FROM PREVENTION TO TREATMENT:
THE ROLE OF QUALITY AND READINESS IN MALARIA SERVICE DELIVERY FOR VULNERABLE POPULATIONS IN SUB-SAHARAN AFRICA

by

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ABSTRACT

Title of Dissertation: From Prevention to Treatment: The Role of Quality and Readiness in Malaria Service Delivery for Vulnerable Populations in Sub-Saharan Africa

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Many African countries remain well behind international targets for use of preventive malaria interventions in pregnancy and childhood as well as provision of quality case management services. The objectives of this study were: 1) to develop a quality of care diagnostic and use it to assess sub-national antenatal care (ANC) quality in Kenya for provinces, health facility types, and managing authorities; 2) to determine whether the quality of integrated ANC and malaria in pregnancy services in Kenya, Namibia, Senegal, and Tanzania was associated with prophylaxis use in pregnancy and insecticide-treated net use in pregnancy and children under-five; and 3) to determine whether health facility readiness to deliver malaria case management services varied with malaria endemicity in Kenya, Senegal, Namibia.

Publicly-available facility and household surveys and malaria endemicity data were used for these analyses. I constructed overall and by dimension ANC quality scores and explored performance across Kenyan provinces and facility characteristics. Second, I extended this method to construct regionally-aggregated malaria in pregnancy and ANC

quality scores for Kenya, Namibia, Senegal, and Tanzania, and built multilevel mixed effects modified Poisson pooled and country stratified models to predict individual use of prophylaxis and nets given regional quality scores. Third, I ran a multiple linear regression to examine pooled data to determine the association between the natural log of malaria endemicity and facility readiness to deliver malaria services.

ANC quality varied overall and by dimension across facility types, managing authorities, and provinces in Kenya. Regional malaria in pregnancy quality was modestly associated with uptake of interventions in pooled, Kenya, Namibia, Senegal, and Tanzania models. There was a modest association of malaria endemicity with malaria service readiness for rural facilities using pooled data for Kenya, Namibia, and Senegal.

Results suggested substantial variations in quality of care were present across geography and facility characteristics, and that disease burden may predict readiness of facilities to deliver care. This study has implications for systematic quality assessment, and routine service delivery and health system performance evaluation. Study findings may be used to support targeted improvements in malaria service delivery quality and facility readiness.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

ACT	Artemisinin-based combination therapy
AIM	Action and Investment to defeat malaria
ANC	Antenatal care
CDHS	Continuous Demographic and Health Survey
CSPA	Continuous Service Provision Assessment
CHW	Community health worker
DALY	Disability-adjusted life year
DHS	Demographic and Health Surveys
DOT	Directly observed therapy
EIR	Entomological inoculation rate
FANC	Focused antenatal care
FBO	Faith-based organization
GBD	Global Burden of Disease Project
GIS	Geographic information system
GMAP	Global Malaria Action Plan
GTS	Global Technical Strategy for malaria
HIV/AIDS	Human immunodeficiency virus/acquired immune deficiency syndrome
HMIS	Health management information system
IOM	Institute of Medicine
IMCI	Integrated Management of Childhood Illness
IPTp	Intermittent preventive treatment in pregnancy
IRS	Indoor residual spraying
ITN	Insecticide-treated bed net
IVM	Integrated vector management
LLIN	Long-lasting insecticide-treated bed net
LMIC	Low or middle income country
MAP	Malaria Atlas Project
MCSP	Maternal and Child Survival Program
MDG	Millennium Development Goal
MFL	Master Facility List
MiP	Malaria in pregnancy
mRDT	Malaria Rapid Diagnostic Test
NGO	Non-governmental organization
OECD	Organisation for Economic Co-operation and Development
PBF	Performance-based financing
PBI	Performance-based incentives
PCA	Principal components analysis
PMI	President's Malaria Initiative
P*f*PR	*Plasmodium falciparum* parasite rate
RBM	Roll Back Malaria
RBF	Results-based financing
SARA	Service Availability and Readiness Assessment
SDG	Sustainable Development Goal
SDI	Service Delivery Indicators

SP	Sulfadoxine-pyrimethamine
SPA	Service Provision Assessment
SSA	Sub-Saharan Africa
UHC	Universal Health Coverage
USAID	United States Agency for International Development
VCT	Voluntary counseling and testing center
WHO	World Health Organization

CHAPTER 1: INTRODUCTION, BACKGROUND AND STUDY OVERVIEW

A. INTRODUCTION

Integrated malaria and antenatal service delivery presents an opportunity to reduce total malaria-related mortality globally by up to 40% through bed net distribution (246). Further, integrated services could avert an average of nine additional maternal and under-five deaths per 10,000 second doses of preventive prophylaxis given during pregnancy across 21 African countries (45). In spite of these proven interventions, gains in the area of malaria in pregnancy (MiP) have been slow to materialize in Africa. Many countries remain far behind in reaching targets for the established three-prong strategy for malaria in pregnancy prevention and control, namely use of insecticide-treated bed nets (ITN), uptake of intermittent preventive treatment in pregnancy (IPTp), and provision of quality case management services (22; 130; 267; 273).

A woman-centered approach is necessary in order to tackle malaria control in pregnant women and children under the age of five (266). Pregnant women and children are particularly vulnerable to malaria infection, in part due to no or reduced partially acquired-immunity (44; 331), as well as virulence of *Plasmodium falciparum*, which is endemic to much of sub-Saharan Africa (331). In 2015, African children under the age of five accounted for approximately 70% of annual deaths due to malaria globally (331). Further, pregnant women are at increased biological risk for malaria during pregnancy (242), which can result in maternal, fetal, and newborn complications, including death (44; 121).

Service integration during pregnancy is based on the premise that coordinated care presents an opportunity to deliver proven interventions and related counseling, leading to improved intervention coverage and uptake for mothers and their children (301; 330). This should lead to a reduction in the burden of malaria in pregnancy and associated maternal, fetal, and child health outcomes. Women are the primary care takers for young children, in addition to caring for themselves during pregnancy, making this a logical approach for addressing both maternal and pediatric malaria.

Investigation of IPTp and ITN coverage and challenges related to their adoption by populations has primarily been undertaken through the lens of individual-level factors, late initiation of ANC, or women's knowledge of malaria (145). A recent review of 81 studies suggested the presence of a number of facility and policy-level barriers to coverage with ITN and IPTp delivered via health services (165). However, relatively little is known about the effect of quality of integrated services on determining uptake of malaria interventions by antenatal clients and their families. I aim to address this question through a multi-country comparative analysis.

Further, provision of quality case management is a crucial prong of malaria in pregnancy intervention (22). Appropriate case management requires two features to be in place. First, facilities should have the necessary structural components in place that facilitate providers' provision of the accepted standard of care, defined as 'malaria service readiness' by the World Health Organization (WHO) (243). Second, quality of diagnosis and treatment should be high. Structural metrics to assess service readiness are readily available through routine facility surveys and health management information systems (243), but reliable metrics for case management quality assessment are not (321).

It has been suggested but is unknown whether malaria endemicity may be associated with case management (81). I sought to address this question utilizing available service readiness metrics for case management.

My long-term goal is to reduce malaria morbidity and mortality in vulnerable populations through improvements in health service delivery and health systems strengthening. As one step toward pursuing this goal, I aimed to answer the following over-arching research question: What is the role of facility-based readiness and quality in malaria service delivery for vulnerable populations in sub-Saharan Africa? To address this question, I investigated three research objectives. Objective 1 was to develop a quality of care diagnostic and use it to assess sub-national ANC quality in Kenya for provinces, health facility types, and managing authorities. Objective 2 was to extend the diagnostic to malaria in pregnancy, and determine whether the quality of integrated antenatal and malaria in pregnancy services across four African countries (Kenya, Namibia, Senegal, Tanzania) was associated with use of malaria interventions (IPTp, ITNs) in vulnerable populations (pregnant women, children under the age of five). Objective 3 was to determine whether health facility readiness to deliver malaria case management services varied with malaria endemicity in three African countries (Kenya, Senegal, Namibia) which have previously been demonstrated to be of heterogeneous endemicity. The central hypotheses were that antenatal care quality would vary by Kenyan provinces, managing authorities, and facility type, that better antenatal care and malaria in pregnancy service quality would lead to increased use of proven interventions for both pregnant women and children under five, and that facilities in areas of high malaria disease would demonstrate greater malaria service readiness.

The rationale for undertaking this research was that a woman-centered approach is necessary to address malaria prevention and control in pregnant women and children under five. Integrating services for malaria prevention with antenatal services for women during pregnancy provides an opportunity to identify cases of maternal malaria, educate mothers who serve as primary care givers for children under five, and distribute proven interventions (13; 51; 164). If service delivery quality is poor, then antenatal visit content and messaging may be an area for targeted quality improvement. If service readiness to provide good case management varies with malaria endemicity, it may be inappropriate to track performance at the national level, as this may mask subnational variation in service readiness.

Specific Aims

The following specific aims were undertaken in order to answer the three research objectives:

- Specific Aim 1.1 Review quality frameworks in the published literature and select the most appropriate for low and middle income contexts.
- Specific Aim 1.2 Generate quality dimension scores and an overall quality score for antenatal care at the health facility level.
- Specific Aim 1.3 Examine performance in terms of ANC quality according to quality dimensions and overall by facility type, managing authority, and province in Kenya.

- Specific Aim 2.1 Generate two service quality scores at the health facility level: antenatal care quality and malaria in pregnancy service quality.
- Specific Aim 2.2 Establish the validity and reliability of each of the quality scores, and determine their level of correlation.
- Specific Aim 2.3 Determine whether a positive association exists between regional antenatal and malaria in pregnancy service quality and each of three individual-level outcomes:

- whether woman 15-49 years with a live birth within prior two years self-reports uptake of IPTp according to established guidelines;
- whether pregnant woman 15-49 years of age self-reports sleeping under an ITN the night prior;
- whether mother reports that her child(ren) 0-59 months of age slept under an ITN the night prior.

- Specific Aim 3.1 Generate the malaria service readiness score at the health facility level across three countries.
- Specific Aim 3.2 Establish the validity and reliability of the malaria service readiness index.
- Specific Aim 3.3 Determine whether facility readiness to deliver malaria services varies by endemicity, after controlling for management authority, region, and modifiable structural variables.

With respect to outcomes, this work demonstrated the need for subnational analyses as opposed to reporting national performance statistics, the need for tools to systematically assess service quality, and the relationship between antenatal and malaria in pregnancy service quality and individual-level uptake of key preventive malaria interventions. Further, I determined the relationship between endemicity and malaria service readiness at the facility level. This work provides an example of how to operationalize quality of care frameworks within the context of antenatal and malaria services, while creating a tool for assessing quality. The results of this work have implications for programmatic and policy-related decision-making, including for targeted allocation of resources toward ongoing health systems-level quality and readiness improvement initiatives based on identified low performing areas (26; 34; 311).

B. BACKGROUND

Malaria Burden and Epidemiology

The Global Burden of Malaria

Malaria contributes to a significant, preventable portion of the global burden of disease, ranking 7th overall and accounting for 3.3% of disability-adjusted life years (DALYs) lost globally in 2010 (229). The Anopheles mosquito transmits five different malaria parasites that can cause illness in humans: *Plasmodium falciparum, vivax, ovale, malariae,* and *knowlesi*. While *P. vivax* is most widespread, *P. falciparum* causes the most clinical illness and mortality worldwide (331). Globally, over 3 billion people were at risk of exposure to malaria in 2013 (331).

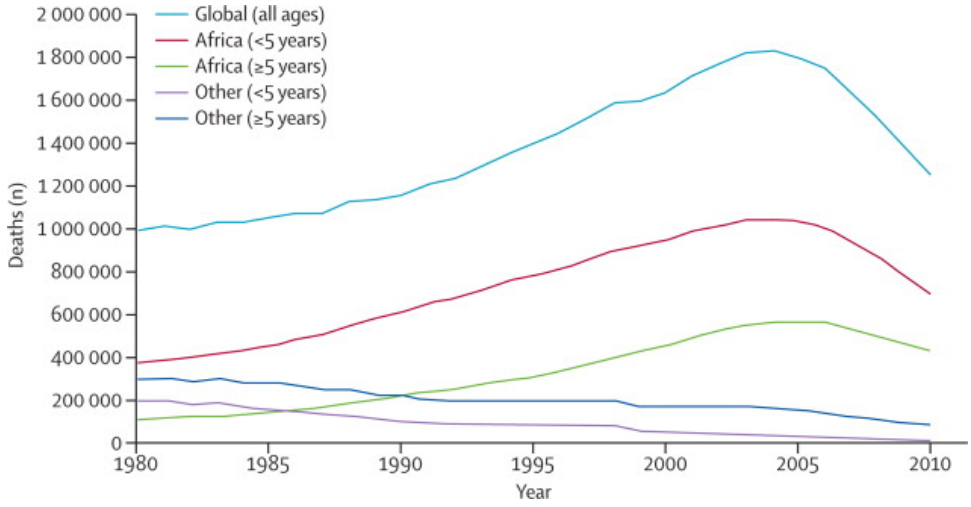
The global incidence of malaria increased steadily from 1990 until a peak in 2003 at 232 million cases (95% CI: 143-387 million cases), and a congruent mortality rate of 1.2 million deaths (95% CI: 1.1-1.4 million deaths) in 2004 (227). In 2015, global incidence was estimated at 212 million new cases (95% CI: 148-304 million – a 41% decrease since 2000 (331). Similarly, global mortality declined to 429,000 deaths (95% CI: 235,000-639,000 deaths) in 2015. Total cases are highest in children under fifteen years of age, and total deaths are highest in children under-five (227). As of 2015, 98 out of 106 countries with malaria transmission in 2000 had met the Millennium Development Goal (MDG) target to reverse malaria incidence; most of these were low burden countries (309).

Malaria Epidemiology in Sub-Saharan Africa

Sub-Saharan Africa (SSA) is disproportionately affected by malaria, with more than 840 million people at risk and high rates of mortality (37). Ninety percent of infections were in SSA in 2015 (331). Estimates from the Global Burden of Disease

project rank malaria first in terms of disease burden in western and central SSA, and second in eastern SSA (229). While elsewhere mortality has generally been in decline since 1990, the burden in SSA was a major driver in global burden rates continuing to increase into the early 2000s (227). Figure 1 demonstrates this relationship, by providing a comparison of trends in global malaria deaths in all ages to deaths in Africa and deaths elsewhere, stratified by age (228). Further, it demonstrates the disproportionate burden of malaria deaths in African children under the age of five.

Figure 1: Trends in global malaria deaths by age and geographical region, 1980-2010



Source: Murray, C.J.L., et al., Global malaria mortality between 1980 and 2010: a systematic analysis. The Lancet, 2012. 379(9814): p. 413-431.

Epidemiology and Pathogenesis of Malaria-Vulnerable Populations

Epidemiology

Pregnant women and children under-five in Sub-Saharan Africa bear the greatest burden of morbidity and mortality due to *P. falciparum* (10; 328). An estimated 30.3 million African pregnancies occur in a malaria risk zone annually (105). *P. falciparum* infections in pregnancy may be detected peripherally, in the placenta post-delivery, or both. Prevalence of peripheral malaria in pregnancy in SSA has been shown to vary, from

29.5% (95% CI: 22.4 -36.5) in East and Southern Africa, to 35.1% (95% CI: 28.2-41.9) in West and Central Africa (91). Placental malaria prevalence is estimated to range from an average of 26.5% (95% CI: 16.7-36.4) in East and Southern Africa to 38% (95% CI: 28.4-47.6) in West and Central Africa (91).

Malaria in pregnancy contributes substantially to maternal, fetal and infant morbidity and mortality. It has been estimated that MiP is implicated in 2-15% of maternal anemia cases in SSA (20). For the year 2010, Walker et al. 2014 estimated *P. falciparum* placental infections had the potential to result in as many as 900,000 low birth weight deliveries (316). Further, *P. falciparum* infection during pregnancy is estimated to cause 11% of neonate mortality in Sub-Saharan Africa (121).

In 2015, the WHO reported average malaria prevalence in SSA children ages 2-10 years was estimated at just over 20%, down from 26% in 2000 (37; 331). Prevalence in children has been shown to vary widely by country (37). In 2015, there were an estimated 292,000 (95%CI: 171,000 – 408,000) malaria deaths in children under 5 years of age for the African Region (331).

Pathogenesis

Symptomatic or clinical illness due to *P. falciparum* infection tends to occur in individuals with little or no acquired immunity, particularly young children and pregnant women (168). In areas of <1 infective bite per year, the likelihood of repeat infection in childhood is reduced. This generally results in a longer duration of time to develop clinical immunity, as time between incident infections is increased and total number of lifetime infections may be reduced (168). This leads to the potential for clinical illness in childhood as well as adulthood (296), with the possibility of severe illness in adults,

including during pregnancy (242). By contrast, in areas with greater than 10 infective bites per year, there is increased likelihood of repeat exposure throughout childhood and into adulthood. This concentrated exposure in children under-five leads to more rapid development of acquired immunity, but also results in increased frequency of clinical illness and severe presentation in young children (10). Thus, by adulthood, most adults have acquired sufficient immunity to control untreated chronic infections at subclinical levels (261).

However, pregnancy presents particular challenges with respect to acquired immunity and the ability of the human immune system to control the malaria parasite. In general, pregnant women are at increased risk for malaria compared to non-pregnant women as well as adult men, due to increased susceptibility to infection and increased likelihood of being bitten by malarial vectors (119; 202; 242). Pregnant women living in low endemicity areas are more likely to be symptomatic than those living in high (242). Further, clinical presentation in pregnancy generally differs by malaria endemicity level, with a tendency for more severe presentation in low malaria burden areas. Women living in low endemicity areas may present with hypoglycemia, pulmonary edema and cerebral malaria (242; 310); by contrast, in high endemicity areas, severe anemia is a common presentation (119). Additionally, co-morbid human immunodeficiency virus (HIV) infections in pregnancy are associated with increased risk for symptomatic malarial infection, maternal anemia, placental malaria infection, and low birth weight in infants (67; 138). HIV/malaria co-infection is of particular concern given the high burden of both illnesses in the SSA context.

Of the five human-infecting malaria parasites, *P. falciparum* is unique in its ability to sequester as infected erythrocytes, or adhere to certain tissues, including the placenta (242). In primigravidae, development of placental tissue presents a novel environment for parasite sequestration (242). Parasite expression of var2CSA subgroup antigens as part of PfEMP1, a variant surface antigen family, permits parasite adherence to placental tissue, and only to placental tissue (269). When expression of var2CSA on infected red blood cells occurs for the first time in pregnancy, the parasite can grow unchecked. The mother's immune system will not have the appropriate antibodies in her preexisting acquired immune repertoire, leading to increased risk of symptomatic infection as well as risk for increased parasitemia, with peaks in gestational weeks 13-16 (76; 269). This translates to increased risk of severe presentation for primigravidae or secundigravidae as compared to multigravidae, as expression of var2CSA is more likely to be novel in first or second pregnancies (264; 295). Further, younger maternal age and earlier gestational age may also increase risk for symptomatic infection, as these pregnancies may have lower partial immunity (295). Sequestration of both subclinical chronic and newly-acquired infections places mother and fetus at significant risk for malaria-related morbidity and mortality (99).

Placental infection with *P. falciparum* has been implicated in disruption of blood and nutrient flow to the fetus across the syncytiotrophoblast (87). Disruption of this process, in addition to placental inflammatory responses, has the potential to result in significant fetal and infant morbidities and death (72; 264). Additionally, fever and severe anemia resulting from malaria infection during pregnancy, rather than parasitemia, may increase risk of preterm delivery and stillbirth (257). Poor neonate outcomes also include

spontaneous abortion, intrauterine growth restriction, and low birth weight (128; 291; 295). Finally, congenital malaria may occur and become symptomatic in the infant once maternal antibodies have waned (276).

Malaria Endemicity: Heterogeneity in Levels and Established Guidelines

Clinical presentation, treatment guidelines, and approaches for prevention of malaria transmission differ based on endemicity level. Accordingly, it is worth briefly discussing variants in terminology and taxonomy for malaria endemicity, which have varied historically. The first malaria-related spleen enlargement population studies in India in the 19th century employed the term 'rate' instead of what is today understood as 'prevalence', which eventually led to widespread use of 'prevalence rate' to refer to malaria parasitemia in a population (159). The era of the Global Malaria Eradication Programme in the latter half of the 20th century introduced widespread nomenclature and aligned prevalence thresholds with malaria control activities/phases (159). Today, following the three-pronged, targeted Global Strategy outlined by the Roll Back Malaria Partnership (RBM), control, elimination, and research are the principal focus areas, with control and elimination activities aligning with endemicity levels and countries' overall contribution to the global burden of malaria (10). WHO currently utilizes the following transmission definitions in making policy recommendations, which are aligned with RBM guidance:

- "Low transmission": hypo-endemic areas where prevalence in children 2-9 years is 10% or less during most of the year. Malaria prevalence is similarly low across age groups.
- "Moderate transmission": meso-endemic areas where prevalence in children 2-9 years is 11–50% during most times of the year. Although maximum prevalence occurs in childhood and adolescence, first-time adult infections are still not uncommon.

- "High transmission": hyper-endemic and holo-endemic areas where prevalence in children 2-9 years is over 50% during most time of the year, and it would be uncommon to see a first infection after early childhood. (36)

Alternative measurements are also in use. For example, Hay et al. 2008 suggest use of a scheme aligned with the original Global Malaria Eradication Programme phases which is employed in Malaria Atlas Project 2010 modeling and publications; this utilizes the *P. falciparum* prevalence rate standardized to children ages 2-10 years of age ($Pf PR_{2-10}$) and cut points at 40%, 5% and 0% P*f*PR (159). Further, a more direct measure of the intensity of transmission, although more technically and labor-intensive to determine, is the entomological inoculation rate (EIR), or the vector biting rate multiplied by the proportion of mosquitoes infected with sporozoite-stage malaria parasites (69). The EIR is often used to divide endemic regions into high transmission (EIR >10 infective bites a year) and low transmission (EIR <1 infective bites a year) (69).

Activities outlined in the RBM Global Technical Strategy vary according to WHO transmission level and the predominant parasite in an area (329). For example, in high transmission areas of *P. falciparum,* it is recommended that every person at risk be covered by either an insecticide-treated bed net or indoor residual spraying (IRS). In Africa, pregnant women should receive intermittent preventive therapy (IPTp) starting in the second trimester. Further, everyone should be screened using microscopy or a malaria rapid diagnostic test (mRDT) (138), and the first line of treatment are ACTs, or artemisinin-based combination therapies (10). Low to moderate transmission areas of *P. falciparum*, typically where transmission is seasonally-driven or localized and at greater risk for epidemics, require targeted use of vector-control strategies like IRS or integrated vector management (IVM) activities, bed nets, and confirmatory testing for all suspected cases prior to starting treatment (10). Although previously IPTp was not recommended

for pregnant women in low to moderate transmission areas, it is now recommended that in certain countries where substantial progress has been made, administration of IPTp should continue for the foreseeable future (10; 36). *P. vivax* or mixed transmission settings (both *P. vivax* and *P. falciparum*) require parasite differentiation in order to ensure appropriate treatment, due to the ability of vivax to persist in the liver and result in relapse at a later date (10; 259).

Endemicity level has also been demonstrated to be associated and vary with other factors important for prevention and control efforts. It is well-established that transmission is directly impacted by urbanization. The malaria vector Anopheles and its behaviors are negatively affected in urban environments due to elimination of preferred open, freshwater breeding spaces and increased pollution in remaining breeding sites leading to reduced vector range (203; 305), resulting in decreased transmission (158). Endemicity level may also be associated with care seeking behaviors and drug prescription practices for malaria treatment, although most studies have looked at either in the context of specific low or high transmission areas (109; 236; 244). Other work has suggested the possibility of a relationship between per capita cost burden of treating malaria and endemicity level in Kenya where endemicity is heterogeneous (95). A recent study by Burgert et al. demonstrated variation in bed net ownership by endemicity level in heterogeneous African countries and implications for the potentially short-sighted use of national level metrics over sub-national progress tracking. This study also identified an important gap in the literature with respect to whether case management may vary according to endemicity levels (81). I sought to address this gap through objective 3 of this dissertation.

Established Interventions for Malaria in Pregnancy

Strong evidence compiled over the last two decades has led to international consensus and establishment of a three-pronged approach to malaria prevention and control during pregnancy. Priority interventions are use of insecticide-treated bed nets (ITN), uptake of intermittent preventive treatment in pregnancy (IPTp), and case management (22). A review of each follows.

Insecticide-treated bed nets

Effectiveness of bed nets as an intervention against malaria transmission has long been established (92). Insecticide-treated nets (ITNs) using the insecticide permethrin are in widespread use globally. They consist of either pre-treated nets which require annual re-treatment by the household, or the current gold standard, long-lasting insecticide-treated nets (LLINs), which are designed to last for up to three years. In recent years, vector resistance to permethrin-based insecticides has been demonstrated (53; 226) which has raised concern over effectiveness of the current generation of ITNs for the long term. For now, ITNs continue to be a hallmark of malaria prevention activities, with a combination of permethrin-based insecticides recommended for areas of permethrin resistance (53). ITNs are particularly crucial during the first trimester of pregnancy when pregnant women cannot receive prophylactic therapy, as well as for preventing transmission in children under-five (295).

Numerous studies have looked at factors associated with bed net ownership and use. Commonly identified factors include household size, the number of ITNs in a household, rural/urban residence, household wealth/poverty, breastfeeding status in children, physical proximity to purchase points, distance to nearest health service, transportation accessibility, mother's education, and household head age and marital

status (183; 214; 241; 277). Widespread use of ITNs has a protective community-wide effect (155; 170; 212; 297). The demonstrated individual and community-wide protective effect of ITNs, paired with evidence for inequities in net ownership due to wealth and rural residence (211), have led in part to the WHO recommendation that countries adopt a goal of universal coverage with ITNs (28; 29). Universal coverage campaigns (UCC) have been widely adopted by African countries as a mass distribution strategy, and early evidence suggests they may be successful in reducing inequities in ownership (332). The WHO has subsequently called for a focus on sustaining universal coverage of ITNs moving forward (28; 321). This includes through mass distribution campaigns, as well as continuous distribution routes, including during antenatal and childhood immunization services in health facilities (28; 321).

Key population indicators for ITN ownership and use (as well as other indicators for tracking malaria progress using routine surveys) are periodically published by the Roll Back Malaria Partnership and were recently updated in 2013 (24). Monitoring trends in ownership and use over time using these established indicators is one mechanism for monitoring progress towards universal coverage. The guidelines lay out nine indicators related to ITN ownership and use. Two are of relevance to the proposed research: the 'proportion of children under five years old who slept under an ITN the previous night' and the 'proportion of pregnant women who slept under an ITN the previous night' (24).

Intermittent Preventive Treatment

Intermittent preventive treatment (IPT) can be used as a preventive mechanism for malaria infection in pregnant women (IPTp), children (IPTc) or infants (IPTi). It requires directly administering a full course of an effective antimalarial treatment, regardless of parasitemia, in order to reduce the burden of malaria in the target population

(24). Current guidelines suggest IPTp should be administered as directly-observed therapy (DOT). I focus this review on IPTp, as it has been a component of the focused antenatal care (FANC) package of essential pregnancy services since updated guidelines were first published in 2003 (3). The WHO recommends a minimum of 8 ANC visits during pregnancy, providing an ideal opportunity for IPTp delivery (330).

WHO guidelines recommend that IPTp should be administered to pregnant women as sulfadoxine-pyrimethamine (IPTp-SP) or another prophylactic antimalarial according to national guidelines, as early as possible in the second trimester and in doses at least one month apart in high or moderate transmission/endemic areas (36). In 2012, based on a review of evidence demonstrating a dose dependent effect of IPTp-SP, the WHO recommended a change from a minimum of 2 or more doses of SP to provision of IPTp at every ANC visit, beginning with the second trimester (208). This change was made in order to avoid incorrect interpretation of the recommendation and to increase dosing to three or more doses, under FANC guidelines where at least three ANC visits might be expected from the second trimester onward (36). In addition to providing additional protection from malaria infection, three doses of IPTp remain cost-effective as compared to only two doses (126). Further, a review of new evidence led to the determination that, in spite of SP resistance in some areas, IPTp-SP remains effective for prevention of peripheral parasitemia, maternal anemia, and clinical malaria in pregnancy, and results in reduced neonate mortality (178; 208; 216; 217; 222; 323). As a result, the standard indicator for IPTp was updated in 2013 from two or more doses to three or more doses (24). Individual-level factors associated with uptake of IPTp include older age,

marital status, primi or secundigravidae, and initiation of ANC visits during the first or second trimester (184).

Case Management in Pregnancy

Case management of malaria broadly consists of diagnostic and treatment services. In pregnancy, rapid diagnosis and identification of case severity allows for proper treatment response. Microscopy with placenta histology is the gold standard for diagnosis in pregnancy with 60% and 45% sensitivity for peripheral and placental *P. falciparum* infections in African women in stable transmission areas, respectively (179). However, mRDTs are becoming widespread in availability and use, although they generally have a lower sensitivity than microscopy. Yet, as microscopy requires a well-trained microscopist, in some settings mRDT may be a more sensitive test (295). Once a suspected case is confirmed, appropriate treatment is both severity and trimester-dependent (295).

