem is the culture, customs, and laws.

Building on Bronfenbrenner's model, McLeroy et al. (1988) stated that several levels of intrapersonal, interpersonal, organizational, community, and public policy factors and processes influence health outcomes. For example, Ngnie-Teta et al. (2007) applied the social ecological model as a theoretical framework for the study of anemia in children in developing countries. They grouped the determinants of anemia into individual-level (corresponding to intrapersonal level), household-level (i.e., the interpersonal level), and community-level variables. These variables contribute by

interrelated pathways to childhood anemia, but their relationships are not identical because different pathways exist. These variables range from proximal variables that affect individuals directly to distal variables that indirectly influence health behavior and health outcomes. Therefore, it is critical to distinguish the relative contributions of these different factors to childhood anemia. I will discuss the theoretical framework in more detail in Chapter 2.

Nature of Study

The concept of causality underlies quantitative research (Rothman, 2002). The ideal comparison would be the simultaneous comparison of children with themselves in both an exposed state (i.e., the use of ITNs) and an unexposed state (i.e., the non-use of ITN). This counterfactual paradigm envisions the impossible goal of matching each child with themself in both an exposed and an unexposed state during the same time. Since the counterfactual ideal is impossible, the best design to test causality is an experimental design that manipulates the independent variable and can control potential confounding variables (Rothman, 2002). An experimental design was not possible in this study, so I used a correlational design to test the hypotheses about the associations between ITN use, anemia, and malaria.

In this study, I used a cross-sectional design to examine the relationships between ITN use, hemoglobin level, and malaria infection status in children between the ages of 6–59 months. The predictor or antecedent variable was ITN use, and the outcome variables were hemoglobin level and malaria. The relationship of sociodemographic variables to the predictor and outcome variables were also examined in this study. I used

a quantitative method and several secondary data sources to measure the effect of ITN use on childhood anemia and malaria in Nigeria. The nationally representative secondary data were drawn from health surveys from the 2010 and 2015 Nigeria Malaria Indicator Surveys (MISs) and the 2018 Nigeria Demographic Health Survey (DHS). These surveys collected data on ITN use, hemoglobin level, malaria infection, and sociodemographic variables. I used the statistical technique of multilevel regression modeling to examine the relationships between these variables. The details of the study design, survey methods, datasets, and statistical methods are provided in Chapter 3.

Definitions

The following terms used in this study are defined as:

Anemia: A reduction in the number of red blood cells. The insufficient number of red blood cells leads to their oxygen-carrying capacity being unable to meet the body's physiologic needs. Anemia in children aged 6–59 months is defined as a hemoglobin level < 11 g/dl (WHO, 2011).

Asymptomatic malaria infection: The presence of malaria parasites in the blood in the absence of fever or other symptoms and without recent antimalarial treatment (Chen et al., 2016). In this study, asymptomatic malaria infection is the presence of the *Plasmodium* species on the blood smear without fever.

Malaria infection: The presence of *Plasmodium* parasites in the blood confirmed by microscopy, a rapid diagnostic test, or a molecular diagnostic test (WHO, 2016). In this study, malaria infection is the presence of *Plasmodium* species on the blood smear with or without fever.

Malarial anemia: Anemia together with the presence of *Plasmodium* species on the blood smear (Brickley et al., 2017).

Plasmodium parasitemia: The presence of *Plasmodium* species on the blood smear (White, 2018).

Severe anemia: For this study, severe anemia in children aged 6–59 months is a hemoglobin level < 7 g/dl (WHO, 2011), even though in several malarial studies, severe anemia is a hemoglobin level ≤ 5 g/dl (White, 2018).

Symptomatic malaria infection: *Plasmodium* parasitemia with fever (White, 2018).

Assumptions

The assumptions in this study are related to the use of secondary data. The first assumption was that the surveys were conducted rigorously, with the right study design and valid data collection methods. To answer the research questions for this study, I used data from national demographic surveys in Nigeria. Hence, I assumed that the individuals surveyed were representative of children under 5 years old in Nigeria. Another assumption was that the variables relevant to this study were available in these data sets. The final assumption was that the data available are accurate and complete. These assumptions were critical for obtaining meaningful results.

Scope and Delimitations

The scope of this study was limited to examining how the use of ITNs is related to hemoglobin levels in children under the age of 5 years old in Nigeria. This study excluded children older than 5 years old and adults. Biological processes were not studied

because only a limited set of variables were evaluated using the theoretical foundation of the social ecological model. The results of this study are valid and generalizable to young children in Nigeria.

Limitations

The major limitation of this study was the cross-sectional study design. According to Campbell and Stanley (1963), the cross-sectional design, which is a form of correlational design, is weak. The cross-sectional design compares naturally occurring units of observations that differ not just in the presence and absence of an observed variable but also in other unobserved attributes. These unobserved variables could create differences in the expected outcome variable. These unobserved variables, therefore, provide plausible rival hypotheses to the primary hypothesis. In the context of this study, anemia has other causes apart from malaria (see Petry et al., 2016). These other causes (i.e., iron deficiency, micronutrient deficiencies, sickle cell anemia, hookworm infestation, and schistosomiasis) were not measured. Not measuring these other causes of anemia was a limitation of this study because any effect could be partly confounded due to these other causes. Another possible limitation was the information bias arising from the survey participants' self-reports and possible measurement errors for the hemoglobin and malaria parasite measurements. The incorrect determination of either exposure, or outcome, or both lead to information bias (Grimes & Schulz, 2002).

Significance

Children are a vulnerable population. Children in sub-Saharan Africa, and especially in Nigeria, have an increased risk of illness and death from anemia and malaria

(White, 2018; White et al., 2014). Systematic reviews have shown that ITN use effectively prevents malaria, but it is uncertain if the use of ITN will also reduce the prevalence of anemia (Pryce et al., 2018). Since there is little research on the effectiveness of ITNs against anemia in Nigerian children, there is a significant research gap concerning this topic. The effect of this public health intervention on anemia prevalence in Nigeria following ITNs distribution campaigns is unknown. Given that cheap and affordable public health interventions directed against childhood anemia are needed, this study can potentially provide the necessary evidence to influence public health policy and contribute to positive social change.

Summary

Anemia and malaria are two conditions with significant morbidity and mortality in Nigerian children. An understanding of the relationship between anemia, malaria, and the use of ITN may inform appropriate interventions to reduce the burden of childhood anemia in Nigeria. The use of ITNs may be a possible protective factor for anemia, but few studies have examined this association in Nigerian children. The objective of this research was to fill this knowledge gap and improve the understanding of this association in the population of children in Nigeria.

In this chapter, I introduced the problem and provided background, purpose, theoretical framework, terms, assumptions, limitations, and significance to support the study. In Chapter 2, I will review selected literature and studies related to anemia, malaria, and ITNs. Additional details about the theoretical foundation of this study will also be provided.

Chapter 2: Literature Review

Introduction

Childhood anemia is a significant public health problem in malaria-endemic regions like Nigeria. The highest prevalence of anemia globally is in African children under 5 years old (WHO, 2017). There are poor health outcomes associated with anemia, worsening when the anemia coexists with malaria (Scott et al., 2014). Anemia can lead to long-term adverse health consequences like impaired neurocognitive development in children (Ssenkusu et al., 2016). Malaria is a leading cause of childhood anemia in Nigeria, and anemia is a significant contributor to malaria-associated deaths (White, 2018). Preventing malaria reduces the incidence of anemia (White, 2018). ITNs prevent malaria (Pryce et al., 2018; Tokponnon et al., 2014, 2019).

In this chapter, I provide a review of relevant literature on the public health significance of childhood anemia and the adverse consequences of anemia in children. A key area reviewed is risk factors for childhood anemia, including the relationship between malaria and anemia. There is also a review of interventions against anemia in children and malaria prevention strategies focusing on ITNs and anemia as well as factors that influence the effectiveness of ITNs. I also discuss the social ecological model, which is the theoretical framework of this study, followed by a summary of this chapter and transition to the next chapter.

Literature Search Strategy

I searched the Cochrane Database of Systematic Reviews, Embase, ProQuest, ScienceDirect, and the combined CINAHL Plus and MEDLINE databases through the

Walden Library. The literature search was limited to full-text, peer-reviewed articles published in English from January 2014 through June 2019 using the search terms *anemia* AND *malaria* AND *net* OR *insecticide net* OR *long-lasting net*. This initial search yielded 910 articles: CINAHL Plus and MEDLINE (53), Embase (27), Proquest (590), ScienceDirect (233), and Cochrane Database of Systematic Reviews (7). The search was augmented using Google Scholar with the same search terms. I also expanded the literature search to PubMed and ResearchGate using the search terms of *anemia, malaria*, *anemia in Nigeria,* and *malarial anemia*. In addition, the references of selected articles were searched. The titles and abstracts of the articles were then screened to select relevant articles for inclusion in the literature review.

Childhood Anemia

Public Health Significance of Childhood Anemia

Anemia is common worldwide. Analyzing the trend in the prevalence of anemia in children from 1995 to 2011, Stevens et al. (2013) estimated that the global prevalence of anemia in children dropped from 47% in 1995 to 43% in 2011. These figures corresponded to about 273 million children with anemia worldwide. Most of the children affected by anemia live in Africa and South Asia (Stevens et al., 2013). Based on data from the Global Health Observatory, the WHO (2017) reported that the prevalence of childhood anemia in Africa ranged from 30% to as high as 86.2%. The overall prevalence of anemia in African children less than 5 years of age in 2016 was 59.3% compared to the global prevalence of childhood anemia of 41.7% (WHO, 2017).

The public health significance of anemia is graded based on the overall anemia prevalence as mild (5%–19%), moderate (20%–39%), and severe (≥ 40%; De Benoist et al., 2008). The public health significance of anemia in Nigeria is severe, and there is a significantly increased risk of anemia in children in Nigeria. The 2010 Nigeria Malaria Indicator Survey estimated that 72% of Nigerian children aged 6–59 months were anemic (NPC et al., 2012).

Adverse Consequences of Childhood Anemia

Anemia predisposes to adverse health outcomes in children; there is increased mortality in the presence of anemia. Scott et al. (2014) did a meta-analysis of 11,811 children from six African countries and found that the risk of mortality fell by 24% for each 10 g/l rise in hemoglobin level: *OR* = 0.76, 95% CI [0.62, 0.93]. Hau et al. (2018) also found that each 10 g/dl rise in hemoglobin level reduced the risk of death by 10% to 24%, hazard ratio [HR] = 0.83, 95% CI [0.76, 0.90], over the 1-year posthospitalization. Similarly, Chami et al. (2019) reported that over a 12-month posthospital period, children aged 2 to 12 years old with severe anemia were more likely to die (HR = 2.42, 95% CI [1.53, 3.83]) compared to children without severe anemia.

Anemia harms child development, interfering with proper motor functioning and cognitive development (Bangirana et al., 2014; Boivin et al., 2016; Ssenkusu et al., 2016). Children with anemia have lower average IQs than those without anemia. The average IQ decreases by 2 points for every 10 g/l decrease in hemoglobin (Stoltzfus et al., 2004). Children with anemia have poorer numeracy and literacy test scores (Gupta, 2017). These impacts on brain function may be due to structural brain changes caused by

anemia. S. Choi et al. (2019) found that children with severe anemia had reduced brain white matter volume and increased risk of white matter strokes. The lower white matter volumes were associated with reduced nonverbal intellectual functioning. The association with reduced nonverbal functioning was found only in males, suggesting sex differences in brain injury response to anemia. There is also the possibility of long-term behavioral problems in children with severe malaria anemia (Ssenkusu et al., 2016).

There is a complex relationship between anemia and infection. Anemia is often associated with chronic infections and often shares the same underlying causes (Viana, 2011). Following a prospective study of infants, Levy et al. (2005) reported an increased risk of diarrhea (*OR* = 2.9, 95% [CI 1.6, 5.3]) and respiratory illness (*OR* = 2.0, [1.1, 3.7]) from 7 to 18 months of age when anemia (Hb < 11 g/dl) was present at 6 months of age after controlling for environmental and socioeconomic factors.

Risk Factors for Childhood Anemia in Sub-Saharan Africa

The risk factors for anemia in African children are myriad with complex interrelations. Dietary iron deficiency and nutritional deficiencies, sickle cell anemia, thalassemias, malaria, hookworm infestation, and schistosomiasis are the most prevalent causes of anemia in African children (Kassebaum et al., 2014; Petry et al., 2016). These conditions cause anemia through various mechanisms like reduced or abnormal red blood cell (RBC) formation, shortened RBC life span, or blood loss (Powell & Achebe, 2016).

Nutritional Factors

Nutritional factors include iron deficiency, other nutritional deficiencies, and feeding practices.

Iron and Other Nutritional Deficiencies

There are several nutritional causes of anemia, but iron deficiency is the most frequent cause of anemia worldwide (Allali et al., 2017). Iron deficiency can arise from reduced dietary intake of iron, malabsorption of iron, increased need for iron during rapid growth in children, and chronic blood loss (Lopez et al., 2016). Petry et al. (2016) reviewed data from surveys that measured iron deficiency, iron deficiency anemia, and anemia prevalence amongst preschool children and women of reproductive age. They estimated that the proportion of anemia in preschool children attributable to iron deficiency was 24.6%, 95% CI [17.7, 32.2].

Other nutrition-related causes are folic acid and vitamin B12 and vitamin A deficiencies (Janus & Moerschel, 2010). Using a randomized clinical trial design, Egbi et al. (2018) measured the effect of a food supplement of dried green leafy vegetables on anemia and vitamin A status of children. They found a statistically significant rise in hemoglobin level from 117.6 g/l to 121.9 g/l for children receiving the supplement compared to a drop from 116.9 g/l to 113.4 g/l for those who did not receive the supplement. Somassè et al. (2018) also found that home fortification of food using multiple-micronutrient powder had a modest but statistically significant effect on hemoglobin level after 3 months among children aged 6–23 months who received the intervention compared to those who did not (0.50 vs. 0.09 g/dl, $p = .023$). The proportion of severe anemia was reduced by 84 % (from 9.8% to 1.6 %) in the intervention group.

Feeding Practices

Several studies showed a link between feeding practices, malnutrition (i.e., stunting or wasting), and anemia. Malako et al. (2018) reported that household food insecurity (AOR = 2.74), poor dietary diversity (AOR = 2.86), early or late initiation of complementary feeding (AOR = 2.00), poor breastfeeding practice (AOR = 2.60), and poor use of folic acid by mothers (AOR = 2.75) were significantly associated with anemia in children. In a study of infants and young children aged 6–23 months, Mohammed et al. (2019) found a joint prevalence of anemia and stunting of 23.9% that was significantly related to lower intake of vitamin A supplement (AOR = 1.19, $p = .003$), lower intake of fruit and vegetables rich in vitamin A (AOR = 1.15, $p = .006$), less meat in the diet (AOR = 1.55, $p = .002$), lower ingestion of legumes (AOR = 1.38, $p = .021$), and eating less than three daily meals (AOR = 1.22, $p = .020$). In other studies, children with reduced dietary diversity were about 3 times more likely to have anemia, with the early introduction of complementary foods before 6 months of age being a strong risk factor for anemia (Gebreweld et al., 2019; Woldie et al., 2015). Stunted or wasted children have more risk of anemia than nonmalnourished children (Gari et al., 2017; Melku et al., 2018). Wilson et al. (2018) also found that stunted children and underweight children were significantly more likely to have mild or moderate anemia but did not find any association between stunting and malaria.

Soil-Transmitted Helminths and Schistosomiasis

Soil-transmitted helminths and schistosomiasis are frequent causes of anemia in Africa (Petry et al., 2016). Soil-transmitted helminth infections can lead to anemia

through various mechanisms, including internal bleeding; intestinal inflammation and obstruction; diarrhea; and impairment of nutrient intake, digestion, and absorption (Parija et al., 2017).

These helminth infestations often coexist with malaria. In a cross-sectional survey, Babamale et al. (2018) found a 63% prevalence of coinfection with two or more parasite species (i.e., *Plasmodium falciparum*, *Ascaris lumbricoides*, *Tricuris trichiura*, and hookworm). The prevalence of ascariasis was significantly higher in individuals infected with *Plasmodium falciparum* (AOR = 5.87). Heavy *Ascaris lumbricoides* and *Tricuris trichiura* infections were associated with high *Plasmodium falciparum* parasitemia (Babamale et al., 2018). These results were similar to those of an earlier systematic review by Degarege et al. (2016) who found that the odds of asymptomatic or uncomplicated *Plasmodium falciparum* infection and the mean malaria parasite density were higher in children with soil-transmitted helminths infection. In contrast, helminth infection had less likelihood (*OR* = 0.5 [95 % CI 0.21, 0.78]) of malaria-related anemia (Degarege et al., 2016). In a study of a cohort of children in Cameroon, Njua-Yafi et al. (2016) reported that the mean hemoglobin level of children coinfected with *Plasmodium* and helminths (10.53 g/dl) was significantly (p = .006) higher than in children infected with *Plasmodium* (9.61) or helminths (10.45) alone. However, preventive deworming programs either for infected children or the community have not been proven to be beneficial in reducing the burden of illness associated with soil-transmitted helminth infections or improving nutritional status, hemoglobin levels, or school performance (Taylor-Robinson et al., 2015; Welch et al., 2017).

Malaria and Anemia

There is an intimate association between malaria and anemia in endemic malaria regions. Malaria is a leading cause of anemia in tropical areas (White, 2018). In areas of high malaria transmission, nearly all infants and young children as well as many older children and adults have a reduced hemoglobin concentration (White, 2018). Wanzira et al. (2017) found that malaria parasite prevalence significantly increased from 11.08% among children with no anemia to 50.99% in children with severe anemia ($p = .001$).

Even asymptomatic malaria raises the risk of anemia in children (Chen et al., 2016). Maketa et al. (2015) found a strong predictive relationship between *Plasmodium* infection and anemia in asymptomatic children (AOR = 3.5, $p = .01$) and an inverse relationship between parasite density and hemoglobin level ($p < .001$) among asymptomatic *Plasmodium*-infected children. Abdulkareem et al. (2017) suggested that the level of serum micronutrients (i.e., iron, copper, and zinc) mediated the relationship between anemia and parasite density in asymptomatic children.

The proportion of deaths attributable to malaria in children younger than 5 years of age ranged from more than 80% at a rate of more than 25 deaths per 10,000 to less than 40% at rates below 1 per 10,000 (Gething et al., 2016). Anemia increases the mortality risk associated with malaria in children. Severe life-threatening malarial anemia requiring blood transfusion in young children is a significant cause of hospital admission (White, 2018). In severe malaria, the mortality rises steeply for hemoglobin < 3 g/dL, but it also increases with higher hemoglobin concentrations approaching the normal range (White, 2018). Severe anemia can contribute to malaria mortality through lower blood

oxygen concentration and heart failure. *Plasmodium falciparum* is the most critical species of malaria-causing *Plasmodia* that causes anemia in children. *Plasmodium falciparum* rapidly causes severe anemia within 48 hours of the start of the fever (Sanou & Ngnie-Tet, 2012). Malaria-anemia comorbidity prevalence has been suggested as a measure of malaria-related deaths in sub-Saharan Africa (Papaioannou et al., 2019). In a cross-sectional study, Abhulimhen-Iyoha and Israel-Aina (2014) found that poor parental education, low social class, lack of a skilled job, poor recognition of pallor by mothers, religious practices, and use of alternative medicine sources were related to high mortality in children under 5 years old with malaria-associated anemia.

The influence of malaria on anemia can precede birth. Accrombessi et al. (2015) studied a cohort of 1,005 pregnant women from the beginning of pregnancy until delivery and the first 400 offspring until the first year of life. They found that placental malaria and maternal *Plasmodium* parasitemia were statistically significantly associated with reduced hemoglobin concentrations during the first 12 months of the child's life. Children born to mothers infected by malaria had a lower hemoglobin concentration than children born to non-infected mothers, and this trend persisted throughout the first year of life (Accrombessi et al., 2015). A risk prediction model from the Mother Offspring Malaria Study showed that the number of times the woman had been pregnant and the transmission season at delivery were predictors of severe malarial anemia in infants (Brickley et al., 2017).

The morbidity associated with anemia and malaria may vary by geographic area or malaria transmission setting. Adebayo et al. (2016) reported significant geographical

variations in the effects of place of residence, mother's level of education, household wealth index, ethnicity, whether or not the child had fever 2 weeks before the survey and the number of sleeping rooms on morbidity from malaria and anemia among young children under 5 years old in Nigeria. Gawayan et al. (2014) found a distinct North-South divide in Nigeria in child hemoglobin levels following spatial analysis with the states in Northern Nigeria having higher anemia risk. Birhanu et al. (2017) examined the association between hemoglobin levels and malaria status across different malaria transmission settings in Ethiopia but did not find a significant association between repeated malaria infections and malaria parasitemia and anemia. Their results did not align with the evidence that malaria is associated with anemia, suggesting that this relationship may not hold in areas with low malaria endemicity.

Similarly, in a study by Ferrari et al. (2016) to identify risk factors for *Plasmodium* infection and anemia in children aged 6 – 59 months and in older individuals, the study investigators did not find evidence that malaria infection increased the risk of anemia in low transmission settings (AOR = 2.01, 95 % CI [0.89, 4.51]). However, there was a significant effect of malaria infection on anemia in higher transmission areas (AOR = 3.40, [2.60, 4.44]). Also, the risk of anemia decreased with increasing age and increased with malaria infection and reported fever (Ferrari, Ntuku, Ross, et al., 2016).

Paradoxically, some genetic causes of anemia protect against malaria. Amoako et al. (2014) studied the association between clinical malaria and RBC polymorphisms. They found that the hemoglobin AS genotype had a 79% less risk of malaria than the AA

genotype, while glucose-6-phosphate-dehydrogenase deficiency marginally increased the risk of malaria. This relationship was a potential study limitation as any study of anemia and malaria needs to measure the presence of these RBC polymorphisms.

Interventions Against Childhood Anemia

Mason et al. (2013) suggested some large-scale interventions to prevent or treat anemia. These preventive strategies include iron and folic acid supplementation, helminth control, malaria prevention and control, fortified supplementary foods, delayed cord clamping at birth, education, and counseling to increase iron intake through diet, promotion of consumption of fortified complementary foods, home-based fortification of food, promote animal source foods through household production.

Magalhães and Clements (2011) had estimated that treating malnutrition, malaria, *Schistosoma haematobium* infections, hookworm infections, and *Schistosoma haematobium*/hookworm coinfections could prevent 36.8%, 14.9%, 3.7%, 4.2%, and 0.9% of anemia cases respectively. McCuskee et al. (2014) emphasized that malaria was a more significant cause of anemia in children than undernutrition in malaria-endemic regions. These conditions often coexist with varying degrees of interaction (Babamale et al., 2018; Petry et al., 2016). De-Regil et al. (2014) found that home fortification of food with micronutrient powders effectively reduced anemia in young children. However, it was unclear if this intervention affected malaria-associated outcomes.

Concerns about iron supplementation emphasize the complicated relationship between malaria and anemia. Iron deficiency is a recognized cause of anemia, but there were concerns that iron supplementation might lead to an increased risk of malaria and

other infections (Viana, 2011). However, in a meta-analysis, Neuberger et al. (2016) evaluated the effects and safety of iron supplementation in children living in malaria hyperepidemic and holoendemic areas. The results were that iron did not increase the risk of clinical malaria, where malaria prevention and treatment programs were available.

Malaria Prevention Strategies

The fundamental approach to preventing malaria is vector control through, for example, screening of doors and windows using wire mesh (Getawen et al., 2018); indoor residual spraying, and use of ITNs (Giardina et al., 2014); improving household surroundings and drainage systems (Mokuolu et al., 2018). Another approach involves intermittent preventive antimalarial treatment (IPT). Athuman et al. (2015) did a meta-analysis of randomized clinical trials of the effect of IPT on children with anemia living in malaria-endemic areas. They found a small effect of IPT on mean hemoglobin levels but not on mortality or hospital admissions rates. The trials included in the review were of low to moderate quality. Half of the trials were in areas of low malaria endemicity, implying that the results could not be generalized to areas of high malaria endemicity.

Cissé et al. (2016) using a cluster-randomized design found that seasonal malaria chemotherapy during the malaria transmission season reduced the incidence of malaria by 60% (95% CI [54, 64], $p < .001$) and of severe malaria in children by 45% (95% CI [5, 68], $p = .031$), but found no difference in all-cause mortality (0.90, [0.68, 1.2], $p = .496$). Staedke et al. (2018) also studied if IPT affected community-level indicators of malaria. They found that community-level parasite prevalence was lower in the

intervention clusters than in the control clusters (19% vs. 23%, adjusted risk ratio 0·85, 95% CI [0·73, 1·00], $p = .05$).

Indoor Residual Spraying and Insecticide-Treated Nets

Several studies have compared indoor residual spraying (IRS) with ITN (L. Choi et al., 2019; Fullman et al., 2013; West et al., 2014). The spraying of houses with insecticides (IRS) to kill mosquitoes is an important method to control malaria on a large scale. IRS has played a crucial role in eliminating malaria in parts of the world. Pluess et al. (2010) did a meta-analysis of studies comparing IRS versus no IRS or ITN. They found that IRS reduced malaria transmission in young children by about half compared to no IRS in areas of stable malaria transmission, relative risk (RR) = 0.46, 95% CI [0.42, 0.51]. It was unknown if this effect was sustained across areas of variable malaria transmission. Afoakwah et al. (2018) compared IRS, ITN, and behavior change communication (BCC) as large scale strategies to prevent malaria in children under 5 years old. They found that IRS was the most effective method ($OR = 0.31$, $p < .01$). Their results also showed that ITN was effective only in children of mothers with at least secondary education, while BCC through television was the most effective BCC strategy. BCC using print was only useful for children with educated mothers.

As a comparison, Fullman et al. (2013), using nationally representative data from 17 sub-Saharan African countries, studied the effectiveness of both ITNs and IRS compared to IRS alone or ITN alone in children under 5 years old. They found that not only did children living in households with both ITNs and IRS have a significant risk reduction against malaria parasitemia in medium (53%, 95% CI [37%, 67%]) and high

transmission areas (31%, [11%, 47%]) but that the use of ITNs and IRS together provided additional protection (36%, [7%, 53%]) compared to only ITNs or only IRS in medium transmission areas. Having both ITNs and IRS was not significantly more protective against parasitemia than either intervention alone in low or high malaria transmission areas (Fullman et al., 2013). This result contrasted with the results by West et al. (2014) from a randomized cluster trial comparing IRS and ITN to ITN only in an area of high malaria transmission. They found that the mean *Plasmodium falciparum* prevalence rate was 13% in the ITN and IRS arm and 26% in the ITN only arm (*OR* = 0.43, 95% CI [0.19, 0.97]). They also found that the mean monthly entomological inoculation rate was not significantly lower in the ITN and IRS arm (*RR* = 0.17, 95% CI [0.03, 1.08]) compared to the ITN only arm (West et al., 2014). In a related research work West et al. (2015) reported that IRS protected both those sleeping under nets (*OR* = 0.38, 95%CI [0.26, 0.57]) and those who did not (*OR* = 0.43, [0.29, 0.63]) but community-level use of ITN did not modify this protective effect of IRS. The additional protection from IRS was similar in both low (*OR* = 0.38, [0.19, 0.75]) and high transmission areas (*OR* = 0.34, [0.18, 0.67]). ITN use was also protective at the individual level (*OR* = 0.83, [0.70, 0.98]) regardless of whether the village had received IRS (West et al., 2015).

In a further systematic review, L. Choi et al. (2019) assessed whether adding IRS to ITN would improve effectiveness given resistance to the insecticide. The results of this systematic review were equivocal for malaria incidence, parasite prevalence, and anemia, possibly due to the large variability of the studies in terms of endemicity, transmission patterns, and resistance.

A possible explanation for the equivocal results of studies combining IRS and ITNs despite evidence of the effectiveness of both IRS and ITN could be the short-lived protective effect of IRS. Tukei et al. (2017) measured the changes in slide positivity rate (SPR) over time to assess the change in the effect of IRS on malaria morbidity and found that the IRS protective effect lasted only about 3 months — the highest decrease in the SPR was in the 3rd month following IRS (−6.53%, 95%CI [−12.74, −0.31], p = .04), with the effect waning by the 4th month in the population. SPR rose in the 6th month. Furthermore, Hailu et al. (2018) examined the cost-effectiveness of LLINs and IRS, compared with LLINs alone, IRS alone, and found that the use of ITNs alone was more cost-effective than combining IRS and ITNs.

Effectiveness of ITNs

Several studies in sub-Saharan Africa show the effectiveness of ITNs (Chinwe et al., 2018; Florey, 2012; Pryce et al., 2018; Tokponnon et al., 2014, 2019). Over 22 years, during which treatment and interventions changed, Trape et al. (2014) found that the greatest reductions in malaria incidence in a West African rural community were associated with the replacement of chloroquine and the introduction of ITNs. The parasite prevalence in children in the community reduced from 87% in 1990 to 0.3% in 2012. Tokponnon et al. (2014) assessed the efficacy of LLIN in preventing malaria among children in high and low resistance areas in Benin to determine the impact of resistance on the effectiveness of LLIN. They found that the use of LLINs was highly associated with reduced malaria prevalence irrespective of resistance. Okoyo et al. (2015) investigated the effect of ITN use on malaria infection among Kenyan children in areas of

intense malaria transmission. They found a 14% reduction (AOR = 0.86, 95 % CI [0.74, 0.98], p = .027) in malaria infection among the school children who used LLIN the previous night compared to those who did not use nets. In contrast, Coulibaly et al. (2014), who followed a cohort of 400 children aged 0–14 years old for 3 to 4 years, did not find a decrease in malaria incidence during the study period despite the free distribution of ITNs to children but found seasonal variation in parasite and anemia point prevalence with higher prevalence rates during rainy seasons. Dolan et al. (2019) evaluated the impact of a nationwide ITN distribution on all-cause mortality in children in the Democratic Republic of Congo across diverse areas of malaria endemicity. There was a 41% reduction in under-5 mortality risk for children living in rural areas with above median malaria transmission intensity, but none for children living in areas below median malaria transmission intensity.

Factors Affecting ITN Effectiveness

Several factors influence the effectiveness of treated nets. There is a difference between LLINs and ITNs, although the two terms are often used interchangeably. LLINs are a subset of ITNs made of insecticide-impregnated net fibers and can last up to three years (Centers for Disease Control and Prevention, 2019). Yang et al. (2018) did a systematic review to examine the relative effectiveness and characteristics of LLINs and ITNs. They found that both LLINs and ITNs were effective in preventing malaria, with the odds ratio for reducing malaria by LLIN being 0.44 (95% CI [0.41, 0.48], p < .01), while ITNs were slightly less effective with an *OR* of 0.59 (95% CI [0.57, 0.61], p < .01). Janko et al. (2018) estimated the associations between age of the net, insecticide type,

and malaria and found that nets less than one year of age had the most potent protective effect, *OR* = 0.75, [95% uncertainty interval 0.72, 0.79], with the protection weakening as net age increased.

The availability of ITNs within the household influences its use. Olapeju et al. (2018) explored the role of household ITN supply in the variation in ITN use among household members in sub-Saharan Africa. There was a double-peaked pattern of use with increased use among children < 5 years and adults at 30–40 years when there were not enough nets. They also found that females were more likely to use nets than males. Nkoka et al. (2019) found similar results when they compared the rate of ITN use and the factors associated with ITN use among children under 5 years old living in a household with at least one ITN. Nkoka et al. found that being older than 24 months, having mothers with no formal education or primary education, living in a female-headed household, and living in households with inadequate household ITN supply were significantly associated with reduced likelihood of using an ITN. Ricotta et al. (2019) found that increased wealth was associated with decreased net use among those with access to treated nets in households when compared to the poorest category. Ricotta et al. also found that exposure to messages about ITN use was associated with increased net use (*OR* = 2.5 [1.5, 4.2]). Orji et al. (2018) surveyed 410 caregivers of children under 5 years old and found that despite a high awareness (93.7%) that ITNs can prevent malaria infection, and 81.2% having at least one ITN at home, only 52.4% used ITNs every night.

The use of ITNs varies depending on whether the location is urban or rural. According to Apinjoh et al. (2015), ITN ownership and ITN use were significantly higher

in semi-urban areas compared to rural localities (AOR = 1.93, 95% CI [1.36, 2.74], $p <$ .001). This difference occurred despite the higher likelihood of malaria parasitemia in rural regions (AOR = 1.63, [1.07, 2.49]).

There is seasonal variation in the use of ITNs. Koenker et al. (2019) studied seasonal variation in ITN use while controlling for ITN access. They found that peak ITN use occurred 1–3 months after peak rainfall and corresponded with peak malaria incidence and average malaria transmission season. The findings suggested that mosquito density triggers treated bed net use.