The WHO has identified national monitoring and evaluation of case management quality as a priority for malaria control. However, key challenges moving forward include the need to link national program data on diagnostic and treatment practices in a way which will expedite their routine monitoring (321). Furthermore, solid case management indicators which are not reliant on patient recall remains a challenge in most settings (321), and most facility-based surveys such as the WHO's Service Availability and Readiness Assessment (SARA), USAID's Service Provision Assessment (SPA), or the World Bank's Service Delivery Indicators are not currently designed to systematically collect these data. Case management indicators for children under-five currently include: the 'proportion receiving any ACT (or other appropriate treatment) among children under five years old with fever in the last two weeks who received any

antimalarial drugs,' and the 'proportion of children under five years old with fever in last two weeks who had a finger or heel stick' (24). However, as pregnancy is often self-reported in household surveys and this self-report is considered unreliable given challenges with awareness of and willingness to divulge pregnancy status in the first trimester, no standard case management indicators are routinely collected for pregnant women (24).

Health Systems: Components, Actors, and Service Delivery

The three aforementioned prongs of malaria in pregnancy intervention are routinely delivered through facility-based malaria care. While universal coverage campaigns have broadly facilitated mass distribution of bed nets, IPTp coverage has lagged behind. A review of the facility-based service delivery literature follows, in order to understand existing evidence and any gaps therein.

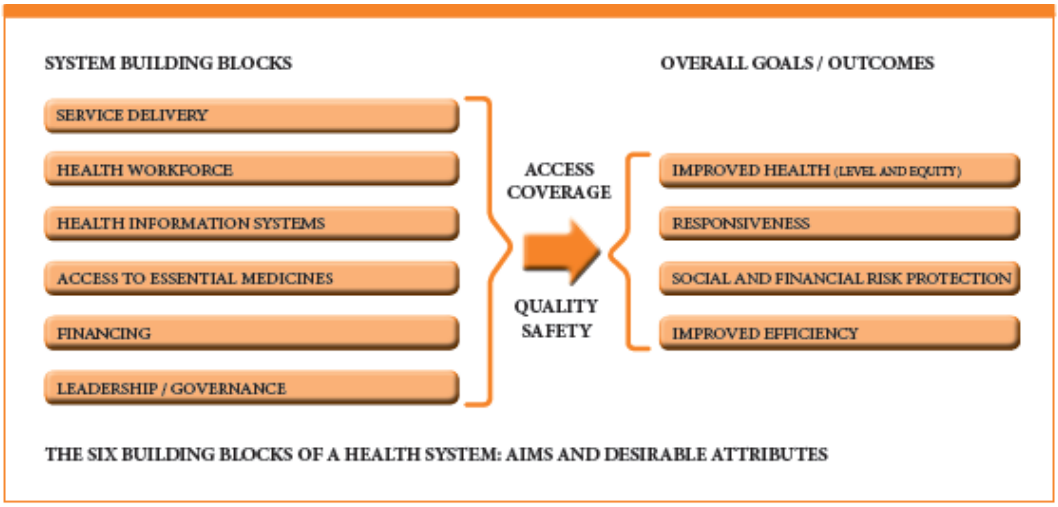
Building Blocks of a Health System

Country health performance and ability to meet global health targets, such as those laid out under the United Nation's Millennium Development Goals (MDGs) and their successors the Sustainable Development Goals (SDGs), is largely dependent on the strength of a nation's health system (8). A health system is comprised of the organizations, institutions, resources and people whose primary purpose is to promote, restore, or maintain health (8; 16; 231). Key tenets of a well-functioning health system, which must necessarily be balanced in response to a population's health needs, include four components: improvement of the health status of individuals, families and communities; defense of the population against what threatens its health; protection of people against the financial consequences of ill-health; and provision of equitable access

to people-centered care (15). Further, people-centered and integrated health services are central to reaching the primary goal of the Universal Health Coverage movement, which strives for universal access to services globally (41).

Although many health gains were made globally in the first decade of the twenty-first century, these were not universal for countries, nor were they broad-based in nature (16). To this end, in 2007, the WHO outlined a health systems framework for action comprised of six 'building blocks' of a health system: service delivery, health workforce, information, medicines, financing and governance (Figure 2) (8), which, when operationalized should lead to overall strengthening of a health system(s) (51).

Figure 2: The WHO Health Systems Framework



These six building blocks have varying roles in health systems strengthening, including as cross-cutting policy and regulatory support (leadership/governance, health information systems), system inputs (financing, health workforce), and system outputs around care availability and distribution (medical products and technologies, service delivery) (16). In order to operationalize the building blocks for practice and research purposes, a corresponding monitoring and evaluation framework was developed which

links the building blocks as inputs, processes and outputs, to system outputs, outcomes and impact (Appendix A (16).

While malaria prevention and control activities are impacted by each of the building blocks, this dissertation research was concerned with malaria service delivery as a primary avenue for routine delivery of proven malaria in pregnancy interventions. This was in line with the operational research agenda for malaria elimination, as set by the Malaria Eradication Research Consultative Group on Health Systems Operational Research (301). A discussion of service delivery and related health systems strengthening tools follows.

Service Delivery in Developing Countries

Service delivery deals with organization and management of inputs and services into a health system, in order to ensure access, quality, safety and care coverage across conditions, locations, and over time (8). The WHO has defined 'good' health services as "those which deliver effective, safe, good quality personal and non-personal [population-based] care to those that need it, when needed, with minimum waste" in a variety of locations including the home, the community, the workplace or health facilities (8). Further, in order to achieve 'good' service delivery, countries should strive for high performance across eight key attributes of care: comprehensiveness of the range of services offered; accessibility; coverage; continuity; quality; person-centeredness; coordination; and accountability and efficiency (16).

Service delivery is comprised of two core areas: service availability and service readiness. Service availability is, "the physical presence of delivery of services that meet a minimum standard…[including]… health infrastructure,… the health workforce,…

[and] aspects of service utilization" (16). Service readiness is the capacity of health facilities to deliver offered services, including presence of staff, guidelines, infrastructure, equipment, medicines, and diagnostics (161). Together, service availability and readiness are prerequisite components for quality service delivery to occur (161). Whereas service availability is a metric constructed nationally from a complete census of all facilities, national and sub-national service readiness can be evaluated from a sample of facilities, and is constructed on the facility level. Further, service readiness can be measured according to specific services, through the same domains as overall readiness and using established indicators for the service of interest (35). This is true for malaria service readiness, which is measured according to three domains: staff and guidelines, diagnostics, and medicines and commodities (243).

Service Integration: A Health Systems Strengthening Intervention

Integration of services has been identified as a service delivery strengthening activity which facilitates concurrent receipt of multiple health services and promotes increased service utilization and uptake of healthy behaviors (154). Service integration requires collaboration between multiple national programs responsible for care delivery to harmonize policies, guidelines, and training materials, and effectively coordinate overlapping program implementation (185; 267). Further, integration at both the inter-specialty (e.g. primary care + infectious disease) and intra-specialty (infectious disease + infectious disease, e.g. HIV/AIDS and tuberculosis) levels should be considered as opportunities within service delivery (210). Although the limited available evidence is mixed (118; 154; 156), it is thought that service integration should lead to improved

quality of service delivery and, in turn, improved health status and outcomes (156; 194; 201; 288).

Service integration has emerged as a necessary mechanism for ensuring coordinated, accessible, cost-effective care, in the face of systemic barriers creating hurdles to care seeking (82; 142; 185; 210). By integrating services for specific diseases such as malaria or HIV/AIDS in endemic areas at the point of care for basic health service delivery, patients who have already overcome barriers to seeking care are a ready audience for testing and further intervention as necessary (142). On the other hand, integration of multiple services may create competition for constrained visit time, and this has raised concern that integration may unintentionally squeeze out or impede provision of adequate essential services; evidence for this, however, is mixed (77; 152; 258). For this research, I concerned myself with integration of malaria services with antenatal services, and address the available evidence further in the section Quality of Integrated Malaria Services with Antenatal Services.

Quality: A Health Systems Strengthening Intervention

Quality is a cross-cutting theme of health systems and their formal building blocks (8). It is central to ensuring care standards are implemented as intended through service delivery, and to ensuring the best possible patient health outcomes. It is also a mechanism for strengthening health systems through service delivery (239). Yet, most countries do not have national accreditation systems or other monitoring mechanisms for quality provided in the formal sector, in spite of existing tools (30). Furthermore, systematic, routine measurement of quality of health service delivery in the formal sector remains a long-sought after and crucial undertaking (251; 253). Not only are structural

inputs a necessary prerequisite at the facility level, but content of care, patient satisfaction with health visit encounters, as well as actual patient outcomes are integral to full realization of quality services (16). This presents a substantial challenge in terms of how to best collect these data in comprehensive, routine, and financially sustainable fashion.

In a seminal 1988 article, Donabedian described quality assessment in health care according to the domains of structure, process, and outcome (114). Structure is defined as attributes of material and human resources as well as organizational structure, process as patient and practitioner activities in giving and receiving care, and outcome as the effects of care on health, including on patient knowledge, behavior and satisfaction (114). Many examples of the employ of this framework exist, in terms of efforts to assess quality in the formal health sector (30; 149). Still others focus on one aspect alone, such as care content or other process-related indicators. For example, process-related content assessments can include visit content analysis using standardized patients (103; 136), provider knowledge assessment using vignettes (111; 252), or provider improvement interventions using covert observation to examine the Hawthorne effect, whereby individuals modify behavior in response to awareness that they are being observed (198-200).

However, quality of care is also seen as a multidimensional concept (16; 30), where dimensions may cross-cut structure, process and outcomes domains. Several leading organizations have put forth quality frameworks, including the Institute of Medicine (IOM)'s six dimension framework in 2001 (1) and the Organisation for Economic Co-operation and Development (OECD) in 2011, which conducted a review of quality dimensions from the literature in an effort to develop a framework for quality

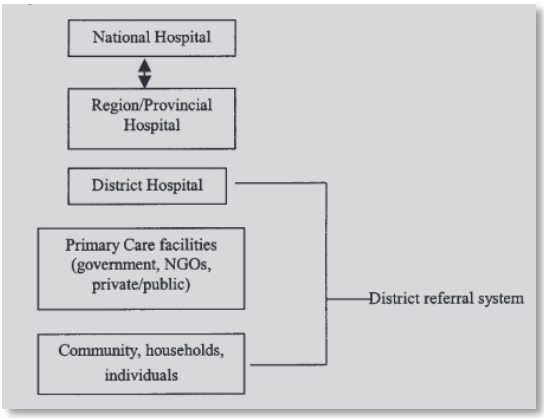
assessment and tracking in more advanced health systems (180). The WHO also introduced a multidimensional quality framework with an eye toward both developed and developing country contexts in 2006, in close alignment with the 2001 IOM framework. The six dimension WHO framework defines quality in terms of effectiveness, efficiency, accessibility, acceptability/patient-centeredness, equity and safety (327).

Examples of operationalization of quality frameworks have tended to employ the Donabedian categories alone, to construct a quality score in terms of whether a set of standard guidelines was met, or to focus on a subset of quality dimensions (73; 80; 171; 234; 289). Yet, assessing quality in its fullest sense arguably requires attention to both the structure-process-outcome service delivery continuum, as well as the multi-dimensional aspects of quality (195), all while rationalizing indicator selection in line with clinical standards. I attempted to address this through development of a quality diagnostic for objectives 1 and 2.

Health System Composition in Africa: Infrastructure and Human Resources

The African region has largely moved towards decentralized service delivery. Management responsibility has increasingly been shifted away from the national level toward the sub-national or district levels. Commonly, first level facilities providing mostly preventive and essential services include health posts, clinics, dispensaries, rural maternities and health centers, and nursing homes, although this is sometimes split into two with posts,

Figure 3: Health Referral System
Source: Chatora et al. 2004



clinics, and dispensaries as a separate lowest level (19). In general, the first 'level' of formal health services (which can include both the public and private sectors) is responsible for roughly 80% of all primary health care service provision, yet receives only 20% of total available financial resourcing (11). First level facilities often operate at reduced capacity without proper resourcing, contributing to poor national health systems functioning overall and across the region (11). These facilities are the interface between the population and secondary and tertiary facilities such as district and referral, and national hospitals respectively, which provide more specialized, curative care as well as some primary care (11; 19). In spite of unequal resource allocation favoring hospitals, African hospitals continue to be under-resourced across the region (11). This under-resourcing contributes to poor functioning of health systems both nationally and regionally. Figure 3 depicts the district referral system which consists of community level actors, level one facilities providing primary care, and district hospitals. For more specialized care and curative services, district hospitals would generally refer patients out to provincial or regional hospitals, or possibly to a national hospital for highly specialized care.

African regional densities of primary, secondary and tertiary facilities are lower than WHO-recommended averages and estimated global averages. For African countries reporting data in 2013, statistics on facility densities per 100,000 population were as follows:56% had <10 health posts, 82% had <1 district hospital, 41% had <0.1 provincial hospitals, and 66% had <0.1 tertiary hospitals (273). Low primary and secondary facility densities may contribute to poor coverage of essential and curative health services, and low tertiary hospital densities impact countries' ability to refer to specialized services,

train specialized health care providers, conduct research, and provide quality diagnostic and treatment services (273).

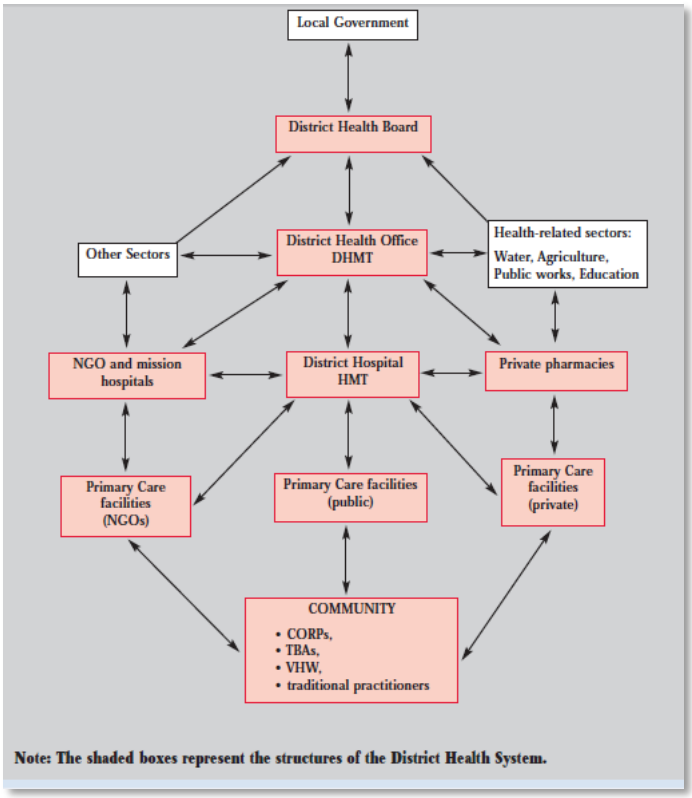
In terms of human resource capacity, the African region has an estimated deficit of at least 817, 992 health care professionals, including doctors, nurses and midwives, making it the region with the most severe shortage worldwide (7). In 2006, thirty-six of fifty-seven countries globally facing a health workforce crisis, or those which have a workforce density ratio below a minimum recommended density of 2.3 providers per 1000 population, were in Africa (7). Later estimates suggest some progress made in twenty of those countries is still offset by 16 which still have an estimated density of 0.16 to 0.47 providers per 1000 population (33). The regional average is 0.26 physicians per 1000 population and 1.2 nurses and midwives per 1000 population, or 5.4 times and 2.4 times lower than global averages, respectively (273). These deficits, paired with other challenges related to limited infrastructure, have led to inadequate coverage and provision of essential health services. Constraints for health workforce coverage include poor management, poor retention, low output from and slow reform of training programs, existing health worker geographic distribution challenges, and insufficient incentives (11; 33). To offset coverage issues and rapidly scale-up access to care, some African countries have shifted focus toward training community-health workers as part of the formal system to provide a portion of essential health services. For example, Health Surveillance Assistants in Malawi and community health extension workers in Ethiopia help deliver basic interventions and refer patients to facility-based care (279; 285).

Health System Composition in Africa: Service Delivery Actors

Service delivery provision falls to a complex range of organizational actors in decentralized African health systems, and is country-specific. However, generally these actors can be broken down by status as either state (i.e. public) or non-state (i.e. all private providers existing outside of the public system who provide services to prevent or treat illness, including faith based organizations) (70; 221). Alternatively, actors can be categorized by whether they deliver care through the formal or informal sectors. These classification schemes overlap considerably, as both formal and informal sector providers are also considered non-state sector, whereas state actors fall entirely within the formal sector. Figure 4 depicts hypothetical relationships between facilities within a district health system, and the sector each level of facility belongs to, by private, public, and NGO status, as well as where other multi-sectoral linkages can be made in relation to health service provision.

The state, or public, sector consists of all government-managed health facilities which are by default, part of the formal sector. In Africa, this includes facilities across the various district, provincial and national levels previously discussed (88). This may also include public sector providers at the community level who have been integrated into the formal system in salaried positions, such as various types of community health workers.

Figure 4: District Health System and its Linkage to Other District Structures (Hypothetical Model)
Source: Chatora et al. 2004



The non-state (private) sector consists of a very broad base of both formal and informal actors delivering services (70). These may include private for profit and private not-for-profit organizations and private independent physicians which are part of the recognized formal delivery system, as well as private informal providers. Private not-for-profit actors often include faith-based organizations (FBOs) and/or non-governmental organizations (NGOs) which manage health facilities. For example, in Malawi, the Christian Health Association of Malawi (CHAM) is an FBO responsible for managing a network of health facilities at multiple levels of formal sector service delivery (31). Faith-based organizations are thought to provide a substantial portion of care in many sub-Saharan African countries,

yet comparatively little is known about the FBO service delivery environment, the clientele serviced, and quality of care provided (247). In developing countries, non-state, informal providers may consist of drug shops and pharmacies, traditional healers, unskilled birth attendants, unqualified 'doctors' or quacks, to name but a few (70).

In Africa, a variety of formal sector actors are responsible for providing care. Table 1 depicts the nationally-representative composition of formal sector actors for the four countries examined in this research. This includes both state and non-state actors comprising the formal, facility-based care delivery system, as has been the focus of this research. It does not include individual providers or community-level actors.

Table 1: National Composition of Formal Health Service Management Authorities in Four African Countries

	Kenya 2010	Namibia 2009	Senegal 2014	Tanzania 2006
Public	**50%**	**77%**	**81%**	**77%**
Private	**50%**	**22%**	**19%**	**23%**
- **for Profit**	34%	12%	9%	--
- **not-for-profit**	3%	10%	4%	--
- **Faith-based**	13%		6%	--

Data presented in this table suggest that the proportion of facilities managed by state and non-state actors is nearly equal in Kenya, whereas in Namibia, Tanzania and Senegal, the public sector manages roughly three-quarters of facilities, and in Senegal is responsible for managing 81% of facilities (9; 12; 17; 19; 31; 46). These complex care delivery environments have implications for systems strengthening and continuity of care. A recent study from the East and South Africa regions demonstrated that the regulation of service types offered by private providers, as well as quality of services, is poorly regulated and monitored, which can "lead to distortions in the type, quantity,

distribution, quality and price of health services, as well as anti-competitive behavior" (113).

Further, the private informal sector is diverse and country-specific. Sudhinaraset et al. 2013 define characteristics of informal providers as lack of formal training, lack of official registration with a regulatory body, and payment collection occurring directly from patients rather than through an institution (293). Their review indicated that while it is uncommon for the literature to address estimates of the proportion of providers in a country who are informal (293), one Ugandan study estimated informal providers make up 77% of all providers (188). Utilization studies are more common, with national estimates for informal providers reported as the preferred first provider ranging from 9-90% across all regions, indicating wide variability (293).

With respect to informal malaria services, it is estimated that informal providers are sought 9-33% of the time for suspected malaria fever treatment in Kenya (56; 147). Similarly, in Tanzania informal providers are sought an estimated 31% of the time, generally (98). There is likely to be wide variation in quality of care provided across contexts and informal providers.

Although the proposed study addresses provision of care through formal delivery routes rather than informal, it is important to be mindful of the composition of the service delivery environment in studied countries, and recognize a substantial proportion of care (and all the gradations that entails) may be sought outside of the formal delivery sector. This includes malaria treatment and maternity services in certain contexts, such as Malawi's use of community health workers and volunteers to deliver care (249; 285).

Antenatal Care as a Vehicle for Malaria in Pregnancy Service Delivery

The antenatal period is critical in terms of maternal and child health. Delivery of an essential package of basic services and routine monitoring of pregnant women are indispensable components of pregnancy care. In Africa, formal sector delivery of this care principally occurs in the health facility setting. The following provides background on opportunities for integrated service delivery during the antenatal period in this context, and examines available evidence with respect to quality of these services.

Antenatal Care Standards, Delivery, and Quality

The WHO adopted the 2002 four-visit or focused antenatal care (FANC) model to delivery of ANC after a 2001 randomized-controlled trial demonstrated its effectiveness at identifying and improving maternal morbidities, thereby moving away from the 'traditional' model emphasizing frequency of contact rather than evidence-based content provision (314). The current core clinical ANC approach, updated in 2016 based on evidence to suggest increased fetal deaths and mothers' dissatisfaction with the four-visit model, has three prongs: risk identification, prevention and management of pregnancy-related or concurrent diseases, and health education and health promotion activities (330). 49 recommendations emphasizing patient-centered care and integrated service delivery are made across five intervention areas: nutritional interventions, maternal and fetal assessment, preventive measures, common physiological symptoms, and health systems interventions to improve utilization and quality of ANC (330). The current recommended minimum number of ANC visits is eight. Policy-makers are encouraged to consider providing women with IPTp-SP at ANC in the first trimester with explicit instructions on how to take it by week 13 as oppose to quickening (330).

There is strong evidence demonstrating the efficacy of single ANC interventions (e.g. iron supplementation to reduce anemia) in preventing maternal morbidities (83), as well as the effectiveness of ANC on reducing infant mortality rates and preterm birth (169; 268). Further, there is evidence to suggest that improving ANC care content may encourage use and early initiation of ANC visits (85). Notably, ANC content and national guidelines vary somewhat between countries (96). An estimated 75% of pregnant women in SSA had at least one ANC visit in 2013, and 47% had four or more visits (273). Although this indicates a need for continued expansion of ANC, the current relatively high coverage presents an opportunity for delivery of proven interventions and reinforcement of health-related messaging across ANC visits (174).

Prior assessments of antenatal service quality indicate that, across countries with high antenatal care attendance, there is room for improvement in coverage and quality of specific services (80; 125). Comprehensive assessment includes structural system inputs, the process of care including content of care delivered, and should also consider outcomes of structural and process inputs. Structural assessments of facility data have indicated presence of extensive gaps in infrastructure necessary for provision of maternal health services in low-income sub-Saharan African countries (171) and differences in public versus private facilities in certain settings (110). Quality dimensions as conceptualized by the WHO are also reflected in the context of antenatal service delivery, such as attention to safety, the effectiveness of the care, and efficiency of services provided. For instance, there are numerous examples of evaluations of interventions at the point of antenatal care designed to address documented system inefficiencies and improve effectiveness (143; 206; 218; 313).

The delivery of health education information through counseling expectant mothers is aimed at improving both maternal and pediatric health outcomes (174). While there is a dearth of data on interactions between health provider and pregnant mothers attending ANC and the quality of that interaction (63; 153), available evidence suggests there is potential for health messaging provided during ANC to be effective at increasing knowledge and eliciting improved health-related practices (224; 294). Further, pregnant women prefer care that is explained and delivered knowledgeably, respectfully and in a supportive manner (116). However, general quality of health messaging delivered during ANC may be lower than is desirable (61; 204; 278; 298). Perceived quality of counseling is also low in some contexts (68), and poor or insufficient antenatal counseling has been blamed for lack of maternal knowledge and associated health behaviors (94; 106; 263). These gaps may derive from systemic issues or individual provider issues. For example, a review of four antenatal guidelines in use in the United States between 2005-2009 revealed wide content variation between guidelines, particularly with respect to education which was inconsistently addressed and lacking in detail (150). Further, variation may exist in provider training on education/counseling (63), both of which may lead to variation in the content, timing, and way in which counseling on health matters is delivered during ANC visits (96).

Additionally, service integration during antenatal care is intended to lead to improved service quality (51). However, in resource-constrained environments such as small clinics and dispensaries, staffing is often low (151; 292) and the number of services integrated in ANC programming may be large (234). This presents challenges in terms of comprehensive delivery of the essential package of antenatal services within limited

resources, including time allotted for visits. Yet, even in these resource-constrained service delivery environments, interventions targeting improvement in quality of integrated services can be effective (234).

Antenatal Services and Care Seeking Behavior in the Context of HIV/AIDS

The impact of the HIV/AIDS epidemic on African health systems has been significant, and its potential impact on antenatal services warrants some discussion. Age-standardized HIV prevalence estimates from the Global Burden of Disease project ranged from 1,328 per 100,000 population in central SSA to 11,850 per 100,000 in southern SSA in 2013 (227). Increased donor support activities directed toward both siloed and integrated HIV services with essential services resulted in approximately US $51.6 billion invested globally 2001-2011, the bulk of which was directed towards the epidemic in sub-Saharan Africa (23).

There is evidence to suggest that vertical HIV/AIDS programming has been responsible for horizontal strengthening of health systems in target countries (319). This impact includes improvements in quality of basic services like antenatal care which have integrated components of vertical programming into service delivery. For example, a recent assessment of Kenya facility data demonstrated that facilities providing prevention of mother-to-child HIV transmission services had improved antenatal care inputs including infrastructure and supplies, and that facilities offering antiretroviral therapy also performed better in terms of process quality (191). Notably, vertical programming impacts, while primarily driven by HIV/AIDS investments, are not limited to HIV/AIDS – they also include malaria and tuberculosis services (319).

High burden of HIV/AIDS in sub-Saharan Africa also leads to increased contacts with the health care system. HIV infection may act as a motivator of care-seeking behavior, particularly as advanced illness presents (232). This creates opportunity for demand-driven increases in coverage of essential services like antenatal care where clients may access services after overcoming extensive barriers to seeking care (59). It likewise may create supply-side opportunities for providers to direct clients into routine preventive and essential health services, thus increasing coverage (59). As a result, countries with higher HIV/AIDS burden may have both strengthened health systems, as well as increased care-seeking, with the potential to influence coverage and quality of antenatal services in general (77), as well as other services integrated with antenatal care, such as malaria services.

Quality of Integrated Malaria and Antenatal Services

Over time, antenatal care has become a strategic platform for integration of single pregnancy-related interventions like provision of malaria prophylaxis and diagnosis or treatment of HIV/AIDS during pregnancy (82). This was, in part, due to the prescribed four-visit schedule of ANC visits, which created opportunity for integrated service delivery and cost-effective use of resources in resource-limited settings, where women already had to overcome extensive barriers to access in order to receive care (82; 142). Under the new eight-visit model, the aim is for integrated services delivered through ANC to be timed appropriately and be allotted sufficient time and attention (330). Perceived and actual barriers to ANC include perceptions about health worker skill-level, perceived possibility of malpractice, anticipated quality of the health provider-client interaction, availability of drugs, and service cost, to name but a few (166). Yet in spite of

these barriers, generally high ANC utilization rates in Africa overall (38) continue to make clear the opportunity for using this service to reach women, and, by extension, their children.

The WHO released the first iteration of *Pregnancy, Childbirth, Postpartum and Newborn Care: A guide for essential practice* in 2003 and an updated edition in 2009 which both outline integration of malaria services into antenatal care in the area of preventive services. Integration activities for malaria through antenatal services include checking when the last dose of antimalarial prophylaxis was given, provision of IPTp according to guidelines, asking if the mother and her children are sleeping under ITNs, and provision of an ITN (3; 6). Further, guidelines outline the need for providers to advise the mother on the need to dip the net every 6 months (if using ITN as opposed to LLIN) and to provide information on how to dip the net (13). Building on these documents, the most recent 2016 recommendations are harmonized with ANC guidance found across all standing WHO documents, and include an updated provision for IPTp-SP3+ (330).

The success of integration of malaria services with ANC has varied. A recent systematic case study of integration exemplars Malawi, Senegal and Zambia demonstrated that overall, each country had successfully integrated malaria interventions into ANC services, although there was variation in performance of domains assessed and between countries (267). In other settings such as Uganda, integration has proven more challenging across different types of health service delivery platforms (213).

Although sparse, studies have demonstrated the potential for high impact of ANC services as a delivery channel for malaria interventions (187; 246). The literature

suggests ANC can be an effective delivery mechanism for specific malaria in pregnancy interventions. For example, one study of a Kenyan district used population data to examine the systems effectiveness of ANC facilities to deliver intermittent preventive treatment in pregnancy (IPTp) and insecticide-treated bed nets (ITN), and found a 27% cumulative effectiveness for IPTp, with 96% of those women reporting use of an ITN (164). These findings also suggest room for improvement, as due to this coverage gap in malaria services and presumed malaria exposure during pregnancy, an estimated 231 low birth weight infants per 10,000 pregnant women could have been avoided if delivery of IPTp had been fully effective (164). Further, the combination of mass bed net delivery campaigns and ANC services as ITN delivery routes could result in up to an estimated 1.4 times higher mortality reduction than mass delivery systems alone in endemic areas, if implemented perfectly through ANC (246).