Levitz et al. (2018) examined the effects of individual and community-level LLIN usage in young children in an area of high ITN usage. Individual and community LLIN usage were significantly associated with protection against malaria in children under 5 years old in the Democratic Republic of Congo. The study by Levitz et al. showed that higher community LLIN coverage strengthens the protective effect of individual LLIN.

Exposure to messages on ITN use may influence the use of ITN. Russell et al. (2015), in a study limited to a small, mostly rural, and poor state in Nigeria, assessed the relationship between caregiver exposure to malaria messages and ITN use among children under 5 years old. They found that exposure to ITN-related social behavior change messages was significantly associated with ITN use (*OR* = 17.1, 95% CI [4.5, 65.8]) and that net use was positively affected by social support ($p <$ .001). Russell et al. also found that decreased net use was more likely with more education (p = .020), more knowledge of malaria (p = .022), and believing that treated nets had disadvantages (*OR* = 0.39, 95% CI [0.23, 0.78]).

Providing the nets free does not seem to improve the rate of use. Clark et al. (2016) found that direct house to house distribution of free LLINs did not lead to increased ownership and use of LLIN. Ironically, ownership of nets rapidly reduced during the three months following the free distribution and declined steadily up to 18 months after. Clark et al. also found that household wealth was a significant predictor of LLIN retention, with the richest tercile being three times more likely, *OR* = 3.32, 95% CI [1.54, 6.49], to have a treated net compared to the poorest tercile. Therefore, providing free nets may not be enough to ensure retention and use. Moscibrodzki et al. (2018) explored how the source of the net influences its use and found similar results from their study. The likelihood of the correct use of the net was significantly lower for free nets compared to purchased nets (*OR* = 0.33, 95% CI [0.21, 0.51], $p < .01$) among those who owned nets after adjusting for potential confounders.

Gonahasa et al. (2018) found that the factors most strongly associated with LLIN ownership were living in a wealthier household (highest tercile vs. lowest; AOR = 1.94, 95% CI [1.66, 2.28]) and time since the last free treated net distribution campaign (29–37 vs. 42–53 months; AOR 1.91, 95% CI [1.60, 2.28]). Gonahasa et al. also found that only 17.9% of households had adequate LLIN coverage (at least one LLIN per two residents): a reduction from 65% in 2014. The factors most strongly associated with adequate coverage were fewer household residents (2–4 vs. ≥ 7; AOR 6.52, [5.13, 8.29]), living in a wealthier household (highest tercile vs. lowest; AOR = 2,32, [1.88, 2.85]) and time since the last campaign (29–37 vs. 42–53 months; AOR = 2.13, [1.61, 2.81]). Only

39.5% of household inhabitants had used an LLIN the previous night. Children < 5 years and older than 15 years were more likely to use LLINs than children aged 5–15 years.

Nigeria is an area of high malaria mortality with low coverage of ITN and antimalarial drugs (Gething et al., 2016). There are regional variations in ITN coverage and ITN use in Nigeria. Heilmann et al. (2017) assessed the effect of ITN use on malaria parasite prevalence and anemia in Abia (South East) and Plateau (North Central) states in Nigeria. There was an increase in ITN use with a significant reduction in the microscopy-diagnosed parasite prevalence in both states and a significant reduction in the level of anemia in Abia state. The difference in the effect of ITN use on anemia in the two states may have been due to varying malaria transmission patterns. Andrada et al. (2019) carried out a secondary analysis of data from the 2015 Nigeria Malaria Indicator Survey and looked at subnational differences in household ITN ownership and use. They found that the region of the country was the best predictor of household ownership of at least one ITN and its use in the general population. There was higher ownership and use in the northern regions. The odds of a household owning an ITN were 5 times greater in the North West region compared with the North Central region ($OR = 5.47$, 95% CI [4.46, 6.72], $p < .001$). Also, the odds of ITN use were 2 times greater for those living in the North West region compared with the North Central region ($OR = 2.04$ [1.73, 2.41], $p < .001$). Other significant predictors of ITN use were household size, head of household education level, household wealth quintile, and place of residence.

ITNs and Anemia

Florey (2012) investigated the usefulness of anemia as an impact measure of malaria control interventions using data from DHS or MIS conducted between 2001 and 2011 in sub-Saharan Africa countries. Florey found that the weighted average ITN use increased from 12.2% in baseline surveys to 44.3% in latter surveys, and moderate-to-severe anemia decreased from 17.9% to 12.1%. Also, using multivariate logistic regression models that controlled for residence, household wealth, multiple birth status, mother's education, child's age, and sex, and history of recent fever, there was significantly lower odds of anemia for children who used an ITN the previous night compared to those who did not (pooled AOR = 0.81, 95% CI [0.70, 0.94]). In contrast, Gimnig et al. (2016), using a randomized cluster design, studied the effect of ITN together with the use of IRS on malaria parasitemia, clinical malaria, and anemia against the background of moderate ITN coverage in an area of intense perennial malaria transmission. Gimnig et al. found no statistically significant independent effect of ITNs on anemia. In another study, Ferrari et al. (2016) also found that ITN use did not protect against anemia in both low and high malaria transmission settings (AOR = 1.09, 95% CI [0.90, 1.32]).

Literature Gap

There is little literature on how ITN use following the campaigns of net distribution has impacted the prevalence of anemia in Nigeria. Three studies sought to measure the effect of ITN use on anemia in Nigerian children (Adah et al., 2009; Florey, 2012; Oladeinde et al., 2012). The facility-based cross-sectional study by Adah et al.

(2009) was limited to three locations in one state in Southern Nigeria. It evaluated the relationship between ITN use and parasitemia and anemia in 1,580 children aged between 6 months and 2 years in Ogun state. Adah et al. found that the mean hemoglobin level of ITN users was higher than for non-ITN users (10.24 g/dl vs. 8.56 g/dl). However, they did not adjust for the effects of sociodemographic variables, and there was a lack of clarity on how the sample was selected.

Oladeinde et al. (2012), on the other hand, surveyed 226 children aged 2 months to 10 years with signs and symptoms of malaria in a single rural facility in Edo state in Southern Nigeria. They reported that the prevalence of ITN use was low (4.9%) and that ITN use did not protect against malaria (*OR* = 0.57, 95% CI [0.15, 2.26], *p* = .424) or protect against anemia (*OR* = 0.62, [0.18, 2.19], *p* = .545). However, their results suggested some effect modification because, among malaria parasite-infected children, ITN use significantly reduced the prevalence of anemia (*OR* = 0.13, [0.02, 1.05], *p* = .031). The major weaknesses of this study were that it was hospital based, and all the children recruited for the study were clinically ill. These weaknesses limited the generalizability of the results.

The study by Florey (2012) used data from the baseline 2010 Nigeria MIS and found for Nigeria that the AOR for moderate to severe anemia in children using an ITN the night before was 0.88, 95% CI [0.61, 1.28], *p* = .496. This study was limited to only last-born children 6–23 months old and excluded children 24–59 months old. Also, the study used only data from the baseline 2010 Nigeria MIS. The study also did not look at subnational differences in ITN use and anemia. Newer data from the follow-up 2015 MIS

and the 2018 DHS are now available. The more recent data provide an opportunity for a study to close this literature gap.

Theoretical Framework

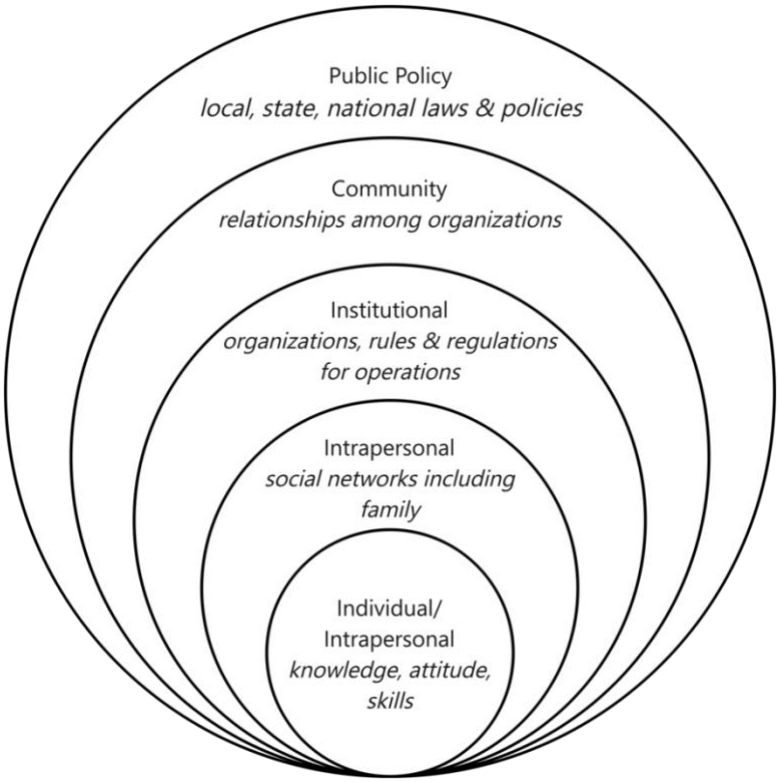
The social ecological model is widely used to study health outcomes and design and implement health interventions (Golden & Earp, 2012). The social ecological model is an offshoot of Bronfenbrenner's (1979) ecology of human development, which posits that different factors act at different interrelated but nested levels to influence human development. In Bronfenbrenner's original model, these nested, hierarchical levels are the microsystem, mesosystem, exosystem, and macrosystem. The relations between the individual and their immediate settings, which are the home, school, or workplace, make up the microsystem (p. 22). Interpersonal relations are the constituent parts of the microsystem. The mesosystem is the interrelations among these settings; that is, the mesosystem is the system of microsystems (p. 25). The mesosystem extends into the exosystem to encompass other social systems. The critical distinction between the mesosystem and the exosystem is that the individual actively participates in the mesosystem, whereas they are passively involved in the exosystem (p. 25). Thus, the exosystem includes the neighborhood, government agencies, communication and transport systems, and social networks. The macrosystem is made up of the culture, norms, and laws that provide the "blueprints" for society (p. 26).

The social ecological model is an extension of Bronfenbrenner's model (McLeroy et al., 1988). In the social ecological model, intrapersonal factors, interpersonal processes, and primary groups, organizational factors, community factors, and public

policy determine health-related behaviors and health-related outcomes. Intrapersonal factors are the characteristics of individuals, such as knowledge, attitudes, and behavior. Family, social networks, and social support systems constitute interpersonal processes and primary groups. Organizational or institutional factors are social institutions with their operational rules and regulations. The relationships among organizations and networks within defined boundaries are community factors. Local, state, and national laws and policies are public policy factors (McLeroy et al., 1988). The social ecological model's central proposition is that the dynamic interplay of intrapersonal, interpersonal, institutional, community, and policy factors influences health behaviors and health outcomes (McLeroy et al., 1988). Figure 1 illustrates the social ecological model as expounded by McLeroy et al. (1988).

Figure 1

The Social Ecological Model



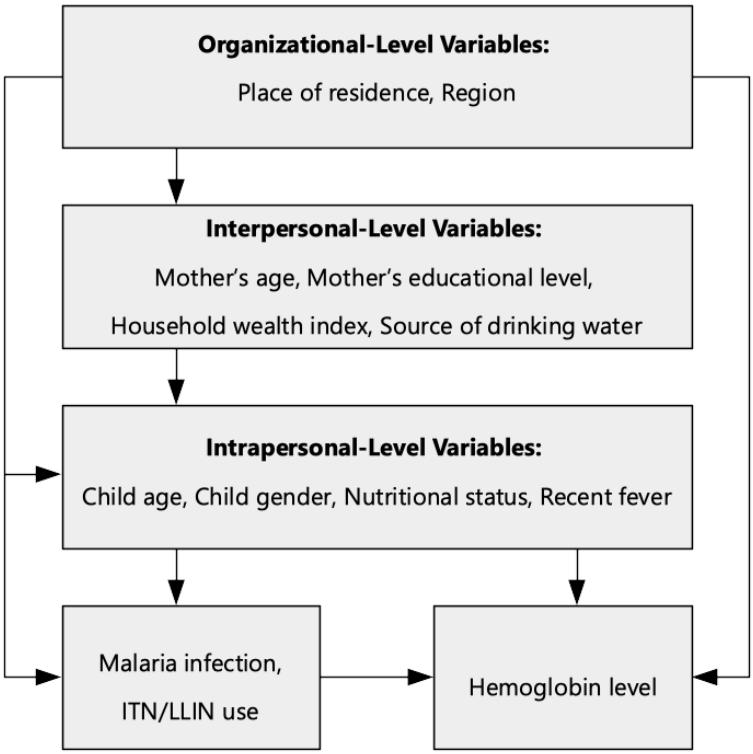
The strength of the social ecological model is that it offers a framework for health interventions at each of the model levels. Smedley and Syme (2000) provided examples of interventions at each level: intrapersonal (motivational interventions, skills-building opportunities, tailored intervention materials); interpersonal (interventions targeting social norms and social networks); organizational (interventions in the health care system, interventions in workplaces, interventions in schools); community (networking with community resources, social service advocacy, structural/environmental interventions in communities, community-based interventions); policy (local, state, and federal laws, intervention with federal regulatory agencies; p. 277). Another strength of

the model is that it integrates behavior change strategies and environmental enhancements within a systems framework. The model emphasizes and incorporates several analytic levels to make possible the examination of both individual and aggregate manifestations of health problems (Stokols, 1992, 1996). Ironically, this strength can also be a weakness due to the model's complexity, which requires close integration of different disciplines (Stokols, 1996).

I chose the social ecological model for this study because it provides a theoretical foundation for understanding the different factors influencing childhood anemia. Several studies of risk factors for childhood anemia have used the social ecological model as the theoretical foundation. For example, Ngnie-Teta et al. (2007) used the social ecological model as the theoretical framework to investigate potential risk factors of childhood anemia at the individual, household, and community levels in Benin and Mali. More recently, Prieto-Patron et al. (2018) studied risk factors for anemia in children aged 6 to 23 months across several countries. Prieto-Patron et al. extended the model used by Ngnie-Teta et al. to include the countries' human development, geographical regions, community, household, maternal, child, and nutritional variables. Figure 2 is a visual representation of the study variables as they relate to the social ecological model.

Figure 2

Study Variables in Relation to the Social Ecological Model



Ntenda et al. (2018) used the social ecological model to do a multilevel analysis of individual-level and community-level factors associated with anemia in Malawian children. Furthermore, Ntenda et al. examined the influence of maternal anemia on childhood anemia while controlling for individual, household, and community-level factors. Also, Kawo et al. (2018), in a multilevel analysis of childhood anemia, compared different approaches to analyzing the data and concluded that multilevel regression using a random effects model, best explained the data. Examining the factors related to anemia at these different but interrelated levels provided a better understanding of the influences

on anemia. The social ecological model provided a framework for understanding the risk factors for anemia and also helps situate this study in the context of other similar studies.

Summary

This chapter included a literature review of childhood anemia and its relationship to malaria. Malaria is a significant risk factor for anemia in endemic malaria regions. Concurrent malaria and anemia increase the risk of death and long-term adverse health outcomes in children. Several studies show the effectiveness of ITN use in preventing malaria, but there are conflicting results on whether ITN use can prevent anemia. The literature review highlighted the limited research on the impact of ITN use on anemia in children in Nigeria. In this study, I sought to assess the relationship between ITN use and anemia in Nigerian children through the social ecological model. Chapter 3 will provide the details of the study, including the research design and its rationale. There will also be a description of the population, the dependent and independent variables, and data analysis techniques in Chapter 3.

Chapter 3: Methods

Introduction

The purpose of this study was to measure the effect of ITN use on hemoglobin level and anemia among children aged 6 to 59 months in Nigeria. Using national secondary survey data, I employed a cross-sectional design and Bayesian multilevel/hierarchical regression modeling to assess the relationship between ITN use and hemoglobin levels and anemia in these children. I also evaluated the influence of other sociodemographic variables on the relationship between ITN use and hemoglobin levels and anemia in these children.

In this chapter, I explain the research methodology and study design. The study population and sampling procedures are also described. I provide a brief discussion of the data analysis plan, followed by a consideration of the threats to validity for this study. The chapter then concludes with a summary of the main points and a transition to the next chapter.

Research Design and Rationale

The nature of causal research is quantitative. For this study, the ideal comparison would be of a child simultaneously with themself in both an exposed state (i.e., use of ITN) and an unexposed state (i.e., nonuse of ITN). This scenario is the counterfactual paradigm. It is counterfactual because of the impossible goal of matching each child with themself in both an exposed and an unexposed state during the same time. Given the preceding, the best design to test a hypothesis of causality would be an experimental design that manipulates the exposure variable and can control potential confounding

variables (see Rothman, 2002). An experimental design was not possible in this study, so I used a correlational design to test hypotheses about the associations between ITN use, malaria, hemoglobin level, and anemia.

In this study, I used a cross-sectional design to answer the research questions concerning ITN use, hemoglobin level, anemia, and malaria infection status in children between the ages of 6–59 months in Nigeria. ITN use was the predictor variable, and the outcome variables were hemoglobin level, anemia, and malaria infection status. I also evaluated the relationship of sociodemographic variables to the predictor and outcome variables; therefore, multilevel regression methods and several secondary data sources were used to measure the effect of ITN use on childhood anemia and malaria in Nigeria.

Research Questions and Hypotheses

The following research questions and corresponding null and alternative hypotheses guided this study:

RQ1: Is there an association between malaria infection status and hemoglobin level in children aged 6 to 59 months?

$H_0$1: There is no statistically significant association between malaria infection status and hemoglobin level in children aged 6 to 59 months.

H_A1: There is a statistically significant association between malaria infection status and hemoglobin level in children aged 6 to 59 months.

RQ2: Is there an association between the use of ITNs and malaria infection status in children aged 6 to 59 months?

$H_0$2: There is no statistically significant association between the use of ITNs and malaria infection status in children aged 6 to 59 months.

H_A2: There is a statistically significant association between the use of ITNs and malaria infection status in children aged 6 to 59 months.

RQ3: Is there an association between the use of ITNs and hemoglobin level in children aged 6 to 59 months?

$H_0$3: There is no statistically significant association between the use of ITNs and hemoglobin level in children aged 6 to 59 months.

H_A3: There is a statistically significant association between the use of ITNs and hemoglobin level in children aged 6 to 59 months.

Methodology

In this study, I used freely available, nationally representative secondary data from health surveys. These surveys collected sociodemographic data and data on the ITN use, hemoglobin levels, malaria infection status, and other variables.

Data Sources

The data sources for this study were (a) 2010 Nigeria MIS, (b) 2015 Nigeria MIS, and (c) 2018 Nigeria DHS. The 2010 Nigeria MIS was carried out from October to December 2010 on a nationally representative sample of 6,197 households (NPC et al., 2012). The 2015 Nigeria MIS was a follow up to the baseline survey conducted in 2010. The survey was carried out from October to November 2015 with a nationally representative sample of more than 8,325 households in 333 clusters, comprising 138 urban and 195 rural clusters (NMEP et al., 2016). The 2018 Nigeria DHS survey

involved 40,427 households across 1,389 urban and rural clusters from August to December 2018 (NPC & ICF, 2019).

Population

Nigeria is the most populous country in Africa (Central Intelligence Agency [CIA], 2019). Nigeria is a federal republic of 36 states grouped into six state regions (i.e., North West, North East, North Central, South East, South West, and South-South) and a Federal Capital Territory (CIA, 2019). Nigeria had an estimated population of 203,452,505 as of July 2018, with roughly 4 out of 10 Nigerians (i.e., 42.5%) younger than 15 years old (CIA, 2019). In this study, I used national data covering the 36 states of Nigeria and the Federal Capital Territory. The target population for this study was children aged 6–59 months.

Sampling and Sampling Procedures

Sampling Strategy

The sampling strategy used in this study was a two-stage stratified sampling method. The strata were urban and rural areas. Multistage sampling involves two or more random sampling stages based on the hierarchical structure of natural clusters within the population (Subramanian, 2004). Multistage sampling is an efficient approach when the population is geographically diverse, and it is impractical and expensive to survey the entire population (Sedgwick, 2015).

Sample Size and Power Analysis

The dependent variable of hemoglobin level was measured in two ways: (a) on a continuous scale for better statistical power and also to explore the effect of ITN use

throughout the range of hemoglobin values (see Altman & Royston, 2006) and (b) as a categorical variable (i.e., anemia). The sample size calculations used the effect size, Type I error, and desired level of statistical significance. I used G*power to calculate the sample size using the exact test and the linear multiple regression random model options (see Faul et al., 2007, 2009). The continuous dependent variable of hemoglobin level was assumed to be random as were the predictors. I also assumed that a set of 36 indicator variables predicted the hemoglobin level and that the parameter H_A: $\rho^2 = .45$ (i.e., the independent variables accounted for 45% of the variance of hemoglobin) and H_0: $\rho^2 = 0$. Seventy-nine subjects were needed for a desired power of 90%, lower critical $R^2 = .31$, upper critical $R^2 = .62$, and a significance level of 5%, with two-tails hypothesis testing. With the dependent variable as a binary variable (i.e., anemia) and an assumed odds ratio of 0.80 for the effect of ITN on anemia in children, at the same desired power of 90% and a significance level of 5%, 5,664 subjects were required under the binomial distribution.

Sampling Procedure

This section contains a summary of the sampling procedures. More detailed descriptions of the sampling procedures for these three national surveys are reported elsewhere (see NMEP et al., 2016; NPC & ICF, 2019; NPC et al., 2012). The census enumeration areas (EAs) from the 2006 Population and Housing Census were the sampling frame for these three surveys. These EAs were the primary sampling units (i.e., the clusters) for the surveys. The samples for the 2010, 2015, and 2018 surveys were selected using a two-stage stratified design.

During the first stage of the 2010 Nigeria MIS sample, the survey selected 240 clusters: 83 in the urban areas and 157 in the rural areas. The 2015 Nigeria MIS had 333 clusters throughout the country: 138 in urban areas and 195 in rural areas. The more recent survey of the 2018 DHS was the largest, having selected 1,400 clusters. In the first stage, the probability of selecting the clusters was proportional to the EA size, where the EA size is the number of households residing in the EA.

A list of all the households in the selected EAs served as the sampling frame for selecting households in the second stage. The surveys selected households in the second selection stage using equal probability systematic sampling. In the 2010 Nigeria MIS, 26 households were selected in each cluster, and for the 2015 Nigeria MIS, 25 households were selected per cluster. For the 2018 DHS, 30 households were selected in every cluster. The three surveys applied sampling weights to the data.

All women aged 15–49 years old in the selected households were eligible for individual interviews. During the interviews, respondents were asked questions about malaria prevention during pregnancy and treatment of fever among their children as well as a range of other sociodemographic and health-related questions. Children aged 6 to 59 months were tested for anemia and malaria using finger- or heel-prick blood samples.

Questionnaires and Data Collection

The 2010 and 2015 Nigeria MIS and the 2018 Nigeria DHS surveys collected data relevant to this study through the Household Questionnaire and the Women's Questionnaire. The interviewers administered these questionnaires to all women aged 15–49 years old in selected households.

The Household Questionnaire collected data on sociodemographic and household characteristics, such as the source of water and ownership and use of mosquito nets. The Household Questionnaire was also used to collect data on children aged 6–59 months who were eligible for anemia and malaria testing. The Women's Questionnaire collected data on age, residence, education, media exposure, literacy, birth history, childhood mortality, antenatal care, malaria prevention for most recent birth and pregnancy, malaria prevention and treatment, and knowledge about malaria. The 2015 Nigeria MIS and the 2018 Nigeria DHS also included the Biomarker Questionnaire for recording the results of biomarker testing for anemia and malaria. The 2018 Nigeria DHS Biomarker Questionnaire also included anthropometry and genotype testing for sickle cell anemia.

Survey Questions

The survey questions that were relevant to this study were virtually unchanged across the three surveys. The survey questions that are related to the study variables are listed as follows:

1. ITN/LLIN use: Who slept under this mosquito net last night? Who slept inside this mosquito net last night?
2. Child age (in months): In what month and year was (NAME) born? On what day, month, and year was (NAME) born?
3. Child gender: Is (NAME) male or female? Is (NAME) a boy or a girl?
4. Recent fever: Has (NAME) been ill with a fever at any time in the last 2 weeks?
5. Mother's age (in years): How old were you at your last birthday?

6. Mother's educational level: Have you ever attended school? What is the highest level of school you attended (i.e., primary, secondary, or higher)?
7. Source of drinking water: What is the main source of drinking water for members of your household?

Anemia and Malaria Testing

Children aged 6–59 months were tested for anemia and malaria. Hemoglobin testing was done during the surveys using a portable HemoCue analyzer. Malaria testing used a rapid diagnostic test (RDT). All children tested by malaria RDT in the 2010 and 2015 Nigeria MIS and 75% of the children in the 2018 Nigeria MIS were tested by thick blood smears and thin blood films. The blood films provide a gold standard for determining malaria parasitemia and also to determine the parasite type. Sickle cell genotype testing was done among children aged 6–59 months in the 2018 Nigeria DHS survey using the SickleSCAN RDT kit.

Operationalization of Variables

The Nigeria MIS data and the Nigeria DHS data contain the dependent variables (i.e., hemoglobin level and anemia) and the independent and covariate variables of ITN/LLIN use, malaria infection status, type of *Plasmodium*, child age, child gender, child nutritional status, recent fever, mother's age, mother's education level, household wealth index, source of drinking water, place of residence, and region.

Dependent Variables

The dependent variables for this study were the hemoglobin level and anemia. Hemoglobin was a continuous variable measured in units of g/dl. Anemia was also a

dependent variable with two measurement levels (i.e., yes/no). The definition of anemia is hemoglobin level < 11 g/dl.

Independent Variables and Covariates

The independent variables and covariates are nested within three levels based on the social ecological model, which is the theoretical framework for this study. These levels are intrapersonal (ITN/LLIN use, malaria infection status, type of *Plasmodium*, child age, child gender, nutritional status, recent fever), interpersonal (mother's age, mother's educational level, household wealth index, source of drinking water), and organizational level (place of residence, region). Table 1 shows the variables and their levels of measurement. The household wealth index is a composite measure of the household's living standard. The household wealth index was calculated in the surveys using principal components analysis of data on household ownership of assets like televisions, bicycles, type of housing construction materials, water access, and sanitation facilities (Rutstein & Johnson, 2004).

Table 1

Study Variables and Measurement Levels

Variable Type	Variable Name	Level of Measurement
Dependent	Hemoglobin level	Scale
Dependent	Anemia	Nominal 1 = No 2 = Yes
Independent	ITN/LLIN use	Nominal 1 = No 2 = Yes
Independent	Malaria infection status	Nominal 0 = Negative 1 = Positive
Independent	Type of *Plasmodium*	Nominal 1 = *P. falciparum* 2 = *P. ovale* 3 = *P. vivax*
Independent	Child age (in months)	Scale, and Ordinal 1 = 6 – 11 2 = 12 – 17 3 = 18 – 23 4 = 24 – 29 5 = 30 – 35 6 = 36 – 41 7 = 42 – 47 8 = 48 – 53 9 = 54 – 59
Independent	Child gender	Nominal 1 = Male 2 = Female
Independent	Nutritional status	Ordinal 1 = Underweight 2 = Normal weight 3 = Overweight/obese
Independent	Recent fever	Nominal 1 = No 2 = Yes
Independent	Mother's age (in years)	Scale, and Ordinal 1 = 15 – 19 2 = 20 – 24 3 = 25 – 29 4 = 30 – 34 5 = 35 – 39 6 = 40 – 44 7 = 45 – 49

Variable Type	Variable Name	Level of Measurement
Independent	Mother's educational level	Ordinal 1 = None 2 = Primary 3 = Secondary 4 = Tertiary
Independent	Household wealth index	Ordinal 1 = Lowest 2 = Second 3 = Middle 4 = Fourth 5 = Highest
Independent	Source of drinking water	Nominal 1 = Urban 2 = Rural
Independent	Place of residence	Nominal 1 = Urban 2 = Rural
Independent	Region	Nominal 1 = North Central 2 = North East 3 = North West 4 = South East 5 = South South 6 = South West

Data Analysis Plan

For this study, I used R Version 4.0.3 (see R Core Team, 2020) to perform data cleaning, recoding variables, and preliminary analyses. R and Stan (Carpenter et al., 2017) running Markov Chain Monte Carlo simulations were used to develop Bayesian multilevel/hierarchical linear and logistic regression models. These regression models were used to test the research hypotheses. The medians of the posterior distributions of estimates for linear regression models and odds ratios for logistic regression models and the associated credible intervals are reported in Chapter 4.

According to Subramanian (2004), the term *multilevel* refers to individuals at a lower level who are nested within spatial units at higher levels. Multilevel methods are

suitable for the statistical analysis of data with a nested structure, which is typically hierarchical. The statistical technique of multilevel or hierarchical regression aligns well with the social ecological model used as the theoretical framework for this dissertation. Multilevel regression modeling was a proper approach for the type of secondary data used in this dissertation study. These data are from national population surveys that involved a multi-stage sampling design, with clusters sampled first, then individuals in households.

Multilevel statistical modeling incorporates models at each level of analysis into a full multilevel model. For example, in a two-level nested model, the model at the first level is expressed as

$$y_{ij} = \beta_{0j} + \beta_1 x_{1ij} + e_{0ij}$$

where y_{ij} is the measure of the dependent variable for the i^{th} individual in the j^{th} group. The term β_{0j} is a constant and is the measure of the dependent variable for the j^{th} group, and β_1 is the fixed marginal effect of the predictor variable (x_{1ij}) on the dependent variable. The individual or the level-1 residual term, e_{0ij}, is assumed to have a normal distribution with a mean of 0 and a variance, σ^2_{e0}. In multilevel modeling, the coefficients at level-1 become outcome variables at level-2. Thus, the model at level-2 can be written as

$$\beta_{0j} = \beta_0 + u_{0j}$$

meaning the mean measure of the dependent variable for the j^{th} group is split into β_0 (the average for the dependent variable across all groups), and u_{0j}, the effect specific to the j^{th} group, and u_{0j} can be treated similar to individual-level residuals. Combining the two

equations above yields the full model. This full model is known as a random-intercepts or variance components model:

$$y_{ij} = \beta_0 + \beta_1 x_{1ij} + (u_{0j} + e_{0ij})$$

In this multilevel statistical model, the variance at level-2, σ^2_{u0}, measures the group differences after accounting for the compositional effect of the predictor variable and thus separates the effects of the individual-level variables from the contextual differences between group-level variables (see Subramanian, 2004).

The advantages of using multilevel modeling are that we can (a) account for individual- and group-level variation in estimating group-level coefficients, (b) model the variation in individual-level regression coefficients across groups, and (c) estimate regression coefficients for particular groups (Gelman & Hill, 2007).

The most direct way of overcoming the challenge of fitting multilevel models is through Bayesian inference; hence, the choice of Bayesian hierarchical regression for this study. Bayesian statistical methods treat the group-level model as "prior information" in estimating the posterior distribution of the individual-level coefficients (Gelman & Hill, 2007). In Bayesian theory, a *prior* for a parameter is a guess about the probability distribution for the parameter if the data under analysis is disregarded. The posterior distribution is updated based on the likelihood of the data. Credible Bayesian analyses require that the prior reflects results from previous studies or reviews (Greenland, 2006).

Threats to Validity

Frankfort-Nachmias and Leon-Guerrero (2018) defined validity as the extent to which measures indicate what they are intended to measure. External validity is being

able to generalize the study findings to the population of individuals with similar characteristics, while internal validity means the study is not affected by poor design, measurement error, or poor implementation of study procedures (Crosby et al., 2006). Despite the advantages of the large sample size of secondary data from national surveys for this study, there were potential limitations that could affect the external validity and internal validity of this study. External validity may be threatened because the data were not collected to answer this dissertation's specific research questions, so some variables may not be available or because of nonresponse or missing data. The variables may be available but measured in ways that are not ideal, therefore threatening internal validity. There were a couple of reasons why it was not anticipated that there would be a lack of external validity in this study. Firstly, there were only minor changes in the relevant survey questions across the three surveys. Secondly, the meanings of the questions do not change outside the context of the surveys, e.g., who slept under this mosquito net last night?

Ethical Procedures

Walden institutional review board (IRB) approval was obtained before getting the data (IRB Approval Number 06-30-20-0442465). This dissertation used secondary data from the DHS. These data were collected after obtaining all necessary ethical approvals. The survey protocols were approved by the Nigeria Health Research Ethics Committee of the Federal Ministry of Health. Written informed consent was obtained before data were collected for each individual. The data used for this research work were completely de-identified.