Reasons for gaps in coverage with proven interventions may lie in the broader health system, be systemic at the facility level, or lie with providers. For example, several recent reviews have found that health systems barriers for IPTp and ITN coverage/uptake across Africa include leadership and governance issues affecting management and harmonization of systems, financial challenges to policy implementation, human resource challenges, the confluence of poor implementation of policies and service delivery challenges, and supply chain/information systems challenges (165; 304). Facility-level barriers may also negatively impact receipt of preventive malaria services during ANC. This may be related to structural readiness factors, for example availability of valid prophylactic drugs, or may be more process-oriented such as factors related to provider effort and fidelity to accepted practice standards (167). Modifiable barriers to delivery of

IPTp during antenatal services on the provider and/or facility side may include user-fees for the drugs, drug stock-outs, facilities having IPTp guidelines, facilities' implementation of IPTp as a routine component of ANC services, and providers' receipt of IPTp training (205).

Small-scale studies have similarly demonstrated that provider practice impacts intervention uptake in pregnancy (60; 145; 209; 274), as poor IPTp receipt is predominantly affected by providers' failure to offer treatment rather than ANC attendance or IPTp refusal (164; 238; 274). Evidence also indicates delivery of ITNs via antenatal services is generally a smoother process than IPTp delivery (164), although examples of poor effectiveness in ITN distribution include provider failure to distribute nets to women from outside the facility catchment area (320). This suggests that content of services and the policies guiding service implementation are critical. Low IPTp uptake has been attributed to mothers' low knowledge of its importance during pregnancy due to provider failure to counsel, suggesting room for improvement in terms of delivery of malaria health content during ANC (58). The opportunity for public health impact on maternal, neonate and child health outcomes via integrated malaria and antenatal services is demonstrable, although there remains clear room for improvement.

Quality Improvement through Results-Based Financing Interventions

A variety of existing quantity and quality improvement initiatives appropriate for low and middle income countries and the potential for national scale-up are being piloted and, in some cases, scaled-up across health service delivery systems in African countries. Results-based financing (RBF) is an umbrella term for "a cash payment or non-monetary transfer made to a national or sub-national government, manager, provider, payer or

consumer of health services after predefined results have been attained and verified. Payment is conditional on measurable actions being undertaken" (230). It often includes both supply- and demand-side payments or incentives to providers/facilities and clients seeking care, respectively (26). The term is generally synonymous with performance-based incentives (PBI) and pay-for-performance (P4P), whereas specific subsets of RBF include performance-based financing (PBF) with emphasis on supply-side incentives (325), and demand-side interventions like conditional cash transfers for increasing client uptake of services (127; 230).

RBF schemes are designed to improve quantity and quality of services often with the overall goal of improving health outcomes (66; 230). Checklists of a specified set of services are frequently employed and utilized in both coverage and quality measurement (66). However, as Eichler et al. 2013 suggest, no consensus exists in terms of how quality is defined and measured across limited available evaluations of performance-incentivized schemes (324) designed to improve maternal and neonatal outcomes (120). This is a gap in terms of comparability of 'quality' across sites and within the limited evidence base to date, and suggests that establishment of a standardized quality assessment tool is needed, as part of broader implementation research efforts to determine best practices for RBF implementation (325).

Generally, RBF impact evaluation evidence to date is limited and weak, and what evidence is available has been mixed (32; 66; 131; 141; 144; 315; 324). However, there is some evidence to suggest that RBF schemes targeting improvements in maternal and neonatal health outcomes increase the number of institutional deliveries (66) and may be linked to somewhat improved antenatal care (120). The inherent uncertainty of the

current evidence underlines the necessity of specific implementation research to identify best practices in RBF design and implementation, and the value of reaching consensus on the measurement of quality, particularly for researchers, programmers and policy-makers interested in improving maternal and neonatal health outcomes. Evidence of heterogeneities in service quality across delivery contexts (196), paired with the idea of quality as a multi-dimensional concept (306; 327), supports the suggestion for standardized quality measurement over time and across geography. Further, they demonstrate opportunity for more nuanced RBF payment mechanisms, which could consider baseline quality assessments by targeting performance of specific low-performing quality dimensions.

C. Study Overview

The following chapters 2-4 address objectives 1-3 respectively. The overarching goal was to address aspects of the following research question: 'What is the role of facility-based quality and readiness in malaria service delivery for vulnerable populations in sub-Saharan Africa?' To this end, I explored how quality of services may affect broad-scale uptake of malaria interventions, potential drivers of malaria service readiness, and identified gaps in service delivery at the sub-national level. Knowledge gaps exist with respect to the relationships between formal sector, facility-based service delivery and malaria endemicity, as well as quality of care and preventive interventions on the individual level. Objectives addressed in each chapter or manuscript are as follows:

Chapter 2: Levels and variations in the quality of facility-based antenatal care in Kenya: evidence from the 2010 service provision assessment.

- Objective: to develop a quality of care diagnostic and use it to assess sub-national ANC quality in Kenya for provinces, health facility types, and managing authorities.

Chapter 3: Quality and integrated service delivery: a cross-sectional study of the effects of malaria and antenatal service quality on malaria intervention use in sub-Saharan Africa

- Objective: to extend the diagnostic from objective 1 to malaria in pregnancy, and use it to determine whether quality of integrated antenatal and malaria services across four African countries (Kenya, Namibia, Senegal, Tanzania) was associated with use of malaria interventions (IPTp, ITNs) in vulnerable populations (pregnant women, children under-five).

Chapter 4: Toward improved health systems responsiveness: A cross-sectional study of malaria endemicity and readiness to deliver services in Kenya, Namibia and Senegal

- Objective: to determine whether health facility readiness to deliver malaria case management services varied with malaria endemicity levels in three African countries (Kenya, Senegal, Namibia) demonstrated to be of heterogeneous endemicity.

To address these objectives, several existing, publicly available data sets were used. Most data were from the Demographic and Health Surveys Program (DHS Program) and the Malaria Atlas Project (MAP). DHS Program surveys are overseen and implemented by ICF International in conjunction with national partners, and funded by the United States Agency for International Development (USAID). DHS Program data included the Service Provision Assessment (SPA) which is a facility-based survey, and

household surveys known as the Demographic and Health Surveys (DHS). The Malaria Atlas Project (MAP) is a well-established, multi-disciplinary endeavor with malaria data made available through the University of Oxford in the United Kingdom. MAP endemicity data were sourced from 22,212 eligible *Plasmodium falciparum* parasite rate (P*f*PR) surveys from peer-reviewed, unpublished, and grey literature reports (132; 133). P*f*PR "describes the estimated proportion of 2-10 year-olds in the general population that are infected with *P. falciparum* at any one time, averaged over 12 months" (18). Several other publicly-available sources of data were accessed depending on the manuscript, including SEDAC population data and country-specific regional population estimates available from census estimates.

In Chapter 2, I descriptively examined heterogeneities in quality of care, using quality dimensions and an overall antenatal quality score constructed from SPA data for Kenya. In Chapter 3, I built on the work of the previous chapter by adapting the quality diagnostic to include a second quality framework. I operationalized the tool to reconstruct the antenatal quality score and construct a new score for malaria in pregnancy. I then used these scores aggregated to country regions for Kenya, Namibia, Senegal and Tanzania to look at associations with malaria service delivery outcomes for pregnancy and children under-five. These analyses primarily used SPA and DHS data, as well as MAP and population data. Pooled and country stratified results are presented. In Chapter 4, I turned to thinking about the third prong of malaria in pregnancy control – case management. As process indicators for case management are not routinely captured, I looked at service readiness to deliver malaria services. I built a weighted multiple linear

regression model for pooled data from Kenya, Namibia, and Senegal to examine the association between malaria endemicity and malaria service readiness.

The final Chapter 5 begins by providing a summary of chapters 2-4. I consider the current policy, advocacy, program and research environments in relation to my work. I propose specific recommendations couched within these contexts, which may be relevant for key international actors including advocates, donors, policy-makers, programmers, and researchers. Finally, I consider future directions and draw overall conclusions based on my research and study findings.

CHAPTER 2: LEVELS AND VARIATIONS IN THE QUALITY OF FACILITY-BASED ANTENATAL CARE IN KENYA: EVIDENCE FROM THE 2010 SERVICE PROVISION ASSESSMENT

INTRODUCTION

As many low- and middle-income countries continue to make significant improvements in expanding access to health care services, policy-makers are increasingly cognizant of the need to improve the quality of these services. A growing body of evidence suggests that quality shortfalls are substantial even for basic health care services (101; 102; 175), prompting calls to measure and address these gaps. On a global level, the quality of health care services is featured in the Sustainable Development Goals, the successors of the Millennium Development Goals (42). Many countries are actively exploring how to ensure or raise the quality of care, with policies ranging from supporting access to private sector providers that may offer higher quality to providing financial rewards to providers for achieving quality targets.

However, there is currently little systematic documentation of the levels and variations in quality of care that could support the design and deployment of effective policies (275). One practical constraint to analyzing the quality of care is the shortage of reliable facility data in developing low- and middle-income countries (LMIC) (135).

In this paper, I illustrate how data from large-scale facility surveys currently available for 14 countries can be used to gauge the quality of antenatal care (ANC) services and provide basic decision support to policy-makers. I focus on ANC services which have relatively less complex standards of care than other aspects of health care services. I derived 14 indicators in six dimensions from existing quality of care frameworks and applied these measures to the 2010 Kenya Service Provision Assessment

(SPA) to examine their empirical distributions across geography, facility type and management authority.

I discuss how such analyses can be used to inform the design of quality improvement policies, such as Kenya's nascent results-based financing (RBF) initiative and the country's recent drive to provide free maternal care in public facilities. RBF schemes – programs that pay for pre-defined, measurable outputs as opposed to inputs related to service delivery – have grown in scale and scope across LMICs over the last decade. With support from donors, countries have begun adapting RBF programs to improve quality of care in addition to increasing quantity of care. Meanwhile, demand-side interventions that could substantially increase utilization could lead to deterioration in the quality of care.

This paper illustrates how existing facility surveys can be used to conduct low-cost quality of health care analyses. Such analyses can help identify potential areas of concern that could be addressed in the design of policies like Kenya's free maternal care program, or that could be monitored more closely during implementation. For informing programs like RBF, baseline quality of care analyses can help determine which issues to target and how to design incentive structures to encourage overall improvements and address heterogeneities across facilities. Throughout, I describe the potential and challenges of using surveys like the SPA to evaluate the quality of ANC services.

DATA AND METHODS

To adequately capture the complexities of quality of ANC services, I reviewed quality frameworks proposed by Donabedian (114), the World Health Organization (327), the Organisation for Economic Co-operation and Development (180), and the

Institute of Medicine (1). I selected the six dimensions of quality of care proposed by the WHO as the operative conceptual framework for this study. These dimensions align with the other frameworks and are the most appropriate for quality measurement in the developing country context. WHO provides the following definitions for the six dimensions: 1) effectiveness: “delivering health care that is adherent to an evidence base and results in improved health outcomes for individuals and communities, based on need”; 2) efficiency: “delivering health care in a manner which maximizes resource use and avoids waste”; 3) accessibility: “delivering health care that is timely, geographically reasonable, and provided in a setting where skills and resources are appropriate to medical need”; 4) acceptability/patient-centeredness: “delivering health care which takes into account the preferences and aspirations of individual service users and the cultures of their communities”; 5) equity: “delivering health care which does not vary in quality because of personal characteristics such as gender, race, ethnicity, geographical location, or socioeconomic status”; and 6) safety: “delivering health care which minimizes risks and harm to service users”.

Indicators

I identified ANC quality indicators that can be constructed at the facility level through a review of peer-reviewed and grey literature, as well as ANC-specific indicators used commonly in quality checklists of RBF programs in LMICs; in some cases these overlapped. I included the latter because indicators in RBF programs are clearly of interest to policy-makers and have been operationalized for LMICs. Together, these indicators were mapped to six quality of care dimensions using the WHO dimension definitions and to the SPA survey. I selected candidate indicators in terms of

reproducibility from SPA data and to ensure RBF indicators were represented. The mapping and the final list of 14 indicators are presented in Appendix A1, which also describes how some indicators were adapted to the Kenyan context and data.

Data

I calculated the individual indicators using the 2010 Kenya Service Provision Assessment (SPA), a facility-based cross-sectional survey. The SPA is a standardized survey supported by the Demographic and Health Surveys (DHS) Program of USAID and routinely administered by ICF International and in-country partners.

The 2010 Kenyan SPA consists of several survey instruments that are administered concurrently and generally on the same day: a facility audit, health care worker interviews, and client observations and exit interviews for ANC, family planning and sick child visits (for comprehensive documentation and questionnaires see (19)). The facility audit entails an interview with the in-charge of the facility or the senior-most staff member; direct verification of the presence of certain commodities, equipment and amenities; and verification of their use. The health worker interview asks about specific training received and services offered by the health worker, as well as workers' opinions on the work conditions at the facility. The client-provider observations are based on observation protocols specific to ANC, family planning services and sick child care. The exit interviews capture clients immediately after a consultation and verify the services received and client opinions regarding those services. The exit interviews are also specific to ANC, family planning and sick child services.

Data from the Kenyan SPA are representative at the provincial, facility type, and management authority levels (19). 703 facilities or 11% of all Kenyan facilities were

randomly selected, with 695 successfully surveyed. Voluntary counseling and testing centers (VCT), maternity and hospital facilities were oversampled. Health workers were sampled to cover a range of services provided; for observations and exit interviews clients were systematically sampled. I selected the Kenyan SPA as the data are recent and there is large geographic variation in maternal mortality rates. Figure 5 shows the distribution of public, private for profit and faith-based facilities across Kenya. The SPA was implemented between January and May 2010.

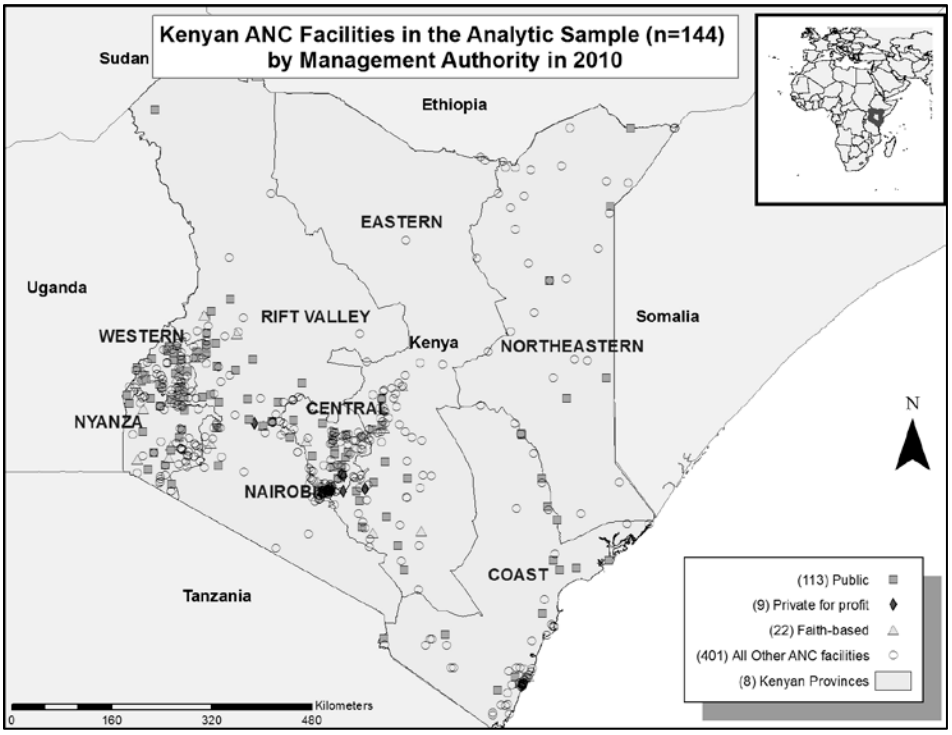


Figure 5: Distribution of ANC facilities in SPA and analytic sample

In this study, I included facilities if they reported providing ANC services and also completed the ANC portion of the facility audit, had non-missing data and were not an HIV voluntary counseling and testing (VCT) facility. I excluded VCTs since they do not routinely provide ANC services. I excluded NGO/private not-for-profit facilities from the final analytic sample due to small sample sizes. Because many facilities have missing

data for one or more indicator, the analysis sample consists of 144 out of 545 non-VCT and non-NGO/private not-for-profit facilities with ANC services with a completed questionnaire (26%). Table 2 shows the basic characteristics of the facilities in the analytic sample. Compared to other eligible facilities that had missing data, the analytical sample has relatively more district or sub-district hospitals and more public facilities. In addition to data from the facility audit, I used client observations (n=654) and exit interviews (n=638) for facilities in the analytic sample with median counts of 5 per facility for both.

Table 2: Characteristics of ANC facilities in the analytic sample and excluded ANC facilities (1)

	Facilities in the Analytic Sample N (%)	Excluded ANC Facilities N (%)	Total ANC Facilities N (%)
Facility Type	**144**	**401**	**545**
National/Provincial Hospitals	6 (4)	3 (1)	9 (2)
District/Sub-District/Other Hospitals	92 (64)	134 (33)	226 (41)
Health Centers/Clinics	30 (21)	113 (28)	143 (26)
Dispensaries/Maternities	16 (11)	151 (38)	167 (31)
Management Authority	**144**	**401**	**545**
Public	113 (78)	209 (52)	322 (59)
Private for Profit	9 (6)	130 (32)	139 (26)
Mission/Faith-Based	22 (15)	62 (15)	84 (15)
Province	**144**	**401**	**545**
Nairobi	7 (5)	43 (11)	50 (9)
Central	20 (14)	57 (14)	77 (14)
Coast	14 (10)	53 (13)	67 (12)
Eastern	19 (13)	55 (14)	74 (14)
Northeastern	9 (6)	33 (8)	42 (8)
Nyanza	16 (11)	61 (15)	77 (14)
Rift Valley	26 (18)	52 (13)	78 (14)
Western	33 (23)	47 (12)	80 (15)

[1] *Percentages may not total to 100 due to rounding.*

Analysis

I first examined the individual indicators as well as dimension-specific indices constructed as equally-weighted averages of the respective indicators. All indicators and indices were constructed at the facility level. The indicators were constructed to range from 0 to 1, with higher values representing better quality. I calculated medians and interquartile ranges (IQR) across all facilities and by facility type (national and provincial hospitals; district, sub-district and other hospitals; health centers and clinics; dispensaries and maternities), management authority (public, private for profit, faith-based), and geography (8 provinces). For the comparisons across facilities, I focus on medians rather than means, as indicators and indices were either non-normally distributed or categorical.

To facilitate overall inter-dimension comparisons, I calculated coefficients of variation, defined as the ratio of the dimension standard deviation to its mean. Finally, I calculated an overall quality of care score for each facility by equally weighting and averaging five dimensions (all but equity) calculated on the facility level.

I address the sixth dimension – equity – separately from the five other dimensions and outside of the overall facility score due to data limitations. The SPA provides data on individual clients only in the observation and exit interviews, and information on client characteristics is limited. I therefore compared median scores for patients with low and high education, defined as no or primary schooling, and secondary school or above, respectively. I used three indicators which are collected in patient observations and which are linked to corresponding patient exit interviews, where education is recorded: ANC physical examination service score, patient satisfaction recorded after the ANC consultation, and whether the visit was conducted by qualified ANC provider. Because

the number of observations/exit interviews at each facility is relatively small, I did not construct facility-level measures for education.

Limitations

The limitations of this study highlight practical challenges in using the SPA data to analyze quality of care. First, I focused on antenatal care, which has limited impact on mortality and may not be reflective of other aspects of quality maternal and neonatal health care. Similarly, the set of 14 indicators for quality antenatal care, though selected based on my review of quality frameworks and the ANC literature, may not adequately cover all aspects of quality. In particular, the selected indicators are mostly structure- and process-oriented as the SPA is not designed to capture outcome indicators. Further, my ability to measure the dimension of equity is impacted by the limited demographic data available in the SPA: age and education level derived from ANC exit interview data. I analyzed equity at the exit interview level but analyzed the remaining five quality dimensions at the facility level.

Low ANC observation/exit interview counts for many facilities may impact the stability of indicators derived from observations. SPA data collection procedures set a maximum limit of 5 observations and associated exit interviews per provider of ANC services, and fifteen total for any given facility (19). In practice, the obtained range for ANC observations from each facility varied from 0 to 10. Where possible, I constructed indicators from the facility audit to avoid the stability issue; for some indicators this was not feasible, e.g. for patient satisfaction levels.

Design choices in the SPA may affect survey responses in several ways. For example, data based on exit interviews can be subject to “courtesy bias”, limiting

variation in scores and introducing an upward bias. Observed visits and subsequent exit interviews may also induce the Hawthorne effect if providers know clients will be surveyed after the consultation and, as a result, lead to inflated client exit interview responses (137).

I included 144 of 545 possible ANC facilities from the original SPA sample once data were restricted to eligible facilities with data for all component indicators. Data for the indicators of evidence-based maternal care, physical exam score, infection prevention score, and whether a visit was conducted by a qualified ANC provider were missing somewhat more frequently than data for other indicators (Appendix A1). To address this issue, I performed a sensitivity analysis excluding the indicator for evidence-based maternal care and found qualitatively similar results for the unaffected dimensions, i.e. the dimensions effectiveness, efficiency and acceptability/patient-centeredness. I also addressed concerns about the analytic sample size by comparing results for component and composite indices, where I allowed the sample size to vary across quality dimensions, compared to the overall sample restricted within and across dimensions. These results, as well as coefficient of variation results, were qualitatively similar for the analytic sample compared to results of the sensitivity analysis.

I conducted two assessments of the missing data and the potential implications (Appendix A3). First, I examined facility characteristics as predictors of missing data in multivariate regressions for all eligible facilities (n=545) across each dimension and the overall quality score. The dependent variable was a binary indicator of whether the facility does or does not have data, and the independent variables were facility characteristics (region, managing authority, facility type, and whether facility has: regular

management meetings, back-up generator with fuel, catchment estimation data available, any first ANC visit observed). Generally, I found that facilities with routine management meetings were consistently less likely to have missing data across dimensions, and that private-for-profit-managed facilities were more likely to have missing data compared to publicly-managed, except for the accessibility dimension. Second, for each quality dimension, I used t-tests to compare mean values of the subset of facilities with quality measures for all domains versus the larger set of facilities with complete data for the specific dimension tested but missing data for alone or more of the other dimensions. I found no differences in quality between facilities with complete and incomplete data at the dimension level.

The analytic sample may be subject to selection bias for several reasons. First, although the SPA's sampling frame is the official Master Facility List it may not adequately represent all facilities in Kenya, e.g., smaller private providers. Second, as noted, there is non-random missing data across facilities, which determines which facilities are included in the analytic sample.

I constructed certain dimensions from overlapping indicators, primarily because several composite indicators included iron and/or folate tablets. Further, I constructed the overall quality of care score from dimensions comprised of several overlapping indicators. This overlap could introduce correlations among the affected dimensions and may give slightly more weight to the relevant indicators in the overall score. Finally, given I did not utilize regression adjustment in my analyses, some of the observed variation, e.g. across facility types, may be related to other observable as well as unobservable factors.

RESULTS

Overall performance on quality of care indicators and dimensions

Table 3 shows the 14 quality indicators as components of five quality of care dimensions measured on the facility level (excluding equity, which I discuss below).

Table 3: Mean, median, and interquartile-range (IQR) of facility scores for each quality of care indicator and dimensions, restricted across dimensions

	Mean	Median	25th percentile	75th percentile
Effectiveness[1] (coefficient of variation CV=0.36)	**0.67**	**0.55**	**0.50**	**0.94**
ANC key services score	0.92	1.00	0.88	1.00
ANC physical exam score	0.42	0.23	0.00	1.00
Efficiency[1] (CV=0.20)	**0.84**	**0.92**	**0.79**	**0.96**
Pre-ANC consultation services score	0.86	1.00	0.80	1.00
Counseling on postpartum family planning offered	0.81	1.00	1.00	1.00
ANC service readiness score	0.85	0.88	0.79	0.94
Accessibility[1] (CV=0.30)	**0.71**	**0.68**	**0.68**	**0.93**
# of days per month ANC services are provided	0.69	0.71	0.71	0.71
Folate availability	0.88	1.00	1.00	1.00
Available and functional equipment/supplies score	0.78	1.00	1.00	1.00
Availability of evidence-based maternal care	0.51	1.00	0.00	1.00
Acceptability/patient-centeredness[1] (CV=0.20)	**0.88**	**1.00**	**0.67**	**1.00**
Availability of ANC visual education material	0.75	1.00	0.50	1.00
Adequate privacy during ANC consultation	0.97	1.00	1.00	1.00
Average patient satisfaction post-ANC consultation	0.91	1.00	1.00	1.00
Safety[1] (CV=0.18)	**0.78**	**0.75**	**0.75**	**0.88**
Infection protection score	0.58	0.50	0.50	0.75
Visit conducted by qualified ANC provider	0.98	1.00	1.00	1.00
Overall Quality of Care Score[2] (CV=0.13)	**0.78**	**0.77**	**0.71**	**0.84**

[1] *N=144. Indicators comprising each dimension are weighted equally. All dimensions and indicators range from 0 (lowest quality) to 1 (highest quality). The analytic sample is restricted across indicators comprising the dimensions of effectiveness, efficiency, accessibility, acceptability/patient-centeredness, and safety.*

[2] *Overall quality of care score is an average of five dimensions: effectiveness, efficiency, accessibility, acceptability/patient-centeredness and safety ranging from 0 (lowest quality) to 1 (highest quality).*

Overall and relative to the maximum score of 1.00, facilities performed well on most indicators. The two lowest performing indicators were: ANC physical exam score (median score of 0.23) and infection prevention score (0.50). Because I first constructed scores at the facility level, and these scores may be continuous, the figures in Table 2 should not be interpreted as the share of facilities meeting a certain standard but rather as the score of the median facility. For instance, the median score of 0.71 for the indicator

'number of days per month ANC services provided' implies that the median facility in my sample offered these services 71% of days in a four-week (28 day) month.

Quality of care dimensions varied considerably in terms of median performance. Facilities performed highest in the areas of acceptability/patient-centeredness (median score of 1.00) and efficiency (0.92). Conversely, performance was lowest for the effectiveness and accessibility dimensions, with respective median scores of 0.55 and 0.68. Safety had a middling performance (0.75). There was substantial variation across indicators within a dimension, e.g., the poor performance for the effectiveness dimension is primarily driven by a lack of adequate ANC physical exam services. The coefficients of variation for dimensions indicate that dispersion was lowest for safety (0.18) and highest for the effectiveness dimension (0.36).

Variation across and within provinces

Quality of care varied substantially across provinces (Figure 6; for means and inter-quartile ranges see Appendix A2). Six out of eight provinces performed relatively poorly or only moderately well in terms of effectiveness, with Central and Nairobi being exceptions. Almost all were high performers in the efficiency dimension (median scores above 0.8), with the limited sample for Nairobi scoring lowest (0.81). Five provinces scored 0.68 or 0.73 on accessibility and the remainder of provinces performed better overall in this dimension (scores larger than 0.79). Most provinces were moderate to high performers in terms of acceptability/patient-centeredness, except Northeastern which performed worse than all other provinces (median score 0.67). Six provinces scored 0.75 in the safety dimension; Nairobi and Central were higher with median safety scores of 0.88. I also found that provinces differed in their relative performance across quality of

care dimensions. For instance, Central performed well overall, whereas Northeastern performed well in accessibility and efficiency, but poorly or only moderately well in other dimensions.