Summary

The purpose of this study was to examine the relationship between treated net use and anemia in children. The sources of data used to answer the research questions were nationally representative surveys. In Chapter 3, I described the research design and provided the rationale for selecting the study design. I then discussed the methodology used for the study. Further, I outlined the population, sampling and sampling procedure, the operational definitions of variables, and research questions and hypotheses necessary to do the study. There was a description of the data analysis plan. I showed how the chosen multilevel or hierarchical regression method aligns well with the social ecological model that is the theoretical framework for this dissertation. Multilevel regression methods are suitable for data from national population surveys that involve a multistage sampling design, with clusters sampled first, then individuals in households. In Chapter 4, I will discuss the data analysis and the results of the study.

Chapter 4: Results

In this study, I examined the effect of ITN use on anemia among children aged 6–59 months in Nigeria using secondary data from national surveys. This chapter includes a discussion of the secondary data used in this study, the data management, and the deviations from the data analysis plan presented in Chapter 3. In this chapter, I also present descriptive statistics of the sample and the results of the Bayesian multilevel regression analyses in narrative and tabular form. The results of the various regression models are in the form of tables and the evaluation of statistical assumptions are in narrative form. These results are organized and presented according to each research question and hypothesis. The chapter ends with a summary of the overall findings.

Data Collection and Data Management

I obtained the data for this study from the DHS website (https://dhsprogram.com), following approval from the Walden University IRB (IRB Approval Number 06-30-20-0442465). The data sets for the Nigeria 2010 MIS, 2015 MIS, and 2018 DHS were in the Stata format. I downloaded these data sets as compressed zip files. The relevant data sets needed to answer the research questions in this study were NGKR61FL, NGKR71FL, NGKR7AFL, NGPR61FL, NGPR71FL, and NGPR7AFL (see Croft et al., 2018). These data sets were the Children's Recode data sets and the Household Member Recode data sets. The Children's Recode data set has one record for every child aged 0–59 months of interviewed women, while the Household Member Recode data set has one record for every household member. The variables needed for this study were present in the different DHS phases and were the same across the different survey years. The Children's

Recode and Household Member Recode data sets contained the variables needed for this study, as shown in Table 2.

Figure 3 shows the data management for this study. The Children's Recode and the Household Member Recode data sets for each survey were imported into R, processed, and merged using a left join. The resulting data sets for each survey were combined into one final data set for analysis. Missing observations were removed based on the listwise deletion strategy leading to a final sample of 15,985 children aged 6–59 months in 10,565 households.

I created new variables from the ones present in the data set. An indicator variable for each survey was created in the data set. The anemia variable was created from the hc56 variable. Anemia was a nominal yes/no variable defined as hemoglobin level < 11 g/dl. The child's age in months was recalculated using the child's date of birth and the survey interview date. There was a need to recalculate the child's age because the original calculation of child's age in the 2010 MIS only used the month and year of birth, unlike for the 2015 MIS and 2018 DHS. I calculated the child's nutritional status from the weight for age *z* score (WAZ) using the WHO nutritional anthropometry standards. Underweight was defined as WAZ below −2 *SD*, while overweight was defined as WAZ above +2 *SD*.

Table 2

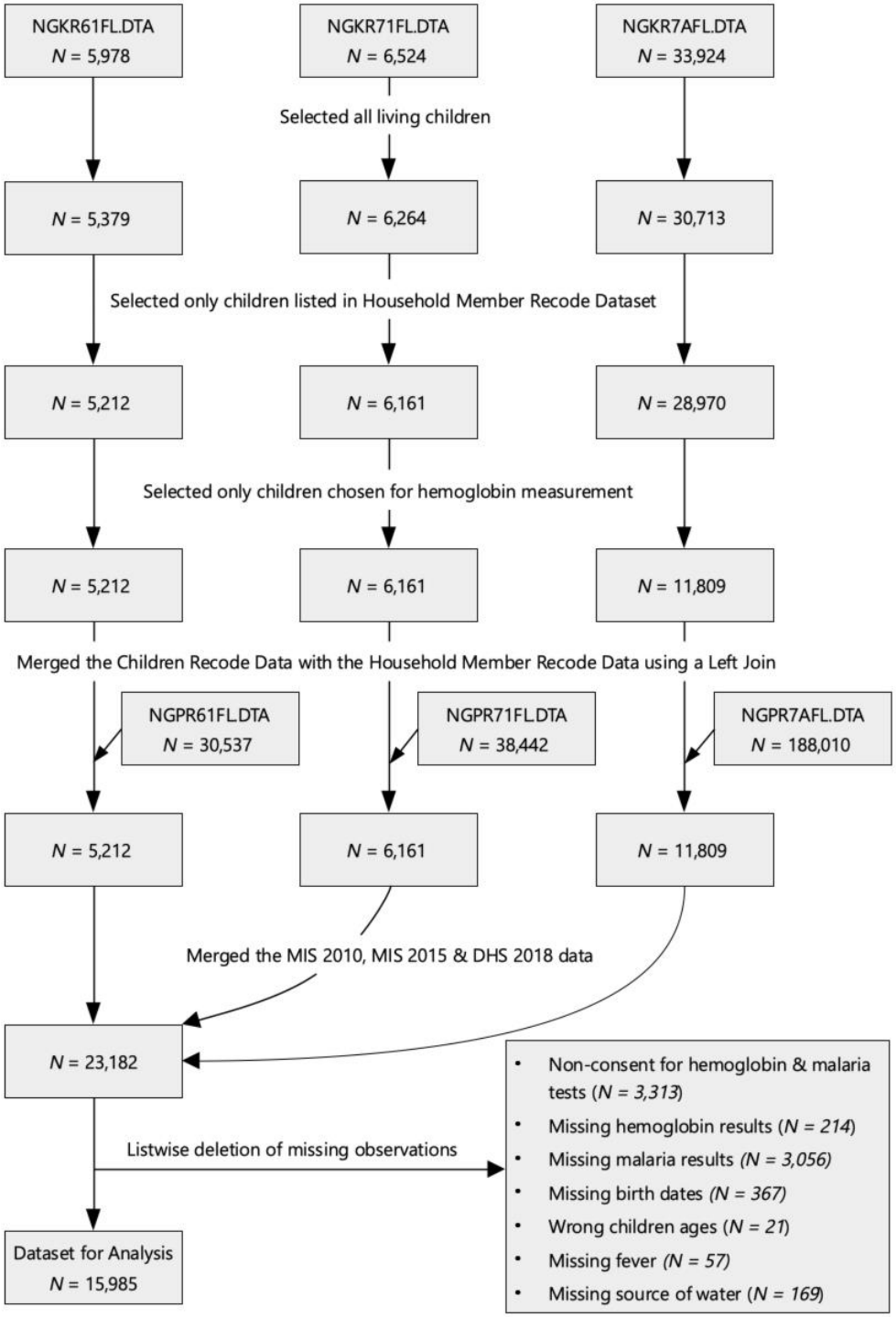
Study Variables Present in the DHS Recode Data Sets

Survey Data Set	Variable in Data Set	Variable Name
Children's Recode Data [a]	b1	Child's month of birth
	b2	Child's year of birth
	b8	Current age of child
	h22	Had fever in last two weeks
	v012	Mother's current age
	v013	Mother's age in 5-year groups
	v024	Region
	v025	Type of place of residence
	v106	Mother's highest educational level
	v113	Source of drinking water
	v190	Household wealth index
Household Member Recode [b]	hv006	Month of interview
	hv007	Year of interview
	hv016	Day of interview
	hc16	Child's day of birth
	hc27	Child's sex
	hc56	Hemoglobin level adjusted for altitude
	hml20	Person slept under an LLIN net
	hml32	Final result of malaria from blood smear test
	hml32a	Presence of species: falciparum [c]
	hc1	Child's age in months
	hc2	Child's weight in kilograms [d]

Note. DHS = Demographic Health Surveys.
[a] NGKR61FL, NGKR71FL, NGKR7AFL. [b] NGPR61FL, NGPR71FL, NGPR7AFL. [c] Not measured in the DHS 2018 data. [d] Not measured in the MIS 2015 data.

Figure 3

Data Management for This Study



Some variables had missing values. The type of *Plasmodium* species was completely missing in the 2018 DHS data. The child's weight data were also completely missing in the 2015 MIS. The missing values for the child's weight meant that child's nutritional status was completely missing for the 2015 MIS data. The final sample of 15,985 children aged 6–59 months consisted of 3,976 children from the 2010 MIS, 4,739 children from the 2015 MIS, and 7,270 children from the 2018 DHS.

Data Analysis

The statistical analysis software used for data cleaning, recoding of variables, and exploratory data analyses was R Version 4.0.3 (see R Core Team, 2020). I examined the characteristics of the study sample using descriptive statistics. A fixed-effects meta-analysis and forest plots were used to examine the statistical heterogeneity of the data across the different surveys with regard to the mean hemoglobin level and the proportions of anemia, malaria, and ITN use. I used Bayesian linear and logistic regression modeling using R and Stan (see Carpenter et al., 2017) to answer the research questions. The interface with Stan from within R was the *brms* package (see Bürkner, 2017, 2018). The evaluation of each model used 2,000 iterations each of four Hamiltonian Monte Carlo Markov chains with weakly informative priors.

The dependent variables for Research Questions 1 and 3 were hemoglobin level and anemia, while the dependent variable for Research Question 2 was malaria infection status. Bayesian linear and logistic regression models, wherein the independent variable of each research question was the single predictor, were compared to fuller models containing the intrapersonal-, interpersonal-, and organizational-level variables as fixed

(i.e., constant) and random (i.e., varying) effects. The regression models included the intrapersonal-level variables (i.e., ITN use, malaria infection status, child age, child sex, and fever), the interpersonal-level variables (i.e., mother's age, mother's education, household wealth index, and source of drinking water), and place of residence (organizational-level variable) as fixed effects. The models also included state region and household as random intercepts to control for by-region and by-household variability. I included the child's age and the mother's age in the regression analyses as continuous variables rather than in their categorical forms. Categorization of continuous variables leads to loss of information, reduction in statistical power, and residual confounding during regression analyses (see Altman & Royston, 2006).

The models' fitness was visually examined using the *shinystan* package (see Gabry, 2018) and Bayesian leave-one-out cross-validation. I used the expected log predictive density (ELPD), which is −2 × leave-one-out cross-validation information criterion (LOOIC), to ascertain which models better explained the relationship between the dependent and independent variables. Better models have larger ELPD (i.e., smaller LOOIC) values. The ELPD and LOOIC have the same purpose as the Akaike Information Criterion used in frequentist statistics (Vehtari et al., 2017).

None of the model parameters had an effective sample size of less than 10% of the total sample size. The sample size in this context refers to the number of posterior draws from the Markov chains. None of the model parameters had a Monte Carlo standard error greater than 10% of the posterior standard deviation, or an $\hat{R}$ value above 1.05. The $\hat{R}$ statistic is the Gelman and Rubin potential scale reduction statistic, which

measures the ratio of the average variance of samples within each Markov chain to the variance of the pooled samples across the chains (see Brooks & Gelman, 1997). $\hat{R}$ provides information about model convergence. At model convergence $\hat{R} = 1$.

The fixed effects (i.e., medians of the posterior distributions of the regression coefficients for the linear regression models and the odds ratios for the logistic regression models) and their associated 95% credible intervals, together with the marginal and conditional Bayes R^2 for the Bayesian regression models, are reported in Tables 6 to 9. The marginal R^2 is the variance of the fixed effects, while the conditional R^2 is the combined variance of the fixed and random effects (Nakagawa et al., 2017). The results of the Bayesian regression models are also presented as marginal effects plots to aid a better understanding of the relationships between predictors and dependent variables conditional on the random effects of region and household. *P* values are not reported as they are not meaningful within the Bayesian paradigm.

Study Results

Characteristics of the Study Sample

Table 3 provides a summary of the characteristics of the study sample. The mean age (and standard deviation) of the children was 31.5 (15.61) months. The mean hemoglobin was 10.1 (1.60) g/dl. The overall proportion of children with anemia was 68.9% [95% CI 68.1%, 69.6%]. The overall proportion of children using an ITN was 40.1% [39.3%, 40.9%]. The overall proportion of children with malaria was 27.7% [27.0%, 28.4%].

Table 3

Characteristics of the Study Sample

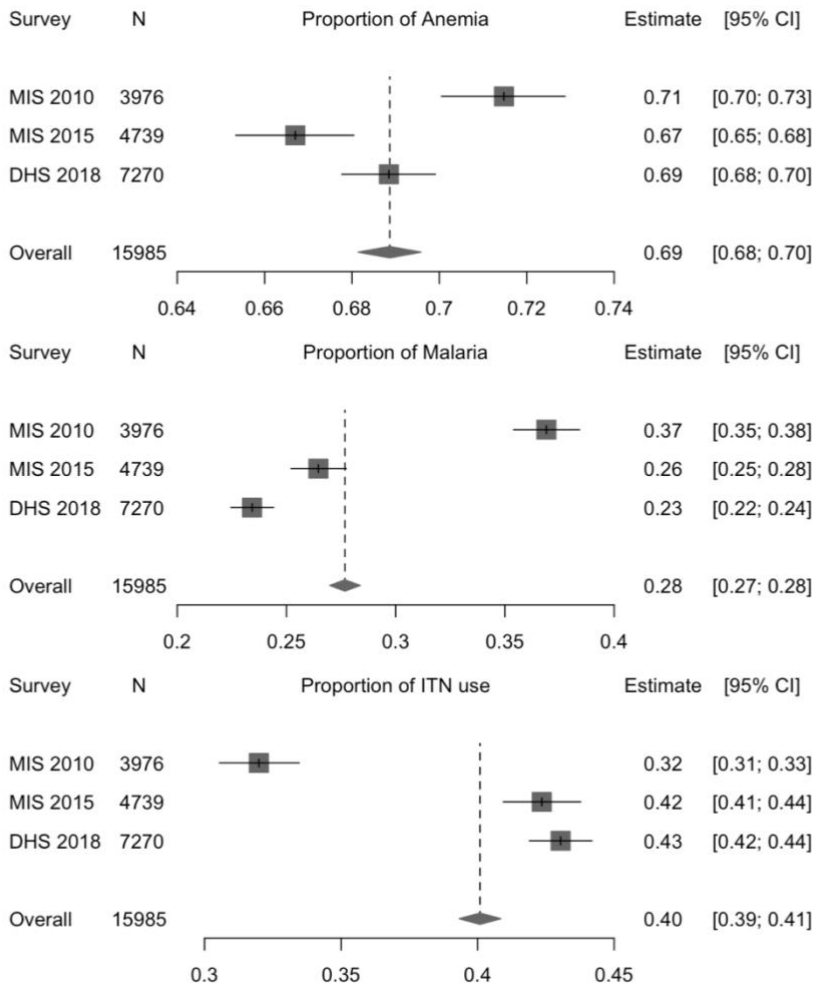
Variables	No of children (%)	Mean Hb [95% CI] [a]	Anemia prevalence (%)	
			No	Yes
Total	15,985 (100.0)	10.09 [10.06, 10.11]	31.1	68.9
Malaria infection status				
No malaria	11,561 (72.3)	10.41 [10.38, 10.43]	37.2	62.8
Malaria	4,424 (27.7)	9.25 [9.20, 9.30]	15.3	84.7
P. falciparum				
No malaria	11,561 (72.3)	10.41 [10.38, 10.43]	37.2	62.8
Non *P. falciparum* malaria	110 (0.7)	9.21 [8.88, 9.54]	18.2	81.8
P. falciparum malaria	2,611 (16.3)	9.31 [9.25, 9.38]	16.1	83.9
Missing	1,703 (10.7)	9.15 [9.07, 9.22]	13.7	86.3
ITN use				
No	9,577 (59.9)	10.12 [10.09, 10.15]	32.0	68.0
Yes	6,408 (40.1)	10.04 [9.99, 10.08]	29.9	70.1
Age group				
6-11	1,923 (12.0)	9.76 [9.69, 9.83]	21.6	78.4
12-17	2,066 (12.9)	9.66 [9.59, 9.72]	19.1	80.9
18-23	1,592 (10.0)	9.84 [9.76, 9.92]	24.6	75.4
24-29	1,934 (12.1)	9.95 [9.87, 10.02]	27.8	72.2
30-35	1,526 (9.5)	10.21 [10.13, 10.29]	35.3	64.7
36-41	2,031 (12.7)	10.27 [10.21, 10.34]	37.1	62.9
42-47	1,474 (9.2)	10.32 [10.23, 10.40]	36.6	63.4
48-53	1,906 (11.9)	10.45 [10.38, 10.52]	40.6	59.4
54-59	1,533 (9.6)	10.46 [10.38, 10.53]	41.3	58.7
Sex				
Male	8,114 (50.8)	10.00 [9.97, 10.04]	29.0	71.0
Female	7,871 (49.2)	10.17 [10.14, 10.21]	33.3	66.7
Nutritional status				
Normal weight	6,689 (41.8)	10.14 [10.10, 10.18]	31.3	68.7
Underweight	2,012 (12.6)	9.55 [9.47, 9.62]	20.8	79.2
Overweight/Obese	124 (0.8)	9.64 [9.33, 9.96]	23.4	76.6
Missing	7,160 (44.8)	10.20 [10.16, 10.23]	34.0	66.0
Fever within the last 2 weeks				
No	10,381 (64.9)	10.29 [10.26, 10.32]	35.2	64.8
Yes	5,604 (35.1)	9.71 [9.67, 9.76]	23.5	76.5

Variables	No of children (%)	Mean Hb [95% CI] [a]	Anemia prevalence (%)	
			No	Yes
Mother's age group				
15-19	602 (3.8)	9.59 [9.46, 9.71]	18.4	81.6
20-24	2,945 (18.4)	9.87 [9.81, 9.93]	26.7	73.3
25-29	4,531 (28.3)	10.10 [10.06, 10.15]	30.9	69.1
30-34	3,712 (23.2)	10.20 [10.15, 10.25]	33.9	66.1
35-39	2,644 (16.5)	10.20 [10.14, 10.26]	33.4	66.6
40-44	1,116 (7.0)	10.18 [10.08, 10.27]	34.2	65.8
45-49	435 (2.7)	10.18 [10.01, 10.34]	36.6	63.4
Mother's education				
No education	6,485 (40.6)	9.77 [9.73, 9.81]	25.1	74.9
Primary	2,941 (18.4)	10.04 [9.99, 10.10]	28.9	71.1
Secondary	5,285 (33.1)	10.31 [10.27, 10.35]	35.3	64.7
Higher	1,274 (8.0)	10.88 [10.81, 10.95]	49.6	50.4
Household wealth index				
Poorest	2,990 (18.7)	9.61 [9.55, 9.67]	21.3	78.7
Poorer	3,152 (19.7)	9.78 [9.72, 9.84]	24.9	75.1
Middle	3,404 (21.3)	10.04 [9.98, 10.09]	29.6	70.4
Richer	3,407 (21.3)	10.27 [10.22, 10.32]	34.3	65.7
Richest	3,032 (19.0)	10.72 [10.68, 10.77]	45.5	54.5
Source of drinking water				
Not Improved	6,518 (40.8)	9.99 [9.95, 10.03]	29.7	70.3
Improved	9,467 (59.2)	10.15 [10.12, 10.18]	32.2	67.8
Place of residence				
Urban	5,858 (36.6)	10.48 [10.44, 10.51]	40.1	59.9
Rural	10,127 (63.4)	9.86 [9.83, 9.89]	25.9	74.1
Region				
North central	2,796 (17.5)	10.29 [10.23, 10.34]	35.4	64.6
North east	2,899 (18.1)	10.19 [10.13, 10.25]	33.4	66.6
North west	3,908 (24.4)	9.70 [9.65, 9.76]	24.6	75.4
South east	2,108 (13.2)	10.19 [10.12, 10.25]	31.5	68.5
South-south	2,178 (13.6)	9.96 [9.90, 10.02]	25.7	74.3
South west	2,096 (13.1)	10.43 [10.36, 10.49]	39.9	60.1
Survey				
MIS 2010	3,976 (24.9)	9.94 [9.89, 9.99]	28.5	71.5
MIS 2015	4,739 (29.6)	10.15 [10.11, 10.20]	33.3	66.7
DHS 2018	7,270 (45.5)	10.12 [10.09, 10.16]	31.2	68.8

Note. Hb = hemoglobin; CI = confidence interval.
[a] unit = g/dl

Figure 4

Changes in Proportions of Anemia, LLIN use, and Malaria Across Surveys



Note. CI = confidence intervals; DHS = Demographic Health Survey; MIS = Malaria Indicator Survey. Squares represent point estimates for the different surveys, diamonds represent the pooled fixed effect estimate. Horizontal lines represent the 95% confidence intervals.

The proportions of children with anemia, malaria, or using an ITN were not the same for the different surveys. Figure 4 shows the changes in the proportion of anemia, ITN use, and malaria by survey year among children aged 6–59 months using forest plots. The fixed-effects meta-analysis showed that there was statistically significant heterogeneity across the demographic surveys in the proportions of children with anemia (I^2 = 88.7%, Q = 22.98, p < .001), with malaria (I^2 = 98.7%, Q = 234.61, p < .001), and using ITN (I^2 = 98.2%, Q = 143.73, p < .001). Similarly, there were statistically significant heterogeneity in the mean hemoglobin across the survey years (I^2 = 95.5%, Q = 44.43, p < .001).

Research Question 1

Is there an association between malaria infection status and hemoglobin level in children aged 6 to 59 months?

$H_0$1: There is no statistically significant association between malaria infection status and hemoglobin level in children aged 6 to 59 months.

H_A1: There is a statistically significant association between malaria infection status and hemoglobin level in children aged 6 to 59 months.

Table 4 and Table 5 show the results of the regression analyses. The independent variable was malaria infection status measured as a nominal variable, and the dependent variable was hemoglobin level measured on both the continuous and nominal scales. The Bayesian linear regression model with hemoglobin level as the single predictor showed a negative relationship between malaria infection status and hemoglobin levels in this national sample of children aged 6–59 months in Nigeria (Model 1 in Table 4). Malaria

reduced the hemoglobin level by 1.09 g/dl [95% credible interval (CI): −1.15, −1.04]. However, this unadjusted estimate does not account for the effects of the other intrapersonal and interpersonal variables. The multiple regression model (Model 2) shows the effect of malaria on hemoglobin level while adjusting for the influence of these other variables (ITN use, child's age, child's sex, recent fever, mother's age, mother's education level, household wealth index, source of drinking water, and place of residence) conditional on the region and household.

After adjusting for the effects of these other variables in Model 2, there was still a statistically significant negative relationship between malaria infection status and hemoglobin status: −0.94, [95% CI: −0.99, −0.89]. When compared to this adjusted estimate, it is seen that the unadjusted estimate is biased away from the null. Model 2 also explained more of the variance in the hemoglobin level than Model 1, R^2 = .368 [95% CI: .348, .387] versus R^2 = .095 [.087, .103]. Comparing the marginal R^2 (the variance due to the fixed effects alone) in Model 2 with the conditional R^2 (the variance due to both the fixed and random effects) shows that much of the variance in hemoglobin is attributable to the random effects.

Table 4

Linear Regression: Predictors of Hemoglobin Levels

	Model 1			Model 2		
	M	95% CI		*M*	95% CI	
Parameters		*LL*	*UL*		LL	UL
Intercept	10.39	10.36	10.41	−0.75	−1.76	0.34
Intrapersonal level variables						
Malaria	−1.09	−1.15	−1.04	−0.94	− 0.99	−0.89
ITN use = yes				0.04	− 0.01	0.09
Child's age (months)				0.02	0.02	0.02
Child's sex = female				0.15	0.11	0.19
Recent fever = yes				−0.31	−0.35	−0.26
Interpersonal level variables						
Mother's age (years)				0.01	0.01	0.01
Mother's education [a]						
Primary				0.11	0.04	0.18
Secondary				0.21	0.14	0.29
Higher				0.39	0.28	0.49
Household wealth index [b]						
Poorer				0.12	0.04	0.19
Middle				0.28	0.2	0.36
Richer				0.37	0.28	0.47
Richest				0.57	0.47	0.67
Source of drinking water = improved				−0.09	−0.14	−0.04
Organizational level variables						
Place of residence = rural				−0.11	−0.16	−0.05
Marginal R^2				.191	.180	0.202
Conditional R^2	.095	.087	.103	.368	.348	0.387
ELPD	−29106.1			−27824.7		

Note. *M* = median estimate of regression coefficient; CI = credible interval; *LL* = lower limit; *UL* = upper limit; ITN = insecticide-treated net; ELPD = expected log predictive density.
[a] reference level = No education. [b] reference level = Poorest.

The Bayesian logistic regression model (Model 3 in Table 5) with malaria infection status as the single predictor of anemia (the dependent variable measured as a nominal variable with two levels: anemia = yes/no) showed that there was a statistically significant positive association between malaria infection status and anemia. The presence of malaria increased about threefold the likelihood of anemia in the child, *OR* = 3.29 [95% CI: 3.00, 3.59]. This positive association was still present after controlling for the effects of the other variables in the multiple logistic regression model (Model 4), *OR* = 3.58 [3.20, 4.02]. Model 4 also explained more of the variance in the data (R^2 = .241 [.214, .263] versus R^2 = .045 [.040, .051]) than Model 3.

Malaria infection status, recent fever, improved source of drinking water, and rural place of residence were associated with reduced hemoglobin level and increased likelihood of anemia in both the full linear regression (Model 2) and the full logistic regression (Model 4) models. Other variables like child age, female sex, mother's age, increasing mother's education level, increasing household wealth index were associated with increased hemoglobin level in the linear regression model, and less likelihood of anemia in the logistic regression model.

Table 5

Logistic Regression: Predictors of Anemia

	Model 3			Model 4		
	OR	95% CI		*OR*	95% CI	
Parameters		*LL*	*UL*		*LL*	*UL*
Intercept	1.69	1.63	1.75	12.32	7.33	19.89
Intrapersonal level variables						
Malaria	3.29	3.00	3.59	3.58	3.20	4.02
ITN use = yes				0.98	0.90	1.08
Child's age (months)				0.97	0.96	0.97
Child's sex = female				0.79	0.73	0.85
Recent fever = yes				1.51	1.38	1.67
Interpersonal level variables						
Mother's age (years)				0.99	0.98	0.99
Mother's education [a]						
Primary				0.93	0.81	1.06
Secondary				0.75	0.65	0.86
Higher				0.58	0.48	0.70
Household wealth index [b]						
Poorer				0.80	0.69	0.93
Middle				0.65	0.56	0.76
Richer				0.57	0.48	0.69
Richest				0.44	0.36	0.53
Source of drinking water = improved				1.17	1.06	1.29
Organizational level variables						
Place of residence = rural				1.24	1.11	1.38
Marginal R^2				.143	.113	.175
Conditional R^2	.045	.040	.051	.241	.214	.263
ELPD	−9522.9			−8809.3		

Note. *OR* = odds ratio; CI = credible interval; *LL* = lower limit; *UL* = upper limit; ITN = insecticide-treated net; ELPD = expected log predictive density.
[a] reference level = No education. [b] reference level = Poorest.

Research Question 2

Is there an association between the use of ITNs and malaria infection status in children aged 6 to 59 months?

$H_0$2: There is no statistically significant association between the use of ITNs and malaria infection status in children aged 6 to 59 months.

H_A2: There is a statistically significant association between the use of ITNs and malaria infection status in children aged 6 to 59 months.

Table 6 includes the results of the Bayesian logistic regression analyses for Research Question 2. The dependent variable was malaria infection status measured as a nominal variable (malaria infection status = no malaria/malaria). The independent variable was ITN use, measured on the nominal scale (ITN use = no/yes).

In the logistic regression model with ITN use as the single predictor (Model 5), ITN use increased the likelihood of malaria infection, *OR* = 1.03 [95% CI: 0.96, 1.10], but this relationship was not statistically significant likely due to confounding. This relationship was reversed in the full Bayesian logistic regression model (Model 6), adjusting for the effects of the other variables. The full regression model showed that the use of an ITN reduced the risk of malaria infection by up to 27%, *OR* = 0.82 [0.73, 0.93]. This relationship was statistically significant because $1 \notin [0.73, 0.93]$. Model 6 explained more of the variance in the data than Model 5 (R^2 = .383 [.359, .404] versus R^2 = .000). The model with only ITN use as the predictor of malaria infection did not explain any of the variability in the data.

Table 6

Logistic Regression: Predictors of Malaria

	Model 5			Model 6		
	OR	95% CI		*OR*	95% CI	
Parameters		*LL*	*UL*		*LL*	*UL*
Intercept	0.38	0.36	0.40	0.14	0.07	0.29
Intrapersonal level variables						
ITN use = yes	1.03	0.96	1.10	0.82	0.73	0.93
Child's age (months)				1.03	1.02	1.03
Child's sex = female				0.90	0.81	1.00
Recent fever = yes				1.76	1.58	1.97
Interpersonal level variables						
Mother's age (years)				1.01	1.00	1.01
Mother's education [a]						
Primary				0.64	0.54	0.76
Secondary				0.49	0.41	0.59
Higher				0.18	0.13	0.25
Household wealth index [b]						
Poorer				0.96	0.80	1.14
Middle				0.70	0.58	0.84
Richer				0.44	0.36	0.55
Richest				0.15	0.12	0.20
Source of drinking water = improved				0.80	0.71	0.90
Organizational level variables						
Place of residence = rural				2.41	2.09	2.84
Marginal R^2				.174	.118	.238
Conditional R^2	.000	.000	.000	.382	.359	.404
ELPD	− 9430.6			− 7894.3		

Note. *OR* = odds ratio; CI = credible interval; *LL* = lower limit; *UL* = upper limit; ITN = insecticide-treated net; ELPD = expected log predictive density.
[a] reference level = No education. [b] reference level = Poorest

ITN use, female sex, increasing maternal education, increasing household wealth index, and improved source of drinking water were associated with reduced odds ratios of malaria infection. In contrast, child's age, recent fever, mother's age, and rural residence had increased odds ratios of malaria infection. Rural place of residence had the highest risk of malaria infection, more than doubling the odds ratio compared to the urban place of residence, *OR* = 2.41 [2.09, 2.84]. Recent fever was also a statistically significant predictor of malaria infection status; *OR* = 1.76 [1.58, 1.97].

Research Question 3

Is there an association between the use of ITNs and hemoglobin level in children aged 6 to 59 months?

$H_0$3: There is no statistically significant association between the use of ITNs and hemoglobin level in children aged 6 to 59 months.

H_A3: There is a statistically significant association between the use of ITNs and hemoglobin level in children aged 6 to 59 months.

The results of the Bayesian linear and logistic regression models with ITN use as the single predictor are in Table 7. The independent variable was ITN use (yes/no) measured as a nominal variable. The dependent variable was hemoglobin level measured on both the continuous and nominal scales.

The linear regression model (Model 7) showed a small negative but statistically significant relationship between ITN use and hemoglobin levels in this sample of children aged 6 – 59 months in Nigeria, *M* = −0.07 [95% CI, −0.11, −0.02]. This relationship is accentuated when the dependent variable is in the nominal form (Model 8), *OR* = 1.10

[1.03, 1.18]. However, both the linear and logistic regression with ITN use as the single predictor are poor models that do not explain any of the variance in the dependent variable, $R^2 = .000$.

Model 2 in Table 4 and Model 4 in Table 5 are the multilevel regression models that control for the effects of the other intrapersonal and interpersonal variables for Research Question 3. Model 2 showed a nonstatistically significant effect of ITN use on hemoglobin level, $M = 0.04$ [− 0.01, 0.09], after adjusting for the other variables. Model 4 showed a slightly reduced likelihood of anemia with LLIN use; $OR = 0.98$ [0.90, 1.08] that was not statistically significant.

Table 7

ITN use as Predictor of Hemoglobin and Anemia

	Hemoglobin (g/dl) Model 7 [a]			Anemia = yes Model 8 [b]		
	M	95% CI		OR	95% CI	
Parameters		*LL*	*UL*		*LL*	*UL*
Intercept	10.11	10.08	10.14	2.13	2.04	2.23
ITN use = yes	−0.07	−0.11	−0.02	1.10	1.03	1.18
R^2	.000	.000	.001	.000	.000	.001
ELPD	−29910.3			−9911.9		

Note. *M* = median estimate of regression coefficient; CI = credible interval; *LL* = lower limit; *UL* = upper limit; *OR* = odds ratio; ITN = insecticide-treated net; ELPD = expected log predictive density.
[a] Linear regression model of hemoglobin level. [b] Logistic regression model of anemia level.

Summary

I used Bayesian multilevel linear and logistic regression modeling of secondary data from the Nigeria MIS 2010, MIS 2015, and DHS 2018 surveys to evaluate whether malaria infection status and ITN use were related to anemia and whether ITN use was

related to malaria infection status in Nigerian children aged 6 - 59 months. In Chapter 4, I presented the results of the data analyses concerning each research question and the corresponding research hypothesis. The medians of the posterior distributions of the regression coefficients and the odds ratios and their associated credible intervals were reported.

For Research Question 1, malaria infection status, recent fever, improved source of drinking water, and rural place of residence were statistically significant predictors of reduced hemoglobin level and anemia. In contrast, child age, female sex, mother's age, increasing mother's education level, and increasing household wealth index were associated with increased hemoglobin level and less likelihood of anemia.