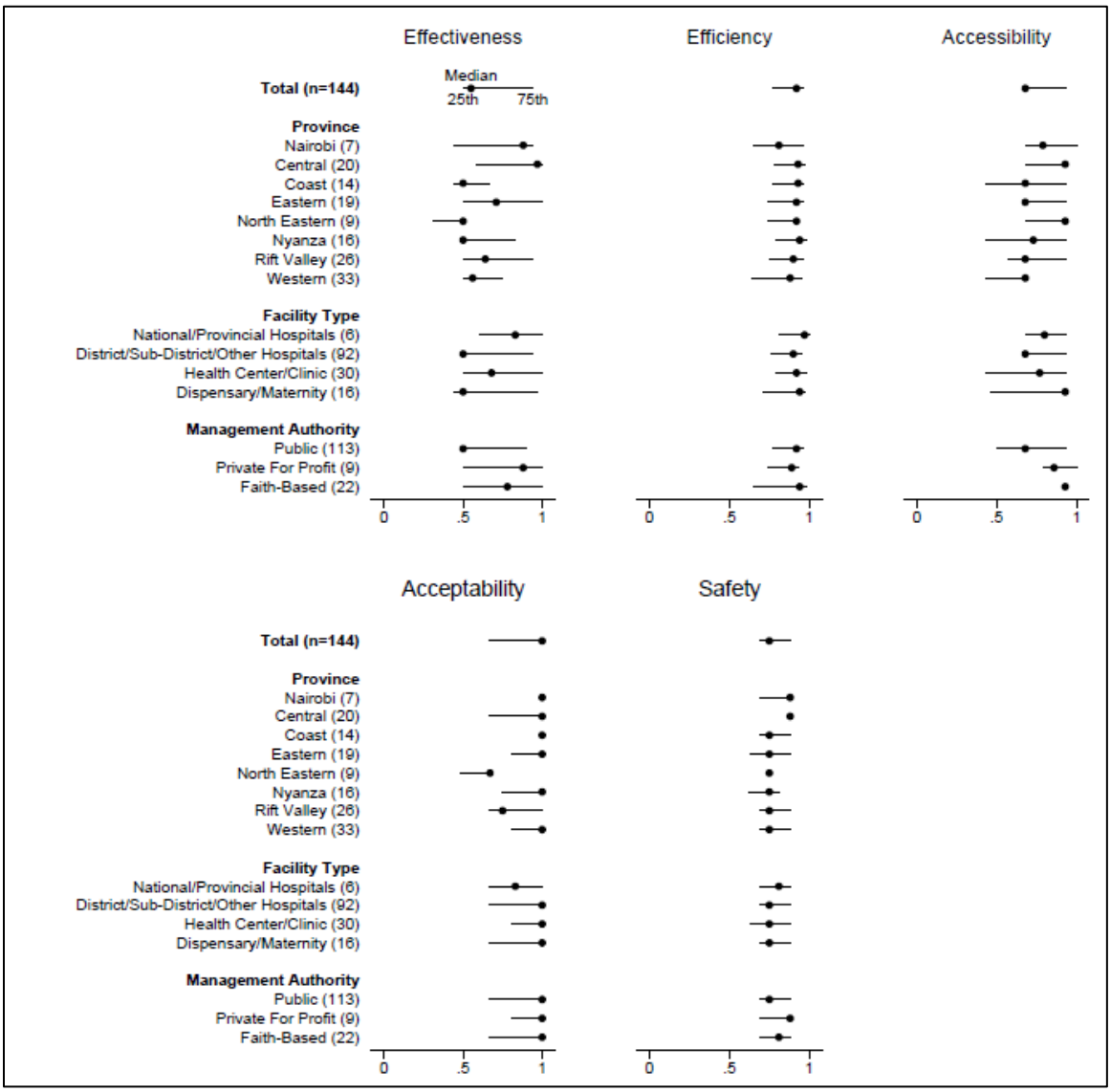


Figure 6: Scores and quality dimensions by province, facility type and management authority. Median and 25th and 75th percentiles.

Variation across and within facility types

Figure 6 also shows scores across four facility types: national/provincial hospitals; district/sub-district/other hospitals; health centers/clinics; and dispensaries/maternities.

All facility types consistently performed well in terms of efficiency (median scores above 0.90). Most performed poorly in terms of effectiveness (median scores of 0.75 or lower) with the exception of national/provincial hospitals (median score 0.83). Facility types varied in their performance for the other dimensions. For instance, district/sub-district/other hospitals and dispensaries/maternities performed comparatively poorly on effectiveness.

Performance also varied within facility types. Within district hospitals and lower-level facilities, effectiveness had the lowest scores; the highest scoring dimensions included efficiency and acceptability/patient-centeredness. Within national and provincial hospitals, the efficiency dimension had the highest median score; these facilities performed moderately well across all other dimensions.

Variation across and within management authorities

Finally, Figure 6 depicts quality dimensions grouped by three management authority types in Kenya. Public facilities performed worse than or about the same as private for profit or faith-based facilities. They performed poorly in the accessibility dimension, relative to other management types. Faith-based facilities performed better or about the same as other facilities. The dimensions of highest consistent performance across management authorities were acceptability/patient-centeredness and efficiency. Within management authorities, facilities run by faith-based organizations performed consistently well in terms of efficiency, accessibility, and acceptability/patient-centeredness and moderately well on effectiveness and safety. Inter-dimension variation was greatest for public facilities.

Variation by education level (equity dimension)

To approximate the equity dimension of the WHO framework, I calculated median scores by low/high education level for three indicators that are available in the ANC observation/patient exit interview data, where patients' education is also recorded. I found that overall median scores for the two groups were similar for all three measures calculated on the ANC client level: ANC physical examination service score (0.75), patient satisfaction post-ANC consultation (1.00), and whether the visit was conducted by qualified ANC provider (1.00; detailed results not shown).

DISCUSSION

Quality of health care is quickly emerging as a major concern in many low- and middle-income countries, particularly as efforts to expand access to care are gaining traction. In this paper, I constructed quality of care indicators from Kenyan facility data to explore the level and heterogeneity in antenatal care quality. Study findings indicate low overall performance (on my specific set of measures) in effectiveness, and comparatively high performance on the efficiency and acceptability/patient-centeredness dimensions. However, I also found substantial variation across Kenyan provinces, facility type and management authority, with public facilities generally underperforming relative to faith-based and private for profit facilities.

A possible explanation for the finding of good performance in the equity dimension is that the available indicators already performed well, so that there is little scope for variations. For instance, almost all patients reported being seen by an adequately trained provider. These findings from the SPA are supported by the 2008-09 household Demographic and Health Survey (181), which suggests that the proportion of women ages 15-49 receiving antenatal care from a skilled provider differs little by

education level. However, almost one-quarter of women with no education did not receive ANC services for the most recent birth, compared to only 3% of women with secondary education or better. One explanation could be that low and high education households have different access to care but, once in the facility, receive comparable care from providers (as measured in the SPA). Thus, this finding also highlights the sensitivity of the results to the choice and availability of indicators.

Lessons from using existing facility surveys to measure the quality of ANC care

This study illustrates the promises and challenges of operationalizing quality of care frameworks on standardized facility surveys, such as the SPA. On the one hand, these data are readily available (and more SPAs are planned) and can facilitate quality assessments and inform the design and scale-up of health policies. They can also serve as diagnostic tools and provide baseline measures against which to measure progress. On the other hand, I had to exclude or modify some accepted facility-based quality metrics in order to operationalize SPA data, and there was substantial missing data. This latter challenge suggests caution in interpreting or extrapolating my specific findings to all of Kenya. I also found variation across indicators within a particular dimension, indicating that the choice (and availability) of quality indicators matters for quality assessments. Similarly, the SPA does not cover several issues that are known to be important for quality, such as provider effort (101; 102). Overall this study therefore also suggests that existing assessment tools may benefit from harmonization and a redesign to rationalize and optimize tracking of meaningful measures that map to existing quality of care frameworks (100). This approach is endorsed in the Roadmap for the Measurement and Accountability for Health Summit held in June 2015 (160). A harmonized instrument

may also allow for more frequent and high-quality data collection, and could help track quality of care over time.

Implications for designing results-based financing programs

The observed variations in quality of care have implications for designing interventions to improve quality, such as results-based financing (RBF) which has emerged as a popular approach for increasing provider performance, especially for primary care. Kenya piloted an RBF scheme in Samburu County in 2011 with support from the World Bank, and is expanding to public facilities across 20 northern, rural counties, with the intent to explore eventual integration of private-side facilities including faith-based facilities (326).

In the design of RBF programs, there are a number of central decisions for consideration which are related to the payout function; for example, what indicators to include and how to reward the rewarded indicators. Specific choices include whether to pay for exceeding thresholds or pay on a linear schedule, and whether to pay directly for quality or scale quantity payments by broader measures of quality (66; 280).

Study methods and findings can help inform these decisions. First, programs should address the quality as well as the quantity of care, as some dimensions of quality are consistently low. Second, the degree of inter-facility variation can provide guidance for determining the relative financial incentives, e.g., rewarding more generously those dimensions and indicators that perform very poorly (to encourage attention) or very highly (to defray potentially high marginal costs of further improvements). Third, baseline variations across facilities imply that it is challenging to set a threshold that simultaneously incentivizes high and low performers. A suitable payout function could

involve graduated payments or only pay for improvements above facilities' baseline performance. Fourth, although variation across provinces could be accommodated by a regionally differentiated RBF, there are substantial variations within each geographic area which also need to be addressed. Finally, study findings indicate scope for interventions to complement the RBF program. I captured basic systemic quality problems – such as number of days ANC services are offered – which may be costly to rectify and for which RBF incentives may be too small to nudge providers into action. Similarly, the consistently low performance in the effectiveness dimension could be addressed in a larger, non-RBF effort.

Implications for demand-side interventions

Study findings can also contribute to designing demand-side interventions and tracking their effects on service quality. Kenya introduced free maternal care in public facilities in 2013 amid concerns that these facilities may find it challenging to adequately respond to the expected increase in demand (173; 235). Institutional delivery rates in Kenya have already increased significantly from 42.6% in 2008-09 (280) to 61.2% in 2014 (43), but there is scope for further growth. In other settings, the combination of rapidly introduced demand-side interventions alongside stagnant supply-side conditions has led to decreases in quality (89). My analysis of facility data collected prior to the start of this initiative indicates potential challenges and could be used to identify "hotspot" areas such as effectiveness, which may need particular attention. Further, I identified groups of facilities which may struggle to maintain or increase quality – a particular concern for public facilities which are likely to experience the largest increase in demand and which already perform comparatively poorly on most quality dimensions.

CONCLUSION

Study findings suggest that policies need to address and account for heterogeneity in quality of antenatal care. In Kenya, the good performance of some facilities (for at least some of their patients) indicates scope for improvement in this context: raising all facilities to the level of best performance should be feasible and would lead to significant overall gains in quality. There is some evidence that changes in payment modalities could facilitate such gains (66; 101), possibly in tandem with other interventions such as targeted training or investments in facility improvements. Generally, there is a need for more systematic and harmonized data on the quality of care in low and middle-income countries.

CHAPTER 3: QUALITY AND INTEGRATED SERVICE DELIVERY: A CROSS-SECTIONAL STUDY OF THE EFFECTS OF MALARIA AND ANTENATAL SERVICE QUALITY ON MALARIA INTERVENTION USE IN SUB-SAHARAN AFRICA

INTRODUCTION

Malaria morbidity and mortality due to infection with the *Plasmodium falciparum* parasite is greatest in pregnant women, neonates and children under-five in Sub-Saharan Africa (168). Children often present with clinical illness due to little or no acquired immunity, which develops over time with repeat infection (10). Infection in pregnancy may led to novel gene expression by *P. falciparum*-infected red blood cells, placental sequestration, and inflammation and disrupted nutrient and blood flow to the fetus, with possibility of spontaneous abortion, intrauterine growth retardation, and low birth weight (87; 128; 242; 264; 269; 291; 295). Annually, an estimated 30.3 million African pregnancies are at risk (105) with regional estimates of peripheral and placental infection ranging from 29.5-35.1 percent and 26.5-38 percent, respectively (91). *P. falciparum* infection during pregnancy causes an estimated 11 percent of neonate mortality in Sub-Saharan Africa (121). Additionally, at least 20 percent of children 2-10 years in the 15 highest burden African countries carried malaria infections in 2013, and there were 437,000 malaria deaths in children under-five for the region (37).

Integrated service delivery has been called for as a key component of health systems strengthening activities (50). While available evidence is mixed (118; 154; 156), well-integrated services are expected to lead to improved quality of malaria service delivery and, in turn, improved health outcomes (156; 194; 201; 288). The antenatal care (ANC) platform has been used for nearly two decades to deliver malaria in pregnancy

(MiP) interventions and counseling (330), with potential to positively influence mothers' health behaviors and those of their children (82). Yet, malaria service coverage during ANC has proven problematic, with lower proportions than for all other antenatal services (14).

Relatively little is known about how facility delivery of integrated MiP services with ANC translates broadly into health systems performance. Facility-level structural barriers such as drug stock-outs, user fees, and availability of malaria guidelines can impact services provided (167; 205). Small scale studies have also demonstrated the impact of provider effort and fidelity to accepted practice standards on patient uptake of malaria interventions in pregnancy (58; 60; 145; 167; 209). Content of services and the way in which services are delivered are critical, yet no consensus exists on how to best measure quality of MiP services - a challenge germane to quality improvement endeavors in low and middle income countries (192).

To address shortfalls in coverage and use of malaria interventions, we need to be able to systematically assess quality of malaria service delivery. My study objectives were (i) to develop a theory-derived score to measure quality of malaria services delivered during antenatal care; (ii) to determine whether quality of integrated antenatal and malaria services predicts malaria intervention use of a) insecticide-treated bed nets (ITNs) in pregnancy and children under-five, and b) two doses of intermittent preventive treatment in pregnancy (IPTp-2); and (iii) to document between country variations in factors associated with ITN use and IPTp-2 uptake.

METHODS

Data Sources

I analyzed publicly available, cross-sectional, geo-located Demographic and Health Survey (DHS) and Service Provision Assessment (SPA) data from USAID's Demographic and Health Surveys Program (108), malaria endemicity data from the Malaria Atlas Project (MAP) (207), and regional population estimates available from national statistics departments for Kenya, Namibia, Senegal and Tanzania (Table 4). DHS household surveys were sampled within regions for household clusters and individuals. SPA data included an inventory, antenatal care observations, and health worker interviews for each health facility. MAP data provided annual, continuous malaria endemicity estimates, or *P. falciparum* prevalence rates (P*f*PR) standardized to 2-10 years (18). I assigned P*f*PR values to DHS survey clusters using latitude and longitude coordinates in ArcGIS 10.3.

I included countries with: five or more regions, 2006 data or later collected after national IPTp-2 policy adoption, and for which collection of SPA and DHS data were proximal. Facilities offering malaria and antenatal services with complete case data were included. Women 15-49 years with a prior live birth in the 24 months prior, children 0-59 months, and currently pregnant women who had complete data were included in the IPTp-2, child ITN, and pregnancy ITN analyses, respectively. ITN analyses were further restricted to households with at least one ITN. Study outcomes were (i) receipt of two or more doses of IPTp with sulfadoxine-pyrimethamine (IPTp-SP2) during last live birth in preceding 24 months; (ii) prior night's ITN use by pregnant women; and (iii) prior night's ITN use by children under-five. Although current IPTp guidelines recommend three or more doses of SP (IPTp-SP3+), I used the previous guideline for at least two doses which was in effect at data collection.

Table 4. Selected unweighted characteristics of country and pooled data by study outcome.

Country	SPA Year	DHS, MAP & Pop. Year	N	Outcome	Outcome prevalence[1]	MiP quality[2]	ANC quality[2]	Malaria endemicity[2]	Facility density[2]
Kenya	2010	2014	7861	IPTp-2	1409 (17.92)	54.47 (53.32, 54.51)	76.32 (74.56, 79.18)	9.02 (4.50, 18.91)	12.01 (6.41, 14.64)
			662	ITN in pregnancy	470 (71.00)	54.47 (53.32, 54.51)	76.32 (74.56, 79.18)	11.03 (5.90, 21.23)	12.01 (6.41, 15.54)
			10116	ITN in childhood	7621 (75.34)	54.47 (53.32, 54.51)	76.90 (74.56, 79.18)	10.89 (5.99, 21.35)	12.01 (6.41, 15.54)
Namibia	2009	2013	1639	IPTp-2	69 (4.21)	30.18 (16.95, 35.64)	73.05 (69.59, 74.35)	5.17 (0.00,7.64)	131.14 (86.12, 184.40)
			207	ITN in pregnancy	23 (11.11)	35.64 (30.18, 38.87)	74.24 (70.03, 77.79)	6.55 (2.37, 7.86)	96.38 (86.12, 184.40)
			1030	ITN in childhood	183 (17.77)	33.45 (30.18, 37.13)	72.42 (69.59, 76.10)	6.09 (1.83, 7.86)	133.84 (92.90, 114.43)
Senegal	2014	2013	2682	IPTp-2	1048 (39.08)	44.51 (42.81, 47.05)	73.56 (71.23, 76.64)	2.54 (2.05, 3.69)	24.60 (20.53, 32.14)
			729	ITN in pregnancy	400 (54.87)	44.51 (42.81, 47.05)	75.09 (71.23, 76.64)	2.46 (1.96, 3.39)	24.60 (20.53, 33.34)
			3729	ITN in childhood	2121 (56.88)	44.51 (42.81, 50.00)	73.56 (71.23, 76.64)	2.46 (1.99, 3.39)	24.60 (20.53, 32.14)
Tanzania	2006	2010	2993	IPTp-2	990 (33.08)	42.26 (38.97, 46.33)	57.83 (53.70, 63.26)	7.13 (4.34, 13.68)	9.30 (6.48, 13.91)
			780	ITN in pregnancy	515 (66.03)	42.70 (38.97, 46.33)	56.64 (53.70, 63.66)	8.12 (4.39, 14.95)	9.16 (6.48, 13.91)
			4270	ITN in childhood	3015 (70.61)	42.26 (38.07, 46.33)	57.83 (53.70, 63.66)	7.20 (4.34, 14.07)	9.40 (6.51, 13.91)
Pooled	--	--	15175	IPTp-2	3516 (23.17)	52.94 (41.94, 54.51)	74.56 (70.03, 76.90)	6.69 (2.84, 13.03)	14.62 (9.02, 20.96)
			2378	ITN in pregnancy	1408 (59.21)	46.33 (41.38, 53.32)	73.37 (63.66, 76.64)	6.16 (2.65, 12.55)	15.54 (9.30, 28.05)
			19145	ITN in childhood	12940 (67.59)	52.94 (43.13, 54.51)	74.56 (69.82, 76.90)	7.41 (3.14, 15.61)	13.57 (9.30, 19.38)

Abbreviations: SPA – Service Provision Assessments; DHS – Demographic and Health Surveys; MAP – Malaria Atlas Project; Pop. – population; N – count; MiP – malaria in pregnancy; ANC – antenatal care; IPTp-2 – intermittent preventive treatment in pregnancy- 2 doses; ITN – insecticide-treated bed net.

[1]Outcome prevalence given as count with percentage in parenthesis.

[2]Median value with and inter-quartile range in parenthesis.

Quality score development

I generated two continuous quality scores for ANC and MiP on a 0 to 100 scale (Appendix B1). I first mapped quality indicators from the literature to a theory-derived, multi-dimensional, multi-domain tool which I constructed to guide comprehensive and systematic selection of indicators, emphasizing MiP process indicators (Figure 7 and Appendix B3). I calculated unweighted averages for five quality dimensions from the tool (327), and an average of dimensions to arrive at overall ANC and MiP scores. I could not operationalize the sixth dimension, equity, in the same manner due to available SPA indicators (196). Finally, I regionally-aggregated weighted ANC and MiP quality scores.

Statistics

I calculated unweighted counts with frequencies, and medians with inter-quartile ranges. I examined crude associations and potential confounders of ANC and MiP quality and respective study outcomes. As data were multilevel (individual, survey cluster, region) and nationally-representative, I built pooled, adjusted, mixed effects multilevel modified Poisson models for each outcome with countries weighted equally and random effects at the region and cluster levels. To account for stratified survey design, I adjusted for urban/rural location. I explored interactions between location and mean-centered quality scores, and between the two mean-centered quality scores in all models. For child's ITN use, I also assessed quality variations by child's sex and age. I tested model assumptions, ran goodness-of-fit tests, and performed a priori stratified analyses by country for each outcome (Appendix B2). All analyses were conducted in Stata 14.0.

		World Health Organization Framework					
		Effectiveness	**Efficiency**	**Accessibility**	**Acceptability**	**Safety**	**Equity**
Donabedian Framework	**Structure**	- Guidelines on IPTp observed (161; 205; 333)	- Frequency of routine meetings for reviewing managerial or administrative matters (90)	- Country first-line treatment available (161; 177; 223; 290) - Valid SP/Fansidar observed available (161; 205; 209) - mRDT or microscopy observed with all components functional: valid RDT OR microscopy: light microscope, glass slides, covers, stain (96; 161; 176; 177; 290) - ITN observed in stock (21; 161)	- Medication fees for medications given during ANC OR general fees for medications other than ARV therapy OR fees for IPTp-SP (163; 205)	- On-duty provider ever received any pre-service or in-service training on IPTp (161; 165; 205) - On-duty provider ever received any in-service training or training updates on pregnancy complications of and management (248)	
	Process	- IPTp reported as routinely offered during ANC (36; 205) - Provider prescribed or gave anti-malarial prophylaxis (320) - Importance of a further dose of IPT explained (164) - Screening for anemia occurred if: tested haemoglobin levels, asked client about tiredness or breathlessness, AND provider asked or client mentioned fever, headache/ blurred vision (10; 161; 333)	- Explained how to take the anti-malarial medications (79) - Observed that the [1st] dose of IPTp is given in the facility (36; 205; 320; 333)	- Provided ITN free of charge or voucher to client as part of consultation or instructed client to obtain ITN elsewhere in facility (36; 164; 320)	- Explicitly explained importance of using ITN (10; 122; 164) - Explained purpose of preventive treatment with malaria medications (10; 96; 163; 165; 333)	- Explained possible side effects of malaria pills (225; 254)	
	Outcome						

Figure 7. Mapping of malaria in pregnancy quality indicators to combined quality framework tool

I mapped indicators of malaria service quality for services routinely conducted during antenatal care to my quality framework tool. The tool combines the WHO quality framework of six dimensions and Donabedian's structure-process-outcomes domains of quality, to aid in systematic selection of a comprehensive, parsimonious set of indicators. Greyed out indicators were not included in the final quality score due to high correlation with other indicators. Abbreviations: IPTp – intermittent preventive treatment in pregnancy; SP – Sulfadoxine-Pyrimethamine; mRDT – malaria rapid diagnostic test; ITN – insecticide treated bed net; ANC – antenatal care; ARV- antiretroviral.

Ethical considerations

The study protocol was reviewed and deemed non-human subjects research by the institutional review board of the Uniformed Services University of the Health Sciences, Bethesda, MD, USA. All data were publicly available and de-identified.

FINDINGS

Pooled analytic sample sizes for the IPTp-2, pregnancy ITN, and child's ITN use analyses were 15,715 women, 2,378 pregnant women, and 19,145 children, respectively (Fig8). Unweighted, pooled malaria prevalence estimates were 6.16-7.14% on average, with substantial cross-country variation (Table 4). Median MiP quality ranged from 30.18 – 54.47, with Namibia with the lowest median. Median ANC quality ranged from 56.64 – 76.90, with Tanzania with the lowest median. Namibia had greater facility density, higher HIV prevalence in reproductive-age women, and more highly-educated mothers. Country and pooled characteristics were otherwise similar (Appendix B4 Tables B4.1-B4.3).

IPTp-2 uptake in pregnancy

Pooled crude results for IPTp-2 uptake indicated a weak, positive association with MiP quality (Figure 9 and Appendix B5.1) which held for the adjusted model (Table 5). After adjustment, ANC quality had no significant effect. Stratified analyses for Kenya, Namibia, and Tanzania were generally consistent with pooled results for MiP quality. ANC quality was negatively associated with ITPp-2 for Kenyan and Tanzanian regions with average MiP quality; there was no association in Senegal or Namibia. In Kenya and Tanzania, as ANC quality improved, the effect of MiP quality on IPTp-2 uptake

weakened. Urban location was consistently associated with IPTp-2 uptake. ANC visit count positively predicted IPTp-2 uptake in all models but Namibia.

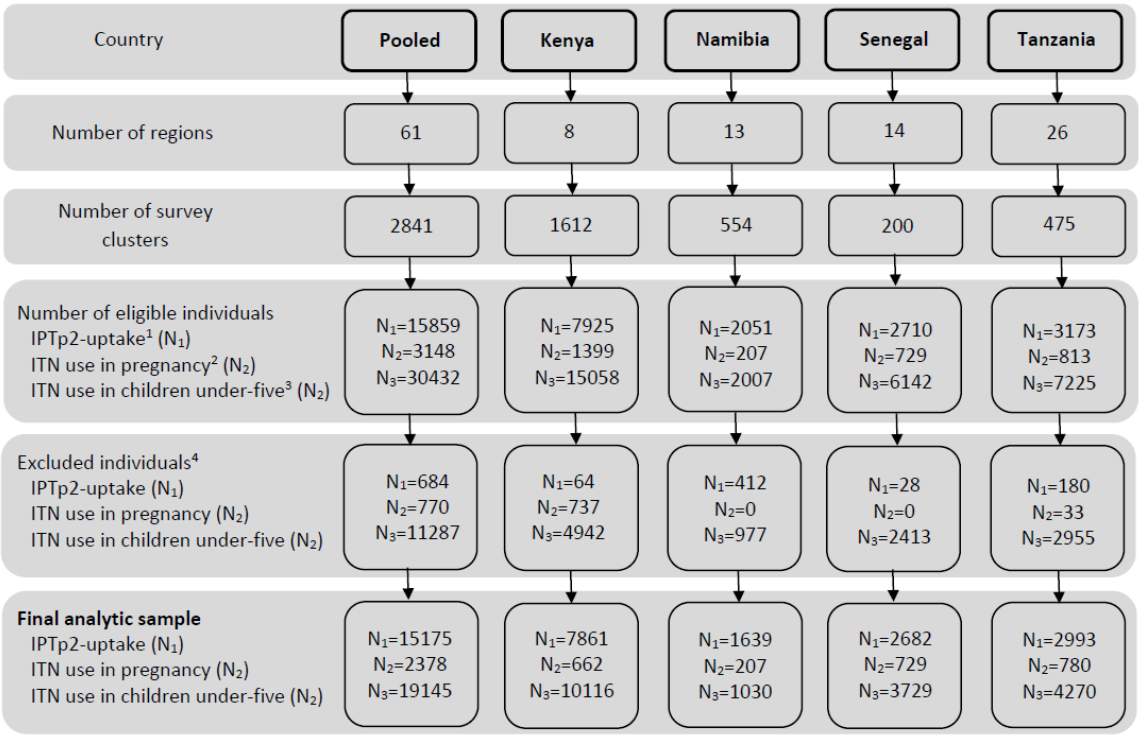


Figure 8. Flowchart of the inclusion of regions, survey clusters, and individuals in each study outcome in the Demographic and Health Surveys for Pooled data, Kenya, Namibia, Senegal and Tanzania (2010-2014).

[1]Eligible if a woman 15-49 years of age who reported a live birth in the prior 24 months and had complete data for every variable of interest.
[2]Eligible if a currently pregnant woman 15-49 years of age living in a household with one or more insecticide-treated bed nets and had complete data for every variable of interest.
[3]Eligible if a child 0-59 months of age living in a household with one or more insecticide-treated bed nets and had complete data for every variable of interest.
[4]Excluded if missing data for any of the analysis variables.

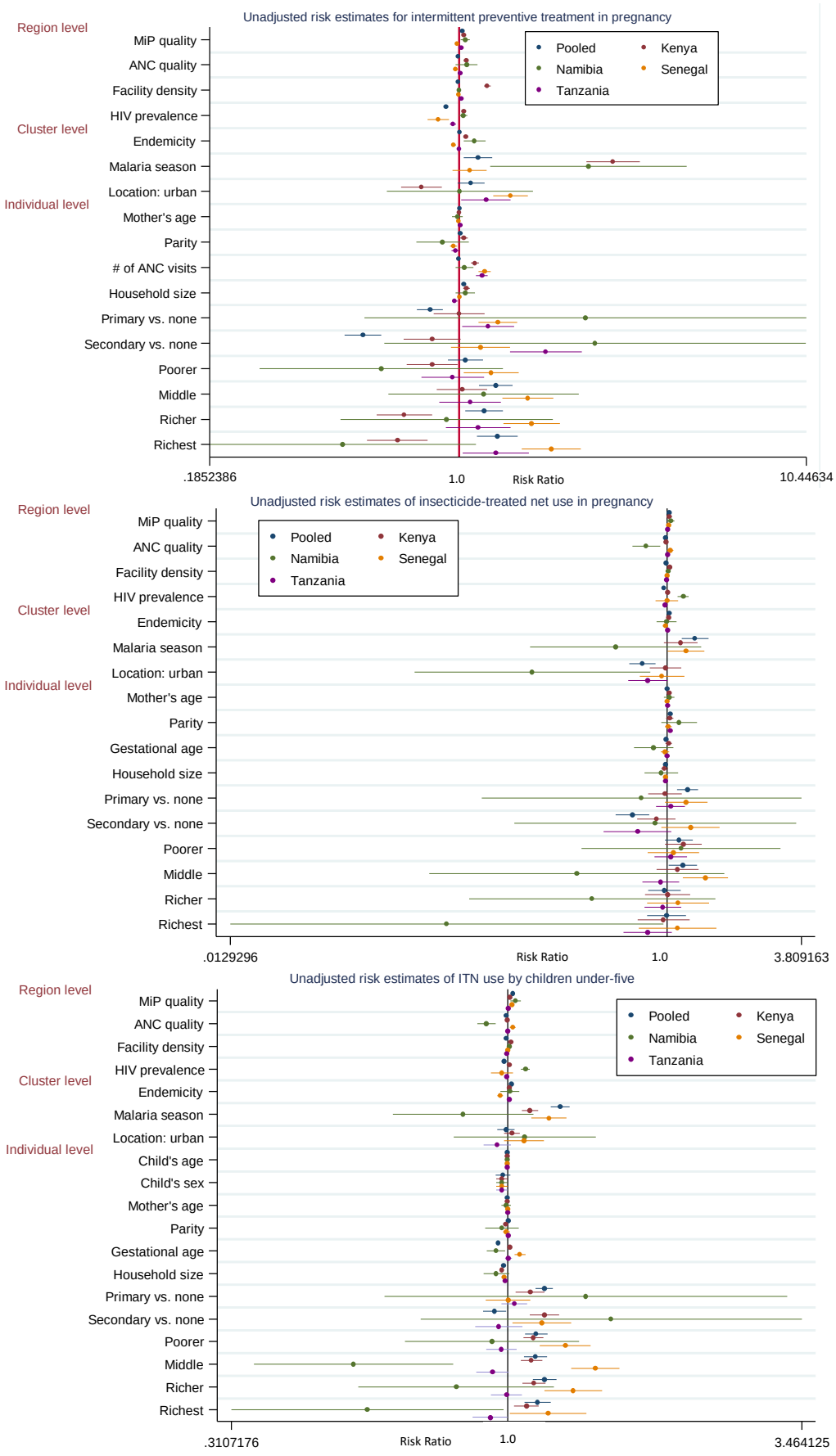


Figure 9. Unadjusted risk estimates for intermittent preventive treatment in pregnancy, insecticide-treated bed net use in pregnancy, and insecticide-treated bed net use in children under-five

Table 5. Adjusted multilevel mixed-effects modified Poisson results for intermittent preventive treatment in pregnancy uptake

I built empty pooled and country models which included random effects for region and cluster levels only, to determine what level, if any, random effects should be included for. I then conducted pooled and stratified country analyses for the parsimonious adjusted model including random effects at region and/or cluster levels and all other variables treated as fixed effects, based on empty model results.