For Research Question 2, ITN use, female sex, increasing maternal education, increasing household wealth index, and improved source of drinking water were statistically significantly associated with reduced odds ratios of malaria infection. In contrast, child's age, recent fever, mother's age, and rural residence had increased odds ratios of malaria infection. For Research Question 3, there was not a statistically significant effect of ITN use on hemoglobin level. There was a reduced likelihood of anemia with ITN use, but this relationship was not statistically significant.

Chapter 5 will include the interpretation of the findings of this study and the discussion of the limitations and strengths of the study. Also, the chapter will include conclusions and recommendations for further study. The next chapter concludes with an explanation of the implications of the findings and the potential impact of this study on positive social change.

Chapter 5: Discussion, Conclusions, and Recommendations

In this study, I sought to address the specific problem of the lack of data on how ITN use following the campaigns of ITN distribution has affected the prevalence of anemia in children in Nigeria. This study was cross-sectional in design to determine whether selected intrapersonal-, interpersonal-, and organizational-level factors influenced the relationships between ITN use, malaria infection status, hemoglobin level, and anemia in Nigerian children aged 6–59 months. I addressed the research gap concerning the effect of ITN use on anemia in Nigerian children after years of ITN distribution. I used secondary data from national surveys to answer the research questions. The independent variables in this study were ITN use and malaria infection status, and the dependent variables were hemoglobin level and anemia.

The results of this study confirmed that while malaria was statistically significantly related to reduced hemoglobin level and increased risk of anemia and ITN use had a protective effect against malaria, ITN use was not associated in a statistically significant way with reduced hemoglobin level or anemia. The results also showed that recent fever, improved drinking water source, and rural residence were associated with reduced hemoglobin levels. Similarly, recent fever, improved source of drinking water, and rural place of residence were associated with an increased risk of anemia.

Factors associated with increased hemoglobin level and a reduced likelihood of anemia in this study were increasing child age, female gender, increasing maternal age, and increasing maternal education. Increasing household wealth quintiles were associated with increased hemoglobin levels and reduced probability of anemia.

Interpretation of Findings

The premise of this was that malaria is a leading cause of anemia in children, and ITN use has a protective effect against malaria; therefore, ITN use may have a protective effect against anemia.

Association Between Malaria and Anemia

The study findings confirmed the relationship of an increased likelihood of anemia with malaria reported by previous studies. The AOR for anemia in the presence of malaria in this study was 3.58 [95% CI 3.20, 4.02], meaning a three- to fourfold increased risk of anemia with malaria. This effect size was similar to that reported by Ferrari et al. (2016), who found an AOR = 3.40 [2.60, 4.44] for anemia with malaria infection in high malaria transmission areas. The AOR is also similar to that found by Maketa et al. (2015) for the relationship between *Plasmodium* infection and anemia in asymptomatic children (AOR = 3.5, $p = .001$). As previously noted, White (2018) reported that nearly all infants and young children have lower hemoglobin levels in areas of high malaria transmission. Nigeria is an area of high malaria transmission (White, 2018). Together, these results suggested that malaria infection is a strong predictor of anemia, whether the infection is symptomatic or asymptomatic, but contrasted with the findings of Birhanu et al. (2017). Birhanu et al. did not find any association between malaria parasitemia and anemia in an area of low malaria transmission intensity by multivariate logistic regression (AOR = 1.79 [0.03, 115.12], $p = .784$).

Association Between ITN use and Malaria

The results of this study also showed that ITN use reduces the risk of malaria infection. In this study, ITN use had an AOR = 0.82 [0.73, 0.93] for malaria infection, meaning ITN use led to a 7%–27% reduction in malaria risk. Several previous studies showed the effectiveness of ITN in preventing malaria (Chinwe et al., 2018; Florey, 2012; Pryce et al., 2018; Tokponnon et al., 2014, 2019). For example, this result is similar those of Okoyo et al. (2015), who found a 14% reduction (AOR = 0.86, [0.74, 0.98], $p = 0.027$) in malaria infection among children who used a LLIN the previous night compared to those who did not use nets. In the meta-analysis by Pryce et al. (2018), the RR for *P. falciparum* incidence was 0.83 [0.71, 0.98] and concerning severe malaria, for ITN use versus no ITN use, the *RR* = 0.56 [0.38, 0.82]. Tokponnon et al. (2014) also found that the use of ITN reduced malaria prevalence by up to 60% in both low and high resistance areas.

It was interesting to compare the unadjusted estimates of the effect of ITN use on malaria (*OR* = 1.03 [0.96, 1.10] versus AOR = 0.82 [0.73, 0.93]) and to note that the regression model with ITN use as the single predictor suggested that ITN use increased the risk of malaria but did not explain any of the variability in the data. This finding implied that several other variables confounded the effect of ITN use. It may mean that ITN use is a marker for other unmeasured health behaviors that explain the presence of malaria.

Association Between ITN use and Anemia

The results of this study did not provide evidence that ITN use confers protection against anemia in Nigerian children. In this study, ITN use had an AOR = 0.98 [0.90, 1.08] for anemia. This finding is different from the results in the two limited studies conducted in Nigeria by Adah et al. (2009) and Oladeinde et al. (2012) and whose findings had suggested that use of ITN reduced the risk of anemia. This result is similar to the pooled estimates from 22 surveys across several African countries by Florey (2012) who reported AOR = 0.84 [0.70, 1.02] of moderate-to-severe anemia for ITN users after controlling for urban-rural residence, wealth quintile, multiple birth status, mother's education, sex, age, and history of recent fever. However, in that same study, Florey also found that children using ITNs were less likely to have anemia compared to those not using ITN (AOR = 0.79 [0.68, 0.93]) after additional adjustment for immunization status, undernutrition, meat consumption, breastfeeding, and low birth weight using 18 surveys (which excluded the survey from Nigeria). I did not include these additional covariates in the regression models in the current study. This exclusion may explain the failure to find a protective effect against anemia for ITN use.

The current study findings were also similar to the results of Gimnig et al. (2016) and Ferrari et al. (2016). Gimnig et al. found no statistically significant independent effect of ITNs on anemia in a multivariate regression model (baseline *OR* = 0.45 [0.19, 1.05]), while Ferrari et al. found that ITN use did not protect against anemia in both low and high malaria transmission settings (AOR = 1.09 [0.90, 1.32]). Comparably, the results of the meta-analysis of five studies involving 11,489 participants by Pryce et al.

(2018) were that ITN use was associated with an increase in mean hemoglobin level (measured as mean packed cell volume) compared to the no ITN net group (mean difference of 1.29 [0.42, 2.16]). In contrast, Moschovis et al. (2015) used a multilevel regression technique similar to that used in this study by grouping the risk factors for childhood anemia into household and individual. They found that in areas with higher malaria prevalence, net use increased the risk of anemia (*OR* = 1.38 [1.24, 1.53]).

Study Findings in the Context of the Social Ecological Model

I used the social ecological model as the theoretical framework of this study. The social ecological model allowed me to highlight the dynamic interplay of nested, hierarchical intrapersonal-level, interpersonal-level, and organizational-level factors influencing the relationships between ITN use, malaria infection status, hemoglobin level, and anemia in Nigerian children. The intrapersonal-level factors were child age, child gender, and recent fever. The interpersonal-level factors were the mother's age, mother's educational level, household wealth index, source of drinking water, and physical household. The organizational-level factors were the place of residence and region.

Intrapersonal-Level Factors

Child Age. The results of this study showed that older children were less likely to have anemia, but at the same time, were more likely to have malaria. For example, the predicted probability of anemia in a 6-month-old female child was 88.9% compared to 47.1% for a female child 59 months old, keeping the other variables constant (i.e., malaria infection status = no malaria, ITN use = no, fever = no, mother's age = 29 years,

mother's education = none, household index = poorest, source of water = nonimproved, and place of residence = urban). These findings are consistent with the results of other studies that found that anemia prevalence reduced with increasing child age (Florey et al., 2012; Gebreweld et al., 2019; Kawo et al., 2018; Moschovis et al., 2015; Woldie et al., 2015). Moschovis et al. (2015) found a similar effect size for every 1-month increase in age on anemia (*OR* = 0.97 [0.96, 0.97]) to that found in this study using multivariate logistic regression.

Likewise, the predicted probability of malaria in a 6-month-old female child was 14.8% compared to 42.1% in a female child 59 months old, keeping the other variables constant as listed above. Afoakwah et al. (2018) found a similar effect size for the relationship between age and malaria and reported *OR* =1.02 ($p < .01$) for every 1-month rise in age. Kateera et al. (2015) also found that malaria parasitemia risk differed by age groups with *OR* = 2.53, $p = .040$ for the age group of 24–35 months; *OR* = 3.5, $p = .037$ for the age group of 36–47 months; and *OR* = 3.03, $p = .014$ for the 48–60 months age group compared to the 6–11 months age group.

Child Gender. Child gender was a statistically significant predictor of anemia in this study. The predicted probability of anemia in a female child (i.e., aged 31 months, malaria infection status = no malaria, ITN use = no, fever = no, mother's age = 29 years, mother's education = none, household index = poorest, source of water = nonimproved, and place of residence = urban) was 69.1% compared to 74.0% in a male with similar characteristics. Ngesa and Mwambi (2014) and Guled et al. (2017) had similar results to this study. Male children were more affected by anemia, AOR = 1.22 [1.08, 1.36] (Ngesa

and Mwambi, 2014) and AOR = 1.66 [1.00, 2.74] (Guled et al., 2017). Unlike this study, Ewusie et al. (2014) did not find a statistically significant gender difference in anemia prevalence (p = .167). Kateera et al. (2015) also did not find a statistically different prevalence of anemia in male children (7.4%) compared to female children (6.6%), OR = 1.14 [0.79, 1.62], p = .470, but they defined anemia as hemoglobin < 90 g/l.

Child gender was also a statistically significant predictor of malaria infection status. The predicted probability of malaria in a female child was 25.5% compared to 27.6% for a male child (i.e., aged 31 months, malaria infection status = no malaria, ITN use = no, fever = no, mother's age = 29 years, mother's education = none, household index = poorest, source of water = nonimproved, and place of residence = urban). This result was a contrast to Kateera et al. (2015), who found that malaria prevalence was higher in females (7.5%) compared to females (5.5%), OR = 0.72, p = .034. Sultana et al. (2017), on the other hand, did not find statistically different malaria prevalence rates among male children (8.23% [7.47%, 9.06%]) compared to female children (8.04% [7.28%, 8.88%]), AOR = 1.09 [0.89, 1.33], as did Dawaki et al. (2016). The latter found a similar prevalence of malaria between males and females (61.2% versus 59.7 %, p = .733) in five rural communities in Kano State, Nigeria. The findings of Kateera et al. and Sultana et al. differed from those in the current study in having much lower malaria prevalence rates and raise the possibility that gender differences in malaria prevalence disappear at low malaria prevalence rates. The reduced rate of malaria infection in female children could be because of a higher rate of ITN use. Moscibrodzki et al. (2018) and

Olapeju et al. (2018) found that under conditions of limited ITN availability, females were more likely to sleep under ITNs.

Recent Fever. Malaria is an infectious disease. Infections are associated with fever due to the body's immune response (El-Radhi, 2018). So, not surprisingly, this study found a statistically significant association between recent fever (defined as occurring within the past 2 weeks) and malaria (*OR* = 1.76 [1.58, 1.97]). There was a similar effect size for the association between recent fever and anemia (*OR* = 1.51 [1.38, 1.67]). This is also not surprising as fever is a marker for infection. Infections are associated with anemia (Viana, 2011).

Interpersonal-Level and Organizational-Level Factors

The results of this study showed that several variables influence anemia and malaria in Nigerian children below the age of 5 years old.

Mother's Age. In this study, the mother's age was associated in a statistically significant way with anemia and malaria. For every 1-year increase in the mother's age, the odds ratio for anemia was 0.99 [0.98, 0.99]. These results did not conform to the findings from a case-control study by Parbey et al. (2019) in which they found that there were no statistically significant differences for maternal age < 20 years (AOR = 4.69 [0.46, 47.58]), 20–29 years (AOR = 0.76 [0.18, 3.16]), and 30–39 years (AOR = 2.55 [0.66, 9.88]) compared to age 40 years and above. While Habte et al. (2013) found a statistically significant relationship between mother's age and child anemia status on bivariate analysis, they did not find a statistically significant association between mother's age and child anemia after multivariate logistic regression.

Mother's Education. There was a progressively increasing protective effect against anemia with each level of mother's education compared to no education: primary (*OR* = 0.93 [0.81, 1.06]), secondary (*OR* = 0.75 [0.65, 0.86]), higher (*OR* = 0.58, [0.48, 0.70]). These findings are similar to those of results from a multilevel logistic regression model of predictors of anemia in children age 6–23 months from different countries (Prieto-Patron et al., 2018). Prieto-Patron et al. (2018) found that AOR for anemia = 0.91 [0.88, 0.95] for primary and AOR = 0.82 [0.78, 0.85] for secondary and above, compared to no education.

Regarding malaria, there was a similar relationship with mother's education. Compared to no education, primary (*OR* = 0.64 [0.54, 0.76]), secondary (*OR* = 0.49 [0.41, 0.59]), higher (*OR* = 0.18 [0.13, 0.25]). The study by Afoakwah et al. (2018) also found a similar association between mother's education: secondary and higher (*OR* = 0.75, $p < .05$) compared to no education for malaria.

Household Wealth Index. With increasing level of household wealth, there was a decreasing likelihood of anemia compared to the poorest level of household wealth: poorer (*OR* = 0.80 [0.69, 0.93]), middle (*OR* = 0.65 [0.56, 0.76]), richer (*OR* = 0.57 [0.48, 0.69]), richest (*OR* = 0.44 [0.36, 0.53]). There was a similar dose-response relationship between household wealth index and malaria. Compared to the poorest household wealth index, poorer (*OR* = 0.96 [0.80, 1.14]), middle (*OR* = 0.70 [0.58, 0.84]), richer (*OR* = 0.44 [0.36, 0.55]), richest (*OR* = 0.15 [0.12, 0.20]). Studies show the relationship between increased household wealth and decreased anemia (Florey, 2012; Moschovis et al., 2018), and decreased malaria prevalence (Wanzira et al., 2017).

Source of Drinking Water. In this study, an improved drinking water source had an increased odds ratio of anemia (*OR* = 1.17 [1.06, 1.29]). This relationship was opposite to that with malaria (*OR* = 0.80 [0.71, 0.90]). Guled et al. (2017) found that children with unprotected drinking water source were about 5 times (AOR = 4.88 [2.20, 10.82]) more likely to have anemia. Also, using ordinal logistic regression, Moschovis et al. (2018) found statistically significant differences for the proportion of unimproved water source in those with no anemia (*OR* = 0.35 [0.34, 0.36]), moderate anemia (*OR* = 0.36 [0.35, 0.37]) and severe anemia (*OR* = 0.41 [0.39, 0.43]).

Place of Residence. In this study, children living in rural areas had an 11%–38% increased risk of anemia than children living in urban areas, *OR* = 1.24 [1.11, 1.38]. These results are comparable with those of Ncogo et al. (2017), who found a higher prevalence of anemia and malaria in Guinea's rural areas. They found that anemia was higher in rural than in urban settings (89.7% versus 82.7%, $p < .001$). On the other hand, Florey (2012) did not find a significant association between rural place of residence and anemia in children aged 6 – 23 years (pooled *OR* = 1.23 [0.94, 1.61], $p = .136$). Gebreweld et al. (2019), however, found that children living in an urban area (AOR = 1.83 [1.05, 3.18]) were more likely to have anemia. Yeka et al. (2015) found a more nuanced relationship between rural residence, anemia, and malaria infection. They carried out a study across three sites (one peri-urban and two rural) with varying malaria transmission intensity (entomological inoculation rates). They found that the prevalence of anemia was significantly lower in one of the rural sites (29.5%) compared to the other rural (49.4%, $p = .03$) and the peri-urban area (40.7%, $p = .03$). The prevalence of

Plasmodium infection was significantly higher (48.3%, $p < .001$) in the rural site with the largest entomological inoculation rate than in the peri-urban area (12.2%) and the other rural area (12.8%). There was no statistically significant difference in parasite prevalence between this other rural site and the peri-urban site.