		Kenya (n=7861)		Namibia (n=1639)		Senegal (n=2682)		Tanzania (n=2993)		Pooled (n=15175)	
		RR	**95% CI**	**RR**	**95% CI**	**RR**	**95% CI**	**RR**	**95% CI**	**RR**	**95% CI**
Adjusted Model[1]	*Measures of Association*										
Individual Level	# of ANC visits	**1.136**	**(1.100, 1.173)**	--	--	**1.169**	**(1.085, 1.259)**	**1.147**	**(1.103, 1.192)**	**1.127**	**(1.092, 1.163)**
	Mother's education (none)	--	--	--	--	Ref	Ref	Ref	Ref	--	--
	Primary	--	--	--	--	1.131	(0.856, 1.493)	1.164	(0.999, 1.355)	--	--
	Secondary/higher	--	--	--	--	**0.832**	**(0.712, 0.972)**	**1.553**	**(1.203, 2.005)**	--	--
Cluster Level	Residence location (urban)	1.014	(0.844, 1.219)	**1.482**	**(1.015, 2.164)**	**1.187**	**(1.056, 1.335)**	1.093	(0.889, 1.345)	**1.133**	**(1.031, 1.244)**
Region Level	ANC quality[3]	**0.751**	**(0.687, 0.821)**	0.935	(0.807, 1.082)	0.984	(0.955, 1.015)	**0.984**	**(0.970, 0.997)**	1.000	(0.971, 1.031)
	MiP quality[3]	**1.459**	**(1.288, 1.652)**	**1.080**	**(1.037, 1.126)**	0.994	(0.978, 1.010)	**1.026**	**(1.016, 1.035)**	**1.024**	**(1.004, 1.045)**
	Facility density[4]	**1.549**	**(1.296, 1.850)**	**0.993**	**(0.986, 0.999)**	--	--	**1.007**	**(1.003, 1.011)**	--	--
	HIV prevalence[5]	--	--	--	--	--	--	**0.969**	**(0.952, 0.987)**	--	--
	ANC quality x MiP quality[6]	**0.931**	**(0.909, 0.953)**	--	--	--	--	**0.998**	**(0.997, 0.999)**	--	--
Country Level	Country (Kenya)	--	--	--	--	--	--	--	--	Ref	Ref
	Namibia	--	--	--	--	--	--	--	--	0.437	(0.148, 1.291)
	Senegal	--	--	--	--	--	--	--	--	**4.251**	**(2.000, 9.036)**
	Tanzania	--	--	--	--	--	--	--	--	**3.611**	**(1.651, 7.897)**
	Measures of Variation										
	Region level	**0.287**	**(0.133, 0.621)**	**0.255**	**(0.105, 0.620)**	**0.011**	**(0.003, 0.045)**	**0.011**	**(0.002, 0.071)**	**0.235**	**(0.130, 0.427)**
	Cluster level	**0.109**	**(0.024, 0.494)**	0.064	(0.000, 56779.11)	--	--	**0.066**	**(0.024, 0.180)**	**0.070**	**(0.033, 0.149)**
	Model AIC	5891.709				3821.163		3852.737		15921.980	
Empty Model[2]	*Measures of Variation*										

Region level	1.244	(0.642, 2.410)	**0.458**	**(0.233, 0.899)**	**0.043**	**(0.019, 0.099)**	**0.052**	**(0.024, 0.115)**	1.019	(0.668, 1.557)
Cluster level	**0.117**	**(0.020, 0.681)**	0.121	(0.000, 74.279)	0.003	(0.00, 1059.45)	**0.092**	**(0.042, 0.199)**	**0.094**	**(0.050, 0.178)**
Model AIC	5958.706		607.0791		3887.345		3899.29		16142.320	

Abbreviations: RR – risk ratio; CI – confidence interval; Ref – reference level; ANC- antenatal care; MiP – malaria in pregnancy; AIC – Akaike's information criterion. [1]Adjusted model: random coefficient of clusters and/or regions with remaining significant variables after adjustment. [2]Empty model: solely random coefficient of clusters and/or regions. [3]Mean-centered for each country and overall for pooled model. [4]Per 1,000,000 population. [5]In women ages 15-49. [6]Calculated using mean-centered quality score(s).

ITN use in pregnancy

Results of the pooled crude analysis for pregnancy ITN use indicated a modest, positive association with MiP quality and an inverse association with ANC quality (Figure 9 and Appendix B5.2). After adjustment, a modest, positive effect of MiP quality remained for regions with average ANC quality (Table 6). As regional ANC quality improved, pregnant women were more likely to use ITNs as MiP quality improved. However, in regions with below average MiP quality, ITN use was inversely related to ANC quality. Country results also generally suggested a modest effect of MiP quality on ITN use in pregnancy for Kenya and Namibia and for regions with average ANC quality in Senegal. In Namibia, ANC quality was negatively associated with pregnancy ITN use. In Senegal, there was an inverse relationship between MiP quality and ITN use for regions with below average ANC quality. In regions of Senegal with above average ANC quality, likelihood of individual ITN use increased with improved MiP quality. As malaria burden increased, pregnancy ITN use tended to increase in pooled, Kenya, and Tanzania models. Additionally, the effect of urban location varied directionally by country.

ITN use in children under-five

Pooled crude and adjusted results for child's ITN use generally suggested a modest, positive association of regional MiP quality (Table 7 and Appendix B5.3). MiP quality significantly interacted with ANC quality, so that there was a positive relationship between MiP quality and ITN use in regions with at least average ANC quality, but little discernable relationship in regions with below average ANC quality. In regions with both high MiP and ANC quality, there was an inverse relationship with ITN use.

MiP quality and child's ITN use were positively associated in all countries but Tanzania, and significant for Senegal and Kenya. In Kenya, the strength of this relationship increased as malaria endemicity increased. ANC quality was not associated with child's ITN use, except in Kenya where there was a modest inverse association. In regions of Kenya and Senegal with average ANC quality, urban children were more likely to use a net. A weak, inverse relationship was apparent in rural areas as ANC quality improved. HIV prevalence in women of reproductive age and urban location were positively associated with child's ITN use in Namibia. Child's ITN use increased with malaria burden in pooled, Kenya, and Tanzania models.

Table 6. Adjusted multilevel mixed-effects modified Poisson results for insecticide-treated net use in pregnancy the night prior

I built empty pooled and country models which included random effects for region and cluster levels only, to determine what level, if any, random effects should be included for. I then conducted pooled and stratified country analyses for the parsimonious adjusted model including random effects at region and/or cluster levels and all other variables treated as fixed effects, based on empty model results.

		Kenya (n=662)		Namibia (n=586)		Senegal (n=729)		Tanzania (n=780)		Pooled model (n=2378)	
		RR	**95% CI**	**RR**	**95% CI**	**RR**	**95% CI**	**RR**	**95% CI**	**RR**	**95% CI**
Adjusted Model[1]	*Measures of Association*										
Individual Level	Mother's age (in years)	**1.019**	**(1.014, 1.025)**	--	--	--	--	--	--	--	--
	Parity	--	--	--	--	--	--	**1.035**	**(1.011, 1.060)**	--	--
	Household size	--	--	--	--	--	--	**0.978**	**(0.963, 0.992)**	--	--
Cluster Level	Malaria endemicity	**1.012**	**(1.007, 1.018)**	--	--	--	--	**1.009**	**(1.003, 1.016)**	**1.009**	**(1.004, 1.014)**
	Residence location (urban)	**1.174**	**(1.062, 1.298)**	**0.393**	**(0.178, 0.869)**	1.068	(0.844, 1.352)	**0.825**	**(0.686, 0.993)**	0.985	(0.873, 1.112)
Region Level	ANC quality[3]	0.987	(0.964, 1.011)	**0.809**	**(0.755, 0.866)**	1.022	(0.974, 1.073)	1.013	(0.996, 1.030)	0.999	(0.978, 1.021)
	MiP quality[3]	**1.022**	**(1.018, 1.026)**	**1.080**	**(1.007, 1.157)**	1.008	(0.988, 1.028)	0.997	(0.992, 1.003)	**1.014**	**(1.003, 1.025)**
	Facility density[4]	**1.034**	**(1.013, 1.054)**	--	--	--	--	--	--	--	--
	ANC quality x MiP quality[5]	--	--	--	--	**1.006**	**(1.001, 1.012)**	--	--	**1.001**	**(1.001, 1.002)**
Country Level	Country (Kenya)	--	--	--	--	--	--	--	--	Ref	Ref
	Namibia	--	--	--	--	--	--	--	--	**0.230**	**(0.110, 0.482)**
	Senegal	--	--	--	--	--	--	--	--	0.957	(0.771, 1.188)
	Tanzania	--	--	--	--	--	--	--	--	1.210	(0.788, 1.858)
	Measures of Variation										
	Region level	**0.000**	**(0.000, 0.000)**	**0.000**	**(0.000, 0.000)**	**0.035**	**(0.006, 0.219)**	**0.000**	**(0.000, 0.000)**	**0.032**	**(0.010, 0.103)**
	Cluster level	--	--	--	--	0.060	(0.003, 1.130)	--	--	**0.025**	**(0.001, 0.736)**
	Model AIC	1191.628		128.191		1096.993		1503.685		4840.075	
Empty Model[2]	*Measures of Variation*										
	Region level	**0.027**	**(0.007, 0.109)**	0.761	(0.169, 3.419)	**0.048**	**(0.014, 0.163)**	0.000	(0.000, 1.3x10^155)	0.048	(0.171, 1.324)
	Cluster level	--	--	--	--	0.063	(0.004, 1.016)	--	--	**0.029**	**(0.119, 0.692)**
	Model AIC	1204.449		140.769		1090.682		1506.818		2774.930	

Abbreviations: RR – risk ratio; CI – confidence interval; Ref – reference level; ANC- antenatal care; MiP – malaria in pregnancy; AIC – Akaike's information criterion. [1]Adjusted model: random coefficient of clusters and/or regions with remaining significant variables after adjustment. [2]Empty model: solely random coefficient of clusters and/or regions. [3]Mean-centered for each country and overall for pooled model. [4]Per 1,000,000 population. [5]Calculated using mean-centered quality score(s).

Table 7. Adjusted multilevel mixed-effects modified Poisson results for insecticide-treated net use in children under-five the night prior

		Kenya (n=10116)		Namibia (n=1030)		Senegal (n=3729)		Tanzania (n=4270)		Pooled (n=19145)	
		RR	**95% CI**	**RR**	**95% CI**	**RR**	**95% CI**	**RR**	**95% CI**	**RR**	**95% CI**
Adjusted Model[1]	*Measures of Association*										
Individual Level	Mother's education (none)	--	--	--	--	--	--	--	--	Ref	Ref
	Primary	--	--	--	--	--	--	--	--	**1.042**	**(1.002, 1.083)**
	Secondary or higher	--	--	--	--	--	--	--	--	**1.125**	**(1.058, 1.196)**
	Number of ANC visits	--	--	--	--	**1.025**	**(1.000, 1.051)**	--	--	--	--
	Household size	**0.968**	**(0.956, 0.979)**	--	--	--	--	**0.984**	**(0.973, 0.994)**	**0.981**	**(0.976, 0.986)**
Cluster Level	Malaria endemicity	**1.004**	**(1.001, 1.007)**	--	--	--	--	**1.008**	**(1.004, 1.011)**	**1.005**	**(1.002, 1.009)**
	Survey timing	--	--	--	--	--	--	--	--	--	--
	Residence location (urban)	**1.054**	**(1.026, 1.084)**	**1.324**	**(1.021, 1.715)**	**1.209**	**(1.097, 1.332)**	0.983	(0.948, 1.019)	**1.086**	**(1.035, 1.140)**
Region Level	ANC quality[3]	**0.991**	**(0.982, 0.999)**	0.985	(0.896, 1.084)	1.026	(0.991, 1.062)	1.003	(0.991, 1.014)	0.989	(0.975,1.002)
	MiP quality[3]	**1.025**	**(1.018, 1.031)**	1.011	(0.972, 1.052)	**1.019**	**(1.001, 1.037)**	0.994	(0.989, 0.999)	**1.018**	**(1.008, 1.028)**
	Facility density[4]	**1.025**	**(1.020, 1.031)**	--	--	--	--	--	--	--	--
	HIV prevalence[5]	--	--	**1.100**	**(1.031, 1.173)**	--	--	--	--	--	--
	Endemicity x MiP quality[6]	**1.002**	**(1.001, 1.002)**	--	--	--	--	--	--	--	--
	ANC quality x location[6]	**0.986**	**(0.978, 0.994)**	--	--	**0.944**	**(0.924, 0.964)**	--	--	--	--
	ANC quality x MiP quality[6]	--	--	--	--	--	--	1.001	(1.001, 1.002)	**1.001**	**(1.001, 1.002)**
Country Level	Country (Kenya)	--	--	--	--	--	--	--	--	Ref	Ref
	Namibia	--	--	--	--	--	--	--	--	**0.295**	**(0.183, 0.475)**
	Senegal	--	--	--	--	--	--	--	--	1.074	(0.881, 1.309)
	Tanzania	--	--	--	--	--	--	--	--	1.020	(0.769, 1.354)
	Measures of Variation										
	Region level	**0.000**	**(0.000, 0.000)**	**0.114**	**(0.041, 0.319)**	**0.042**	**(0.016, 0.111)**	**0.009**	**(0.004, 0.020)**	**0.053**	**(0.028, 0.102)**
	Cluster level	--	--	0.138	(0.012, 1.590)	**0.062**	**(0.025, 0.155)**	--	--	**0.001**	**(0.000, 131950.6)**
	Model AIC	19573.040		897.774		5719.382		8419.257		30268.010	
Empty Model[2]	*Measures of Variation*										
	Region level	**0.006**	**(0.003, 0.014)**	0.469	(0.202, 1.090)	**0.047**	**(0.020, 0.111)**	**0.013**	**(0.007, 0.025)**	0.535	(0.267, 1.071)
	Cluster level	--	--	0.138	(0.014, 1.367)	**0.085**	**(0.041, 0.177)**	--	--	**0.005**	**(0.000, 0.330)**
	Model AIC	19648.02		905.845		5730.449		8428.791		30497.55	

Abbreviations: RR – risk ratio; CI – confidence interval; Ref – reference level; ANC- antenatal care; MiP – malaria in pregnancy; AIC – Akaike's information criterion.
[1]Adjusted model: random coefficient of clusters and/or regions with remaining significant variables after adjustment. [2]Empty model: solely random coefficient of clusters and/or regions. [3]Mean-centered for each country and overall for pooled model. [4]Per 1,000,000 population. [5]In women ages 15-49. [6]Calculated using mean-centered quality score(s).

DISCUSSION

I found low MiP service quality for all countries using my indicator set. I saw nearly consistent, albeit modest, adjusted effects of MiP service quality across pooled and country-specific models for all study outcomes (Figure 10). Country ANC quality scores were somewhat higher overall than for MiP quality, although cautious comparison of ANC and MiP quality is warranted given non-identical services. After controlling for potential confounders and regional and cluster effects in pooled models, there was generally no relationship between average ANC quality and ITN outcomes.

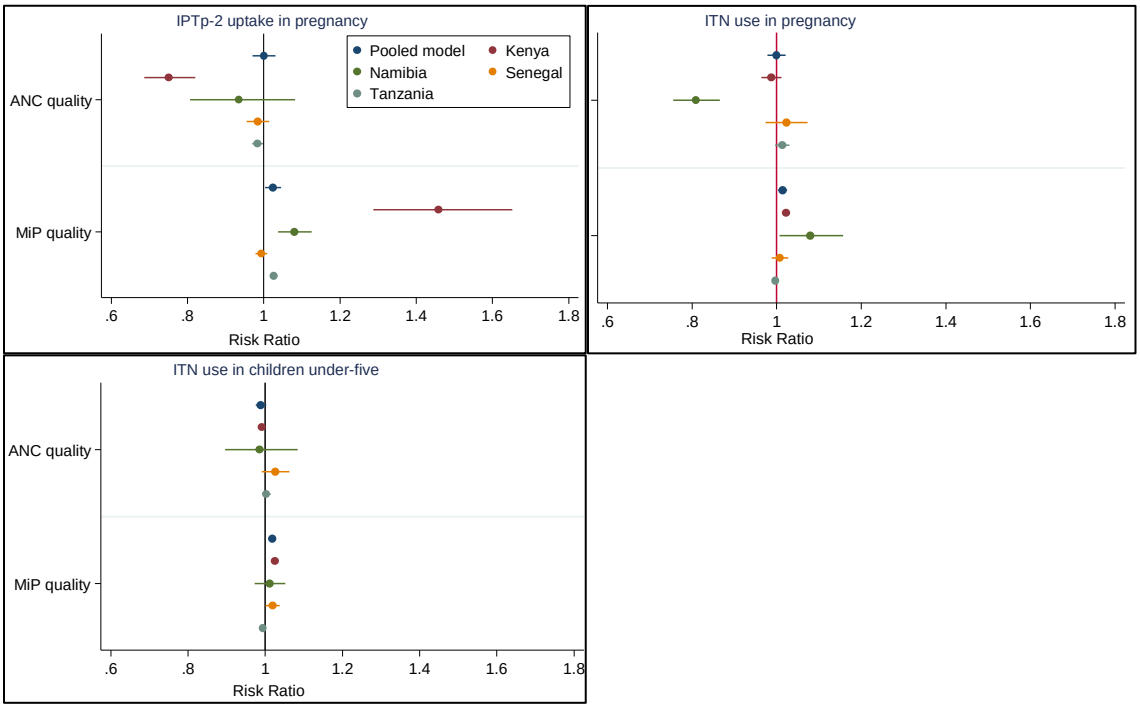


Figure 10. Forest plots of adjusted associations of malaria in pregnancy and antenatal care quality with each of three study outcomes.

Abbreviations: IPTp-2 – intermittent preventive treatment in pregnancy – 2 doses; ITN – insecticide-treated bed net; ANC – antenatal care; MiP – malaria in pregnancy.

The relationship between ANC and MiP quality varied for pooled and stratified models and by outcome. A significant, positive interaction between ANC and MiP

quality was present in the pooled ITN use models and for stratified Senegal ITN use in pregnancy. A negative interaction between ANC and MiP quality was present for Kenya and Tanzania IPTp-2 models, but not for the pooled IPTp-2 model.

Country variations in confounders and effect modifiers of ANC or MiP quality and study outcomes were also present. For example, in Kenya, facility density was an important confounder of MiP quality and child's use of ITNs, but was not important for pooled or other country models. In Kenya, urban households of average ANC quality were more likely to report use of an ITN in pregnancy or childhood, but in Senegal this was only true for children.

Study findings support existing evidence which suggests need for high quality integrated ANC and MiP services to improve health outcomes (121; 164; 246). Although most African countries have rolled out the ANC package, poor national coordinating and planning mechanisms for integration and non-functional quality assurance systems may remain (267). In Kenya, ITNs, compared to IPTp, are more readily delivered via ANC, highlighting the need for improved IPTp services (164). Improved malaria knowledge has had positive influence on both IPTp and ITN use in pregnancy, including via group ANC education sessions (166; 184; 238).

Consistent with previous work, I found ANC visits positively predicted IPTp-2 but not ITN use for pooled and most country data (165). Urban location results aligned with previous findings for IPTp uptake as well as ITN use in childhood; however, they were inconsistent for ITN use in pregnancy across stratified and pooled models (165). Although I could not assess for a reciprocal effect on ANC quality given longstanding integration through the ANC package, presence of MiP programming might be expected

to have a positive effect on ANC quality, as has been similarly demonstrated for HIV programming (191).

Strengths and limitations

This study demonstrates an approach for linking routinely-collected facility and household survey data when individuals cannot be directly associated with facilities where care was sought (318). Current repositories of routine, nationally-representative data offer an alternative method for quality assessment than primary data collection (86), when answers to data-suitable research questions are sought. My approach demonstrates the possibility of combining these data for low-cost, high-yield results in relation to the contemporary issue of service integration and in response to the need for baseline health systems strengthening data and new health systems research methods (220). Further, this method allows for within- and cross-country health systems performance comparisons.

I also highlight how selection of quality metrics can be systematic and theory-driven. I operationalized a novel tool which builds on prior work (192; 196) to ensure representation of multiple, well-accepted quality dimensions (327) while simultaneously selecting indicators across the structure, process and outcome continuum (114). To my knowledge, this is the first study which combines these frameworks for joint operationalization.

This work had several limitations. Residual confounding may remain due to inability to measure certain individual-level predictors, e.g. number of ANC visits during a current pregnancy, or inability to include certain higher-order confounders. For example, a range of external governance, financial, policy, human resource, supply chain

and information systems challenges could affect coverage and uptake of interventions, and might bias results in either direction (165; 304).

While an important alternative to more costly and complex survey designs, aggregating facility-weighted scores to link data regionally results in loss of variation. Feasibility of the approach depends on sufficient linkage level variability, and may require certain country exclusions, e.g. Malawi with a high malaria burden but which only has three regions. This approach may be best reserved for cross-country comparisons to identify performance gaps.

Finally, cautious interpretation of findings is warranted. Cross-sectional data prevent assessment for causality. Further, although pooled findings suggest broad importance of MiP service quality in determining IPTp and ITN outcomes across malaria-endemic sub-Saharan Africa, this is generally, but not wholly upheld by country-stratified findings, e.g. pregnant women's ITN use in Tanzania or IPTp-2 uptake in Senegal. However, it is possible that small sample size may have played a role in nonsignificant findings for stratified country models. For example, I cannot be certain whether smaller sample size for the Namibia analysis of children's ITN use may have limited my ability to detect a significant effect of MiP quality or other important effects. Still, I found important, if modest, associations between quality and outcomes for country and pooled models.

Public health impact

Study findings suggest improved delivery and education on use of interventions continues to be an integral component of malaria prevention in sub-Saharan Africa. Generally low MiP quality in all countries indicated broad quality of care improvements

may be necessary. Strengthening existing facility-based delivery mechanisms is a means to address gaps in national coverage and usage targets, particularly persistently low ITN and IPTp targets.

Strengthening facility delivery mechanisms will require evaluation tools and consensus on a standardized, comprehensive, and readily measured set of indicators for MiP quality. Although malaria components of ANC are well-established (330), I found few literature examples where this translated into consistent use of standardized malaria quality indicators. My quality tool can help ensure systematic, comprehensive selection of relevant indicators measuring the full quality spectrum and can identify indicator gaps, e.g. for outcomes and equity measures.

I also found several negative interactions between ANC and MiP service quality, e.g. for IPTp-2 uptake in Kenya and Tanzania. This could reflect improved ANC and MiP quality in cities with low endemicity where improved malaria knowledge in well-educated populations might attenuate service quality's effect. Indeed, higher education was positively associated with IPTp-2 uptake in Tanzania. Further, nuances in results for pooled ITN use suggested an inverse relationship for child's ITN use in regions of both high MiP and ANC quality, and decreased use in pregnancy as ANC quality improved in regions with below average MiP quality. The former may reflect affluent, urban populations with improved care access and perceived lower threat of malaria as a rural disease of poverty (158). The latter may reflect areas where there was little malaria but ANC quality was higher, and thus little actual or perceived need to consistently deliver MiP services as a part of ANC, e.g., parts of Namibia.

The modest effect of MiP service quality generally, paired with mixed findings for interactions between ANC and MiP, suggest a need for geographically-targeted, improved integration of these services to strengthen impact. Study findings are a starting point for further evidence generation. Agreement on best practices for assessing integrated service delivery performance is needed. Although integration of primary health care services as a tool to strengthen health systems is expected to lead to improved service delivery and health outcomes (86), there is a dearth of evidence to support this. Study methods can potentially be extended to other integrated service areas for baseline and trend analyses to address this gap. Further, adaptation of this methodology to pre- and post- analyses can be used to evaluate progress toward IPTp-SP3+ policy implementation in facilities and identify low performing facility and within country geographic areas for targeted improvement.

The ANC package is a long-standing example of how integrated service delivery requires careful thought and consistent re-evaluation, as evidenced by 2016 updates recommending eight visits, up from four. Study findings support the continued need for high quality integrated antenatal and malaria services as a delivery channel for malaria in pregnancy interventions. Additionally, operationalization of the quality assessment tool may be extended to a range of service delivery environments for systematic quality improvements.

CHAPTER 4: TOWARD IMPROVED HEALTH SYSTEMS RESPONSIVENESS: A CROSS-SECTIONAL STUDY OF MALARIA ENDEMICITY AND READINESS TO DELIVER SERVICES IN KENYA, NAMIBIA AND SENEGAL

INTRODUCTION

Globally, 3.3 billion people are estimated to be at risk of exposure to at least one of five *Plasmodium* parasite strains responsible for causing human malaria (260). In 2015, 88% of cases worldwide or approximately 188 million were in sub-Saharan Africa, where there were an estimated 395,000 malaria deaths (260). Fortunately, a rapid decline in morbidity and mortality since 2003 (227) is due in large part to an emphasis on transmission-prevention interventions, vector control and good case management (260). Yet, new technologies indicate a vast reservoir of subclinical malaria infections exists which has been implicated in maintaining transmission of malaria parasites (245; 265). Sustaining previous gains and efforts toward malaria elimination will require continued readiness of national health systems to respond appropriately with diagnostics and treatment in addition to continued distribution of preventive measures (130).

New and improved evaluation methods are necessary to achieve better health service delivery performance, leading to health systems strengthening (220). Health facility assessment data can be harnessed to help inform the response to international calls for health systems strengthening, access to universal health coverage, and increased focus on delivery of quality services (64; 124; 190; 192; 299). Facility surveys provide routine data on comprehensive and disease- and service delivery-specific baseline performance at the facility level and systems performance in the aggregate (52; 182; 196; 219). They offer disaggregated data reflective of local level performance and outcomes

which may avoid pitfalls of nationally aggregated data that mask underlying variations (81; 97; 193; 262; 287).

Efforts are underway to agree upon and consolidate useful and valid performance metrics, as is evidenced in the Health Data Collaborative's *Global Reference List of 100 Core Health Indicators, 2015* (39). In the meantime, facility survey data linked to household and/or geospatial data offer novel inter- and intra-country options for service delivery and systems evaluation through existing data repositories and standardized assessment metrics. In the past, approaches for evaluation of malaria outcomes such as behavior change counseling or service delivery effectiveness studies have largely been limited in geographic scope, thereby limiting their generalizability to the broader health system (74; 130). Existing, routine facility survey and spatial data offer current alternatives at-scale for baseline health systems performance assessment. They can also inform cross-country comparisons, which help place systems performance within the broader context of regional and international trends (146).

I extended an approach for using spatially-located malaria prevalence, or endemicity, data first utilized by Burgert et al. 2014 to examine insecticide-treated bed net (ITN) ownership patterns. I linked health facility data and malaria endemicity data to demonstrate how facility readiness to deliver services can be measured and used as an indication of health systems responsiveness to malaria prevalence, or demand for services by proxy. I considered three sub-Saharan African countries, Kenya, Namibia and Senegal, where rapidly shifting endemicity maps require improved understanding and measurement of health facility performance. My objectives were three-fold, to: 1) examine general patterns of readiness to deliver services via visual mapping, 2) establish

the validity and reliability of the World Health Organization's (WHO) malaria service readiness index, and 3) explore variations in facility readiness to deliver malaria services. I hypothesized that malaria endemicity would be positively associated with health facility service readiness and that it would vary by rural and urban location. Since donor and national decision-making and investments should target high burden areas including both hyperendemic and localized hot spot transmission zones (75; 281), I might expect facilities with a high level of readiness to deliver care will be found in areas of high burden.

MATERIALS AND METHODS

Study setting and design

I conducted a pooled, cross-sectional analysis of health facilities in three sub-Saharan African countries, Kenya, Namibia and Senegal, where the parasite *Plasmodium falciparum* is responsible for causing malaria-related morbidity and mortality. Country inclusion criteria included a heterogeneous malaria burden, or at least 15% of the population residing in no or low malaria prevalence areas (81), and availability of geo-located national health facility survey data for 2007 or later. Facilities were included if they provided malaria diagnosis and treatment, antenatal, pharmacy and laboratory services, and if they had a completed questionnaire with at least one complete health worker interview. I excluded HIV/AIDS voluntary counseling and testing (VCT) facilities in Kenya and health huts in Senegal, as these facilities are not intended to provide the full range of malaria and antenatal care services (19; 54).

Data Collection

I used USAID's publicly available Service Provision Assessment (SPA: http://www.dhsprogram.com/), a cross-sectional, routine facility-based survey administered in 16 developing countries to date (48). The SPA is designed to capture formal health facility information about infrastructure, staffing, services offered, readiness to deliver care, and certain quality metrics (47). It is comprised of four standard data collection tools administered over a 1-2day period: the facility inventory, linked client observations and exit interviews on topics including antenatal care, and health worker interviews. SPA data for Kenya 2010, Namibia 2009, and Senegal 2012-13 are geo-located, complex survey data which capture standardized indicators for antenatal and malaria services (17; 19; 27). Kenya and Senegal SPAs are representative nationally, regionally, by managing authority and facility type, while the Namibia SPA is a facility census.

Using SPA data, I constructed the WHO malaria service readiness index for each facility. This index was the main outcome of interest and is comprised of a simple average of three domains of readiness, namely availability of: 1) trained staff and guidelines, 2) valid diagnostics, and 3) valid medicines and commodities. Table 8 defines the malaria service readiness domains and indicators comprising each domain. Slight adaptations to individual indicators available from SPA data are noted (e.g. absence of information on trained microscopists). For each domain, facilities received an unweighted average score constructed from associated indicators on a scale of 0 to 1.

Table 8. Definitions of Malaria Service Readiness Domains

Domain	Tracer Item(s)	Definition of Tracer
Staff and Guidelines	Guidelines for diagnosis and treatment of malaria	Country-specific guidelines observed in service area.

	Guidelines for IPT*	Country-specific IPT guidelines observed in service area.
	Staff trained in malaria diagnosis and treatment	At least one staff member providing the service trained in some aspect of malaria diagnosis and treatment in the last two years[1]. Interview response from in-charge of service area day of survey[2].
	Staff trained in IPT*	At least one staff member providing the service trained in some aspect of IPT in the last two years[1]. Interview response from in-charge of service area day of survey[2].
Diagnostics	Malaria diagnostic capacity	Malaria rapid test or smear (microscope, slides, stain, and accredited/certified microscopist[3]). Able to conduct the test on-site (in the facility) and functioning equipment and reagents needed to conduct the test are observed on-site on the day of the survey. In area where tests for malaria are carried out or anywhere in the facility where laboratory testing is routinely conducted.
Medicines and Commodities	First-line antimalarial in stock	Artemisinin-based Combination Therapy or other country specific. Observed in service area or where routinely stored; in stock with at least one valid.
	Paracetamol capsules/ tablets	Observed in service area or where routinely stored; in stock with at least one valid.
	IPT drug*	SP observed in service area or where routinely stored; in stock with at least one valid.
	ITN*	ITNs or vouchers available for distribution.

Abbreviations: IPT, Intermittent preventive treatment in pregnancy; SP, Sulfadoxine + Pyrimethamine; ITN, Insecticide treated bed net.

*Items should only be included in the index for facilities located in malaria-endemic areas. All facilities for Kenya, Namibia and Senegal were considered to be located in an endemic area for this analysis.
[1]Due to inconsistent capture across SPA surveys, this variable was coded as whether at least one staff member providing the service had ever received training in the specific area.
[2]Interview response was captured from individual providers rather than from an in-charge of service area in the Kenya, Namibia and Senegalese SPAs.
[3]Presence of a trained microscopist was not asked in the Kenya, Namibia and Senegalese SPAs and thus was excluded when calculating malaria diagnostic capacity.

Potential confounders of the relationship between malaria burden and service readiness available in SPA data were categorized as: facility type according to level of care provided (tertiary: hospitals; secondary: health centers, maternities; primary: health posts, clinics, dispensaries, sickbays); entity responsible for managing a facility or the managing authority (public, non-governmental organization (NGO) or faith-based organization (FBO), private-for-profit); number of health worker interviews completed

during the survey (1-5, 6-11, 12-21); whether the facility had a drug register updated daily (yes, no); number of funding sources (0, 1, 2, 3, 4 or more); survey month (January-December); administrative meeting frequency (not held/irregularly held, every 2-6 months, monthly); state of the drug storage area (the unweighted average of 4 variables scored 0 or 1: all medicines off the floor, protected from water, protected from sun, whether room is clean of rodent and pest evidence); and state of the physical infrastructure state (unweighted average of availability of 4 variables scored 0 or 1: electricity or backup generator with fuel, protected regular water supply on-site or within 500m, working phone or shortwave radio on-site or within 5 minutes' distance, functional computer).

I also used publicly-available malaria prevalence, or endemicity, data which give *Plasmodium falciparum* prevalence rates (P*f*PR) age-standardized to 2-10 years in 5 x 5 kilometer pixels from Bayesian-estimated global maps from the Malaria Atlas Project (MAP: http://www.map.ox.ac.uk/)(132-134; 250). For MAP data, endemicity was defined as the prevalence of asexual blood-stage *P. falciparum* parasites in a population (283). I used MAP data for 2009, 2010 and 2012 corresponding with respective SPA country and survey years as a proxy for true endemicity. Endemicity, the primary independent variable, was continuously scaled from 0 to 1. I also used United Nations-adjusted population density data for 2010 are from the Gridded Population of the World, Version 4 in raster format with an output resolution of 30 arc-seconds (117). Population density was assessed as a potential confounder and was used to calculate regional facility density per 100,000 population. The potential interaction between endemicity and urban/rural data from the Global Rural-Urban Mapping Project (65) was also considered.

Given malaria has historically been a rural disease, I expected endemicity would vary by degree of urbanization.

I extracted endemicity, population density, and urban/rural raster values in ArcGIS 10.3.1 using the Spatial Analyst extension and geographic coordinates of each facility (Appendix C1). Urban facilities were assigned a value of 1 and rural facilities a value of 0. Continuous values for endemicity and population density were assigned using the raster cell corresponding to a facility's location. Values for endemicity, population density, and urbanization were exported in Excel and linked to facilities using latitude and longitude coordinates.

Statistical Analysis

Statistical analysis was performed in Stata 12.0. I attempted to establish the validity and reliability of the malaria service readiness index using the pooled SPA data. I used the index as originally intended given expert review and selection of indicators comprising the index were used by WHO to establish content validity (with slight modifications due to data availability noted in Table 8) (243). Construct validity was tested by calculating convergent and discriminant validity of the index with other indicators of interest from the data. I hypothesized that the overall index and domains of malaria service readiness would positively correlate with antenatal service readiness and child curative service readiness indices and domains (convergent validity) which have previously been defined elsewhere (161). I hypothesized that the index would show no correlation (discriminant validity) with the following indicators: whether a client feedback system was in place, and whether user-fees were assessed for sick adult services. To test these hypotheses, I calculated Greiner's rho for each correlation of

interest which ranges from -1 to 1, is similar in interpretation to other rho measures, and is suitable for non-normal, complex survey data (237). I tested reliability of the malaria service readiness index components by calculating Cronbach's alpha and using 0.70 as a threshold for good reliability (107).

I calculated unweighted descriptive statistics for variables of interest (Table 9). Unadjusted and adjusted weighted associations were assessed using complete case analysis in linear regression models and alpha=0.05. I took the natural log of the independent variable endemicity due to a posteriori fitting of the data. Managing authority, survey month, drug register availability, and condition of facility infrastructure were considered as potential confounders. Potential interactions between endemicity and urban/rural location, month, and managing authority were evaluated. Inclusion of variables in the model was based on a priori knowledge, literature review, and bivariate testing using an alpha cut-off of 0.25. Region and facility type were accounted for in complex survey analyses. I built the final parsimonious model for pooled country data using manual entry and used Wald's test to determine goodness of fit. Model assumptions including the presence of residual autocorrelation were tested for individual countries. I performed a sensitivity analysis for missing data by creating a dichotomous variable for missing data and examining adjusted associations with the natural log of endemicity, managing authority, month of survey, number of health worker interviews, country, and facility type. I also imputed missing service readiness scores for facilities and compared the adjusted results to those of the original analytic sample.

Table 9. Unweighted Characteristics of Facilities in the Analytic Sample

Variables	Categories	Kenya (n=433) n (%)/ Median (IQR)	Namibia (n=228) n (%)/ Median (IQR)	Senegal (n=165) n (%)/ Median (IQR)	Total (n= 826) n (%)/ Median (IQR)
Malaria service readiness		0.83 (0.67, 0.92)	0.83 (0.75, 0.83)	0.92 (0.75, 1.00)	0.83 (0.75, 0.92)
Endemicity		0.01 (0.01, 0.05)	0.06 (0.03, 0.07)	0.03 (0.02, 0.04)	0.03 (0.01, 0.06)
Health facility type[1]	Tertiary Care	230 (53)	26 (11)	15 (9)	271 (33%)
	Secondary Care	110 (25)	34 (15)	37 (22)	181 (22%)
	Primary Care	93 (21)	168 (74)	113 (68)	374 (45%)
Health facility managing authority	Public	222 (51)	200 (88)	153 (93)	575 (70%)
	NGO/FBO	87 (20)	23 (10)	6 (4)	116 (14%)
	Private-for-profit	124 (29)	5 (2)	6 (4)	135 (16%)
Facility location	Urban	267 (62)	184 (81)	110 (67)	561 (68%)
Kenya	Nairobi	43 (10)	--	--	43 (5%)
	Central	66 (15)	--	--	66 (8%)
	Coast	58 (13)	--	--	58 (7%)
	Eastern	60 (14)	--	--	60 (7%)
	Northeastern	31 (7)	--	--	31 (4%)
	Nyanza	52 (12)	--	--	52 (6%)
	Rift Valley	62 (14)	--	--	62 (8%)
	Western	61 (14)	--	--	61 (7%)
Namibia	Caprivi	--	19 (8)	--	19 (2)
	Erongo	--	5 (2)	--	5 (1)
	Hardap	--	5 (2)	--	5 (1)
	Karas	--	7 (3)	--	7 (1)
	Kavango	--	41 (18)	--	41 (5)
	Khomas	--	4 (2)	--	4 (1)
	Kunene	--	14 (6)	--	14 (2)
	Ohangwena	--	31 (14)	--	31 (4)
	Omaheke	--	14 (6)	--	14 (2)
	Omusati	--	37 (16)	--	37 (4)
	Oshana	--	11 (5)	--	11 (1)
	Oshikoto	--	21 (9)	--	21 (3)
	Otjozondjupa	--	19 (8)	--	19 (2)
Senegal	Dakar	--	--	15 (9)	15 (2)
	Diourbel	--	--	19 (12)	19 (2)
	Fatick	--	--	4 (2)	4 (1)
	Kaffrine	--	--	19 (12)	19 (2)

	Kaolack	--	--	15 (9)	15 (2)
	Kédougou	--	--	3 (2)	3 (1)
	Kolda	--	--	5 (3)	5 (1)
	Louga	--	--	17 (10)	17 (2)
	Matam	--	--	2 (1)	2 (1)
	Saint Louis	--	--	17 (10)	17 (2)
	Sédhiou	--	--	10 (6)	10 (1)
	Tambacounda	--	--	10 (6)	10 (1)
	Thiès	--	--	10 (6)	10 (1)
	Ziguinchor	--	--	19 (12)	19 (2)
Number of health worker interviews	1-5	236 (55)	167 (73)	94 (57)	497 (60)
	6-10	161 (37)	50 (22)	35 (21)	246 (30)
	11-21	36 (8)	11 (5)	36 (22)	83 (10)
Drug register updated daily	Yes	347 (80)	208 (91)	125 (76)	680 (82)
Facility density per 100,000 population		1.3 (1.1, 1.6)	16.7 (12.1, 18.3)	3.0 (2.6, 3.7)	1.7 (1.3, 11.3)
Number of funding sources	0	22 (5)	12 (5)	0 (0)	35 (4)
	1	157 (36)	114 (50)	67 (41)	338 (41)
	2	142 (33)	67 (29)	54 (33)	263 (32)
	3	64 (15)	31 (14)	38 (23)	133 (16)
	4 or more	48 (11)	4 (2)	6 (4)	58 (7)
Month surveyed	January	50 (12)	--	6 (4)	56 (7)
	February	121 (28)	--	6 (4)	127 (15)
	March	154 (36)	--	34 (21)	188 (23)
	April	106 (24)	--	53 (32)	159 (19)
	May	2 (1)	--	42 (25)	44 (5)
	July	--	15 (7)	--	15 (2)
	August	--	68 (30)	--	68 (8)
	September	--	111 (49)	--	111 (13)
	October	--	34 (15)	2 (1)	36 (4)
	November	--	--	14 (8)	14 (2)
	December	--	--	8 (5)	8 (1)
Administrative meetings	Not held/irregular	51 (12)	73 (32)	15 (9)	139 (17)
	Every 2-6 months	74 (17)	26 (11)	21 (13)	121 (15)
	Monthly	308 (71)	129 (57)	129 (78)	566 (69)
Score: state of drug storage area		1.0 (1.0, 1.0)	1.0 (1.0, 1.0)	1.0 (1.0, 1.0)	1.0 (1.0, 1.0)
Score: state of physical infrastructure		0.75 (0.5, 1.0)	0.5 (0.5, 0.75)	0.5 (0.5, 1.0)	0.75 (0.5, 1.0)

Abbreviations: N, count; IQR, inter-quartile range; NGO, non-governmental organization; FBO, faith-based organization.
[1]Tertiary care: hospitals; Secondary care: health centers, maternities; Primary care: health posts, clinics, dispensaries, sickbays.

Ethics

Ethical approval for this study was obtained from the Institutional Review Board of the Uniformed Services University of the Health Sciences, which deemed this study non-human subjects research due to use of secondary, publicly available datasets.

RESULTS

883 facilities met the eligibility criteria for inclusion in this study, out of 1,544 total facilities sampled in the three country surveys. Of those eligible, 826 (93.5%) had complete information for every variable of interest. In the analytic sample, Kenya accounted for 433 (52%) of facilities, followed by Namibia with 228 (28%) of facilities, and Senegal with 165 (20%) (Table 9). Within eligible facilities, the frequency of missing data was low at 55 facilities or 6.2% overall (Appendix C2), or 15 of 448 (3.3%), 15 of 243 (6.2%), and 25 of 190 (13.2%) for Kenya, Namibia and Senegal respectively.

Median malaria service readiness was 0.83 overall (IQR: 0.75, 0.92), and median $Pf PR_{2-10}$ endemicity was 0.03 or 3% (IQR: 0.01, 0.06) with similar country-specific median malaria prevalence. In the overall analytic sample, 575 (70%) of facilities were public, followed by 135 (16%) managed by private-for-profit entities and 116 (14%) by NGOs or FBOs. Namibian and Senegalese facilities were predominantly publicly managed at 200 (88%) and 153 (93%) of facilities respectively, whereas managing authorities of Kenyan facilities were more evenly distributed (51% or 222 public, 29% or 124 private-for-profit, 20% or 87 NGO/FBO). In total, 271 (33%) of the sample provided tertiary, 181 (22%) provided secondary, and 374 (45%) provided primary care. However, the breakdown of facilities across care levels is further differentiated by country, where Kenyan facilities in the sample were skewed toward tertiary or hospital-based care, while

Namibia and Senegal facilities mostly provided primary care. In general, facilities were more likely to be urban than rural (68% or 561 overall; 62% or 267 in Kenya, 81% or 184 in Namibia, 67% or 110 in Senegal).

Mapping of malaria service readiness and endemicity

I calculated and ranked median malaria service readiness performance by country and geographic region (Figure 11).

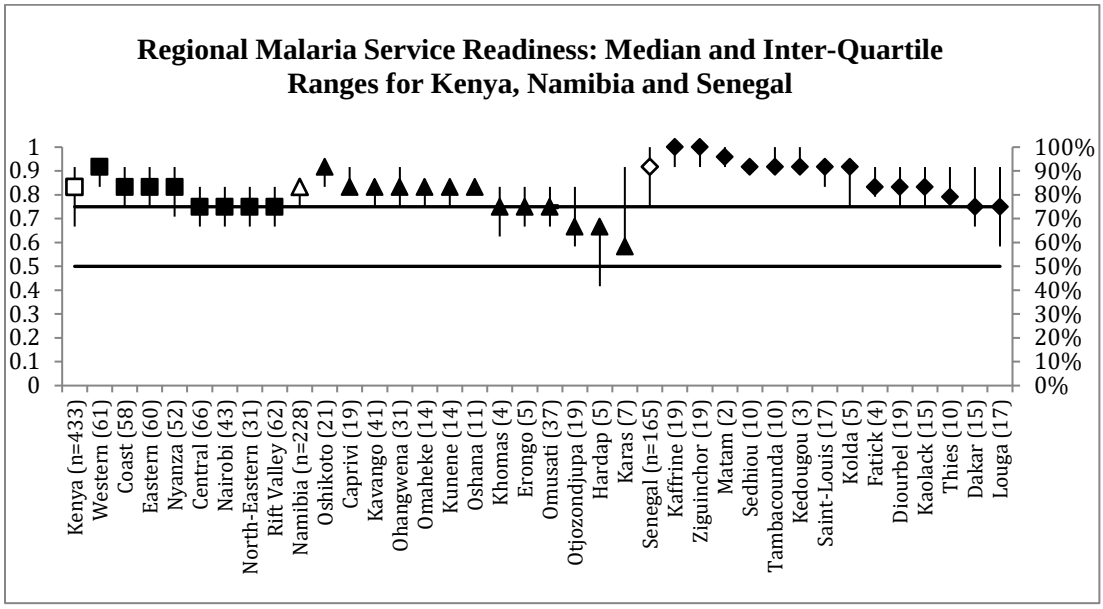


Figure 11. Regional Malaria Service Readiness: Median and Inter-Quartile Ranges for Kenya, Namibia and Senegal

Figure 11 depicts the median and interquartile ranges for malaria service readiness for each country (Kenya, Namibia, Senegal) overall and by region, for facilities in the analytic sample. Hollow symbols indicate median scores at the country level; square symbols represent median scores for the country/regions of Kenya, triangles represent Namibia, and diamonds represent Senegal. For each country, the median country score is given followed by each region ranked in descending order according to median score. Facility counts are provided in parenthesis next to each country/region on the x-axis.

I also mapped malaria service readiness scores at the facility level and overlaid on endemicity data to qualitatively examine facility performance across the sample by country. Generally, facilities were skewed toward having good performance overall, although a fair amount of heterogeneity was still present in each country. For example,

although median performance was high across countries [Kenya: 0.83, IQR: (0.67, 0.92); Namibia: 0.83, IQR: (0.75, 0.83); Senegal: 0.92, IQR: (0.75, 1.00)], certain regions had median performance well below the country median and heterogeneous performance in terms of within-region performance, demonstrated by wider respective inter-quartile ranges (e.g. Karas region in Namibia, Louga region in Senegal). In general, Senegal had higher median performance overall. Both Senegal and Namibia had greater heterogeneity of performance within regions, as compared to Kenya.

Performance within service readiness domains

I also mapped performance at the facility level for each country within each malaria service readiness domain (Figure 12). Qualitatively, there appeared to be greatest heterogeneity in domains 1 (trained staff and guidelines) and 3 (medicines and commodities), as compared to domain 2 (diagnostics). Namibia and Kenya had the greatest heterogeneity in domain 1, whereas Senegal had comparatively fewer low-performing facilities. Performance was similar for all three countries in both domains 2 and 3. Domain 2 showed little variability, with few low-performing facilities in any of the three countries. Domain 3 performance indicated all but three facilities had at least one of four medicines and commodities available, yet substantial variation within all three countries was still present.

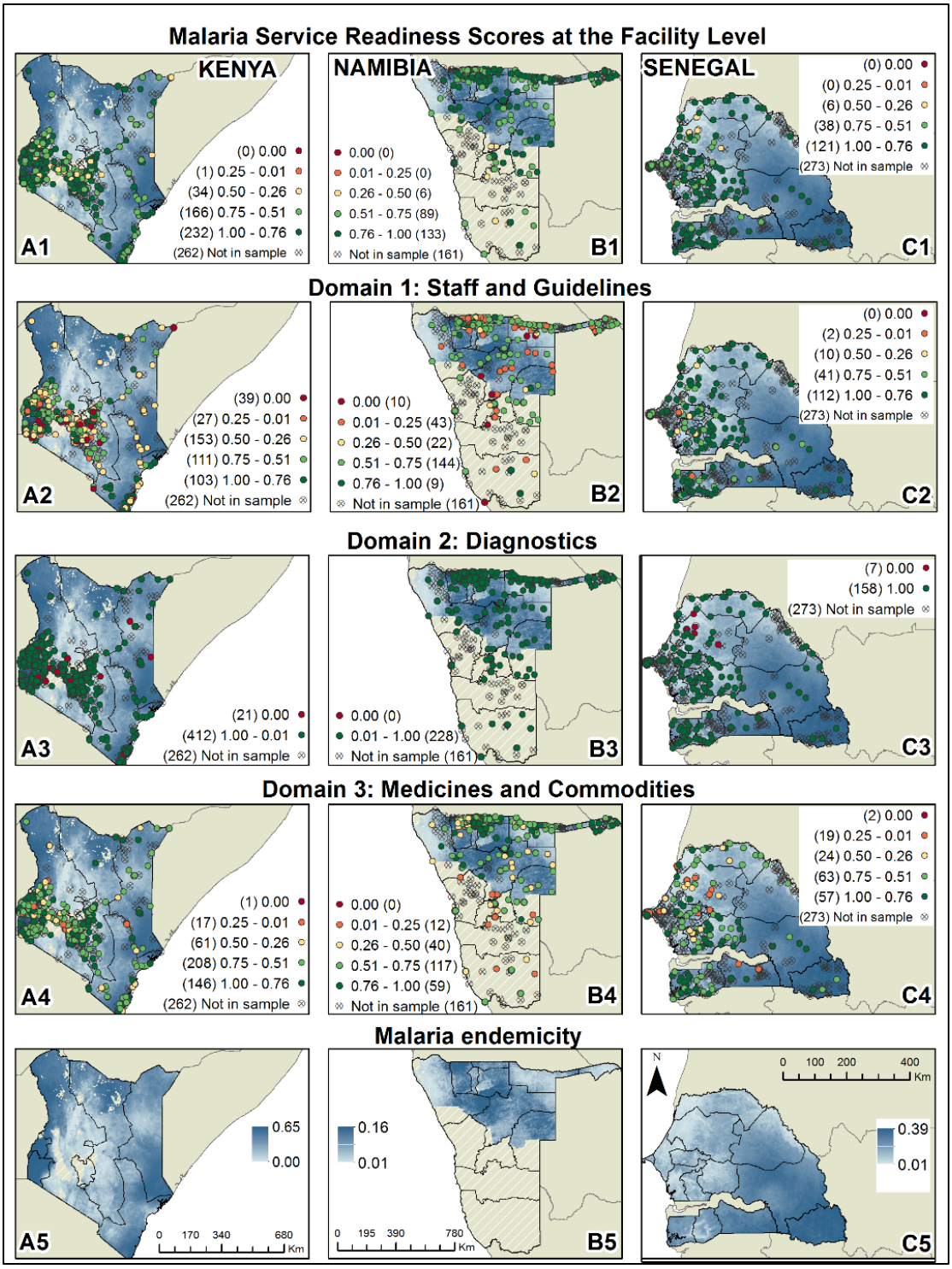


Figure 12. Mapped Facility Performance in Malaria Service Readiness Domains and Overall Index in Kenya, Namibia and Senegal

Maps A1-C1 depict facility-level performance on the overall malaria service readiness index overlaid on endemicity. Maps 2-4 for Kenya (A), Namibia (B), Senegal (C) depict facility-level performance on service readiness domains 1-3, or trained staff and guidelines, diagnostics, and medicines and commodities, respectively, overlaid on endemicity. Maps A5-C5 depict malaria endemicity alone.

Performance within countries

I similarly examined results within countries, or across service readiness domains (Figure 12). Generally, Kenya and Namibia both appeared to have lower and more varied facility performance in terms of availability of clinical guidelines and trained staff, as compared to availability of diagnostics or medicines and commodities. However, in either country lower performing facilities were not necessarily the same in domains 1 and 3. Interestingly, Senegal facilities generally had moderate to high scores in domains 1 and 2 of readiness with somewhat lower performance in domain 3. Generally, domain 1 and 3 performance at the facility level for all three countries appeared to drive overall performance.

Validity and reliability testing

Results of the construct validity testing (Appendix C3) suggested the malaria service readiness index was positively, albeit weakly, correlated with domains of the indices for child curative service readiness. Unexpectedly, malaria service readiness had a negative weak correlation with antenatal service readiness. As hypothesized, the malaria service readiness index was not correlated with the indicators selected to test discriminant validity. I also calculated Cronbach's alpha [alpha=0.59, 95% CI: (0.57)] to test reliability of the index (Appendix C4), which was somewhat lower than a cut-off of 0.70.

Regression results

Unadjusted and adjusted linear regression analyses are presented in Table 10. The final model included the natural log of endemicity, facility location, managing authority, survey month, number of health worker interviews, and the interaction of facility location

with natural log of endemicity. The interaction between facility location and the natural log of endemicity approached significance in the adjusted model (p=0.058).

As endemicity increased in rural areas, facility readiness to deliver malaria services also increased and was statistically significant (Table 10). By contrast, this relationship did not appear to hold for urban facilities. I also found that private-for-profit facilities performed somewhat lower, on average, compared to public [β: -0.102; 95% CI: (-0.154, -0.050)]. I did not find a significant difference in performance for facility management by NGOs/FBOs as compared to government-managed (public) facilities. Results of country stratified analyses (Table 11 and Appendix C5) suggested that the interaction between facility location and endemicity varied by country; however, I could not be certain due to insufficient power to detect an interaction for either Namibia or Senegal alone. The addition of a country variable to the pooled adjusted model did not affect the magnitude of this interaction or its significance. Stratified analyses of Kenyan facilities indicated the significant positive association found in pooled data for rural facilities held, while urban facilities appeared to be less ready to deliver care as endemicity increased. This interaction was not significant for either Namibia or Senegal facilities.

Sensitivity analyses of missing facilities suggested NGO/FBO- and private-for-profit-managed facilities were significantly more likely to have missing data than public facilities, as were facilities in Senegal compared to Kenya (Appendix C6). Facilities with missing data had increased odds of higher endemicity [OR: 2.02; 95%CI: (1.17, 3.49)]. Results of the adjusted model using imputed data were not different from adjusted results of the analytic sample (Appendix C7 and Appendix C8).

Table 10. Results of the Unadjusted and Adjusted Pooled Regression Analyses (n=826 facilities)

I calculated a minimum detectable effect size for the pooled multiple linear regression of Cohen's f2=0.017, with 6 covariates, 80% power, and alpha=0.05. Statistically significant results of the unadjusted and adjusted analyses are bolded.