Rural place of residence had the largest effect size for malaria (*OR* = 2.41 [2.09, 2.84]) in this study. Other studies have also reported the relationship between rural place of residence and malaria (Afoakwah et al., 2018; Apinjoh et al., 2015; Sultana et al., 2017). Afoakwah et al. (2018) reported the effect of rural residence on malaria infection in children aged 6–24 months (*OR* = 1.54, $p < .05$); 25–36 months (*OR* = 1.93, $p < .05$); and 37–59 months (*OR* = 1.89, $p < .01$). Apinjoh et al. (2015) found that malaria parasitemia was 63% higher in rural (AOR = 1.63, [1.07, 2.49]) compared to semi-urban areas. Also, Sultana et al. (2017) reported that the prevalence of malaria infection was also higher among rural children (10.16%) compared to urban children (2.93%) with AOR = 1.71 [1.31, 2.22].

Influence of Household and Region

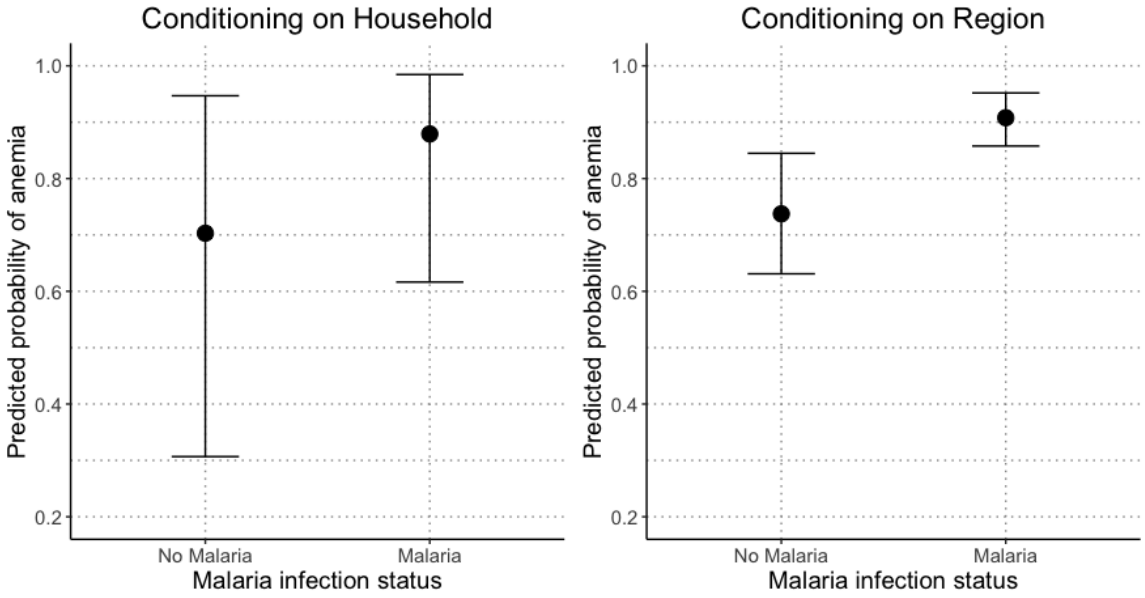
The regression models showed that the household-related interpersonal level variables and the organizational level variable of region explained much of the variability in the outcome variables (hemoglobin level, anemia, malaria infection status) for the research questions. The differences between the conditional R^2 (the variance in the data explained by the full model) and marginal R^2 (the variance in the data explained by the fixed effects) highlight this variability. The regression models included household and region as random effects and place of residence as a fixed effect. To illustrate, Figure 5

shows the marginal effects plots for the predicted probabilities of anemia by malaria infection status while conditioning separately on household and region. There is a lower probability of anemia occurring in the child when there is no malaria. However, the plots in Figure 5 show wider 95% credible intervals for the predicted probabilities of anemia when conditioning on the household compared to when conditioning on the region. Therefore, household encompassing the interpersonal level variables is a more critical influence on anemia and malaria infection status than the region at the organizational level because the household is proximal compared to the region. For the region to be more influential, the household-related effects would have to be small (see Weitkunat & Wildner, 2002).

Still, there is some variability in the probability of anemia and malaria from region to region. Figure 6 shows this variability across regions for anemia. Across all regions, the probability of childhood anemia was lower in the absence of malaria. The North East region had the lowest predicted probability of anemia, while the predicted probability of anemia was highest in the South-South region. So, children were less likely to have anemia if living in the North East while children in the South-South region were the most likely in the country to have anemia.

Figure 5

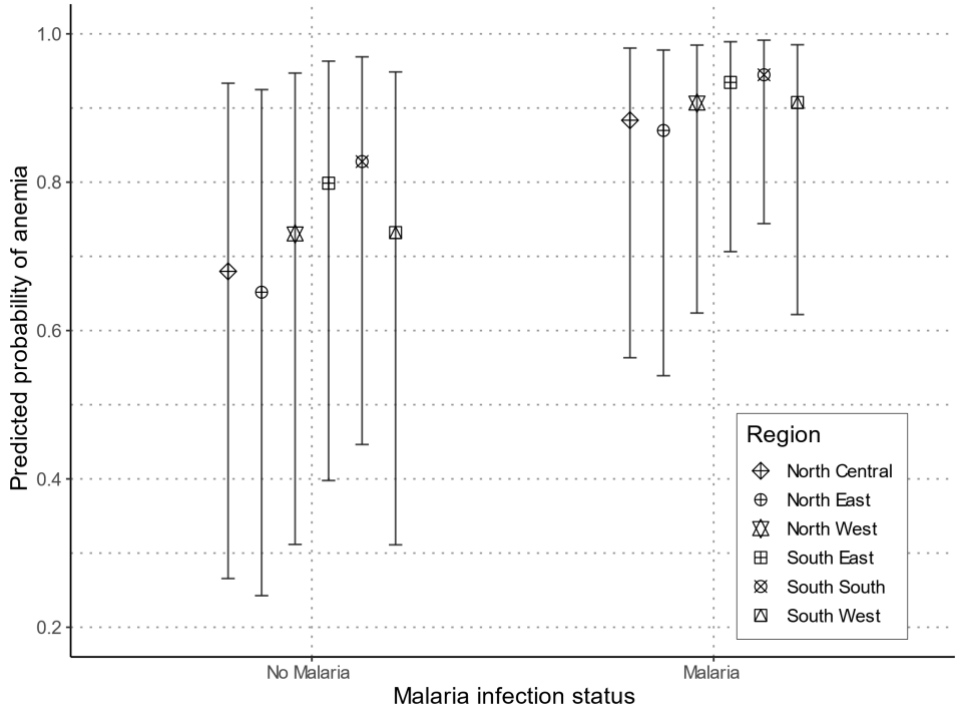
Predicted Probabilities of Anemia Conditional on Household and Region



Note. Lines represent 95% credible intervals for the predicted probabilities. The dots are the point estimates of the predicted probabilities. Adjusted for child age = 31.5 months, child gender = female, ITN use = no, fever = no, mother's age = 29 years, mother's education = no education, household wealth index = poorest, source of drinking water = not improved, and place of residence = urban.

Figure 6

Predicted Probabilities of Anemia by Malaria Status and Region



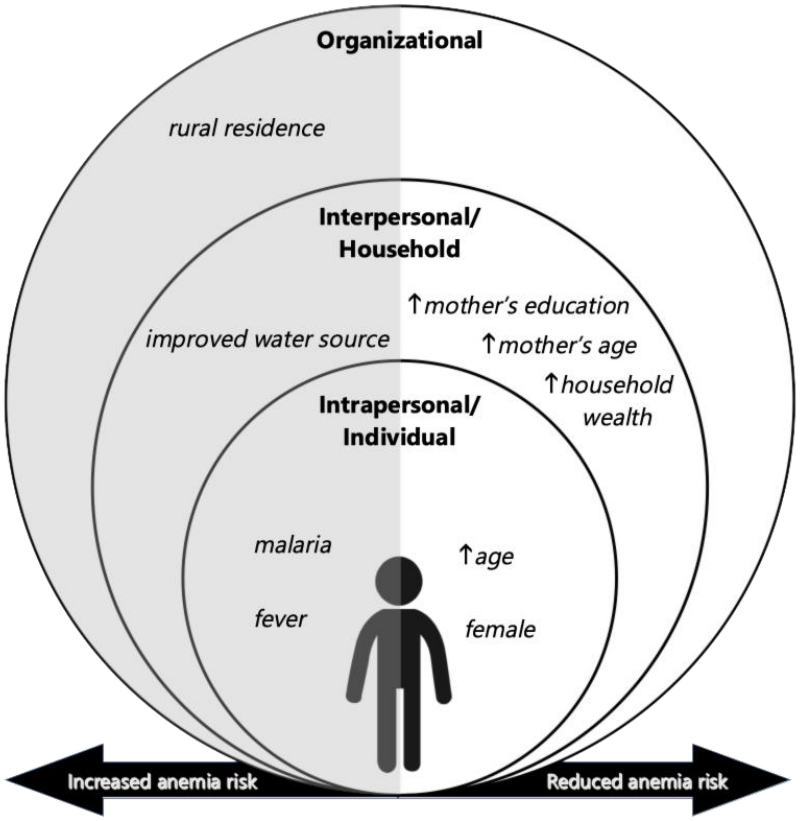
Note. Lines represent 95% credible intervals for the predicted probabilities. The shapes are the point estimates of the predicted probabilities. Adjusted for child age = 31.5 months, child gender = female, fever = no, mother's age = 29 years, mother's education = no education, household wealth index = poorest, source of drinking water = not improved, and place of residence = urban.

In this study, I did not find a statistically significant protective effect of ITN use against anemia despite its statistically significant protective effect against malaria. This lack of evidence might be due to the complex etiology and epidemiology of anemia. The regression models may not have accounted for all possible confounders. As illustrated in Figure 7, this study's results indicated that factors at both intrapersonal (individual) and interpersonal (household) levels influence anemia and malaria in Nigerian children aged

6–59 months with significant variation across households and lesser variation by regions. The interpersonal factors acting at the physical household level significantly influence anemia and malaria, but some intrapersonal factors were also significant in their influence. Some of these intrapersonal and household-related factors are protective, while others are associated with an increased risk of anemia and malaria.

Figure 7

Study Findings in the Context of the Social Ecological Model



Strengths of the Study

To my knowledge, this is the first study of the relationship between ITN use and anemia in Nigeria that used national data from different surveys. This secondary data

analysis provides a unique perspective on the epidemiology of anemia in children aged 6–59 months in Nigeria. The sample (N = 15,985) provided sufficient power to estimate the effect size of risk factors in Bayesian multilevel (hierarchical) regression models adjusting for constant and varying effects. The multilevel regression approach aligns well with the theoretical framework of this study — the multilevel social ecological model.

Limitations of the Study

Firstly, this study did not include all potential explanatory variables for anemia. The interpersonal level variables in this study exert their influence on anemia and malaria infection status at the household level. There are other household-related factors not measured in this study, such as father's educational level, feeding practices, household food security, dietary diversity that are associated with anemia (Gebreweld et al., 2019; Malako et al., 2018; Mohammed et al., 2019; Woldie et al., 2015). Other household-related factors such as availability of ITN within the household, head of household educational level, and household size also influence the relationship between ITN use and malaria (Afoakwah et al., 2018; Andrada et al., 2019; Olapeju et al., 2018). However, the regression models did not include these variables. There are other causes of anemia like iron deficiency, micronutrient deficiencies, sickle cell anemia, hookworm infestation, and schistosomiasis apart from malaria (Petry et al., 2016). This dissertation study did not measure these other causes. This nonmeasurement is a limitation of this study because of the unaccounted effect due to these other causes.

Secondly, the cross-sectional study design limits the ability to assess temporal or causal relationships. Thirdly, the study participants' self-reported responses and possible

measurement errors for the hemoglobin and malaria parasite measurements are subject to information bias. The incorrect determination of either exposure, or outcome, or both leads to information bias (see Grimes & Schulz, 2002). Fourthly, the secondary data used for analysis imposed limitations due to missing or incomplete observations. In this study, I did not include the type of *Plasmodium* species and the child's nutritional status in the analysis as planned because of several missing observations. The absence of these variables could potentially bias the results of the study. However, a subgroup analysis (results not shown), including all observations with complete nutritional status information, did not show any significant difference in effect sizes.

Recommendations for Future Research

This study provided important information regarding the factors associated with childhood anemia in Nigeria against the background of malaria. While the research results demonstrated that several intrapersonal-, interpersonal-, and organizational-level variables are associated with childhood anemia and malaria, it did not provide evidence for the protective effect of ITN use against anemia. This lack of evidence may be due to not measuring other potentially confounding variables shown to be related to anemia. Further research is needed to clarify the relationship between these factors and child anemia. More research is needed to guide the development of effective intervention programs to prevent childhood anemia and hopefully reduce the public health burden and long-term consequences of anemia in Nigerian children.

It may also be that the lack of a protective effect against anemia for ITN use in this study could be due to the low overall ITN use rate (40.1%) juxtaposed with the high

prevalence of anemia (68.9%). The National Malaria Strategic Plan 2014–2020 aimed to achieve 100% coverage of ITN and an 80% ITN use rate by 2020 (Federal Republic of Nigeria, 2014). This study showed that the rate of ITN use fell short of this target, rising from 32% in 2010 to 43% in 2018. Future studies are needed to determine barriers to ITN use among Nigerian children. An unexpected finding in this study was that an improved source of drinking water was associated with an increased odds ratio for anemia and reduced mean hemoglobin levels. This relationship between improved drinking water and anemia warrants more research.

Implications for Social Change

According to Smedley and Syme (2000), the social ecological model provides a structure for intervening at multiple levels of influence. These levels include the individual, interpersonal, institutional, community, and policy levels. The findings of this study can potentially influence positive social change at the individual, household, community, and policy levels. Interventions at the interpersonal level target social norms and social networks, while those at the community level involve networking, advocacy, environmental interventions, and community-based interventions. At the policy level, it may include federal regulatory agencies (Smedley & Syme, 2000).

The findings also suggest that interventions directed at the household level are crucial to preventing childhood anemia and malaria. The mother's education level and household wealth index were significant protective factors. These two factors showed a dose-response relationship with anemia and malaria. Increasing levels of education and household wealth were associated with increasing protective effects against anemia and

malaria. The implication of the preceding is that interventions to improve access to education for females and to improve average household income are essential to reducing anemia levels in Nigerian children.

Female children were less likely to have anemia and malaria in this study. This finding may suggest that cultural or gender roles play a part in the manifestation of anemia and malaria in children. As discussed earlier, female children may be more likely to use ITN when they are less available within the household (Moscibrodzki et al., 2018; Olapeju et al., 2018). The proportion of ITN use was 43% in the most recent survey data used in this study. This rate falls short of the target of 80% for 2020 (Federal Republic of Nigeria, 2014). There is a need to provide more ITNs. Expanding public health interventions that address the barriers to availability and use of ITNs is key.

The results of this study indicated that rural dwelling children were at more risk for anemia and malaria. This finding suggests that interventions directed at the rural areas are necessary for reducing the burden of anemia and malaria. Improved awareness of anemia and malaria at both the household and community levels is needed. Educating the community on the factors protective against anemia and malaria and those that increase the risk of anemia and malaria is important.

At 68.8%, the proportion of children in this sample indicated that the public health significance of anemia in Nigeria is severe (≥ 40%). There is still a significantly increased risk of anemia in children in Nigeria. The findings of this study can also help with public health policy formulation to mitigate childhood anemia in Nigeria. The most

recent national malaria strategic plan ended in 2020. The results of this study can provide some input into the next national malaria strategic plan.

Conclusions

This study explored whether selected intrapersonal-, interpersonal-, and organizational-level factors influenced the relationships between ITN use, malaria infection status, and anemia in Nigerian children aged 6–59 months. The results supported the hypotheses that there was an association between malaria and anemia and between ITN use and malaria. The results did not support the hypothesis that there was an association between ITN use and anemia.

While there is region to region variability in anemia and malaria prevalence, the household-related factors explained more of the variability in anemia. Malaria was the most critical risk factor for anemia, followed by recent fever, place of residence, and improved water source in that order. Older children, female children, children with older mothers, children with more educated mothers, and those residing in wealthier households had a lesser risk of anemia. Rural residence more than doubled the risk of malaria. Older children, children with older mothers, and recent fever also had a greater risk of malaria. Children using ITN, female children, children with more educated mothers, those living in wealthier households, and access to an improved source of drinking water were less likely to have malaria.

Childhood anemia is a significant public health problem in Nigeria. This study provided an understanding of some of the risk factors associated with anemia and malaria prevalence in children in Nigeria. Mitigating the impact of anemia in Nigerian children

requires an integrated multilevel approach that involves individuals, the community, and policymakers at all government levels.

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