	Unadjusted		**Adjusted (R^2: 0.189)**	
Variables	**Estimated β coefficient**	**95% CI**	**Estimated β coefficient**	**95% CI**
Ln(endemicity)[1]	0.015	(-0.067, 0.037)	**0.028**	**(0.008, 0.047)**
Facility location[1] (Rural)	Reference	Reference	Reference	Reference
Urban	**0.058**	**(0.015, 0.102)**	-0.075	(-0.198, 0.049)
Ln(endemicity) x Facility location[2]	-0.0332	(-0.068, 0.001)	-0.032	(-0.064, 0.001)
Managing authority (Public)	Reference	Reference	Reference	Reference
NGO/FBO	-0.029	(-0.091, 0.033)	-0.012	(-0.075, 0.050)
Private for profit	**-0.128**	**(-0.174, -0.083)**	**-0.102**	**(-0.154, -0.050)**
Month of survey (January)	Reference	Reference	Reference	Reference
February	-0.003	(-0.068, 0.062)	-0.011	(-0.078, 0.057)
March	-0.004	(-0.072, 0.064)	-0.002	(-0.068, 0.064)
April	0.051	(-0.012, 0.114)	0.061	(-0.003, 0.125)
May	**0.125**	**(0.061, 0.119)**	**0.092**	**(0.022, 0.162)**
June	Omitted	Omitted	Omitted	Omitted
July	0.047	(-0.010, 0.104)	0.021	(-0.051, 0.092)
August	**0.06**	**(0.005, 0.116)**	0.03	(-0.033, 0.092)
September	-0.0001	(-0.056, 0.055)	-0.024	(-0.086, 0.039)
October	0.033	(-0.050, 0.117)	0.003	(-0.082, 0.089)
November	0.051	(-0.013, 0.117)	0.006	(-0.068, 0.080)
December	-0.011	(-0.108, 0.087)	-0.013	(-0.103, 0.077)
Number of health worker interviews (1-5)	Reference	Reference	Reference	Reference
6-10	0.032	(-0.003, 0.068)	0.029	(-0.011, 0.069)
11-21	**0.067**	**(0.035, 0.099)**	**0.07**	**(0.031, 0.110)**
Drug register observed as updated daily (No)	Reference	Reference	--	--
Yes	0.003	(-0.038, 0.043)	--	--
Facility Type[3] (Tertiary Care)	Reference	Reference	--	--
Secondary Care	-0.001	(-0.031, 0.033)	--	--
Primary Care	-0.029	(-0.060, 0.001)	--	--
Region (Nairobi)	Reference	Reference	--	--
Kenya				
Central	0.008	(-0.072, 0.088)	--	--
Coast	0.068	(-0.014, 0.150)	--	--
Eastern	0.045	(-0.048, 0.137)	--	--
Northeastern	-0.026	(-0.101, 0.049)	--	--

Nyanza	0.068	(-0.002, 0.138)	--	--
Rift Valley	-0.024	(-0.117, 0.068)	--	--
Western	0.071	(-0.009, 0.050)	--	--
Namibia				
Caprivi	**0.125**	**(0.060, 0.190)**	--	--
Erongo	0.008	(-0.099, 0.114)	--	--
Hardap	-0.126	(-0.287, 0.036)	--	--
Karas	-0.035	(-0.155, 0.085)	--	--
Kavango	**0.067**	**(0.003, 0.131)**	--	--
Khomas	0.003	(-0.119, 0.126)	--	--
Kunene	**0.072**	**(0.005, 0.139)**	--	--
Ohangwena	**0.075**	**(0.008, 0.143)**	--	--
Omaheke	**0.078**	**(0.010, 0.146)**	--	--
Omusati	0.024	(-0.043, 0.091)	--	--
Oshana	**0.092**	**(0.019, 0.166)**	--	--
Oshikoto	**0.155**	**(0.094, 0.217)**	--	--
Otjozondjupa	-0.028	(-0.109, 0.052)	--	--
Senegal				
Dakar	0.054	(-0.038, 0.145)	--	--
Diourbel	**0.09**	**(0.007, 0.173)**	--	--
Fatick	0.081	(-0.003, 0.165)	--	--
Kaffrine	**0.255**	**(0.195, 0.315)**	--	--
Kaolack	0.089	(-0.005, 0.183)	--	--
Kédougou	**0.21**	**(0.140, 0.281)**	--	--
Kolda	**0.12**	**(0.034, 0.206)**	--	--
Louga	-0.002	(-0.125, 0.121)	--	--
Matam	**0.248**	**(0.170, 0.325)**	--	--
Saint Louis	**0.184**	**(0.118, 0.250)**	--	--
Sédhiou	**0.169**	**(0.086, 0.251)**	--	--
Tambacounda	**0.206**	**(0.136, 0.277)**	--	--
Thiès	**0.118**	**(0.026, 0.210)**	--	--
Ziguinchor	**0.223**	**(0.155, 0.290)**	--	--
Regional facility density (per 100,000 population)	**288.977**	**(124.795, 441.160)**	--	--
Number of Funding Sources (0 sources)	Reference	Reference	--	--
1 source	-0.045	(-0.103, 0.014)	--	--
2 sources	-0.022	(-0.087, 0.043)	--	--
3 sources	0.057	(-0.004, 0.118)	--	--
4 or more sources	0.045	(-0.016, 0.106)	--	--
Admin. Meeting Frequency (Not held/held irregularly)	Reference	Reference	--	--

Held every 2-6 months	-0.046	(-0.130, 0.038)	--	--
Held at least monthly	0.002	(-0.049, 0.054)	--	--
Score: state of drug storage area	0.012	(-0.099, 0.122)	--	--
Score: state of physical infrastructure	0.024	(-0.059, 0.108)	--	--

Abbreviations: N – count; CI – confidence interval; R2 – coefficient of determination; β – beta; ln – natural log; NGO – non-governmental organization; FBO – faith-based organization.

[1]Unadjusted associations for ln(endemicity) and facility location are each estimated without the interaction term.

[2]The unadjusted association for the interaction term is estimated with both main effects in the model.

[3]Tertiary care facilities: Hospitals; Secondary care facilities: Health centers, maternities; Primary care facilities: Health posts, clinics, dispensaries, sickbays.

Table 11. Weighted mean malaria service readiness scores and 95% confidence intervals by endemicity level and facility location

Endemicity Level	Facility Location	Kenya Mean (95% CI)	Namibia Mean (95% CI)	Senegal Mean (95% CI)	Total Mean (95% CI)
Low (<=5%)	Urban	0.77 (0.74, 0.81)	0.78 (0.77, 0.81)	0.87 (0.84, 0.90)	0.80 (0.78, 0.83)
	Rural	0.71 (0.66, 0.76)	0.76 (0.71, 0.81)	0.79 (0.74, 0.85)	0.73 (0.69, 0.77)
Intermediate/ High (>5%)	Urban	0.74 (0.66, 0.81)	0.79 (0.77, 0.80)	0.93 (0.90, 0.97)	0.79 (0.74, 0.84)
	Rural	0.76 (0.70, 0.82)	0.83 (0.78, 0.89)	0.88 (0.70, 1.06)	0.77 (0.72, 0.83)
Total		0.75 (0.72, 0.78)	0.78 (0.77, 0.80)	0.86 (0.84, 0.88)	0.78 (0.76, 0.80)

Abbreviation: CI – confidence interval.

DISCUSSION

Overall, facilities in this study tended to perform well in terms of readiness to deliver malaria services. Improved facility readiness was associated with higher malaria burden in rural areas, but not in urban areas. I also noted that facility managing authority may be important for determining readiness. On average, private-for-profit facilities performed lower than public facilities. However, I did not find a significant difference between publicly- and NGO/FBO-managed facilities. This may be due to insufficient statistical power to make this comparison, despite relatively high facility counts across all managing authority types.

I also identified wide variations in facility performance across and within domains 1 (trained staff and guidelines) and 3 (medicines and commodities) of malaria service readiness. Performance in domains 1 and 3 qualitatively appeared to drive performance of the overall index within countries. Conversely, nearly all facilities performed well in terms of domain 2, or availability of a valid malaria rapid diagnostic test (mRDT) or microscopy.

Results of validity testing for the malaria service readiness index indicated performance was generally as expected in terms of child curative services, although anticipated positive correlations were not strong overall. Interestingly, a weak, negative statistically significant correlation with antenatal care services was observed. This may have been driven by the negative correlation with diagnostic capacity which was nearly ubiquitous across facilities, and consequently could have artificially affected the results. Similarly, although I anticipated strong performance in terms of reliability testing, Cronbach's alpha of 0.59 was lower than the cut-off value (0.70) usually employed.

However, it is reasonable to consider these findings in conjunction with prior literature and expert review conducted during establishment of this index.

Use of the WHO's readiness indicators in the literature has been limited, despite their utility as expert-reviewed metrics and the practicality and low-cost nature of using existing data sources which capture them. Lee et al. 2016 examined quality of antenatal care service delivery and noted the predominantly structural- and process-oriented nature of the indicators captured in SPA data collection tools, in line with the well-established structure-process-outcome quality continuums (114). I observed similar patterns and the concurrent dearth of outcome indicators. This study uniquely reverses this issue, however, instead using what are traditionally input-oriented indicators of the malaria service readiness index as an outcome associated with malaria endemicity level. I attempted to measure responsiveness of the health system to burden of disease, an integral component of health systems strengthening, although notably data were cross-sectional and causality could not directly be assessed (239).

Prior research examining associations with malaria endemicity has looked at factors important for prevention and control efforts and associated outcomes. Urbanization is a well-established driver of malaria transmission due to habitat preferences of many of the common vectors for open, freshwater breeding spaces often found in rural areas (157; 203; 305). Studies have also shown a link between endemicity levels and care seeking behaviors as well as drug prescription practices for malaria treatment, although the majority have done so in either low or high transmission areas exclusively (109; 236; 244). Interestingly, study findings from Chuma et al. 2010

suggested the possibility of a relationship between per capita cost burden of treating malaria and variations in endemicity in Kenya (95).

Burgert et al. 2014 demonstrated a method for defining endemicity zones ex post facto for use with secondary household survey data through the example of multiple countries' progress in terms of ITN coverage (81). I adapted this method for use with facility data in response to the authors' call for additional studies of the association of endemicity with outcomes data, and considering the opportunity to use under-utilized quality metrics such as the WHO's malaria service readiness index (114; 243). Burgert et al. 2014 also identified an important gap with respect to whether case management varies by endemicity level, paving the way for a preliminary study of readiness to deliver good case management services. Further, where clinical presentation, treatment guidelines, and approaches for transmission prevention all differ based on endemicity level (10; 119; 242), study of the relationship between malaria endemicity and capacity to deliver malaria services was warranted.

Strengths and limitations

This study highlights the availability and utility of expert-reviewed indices like the malaria service readiness index for performance assessment. Analysis of routinely-conducted facility surveys such as the SPA, using standardized metrics of this nature, presents an opportunity for broader comparisons not only within but across countries and regions. I demonstrated a straightforward method for linking alternative sources of disease prevalence data to facility performance data which can be used to assess variations in service delivery performance in response to specific service needs like malaria. Pooled, multi-country analyses can improve statistical power in studies of this

nature, as with the validity and reliability tests I conducted for the malaria service readiness index.

Although health systems are often thought of as uniquely operating within national or sub-national contexts, this analysis suggests broader lessons may be drawn through combined country analysis. Data captured and reported at the facility-level can be aggregated for use at higher levels of a country's health system. Where appropriate, these data can also be used to make cross-country performance comparisons. These comparisons may help identify variations in performance, allowing decision-makers to target low-performing areas. SPA data provide additional information on facility type and managing authority, which can be important drivers of performance (172).

This study has several limitations of note. Unmeasured confounding may remain due to inability to consider certain facility- or regional-level predictors of service readiness because of their unavailability or inconsistent capture in SPA data. For example, potential confounders not considered include donor funding (286), supply chain issues, and policy diffusion at the sub-national level (229). Inconsistent capture may have been due to changes in survey questionnaires over time, varying country contexts or changes in clinical guidelines, and may consequently be unavoidable in multi-country comparisons (93).

I could not separate out facilities primarily servicing low socio-economic areas, nor was I able to differentiate along the urban-to-rural gradient and look specifically at peri-urban areas. These may be important considerations in terms of malaria service delivery and health facility response to actual need for services. Additionally, this study used cross-sectional facility data from a single point in time paired with estimates of

endemicity based on aggregate survey data, rather than real-time surveillance data. Consequently, I could not consider the potential for localized 'hot spot' transmission areas which have been well-documented in the literature (75; 129; 240), and which could increase demand for services. Increased demand might either lead to improved or reduced readiness depending on facility responsiveness to localized epidemics. Poor planning could lead to stock-outs, whereas early identification of epidemics could lead to improved procurement of necessary supplies. Modeled endemicity data are unlikely to capture a localized epidemic, whereas cross-sectional facility data might reflect the response (or lack thereof) to increased demand.

I excluded several facility types based on services offered, which had some effect on the sample size. I excluded VCTs in Kenya, which would have introduced a negligible amount of bias where they accounted for only 1% of Kenyan facilities sampled (19). I also excluded Senegalese health huts which provide a more limited range of malaria and antenatal services. Capacity to deliver these services is generally lower in health huts, and their exclusion may have biased overall and sub-national performance scores for malaria service readiness upward, particularly for largely rural areas where health huts may be an important extension of the health system (54). I also had to consider the possible presence of information bias in terms of health worker interviews, since as the total number of completed interviews increased, average service readiness also increased. Increased total interviews may have led to improved likelihood of interview of an adequately-trained on-duty provider, but they may have also served as a proxy for better staffing in general.

Although of low frequency in this study, missing data have previously been shown to be an issue when analyzing SPA data sets (62; 196). The higher response rate

for malaria indicators in public facilities might either indicate real positive progress in these facilities, or alternatively might suggest respondent bias is present both in terms of perceived incentive to participate and perceived desired response, as supported by study findings regarding public facility performance. However, where feasible, I specifically coded indicators according to observed availability of materials which should have reduced respondent bias. I also chose to impute missing data which were low (6.2% of eligible facilities) based on results of the sensitivity analyses of missing data. Multiple imputation requires data to be missing at random (162), and while I believe this to be the case based on my results, I cannot be fully certain.

Significance and interpretation

Funder decision-making is often driven by national-level performance measures. For countries where malaria burden is homogeneous and where performance might be expected to be similar across geographies, facility types, and managing authorities, it may be reasonable to use national statistics. However, as this study demonstrated, nationally- or regionally-aggregated data often mask underlying heterogeneities. Low performance in certain areas, whether measured in terms of service readiness or population coverage indicators, may lower national averages (81). Furthermore, low performance in high burden areas may result in a significant burden in terms of malaria-related morbidity and mortality, suggesting poor prioritization of resources. In this study, performance was driven both by endemicity as well as facility characteristics. Routinely repeated facility surveys can be used to track performance trends of specific facilities over time, identify low and high performers, and to evaluate the impact of targeted interventions in high-burden areas. Emphasis on national-level performance with failure to completely

consider sub-national data may not allow for a comprehensive assessment and a fully-informed decision-making process.

Study findings suggest that although literature and expert reviews are important for development of indices constructed from multiple indicators (107), quantitative assessment of a composite index such as malaria service readiness may provide an opportunity for its refinement. For example, sensitivity analyses suggested removal of paracetamol, for which availability was nearly ubiquitous, may improve index reliability. Additionally, other readiness measures might be considered for inclusion such as those related to treatment of severe disease (bearing in mind level of care provided). Modification of the survey tools and included measures, might also be considered, e.g. to address the inconsistent capture of indicators like 'availability of a trained on-duty provider' which I observed in study countries. These processes are each integral aspects of formulating valid and reliable indices of health system performance toward measurement of systems responsiveness.

Malaria has traditionally been a rural disease of poverty, in part due to larval habitat preferences of the major sub-Saharan African vectors *Anopheles gambiae, An. arabiensis and An. funestus*, and successful efforts to eliminate larval habitats in urban areas (233; 282; 322). Study results suggest that health systems may be moderately responsive to malaria in rural settings in terms of targeting services to areas of highest incidence. However, urban malaria incidence in sub-Saharan Africa in many settings is surprisingly high and may result in a substantial disease burden due to population density, even where urban incidence is lower than for surrounding rural areas (104). Study findings showed wide variations in both endemicity and facility readiness in urban areas,

which suggests missed opportunities to target interventions generally to higher burden areas, and to ensure high readiness across all urban facilities, even where the adjusted P*f*PR is low but total affected population count may be high. Prior evidence indicates urban transmission may be localized and more common in lower socio-economic status areas such as slums and peri-urban communities (104).

Differences in performance by management authority, as seen in the lower performance of private facilities compared to public, could be driven by several factors. For example, these factors could include: decreased ability of government entities to monitor privately-managed facilities (78; 221; 334), differences in and frequency of provider training (221), or differences in policy and evidence diffusion (78) pertaining to adoption of first-line antimalarial medications in the mid-2000s thereby impacting in-stock pharmaceuticals (57). The latter may be reflected temporally in the 2010 Kenya and 2009 Namibia data.

Broadly, findings with respect to varied performance in domain 1 (trained staff and guidelines) and domain 3 (medicines and commodities) indicate these two readiness domains may warrant further attention practically, even in a country like Senegal which has made good progress in malaria control (267) and for which data were recent. Yet, I cannot rule out the possibility that data capture methods, particularly for separate guidelines for intermittent preventive treatment in pregnancy (IPTp) versus diagnostics and treatment, may have created confusion and resulted in biased interview responses. For example, the 2005 Namibia National Malaria Policy which was in place at time of data collection integrated both sets of guidelines, yet these indicators were captured separately by the SPA. Although the national Namibian policy indicated IPTp should be

administered in low and high endemicity zones (indicating IPTp guidelines should be widely available) (5), only 4% of total facilities had IPTp guidelines observed, compared to 78% observed with a copy of the national malaria policy. Sensitivity analyses substituting the national malaria policy availability indicator for both IPTp and diagnostics and treatment guidelines qualitatively improved performance in this domain for Namibia, but did not affect the pooled adjusted results. The advent of easy-to-use mRDTs and international push for universal diagnostic access (302; 303), coupled with the complexities and staffing shortages associated with microscopy (255), may have driven diffusion of mRDTs and thus consistently high performance in this domain. I would have otherwise expected a lower proportion of primary care facilities to have valid diagnostics available as compared to secondary or tertiary care facilities, as microscopy may well be unavailable at this level of care (255).

Further, performance comparisons between domains must be made cautiously. Scales vary for each domain and the overall index due to the number of indicators included in each. Consequently, caution is warranted when interpreting national, regional or facility performance across domains for a specific country, as performance scores taken at face value may be skewed by the method of measurement within one domain to the next. Conversely, general comparisons within a domain across countries may be more reliably made in terms of relative performance. In either case, a common understanding of what constitutes “acceptable” performance thresholds would help lend credence to comparisons for decision-making purposes.

Study findings require cautious interpretation in terms of generalizability to facilities and countries outside of the analytic sample. The analytic sample was a subset

of the original surveys' sampling schemes for Kenya and Senegal limited to facilities which provided malaria and antenatal services, and the original sampling scheme was not designed to be representative of specific services. Consequently, results may not necessarily be reflective of national or regional performance within Kenya or Senegal for all facilities providing these services. For example, although primary care facilities comprised 79% of the original weighted SPA sample reflecting the national proportion in Kenya for 2010, only 62% of facilities in the weighted analytic sample for Kenya provided primary care (Appendix C9). Caution is warranted when seeking to generalize study findings to other sub-Saharan African countries.

Conclusions

Using readily available, spatially-linked data sources, I demonstrated a straightforward approach for determining facility responsiveness to disease burden using established metrics. This approach could be extended over time to examine trends in responsiveness, and to catalyze discussion of what constitutes adequate malaria service readiness. Further, assessment using a complete facility census such as is available for Namibia could be used to determine gaps in population access to facilities with adequate readiness.

Study findings indicated room for improvement in terms of regional and facility readiness to deliver basic malaria services, even in countries such as Namibia and Senegal where substantial progress has been made. Interventions should be targeted at low performing regions and facilities – including geographic clusters of low performing facilities – with consideration given to the specific readiness domains where facilities fall short. Malaria elimination efforts will continue to require well-stocked facilities with the

capacity to deliver quality preventive, diagnostic and treatment services for the foreseeable future due to the shrinking transmission map and the ensuing reductions in the protective effect of naturally-acquired immunity. Study findings also suggested that efforts to improve data collection and standardization across routine country surveys are needed to facilitate within- and across-country comparisons. These data could provide invaluable baseline information for health systems strengthening initiatives and tracking of country progress. Finally, this study demonstrated the application of routine surveillance data for public health use. These existing data offer a wealth of useful information that should be used to maximally inform the public health knowledge base and targeted interventions.

CHAPTER 5: ADVOCACY, POLICY, PRACTICE AND RESEARCH IMPLICATIONS AND CONCLUSIONS

A. STUDY SUMMARIES

Study rationale, context, and major goal

The major goal of this dissertation was to address the following overarching research question: What is the role of facility-based quality and readiness in malaria service delivery for vulnerable populations in sub-Saharan Africa? Prior to initiating the study, I had identified several gaps in terms of availability of methods for health system performance assessment toward health systems strengthening. These gaps included systematic approaches for measuring service quality, service integration, and health system response to disease burden. Furthermore, coverage with malaria in pregnancy (MiP) interventions and attendance at the recommended numbers of antenatal care (ANC) visits both continue to be low in sub-Saharan Africa, despite nearly two decades of integrated implementation as part of the focused antenatal care (FANC) package of services (328; 330). These challenges, paired with availability of routinely collected MiP and FANC indicators via USAID's Demographic and Health Surveys (DHS) Program, provided the rationale for this dissertation. This work was timely given recent guideline updates for ANC (330), intermittent preventive treatment in pregnancy (IPTp) dosing (25), and calls for expanded integration of primary health care services (317).

I addressed the primary research question through three related studies. The first examined sub-national facility-based ANC quality in Kenya using a novel diagnostic for multi-dimensional aspects of quality. In the second study, I adapted the quality diagnostic and assessed cross-country variations in MiP and ANC quality. I then predicted country

and pooled estimates of malaria intervention use based on regional quality levels. Finally, I proposed a method for assessing health systems performance in response to malaria disease burden. The specific studies' objectives and findings are reviewed briefly below, followed by discussion of implications and future directions.

Measurement of antenatal care quality

In the first study, I sought to develop a quality of care diagnostic. I reviewed the literature for quality frameworks and selected the World Health Organization's (WHO) multi-dimensional framework as the overarching frame well-suited to assessment of quality in the context of low and middle income countries (LMICs). I compiled established indicators of ANC quality, mapped them to the framework, and then averaged scores for each quality dimension and overall. I then used this tool to assess sub-national ANC quality in Kenya for provinces, health facility types, and managing authorities. The diagnostic was meant to be a proof of concept which could be extended and adapted to other service contexts and countries.

Briefly, facility performance was lower than desirable and varied widely for the study's indicator set in terms of overall ANC quality across provinces, facility types, and managing authorities. When broken down by quality dimension, facilities performed highest in the dimensions of efficiency and acceptability/ patient-centeredness, and lowest on effectiveness and accessibility. Public facilities generally performed worse or similarly to private or faith-based facilities.

Integrated malaria and antenatal service quality and service delivery outcomes

The objectives of the second study were two-fold. I revisited the question of systematic and comprehensive service quality assessment, as I wanted to expand on the original diagnostic to adequately characterize quality as both a multidimensional and multi-domain continuum (114; 327). I adapted the original tool, used it to guide selection of indicators for malaria in pregnancy to develop a quality score, and re-constructed the ANC quality score from the first study. Each score was aggregated to the regional level for four countries: Kenya, Namibia, Senegal and Tanzania. Although I had originally intended to include Malawi, with three geographic regions there was not enough variation to justify this country's inclusion. I then used the MiP and ANC quality scores to determine whether quality of integrated antenatal and malaria services in pooled and country models was associated with: a) receipt of at least two doses of intermittent preventive treatment in pregnancy (IPTp-2) in the last pregnancy within the previous 24 months; b) use of an insecticide-treated bed net (ITN) the night prior in pregnancy; and c) use of an ITN the night prior by children under-five. Service integration is receiving much attention as a health systems strengthening strategy, yet with little evidence linking it to improved service delivery or health outcomes. By examining a package of integrated services implemented for nearly two decades and for which facility and population data are readily available, I aimed to address a gap in knowledge with respect to quality of MiP service delivery, and to use integrated MiP and ANC services as a case study to inform the general gap in evidence to support service integration.

I found low MiP service quality across countries and for the pooled model. In general, there was a modest positive association between MiP service quality and each of the three study outcomes. In most cases, for average MiP service quality regions, there

was no association between ANC quality and study interventions. In the pooled models for ITN use, the effect of MiP quality was amplified as ANC quality improved, suggesting high quality of all ANC services may affect success of delivery of a specific service subset such as MiP. Finally, there was substantial heterogeneity by country, between pooled and country models, and by outcome in terms of other region, cluster and individual factors associated with malaria intervention use.

Association of malaria endemicity with malaria service readiness

In the third and final study, the objective was to determine whether health facility readiness to deliver malaria case management services varied with malaria endemicity levels in Kenya, Namibia, and Senegal. In these countries, endemicity was heterogeneous, or at least 15% of the population was living in a low or no endemicity zone (81). I linked facility data in the three countries to several types of spatial data: malaria endemicity, urban/rural status, and population density, using latitude and longitude coordinates in a geographic information system. I was ultimately interested in this as a method for determining health systems performance in terms of malaria service delivery. Although it was not possible to assess for causality given the use of cross-sectional data, these methods were an opportunity for rapid performance assessment using existing data sources.

I determined that as endemicity increased in rural areas, there was a concurrent, modest increase in service readiness at the facility level, but no relationship in urban settings. Private-for-profit facilities were generally less prepared than public. Most facilities had the necessary supplies to diagnose malaria, yet availability of malaria

guidelines and adequately trained staff as well as medicines and commodities varied. Key messages of this study were as follows:

- Heterogeneities in performance were present across countries, management authorities, and by urban or rural facility location.
- Although national performance was generally high, room for improvement exists in terms of regional and facility readiness to deliver basic malaria services with consideration given to the specific readiness domains where facilities fall short, even in countries such as Namibia and Senegal where substantial progress has been made.
- National malaria programs may use results of this analysis to improve targeted malaria elimination efforts, and study methods may be extended to inform decision-making in developing countries for a variety of pressing health care needs.

B. ADVOCACY IMPLICATIONS

The Sustainable Development Goals era, maternal health, and combatting malaria

This dissertation is timely in that the United Nations' millennium development goal (MDG) era closed in 2015 and governments are now invested in meeting the seventeen sustainable development goals (SDGs) from their outset. Progress tracking of the MDGs related to reducing child mortality (goal 4), improving maternal health (goal 5) and combatting HIV/AIDS, malaria and other diseases (goal 6) has made it clear that much remains to be done for maternal and child health. Of 75 countries tracked, only four met both goals 4 and 5 (312). Further, although the MDG target of a 75% reduction in the

global malaria burden compared to 2000 burden was declared met in 2015 (309), coverage with IPTp and ITNs during pregnancy for most countries varied widely and fell far short of the ideal – all women receiving three or more doses of IPTp and consistently sleeping under an ITN every night (312).

The need for continued efforts is reflected in the first three targets of SDG 3: Ensure healthy lives and promote well-being for all at all ages. These relevant targets aim by 2030 to: reduce the global maternal mortality ratio, end preventable deaths of newborns and children under-five, and end the epidemics of malaria and other diseases (49). Access to quality essential health services is similarly reflected in the target of universal health coverage for SDG 3. New methods for systematically assessing quality over the course of the structure-process-outcomes continuum like those demonstrated through this dissertation are a crucial component of efforts to meet this target by 2030.

Global health architecture for maternal and child health and to address malaria

An architecture for addressing and advocating for maternal and child health as well as malaria disease issues exists in the form of global partnerships, strategies, and guidelines, and has grown over time in response to the past MDGs and the current SDGs. The multi-stakeholder movement Every Woman Every Child has expanded since the MDG era to align its efforts with the health-related SDGs. Every Woman Every Child supports and advocates WHO's roadmap for meeting maternal and child health SDG targets by 2030, the *Global Strategy for Women's, Children's and Adolescent's Health 2016-2030*. The Strategy emphasizes country ownership and takes a comprehensive approach by including recognition of and commitment to health systems strengthening and resilience including integrated service delivery, high quality services, health

workforce development, and improved monitoring, evaluation and accountability (40). Further, the need for the full spectrum of research to identify barriers and facilitators of access to quality care is identified within the Strategy.

Under the umbrella of the Roll Back Malaria (RBM) Partnership housed within WHO, there have been two action plans in line with the MDGs (Global Malaria Action Plan (GMAP) – for a malaria-free world 2008-2015) and the SDGs (Action and Investment to defeat Malaria 2016–2030 (AIM) – for a malaria-free world), respectively. Further, the WHO recently released the Global Technical Strategy for Malaria 2016–2030 (GTS). The GTS and AIM are meant to be used in tandem to accelerate country progress towards target 3.3 of the SDGs, or malaria elimination, and their shared global targets for 2030 are the sub-targets of SDG 3.3. The combined role of malaria and ANC teams in increasing ANC attendance to ensure IPTp-SP3+ is laid out in AIM, as part of its promotion of integrated service delivery (328).

Notably, an update to the WHO FANC guidelines was released in 2016. This bears consideration given the new target of eight ANC visits as opposed to four in previous guidelines (330). As coverage rates with four ANC visits and average gestational age at ANC initiation have continued to be low, the new guidelines come as both an opportunity and a challenge, where malaria and ANC teams must work together to increase ANC attendance (328) and improve the consistency and quality of care delivered.

The role of health data in meeting the Sustainable Development Goals

Support for improved measurement, data quality, a ‘common data architecture’, access and use, as well as more efficient investments began formally in 2010 by global

partnerships and the United Nations (148). It is evidenced in a variety of global commitments spearheaded by the nascent Health Data Collaborative, an informal partnership stood up in 2015 to help improve health data availability, quality and use in line with SDG health-related goals and targets, and to help partners align financial and technical resources with their shared measurement and accountability agenda. Two early endeavors include the Roadmap for Health Measurement and Accountability, designed to outline smart investments and support effective measurement and accountability systems for countries' health programs (160). A second was the development of the Global Reference List of 100 Core Health Indicators, an attempt to consolidate and streamline reporting of indicators, given the often overlapping and burdensome reporting requirements of multiple donors which national governments face (39; 148). The global health community has recognized these efforts as necessary to address data challenges and promote country ownership of interventions to improve health outcomes.

Funding environment

Malaria interventions are considered some of the most cost-effective interventions available (328; 329), with cost per case averted estimated at US $5-8 (272). Antenatal detection of intrauterine growth restriction, which can be caused by placental malaria infection, has also been shown to be a cost-effective intervention to prevent low birth weight (71). However, costs to scale-up programming in order to meet 2030 targets are extensive, estimated at US $6.4 billion annually until 2020, $7.7 billion from 2021-2025, and $8.7 billion from 2026-2030 (329). Meeting these funding needs will require continued donor engagement, as well as country ownership and contributions.

Dramatic reductions in malaria morbidity and mortality in Africa have largely been due to a ten-fold increase in international funding between 2000-2015, as well as new prevention tools and treatments (309). U.S. government bilateral aid through the President's Malaria Initiative (PMI) in 18 African countries has played an important role in these reductions (300). With the recent recognition of widespread subclinical infections (99), there is need to dramatically scale up total funding to meet elimination targets by 2030 (329). Scaled up funding through PMI continues to be an important component of total donor contributions. The PMI portfolio includes the technical areas of ITNs, MiP, and diagnosis and treatment, and cross-cutting areas of health systems strengthening, monitoring and evaluation, and social and behavior change communication, among several others. Strengthening malaria service delivery through provider training and country capacity building to monitor and evaluate progress (308) are appropriate and crucial activities under the PMI mandate which should continue to be adequately funded and scaled up.

Advocacy Recommendations

Current advocacy efforts outlined above are well on the way to reducing maternal, newborn and child morbidity and mortality. However, there are clear ways ongoing efforts could address the specific challenge of malaria in women and children. Accordingly, I make the following advocacy-oriented recommendations.

The international malaria community should:

- build a global movement spearheaded by the RBM Partnership to improve malaria curriculum and training in medical schools, other continuing education programs for formal providers, and for community health workers where

appropriate. Roll out should ensure country ownership with context-specific adaptations.

- advocate for consensus on and routine data collection of indicators of quality for MiP and ANC services under the heading of the RBM Partnership.

The U.S. President's Malaria Initiative should:

- request that Congress award an increased annual budget up from US $619 million in 2016 to an appropriate level to meet U.S. bilateral pledges and to help meet the 2030 malaria and maternal and child health targets under the SDGs, in conjunction with a second USAID program - the Maternal and Child Survival Program (MCSP) (307).
- work with MCSP to coordinate joint funding for quality improvement activities, including for provider training on pregnancy complications and malaria during prenatal, delivery and postnatal care.
- work with MCSP to continue to consistently elevate the recognition of MiP interventions and ANC for their important role in reducing early delivery, low birth weight and stillbirths.
- expand the existing operational research portfolio to fund enhanced study of best practices for:
    - integration of malaria services with primary care and sick child visits;
    - training health care providers on malaria prevention, diagnosis, and treatment;
    - community-based delivery of prevention and diagnostic services, including IPTp-SP;

    - national coordination of health programs within ministries of health (e.g. maternal health with infectious disease) or across ministries (health with education) that would be responsible for ensuring adequate service integration and performance monitoring.
- invest in countries' capacity for and ownership of performance evaluation using routinely collected DHS Program and other publicly available data, paired with methods employed in this dissertation (e.g. assessment of geographic variation using GIS; systematic, theory-derived selection of quality of care indicators) to track performance over time and space and ensure accountability. DHS surveys are implemented via ministries of health and other key stakeholders, making additional training on the use and analysis of these data at the local level a natural extension of ongoing collaborative efforts.

C. POLICY IMPLICATIONS

National policy alignment with international guidance and targets

International malaria recommendations are made to clearly lay out best clinical and programmatic practice based on available evidence, with the intent that countries consider adoption of recommendations within national policies. National malaria policy may be supplemented by national guidelines on clinical care, either as a single document for malaria generally, or as multiple documents, e.g. for IPTp administration. In 2014, Gomez et al. reviewed national malaria policy documents in 19 PMI countries in Africa, including three from my work: Kenya, Senegal, and Tanzania. Broadly, they found that

17 of 19 countries, including Kenya, Senegal and Tanzania, had national documents for IPTp-SP, and all had documents for ITN use and MiP treatment (140).

However, national policies do not always align with WHO guidance. As of World Malaria Report release in December 2016, not all countries had adopted a policy in support of ITN distribution via ANC - four countries accounted for 10% of the 61% gap in number of women reporting ANC attendance versus the number of those attending who received an ITN for 2013-2015 (331). This is similarly a challenge with respect to IPTp policy, given the recent guidance updates in 2012 (140). Gomez et al. 2014 determined there were multiple ways in which national policies in Kenya, Senegal and Tanzania did not align with international recommendations and clinical practice standards (140). To be fair, new updates may have transpired since this review took place; for example, an in-depth qualitative study of a short-list of PMI countries including Kenya and Tanzania revealed that Tanzania had updated its policy to reflect new 2012 guidelines indicating IPTp should be initiated as early as possible in the second trimester (139). Kenya's policy was still out of date in terms of IPTp initiation.

Meso-level implementation barriers outside provider control may clearly impact quality of care and IPTp and ITN delivery, for example, outdated clinical guidelines used to inform care delivery (140). I could not capture these factors directly in this work, although I attempted to address their effect indirectly in the second study by controlling for region and cluster random effects. Given findings from Gomez et al. 2014 for Kenya, Senegal and Tanzania, higher-order policy implementation challenges are likely to be partially responsible for low MiP service quality generally across these study countries. A brief review of Namibian policy in effect at time of SPA data collection in 2009 suggests

reasonable alignment with international guidance, which may have helped contribute to rapid prevalence declines, as evidenced by the recent shift from control to a policy of elimination (284). For example, delivery of IPTp-SP was laid out in both the national reproductive health and malaria policies, demonstrating integration across several streams of health programming (2; 4).

Beyond policy alignment challenges, operationalization of national policies continues to prove challenging. In 2015, among 20 reporting countries, 31% of eligible women reported receipt of three or more doses of IPTp (331). National policy roll-out at all health system levels and removal of implementation barriers can help address this coverage gap. My findings pertaining to quality and its effect on service delivery outcomes, paired with existing evidence, indicate that quality should be incorporated as a key component of national malaria and maternal health policies. This includes structural components of quality such as service readiness, and process components such as education and behavior counseling. Careful consideration for roll out of such guidance should be made, to ensure trickle down to all levels of care provision in the health system.

Quality improvement initiatives

Pay for performance pilot schemes such as results-based financing (RBF) have been widespread, if limited in scale to date. Although existing evidence of their impact is mixed and weak (324), the idea that financial reward to health facilities or providers as national policy could help improve quality of care remains intriguing. While I was unable to account for RBF programs in the second study as originally planned, crude analysis of

a maternal health RBF program in Malawi suggested there may have been a positive association with malaria service delivery outcomes.

Even if RBF eventually proves unfruitful in improving service quality in most contexts, the idea that governments could adopt policies for national quality improvement in low and middle income countries is intriguing. As I made the case for in the first study of ANC quality in Kenya, careful selection of indicators for RBF or other quality initiatives aids countries in systematically assessing improvements in service delivery. Indicator selection should be systematic, while comprehensive yet also parsimonious to ensure maximum return and to avoid placing undue burden on the health system. Countries must bear this in mind when adopting policies which call for quality improvement interventions.

Balancing informal, formal and community channels for intervention delivery

The informal care sector is increasingly being relied upon to provide malaria care. This warrants brief consideration in terms of where informal care can provide an important complement to formal, facility-based care. Broadly, the informal care sector includes a variety of unregistered or unlicensed providers and pharmacies, and, depending on the country, community health workers (CHWs). CHWs are increasingly being deliberately and systematically integrated into the health care system, as their role in serving as a trusted link between communities and the formal delivery system has long been recognized (317).

While care must be taken not to overburden CHWs with an overambitious workload (84), in many countries they have an important role in referring pregnant women and possible cases of malaria to facility-based care (55). They can be a care-

providing solution to root causes of delays in ANC attendance, such as stigma associated with early reveal of pregnancy, while simultaneously providing interventions like ITNs or IPTp privately in the home as a backup to ANC attendance (55; 139). Although formal care channels may be considered ideal, in many places national integration of community health workers into the health system can provide an important backstop and linkage between communities and care delivery, particularly where barriers to receiving IPTp or ITN are great, i.e. in terms of ANC attendance or due to poor quality of care. Thus, countries with particularly poor quality of care, low repeat ANC attendance, or late ANC initiation may wish to consider strengthening the role of community health workers in malaria service delivery. A specific example of where this has been successful with Malawi's CHWs, or Health Surveillance Assistants, who play an important role in primary health and emergency services delivery, including for malaria (186). Similarly, a series of recent studies in Burkina Faso, Nigeria and Uganda examining the WHO-recommended elements of community-based treatment guidelines indicated the ability and feasibility of CHWs to diagnose and treat malaria using RDTs (55; 84). CHWs may play an increasingly important role in contributing to high quality malaria service delivery, as has been recognized by major contributors (e.g. WHO, PMI) to the policy dialogue around engagement of and training of CHWs (55; 308).

Policy Recommendations

Given the current policy context and evidence from this dissertation, I make the following recommendations.

Sub-Saharan African countries should:

- continually strive to align national policies (e.g. maternal and reproductive health, malaria for ITN, IPTp) with international, evidence-based standards of care provision, while considering their specific context (e.g. subnational malaria endemicity).
- update malaria guidelines to align with the new ANC guidelines, and provide clear guidance to health workers on when malaria-specific interventions should be delivered during ANC.
- incorporate quality of care priorities within national malaria and maternal health policies. This includes requiring routine monitoring and evaluation, with standard indicators for tracking performance.
- as part of expansion of integrated service delivery, adopt national policies which allow for additional ITN distribution for children under-five in the mother's home via ANC channels, rather than reliance on integrated management of childhood illness or well-child visit avenues.
- Include provisions in national health workforce policies for incorporating community health workers into antenatal care and malaria referral and intervention delivery, where context-appropriate.

D. PRACTICE IMPLICATIONS

Malaria in pregnancy services integrated with the antenatal care delivery platform

ANC has been an established delivery platform for MiP services including education, counseling, and intervention delivery for almost two decades. Study findings of widespread heterogeneities in ANC quality in study one, and low MiP quality across countries and the modest effect ANC quality may have on MiP service quality in study

two reinforce the need for efforts to improve ANC service quality generally, and more specifically in relation to malaria in pregnancy. Providers' documented failure to offer ITNs or IPTp during ANC has contributed to underutilization of the ANC delivery platform and lower coverage with these interventions during pregnancy overall (331). For example, although 20% of sub-Saharan African women do not attend ANC, of the 80% who do at least once, 30% are not given IPTp (331). The reasons for this gap vary, but in the past, provider failure to deliver IPTp at all or on time has been driven by confusion over guidelines (60; 145), effectiveness concerns over growing resistance to sulphadoxine-pyrimethamine (SP) in East Africa (208), and a range of factors at the individual, organizational and systems levels, including lack of water for directly observed therapy, inability to correctly identify gestational age leading to a reliance on quickening for IPTp administration (139), stock outs and lack of supervision & monitoring of IPTp delivery (165). In a review by Hill et al. 2013, the majority of documented facilitators and barriers to providers' delivery IPTp and ITNs had to do with structural or process-related aspects of care quality, which were modifiable, and for which responsibility lay with either the provider or the facility (165). Given dissertation findings and prior evidence, efforts to improve quality of service delivery could have great impact on delivery and counseling on malaria interventions via ANC channels. As their effectiveness is well-established, this is likely to translate into positive health impacts, beyond positive service delivery improvements. There could be positive effects on the health of other children in the home as well, given findings from study two of the positive association between MiP service quality and children under-five's reported use of ITNs the night prior.

I also found substantial heterogeneities in performance sub-nationally in terms of ANC quality and its dimensions in the first study, as well as from country to country in terms of national ANC and MiP service quality in the second study. Malaria service readiness varied nationally and sub-nationally in terms of overall performance but also by domains of readiness. It seems likely that given these findings there would also be substantial subnational variation in terms of MiP quality of care.

By visualizing performance within countries either at a subnational or facility level, it is possible to identify extremes where performance improvement endeavors may need to be targeted. Alternatively, identification of high performers can aid countries in determining what facilitates better performance in either that geographic or facility location, which can inform design of targeted interventions in low performing areas. To this end, GIS mapping is a useful package of tools for visualizing performance extremes and understanding any spatial patterns that may emerge, as demonstrated in the endemicity and service readiness component of my work. There is great potential for using these types of information to strengthen health systems, as I demonstrated could be done for quality improvement and service integration aspects of health systems strengthening.

At the same time, concerted effort to ensure routine monitoring and evaluation of service delivery in terms of quality of services is necessary. The methods I employed are currently most useful to practitioners and program managers from the standpoint of baseline assessment of quality. In large part, availability of health facility survey data drives the extent to which data can be used, as facility data are collected less frequently than nationally-representative household surveys. However, the range of facility surveys

available (e.g. SARA, SPA, World Bank SDIs) and frequency of data collection has grown over the past decade. The widespread recognition of the need to ensure health systems strengthening as a cross-cutting foundation of all health outcomes improvement work may also contribute to availability and frequency of data collection. In turn, this would lead to countries' ability to monitor and evaluate service delivery trends over time, as has transpired with national reliance on nationally-representative household surveys currently for some service delivery and health surveillance information; for example, DHS surveys collecting information on where women deliver or blood draw data on HIV/AIDS prevalence.

Given relevant dissertation findings, a review of indicators included in standard facility surveys may be necessary, especially with the expansion of facility surveys on offer. Low and middle income countries are highly reliant on routine, nationally-representative survey data. The need for routine, high quality data for health systems strengthening assessments makes facility surveys and their components a valuable data source on performance. Survey indicators should be 1) standardized and coordinated across related surveys, 2) continuously reviewed and revised to maximize public health impact on current issues, and 3) incorporated into ongoing national health system evaluation. While a careful balance must be struck between parsimony from a resource standpoint and comprehensiveness of reporting, indicators selected to measure quality, as well as prioritization of specific diseases, require continuous assessment to maximize impact.

For example, through this research I identified lack of malaria case management indicators as a gap in ANC data collection. In part, this may be due to the difficulty of

measuring case management consistently for MiP or other pregnancy complications, as well as relative lack of agreement on and routine use of case management indicators. Standard case management indicators reported to WHO currently include:

- Proportion of patients with confirmed malaria who received first-line antimalarial treatment according to national policy;
- Proportion of treatments with ACTs (or other appropriate treatment according to national policy) among febrile children under-five.

This leaves a reporting gap, particularly with respect to process of managing diagnosed cases and related outcomes. For example, no indicators pertaining to tracking cases of severe malaria or its management are currently collected.

Further, a consistent set of indicators measuring quality must be available across all surveys. MiP service indicators collected during ANC observations in SPA data were fairly consistent across newer surveys indicating some coordinated effort to include a consistent set; however, there were instances where these varied. For example, I considered using 2013-14 data from Malawi, which asked whether women took cotrimoxazole to prevent malaria during pregnancy – a question which would have ideally been captured across all surveys, given this medication's use as IPTp for HIV positive women (31). The ability to assess performance in all contexts in similar fashion dictates ability to make cross-country comparisons. It is also indicative of agreement on what services are important to deliver and how to best track their delivery. This 'ideal' set of indicators should be aligned with accepted indicators of service quality. Where those do not exist, additional research and agreement is warranted. Finally, included indicators

should meet the following established SMART characteristics in that they should be: specific, measurable, achievable, relevant, and time-bound (115).

Practice Recommendations

In light of dissertation findings and in consideration of the current practice environment, I make the following recommendations.

Sub-Saharan African countries should:

- scale up ITN delivery via ANC, given this remains an underutilized delivery channel (331). Activities should include:
    - efforts to ensure stock outs are avoided;
    - education of women about ANC as a public, free source and their right to ask for a net; and
    - education of providers on the need to distribute ITNs and counsel women on their use.

The U.S. President's Malaria Initiative should:

- support newly released ANC guidelines by aligning MiP technical guidance.
- support newly released ANC guidelines by revising and scaling up offer of continuing education programs for malaria and maternal health service providers to include provider knowledge of and facility with:
    - counseling standards during ANC for pregnant women on the importance of ITN use by their children;
    - counseling on the importance of repeat ANC visits (8 total) and their ideal timing;

    - the clinical importance of delivering IPTp-SP3+ in line with the new ANC schedule;
    - identification of gestational age and use of gestational age as a marker for IPTp initiation as opposed to quickening, to ensure earlier prophylaxis initiation during pregnancy.
- in conjunction with other USAID partners including the DHS Program housed at ICF International, adapt existing facility survey tools to:
    - consistently capture data on availability of cotrimoxazole tablets;
    - differentiate between patients receiving IPTp-SP, those receiving no IPTp-SP and who are not on cotrimoxazole therapy, those on cotrimoxazole therapy and do not receive IPTp-SP, and those on cotrimoxazole who incorrectly receive IPTp-SP;
    - consistently capture data on the exact dose of folic acid routinely provided to women in malaria endemic settings;
    - consistently specify and capture data on the availability of folic acid doses.

E. RESEARCH IMPLICATIONS

Health systems research methods toward health systems strengthening

As Mills 2012 wrote, novel methods for assessing health systems strengthening efforts are needed, particularly comparative, multi-country or multi-site methods (220). Existing examples include systems effectiveness research, impact evaluation, observational studies, systematic review and comparative case studies, to name but a few. To distinguish from where these methods are used in other fields, health systems research

includes systems thinking both in terms of effects as well as inputs or influences (220). This dissertation takes a cross-contextual comparative approach, through both stratified country and cross-national comparisons.

Too often, existing data and methods are overlooked in favor of designing new studies to collect new data. On the one hand, there are times where very current data are unavoidably necessary; for example, when assessing health outcomes pre- and post-implementation of a local service delivery intervention. On the other hand, undertaking health systems research on a regional or national scale requires extensive planning, funding, and manpower inputs. Limited resources and the need for routine, consistently high-quality data mean LMICs and their development partners rely on endeavors like USAID's DHS Program to provide health indicator tracking at national scale for evidence-based decision-making (148). The methods I employed are examples of how service delivery, one of the six building blocks of a health system, can be evaluated through a health systems research lens using routinely collected data sources.

Use of existing data sources

Given limited resources and the need to improve health outcomes, a public health imperative exists: to be highly strategic in generating evidence through research. Researchers must be good stewards of data collected and funded through bilateral sources, and ensure it is utilized to its fullest potential to maximize value for money. The routine nature of publicly-funded, publicly-available data sources such as DHS population and facility-based surveys creates an opportunity to use the data beyond basic reporting functions. New, somewhat more complex methods for analyzing secondary survey data may be necessary, for example, use of multilevel modeling as demonstrated

in the second study of MiP service quality. Knowledge of management and linkage of disparate data types in data management systems may be required, for example spatial analysis as in the third study or linking facility to population survey data in the second. The cost of investing in researcher training or outside expertise in these methods compared to new data generating studies is predictably lower, making the former a reasonable, sensible choice.

As cloud-based computing, super computers, and open source data increasingly become the new normal, the imperative to harness technology and large data sources for health research will continue to grow (123). Existing "big data" provide a low-cost, potentially high-yield opportunity to inform baseline knowledge of health systems performance. Generally, they provide a snapshot of the health or service delivery situation. With multiple years of data collection and careful consideration of other health systems factors at play which may not always be captured in the data, it becomes possible to analyze trends over time. Effectively linking data from multiple sources also expands the potential to derive actionable evidence from existing data. For example, with increasing interest in transitioning to electronic health management information systems (HMIS), researchers may be able to link HMIS to routinely collected survey data to more readily study service delivery outputs and health outcomes (197).

Straightforward methods for linking large, routine service delivery data exist, as I have demonstrated. The unit of linkage may most commonly be geographic, for example indirect linkage nationally or at the region or district level as demonstrated in the second study. I also demonstrated this indirect approach by linking continuous malaria endemicity estimates to facilities to achieve the objectives of the third study. Data were

linked in a GIS, which requires geographic information such as latitude and longitude coordinates to assign endemicity values to facilities. Linking may also occur at the facility, household, or individual level if a unique identifier is available in each data set. The value of linking disparate data sets, particularly in the service delivery realm, is increasingly being recognized and used in maternal and child health-related services research. For example, a review by Do et al. 2016 found 51 of 59 eligible publications used indirect or ecologic methods to link individuals to facilities (112).

However, there are clear limits to just how far "big data" sources can be pushed in their utility. For example, as with all secondary data, studies are limited by the set of indicators that the primary stakeholders felt were important to include. What appear to the secondary data researcher to be obvious data gaps may have been created by competing priorities, country-specific context, and the challenges of selecting a comprehensive, yet finite, list of indicators that are reasonable and not burdensome to collect routinely.

Secondary studies are also limited in terms of how often data are collected and the format. In the case of this dissertation, cross-sectional survey data dictate study design and the types of conclusions that can be drawn. Even where multiple years of cross-sectional data allow for trend analyses, it is not possible to determine causality. Frequency and format of data collection and release to the public are often driven by donor priorities, although examples of repeat country-led surveys such as the SARA in Kenya do exist.

Additionally, poor data quality can constrain analyses. For example, population survey data are frequently based on participant self-report, which can be subject to

respondent or recall biases. The impact of potential bias due to data collection methods or other data quality issues must be given appropriate consideration when evaluating reliability of findings for the purposes of informing policy and practice. Efforts to ensure improved data quality are necessary, for example, as is recognized in the mandate of the Health Data Collaborative. Research outputs are only as good as their data inputs, and poor data quality has been a documented challenge in terms of country health information systems including vital statistics tracking (148).

The methodology for linking data sources is also limited in that it requires temporally-aligned data to avoid potential bias introduction. I selected household data sets collected shortly after facility data and which were temporally proximal under the operating assumption that quality of care delivered in facilities may influence use of malaria interventions. Ideally, household data collection would have followed within one year of facility data collection for each country, but secondary data constraints (e.g. year of collection, public release, inconsistent capture of necessary indicators) required compromise as with selection of the 2014 Kenya DHS year. Multi-year time gaps could bias estimates up or down with no way to be certain of the direction, although I aimed to address this challenge in aggregate through use of a pooled country model. Implementation of continuous years of geo-located SPA and DHS as in Senegal is likely to resolve temporality constraints in the future, allow for trend analyses, and make studies of causality more feasible where current single year cross-sectional data are constrained.

Finally, careful consideration is warranted when determining methods for working with multiple countries' worth of data. The study question or questions must be appropriate for the available data. Pooling data versus analyzing separately for each

country depends on factors such as the question asked, the geographic location of countries, or similarity of contextual features. I have justified use of both in studies two and three, given what I broadly hoped to demonstrate, as well as my interest in looking at national and subnational variations in performance.

Quality assessment

Ideal attributes of quality indicators are well documented in the literature (39; 189; 215; 256; 271). There has also been much discussion of quality frameworks, but little practical operationalization of these frameworks in terms of indicator selection. My first study on ANC quality in Kenya attempted to address this gap by using the WHO's quality framework to operationalize indicators of ANC across dimensions of quality, to create a quality diagnostic. In study two, I extended use of this diagnostic to assessing malaria in pregnancy service quality and in three additional countries (Namibia, Senegal, Tanzania) – demonstrating its utility for within- and cross-country performance comparisons. I also adapted it further to include mapping indicators simultaneously as either structure-, process- or outcomes-oriented. The thought was that a tool which combines frameworks will allow users to select a comprehensive set of indicators across domains and dimensions of quality simultaneously. Rather than forcing selection of a single conceptualization of quality through a single framework, it is possible to employ the two simultaneously, thereby selecting indicators to assess quality in its fullest sense. This tool may help guide thinking around selection of good quality indicators, in conjunction with ensuring SMART attributes (115). Ultimately, it is envisioned as a tool with a variety of audiences, including: researchers conducting quality research; experts aiming to reach consensus systematically on a comprehensive set of quality indicators for

subjects like malaria in pregnancy services; and by practitioners such as program managers implementing monitoring and evaluation of quality improvement interventions.

Best practices for measurement of integrated service delivery

This work has highlighted the need to define what constitutes successfully integrated services, as well as for discussion of best practices for: integrating services, monitoring and evaluation of integration, and measurement of successful integration. Although integration has been used in limited service areas for some time, i.e. during ANC with incorporation of malaria and HIV/AIDS services, the recent increased attention from practitioners, policymakers and donors desiring expanded service integration throughout essential primary health care will require consideration of the challenges noted above. Although integration holds great promise, it will require careful planning, implementation, and ongoing evaluation. This will ensure service synergies are realized and that the act of integrating services does not inadvertently result in a loss of quality as compared to standalone service delivery.

Research Recommendations

In light of dissertation findings and the current research context, I make the following research recommendations.

Donors should:

- continue to fund capacity building for LMIC researchers in the areas of malaria and health systems research and policy, with prioritization of small grant money for recent graduates of donor-funded training programs, to allow local researchers to contribute to the necessary malaria evidence base and apply newly-acquired research skills. This should

encourage country capacity and ownership of high quality malaria evidence-generation.

- prioritize funding of malaria and antenatal care research which links HMIS data to routine surveillance data and to primary data collection, to ensure that the recognized importance of facility-based information becomes a reality (329).

The malaria service delivery and health systems research communities should:

- prioritize study of malaria service delivery quality through public and private health management authorities, with special attention paid to quality of care delivered by faith-based organizations given an evidence-base is largely lacking (247).
- prioritize study of integrated service delivery and best practices for its assessment, through both formal and informal mechanisms. Where secondary data limits are reached (e.g. data are not routinely collected on community-based care), impact evaluation and other mechanisms for evaluating a causal relationship in the context of specific intervention delivery are warranted.

F. FUTURE DIRECTIONS

Improvements to methods for measuring quality of care

Given the implications of this work, reflection on ways to improve and/or extend it are also warranted. With regard to assessment of quality, additional work could be done to fine-tune quality scores. I developed a diagnostic tool in study one as a proof of concept and demonstrated its evolution in terms of practical applications in study two.

This tool was used to create two quality scores for ANC and MiP. However, my co-authors and I from study one noted that the ANC score was strategically structural in terms of indicator inclusion, in order to maximize data strength given indicators came from a facility audit as well as ANC observations. This was reasonable given the wide range of ANC indicators available from the audit. One of the primary objectives of the second study differed from the first in that I sought to maximize the range of quality dimensions and domains represented by MiP service quality indicators. The emphasis of MiP interventions on counseling and education delivered during ANC necessitated heavier selection of process-oriented indicators from ANC observation data.

I had originally intended to evaluate the reliability and validity of these scores. Initial results from reliability testing using Cronbach's alpha indicated the ANC quality score was less reliable than ideal (alpha=0.5343), but the MiP quality score was reasonably reliable (alpha=0.7470), based on a cut-off of alpha=0.70 (107). I also attempted to validate the scores using SPA data and several procedures: confirmatory factor analysis (CFA) based on path diagrams, exploratory factor analysis (EFA), and finally principal components analysis (PCA). The higher-order CFA models proved to be complex and would not converge in Stata. Reasons for convergence failure are unknown, but may have had to do with the complexity of a three-level model, mixed indicator format where indicators could be dichotomous or continuous resulting in a polychoric correlation matrix, or even Stata modeling capacity constraints, as higher-order CFAs are a fairly new addition to Stata. I then attempted to use factor loading results of an EFA, but the results did not support my original hypotheses. Finally, I ran several PCA models using a rotated oblique matrix. Although five major factors emerged which could have

resembled the five quality dimensions from the WHO framework, complicated cross-loadings of indicators did not make this a useful form of validation. This was not entirely unexpected, given I had identified sub-domains in thee mapping process from study one, and correlated quality dimensions and indicators in the original path diagrams for the CFA. Consequently, I abandoned efforts to validate and test the reliability of the two scores, and kept the scores as originally derived from theory.

The scores and the underlying validity and reliability tests were all based on mapping indicators to five dimensions of the WHO quality framework. However, I could have chosen to construct a score based on the Donabedian framework. Indeed, results of the EFA began to suggest that factors may have tended to clump together according to how they were measured instead of by content, i.e. whether they were structural measures taken from the facility audit or process measures largely from ANC observations and client exit interviews, versus whether they assessed safety or effectiveness.

Future work could examine this further, in an effort to fine-tune the ANC and MiP quality scores. It might prove fruitful to construct scores according to a structure-process-outcomes framework and then use these to predict uptake and use of malaria interventions. Alternatively, I could look at the utility of single components of service quality (i.e. structure, process) for predicting intervention outcomes. Finally, I could use PCA results to create a single factor score and then use this in models as a measure of quality, to predict malaria intervention use. These methods could be compared to determine a best practice for ANC and MiP quality assessment, at least in terms of these data. Ultimately, I elected not to do these comparative analyses given the original intent of this dissertation was not to determine the best method for measuring quality, but to

propose a reasonable proof of concept tool, which could then be extended and modified as necessary. Further work to adapt these methods would potentially be of high value, where consensus on a consistent, systematic method for measuring quality has yet to be reached.

Opportunities to extend study methods for health systems evidence generation

I demonstrated extension of the quality diagnostic tool from study one to a related assessment of quality of ANC and MiP in study two. In similar fashion, this tool can be used to assess quality of integrated malaria services with childhood immunization services, another existing platform for delivery of ITNs which may be related to childhood ITN use and which should predict other outcomes captured via household survey such as whether a diagnostic was used to confirm cause of fever in children under-five. Further, findings with regard to MiP service quality and childhood ITN use indicate the potential for ANC impacts on other household members via mothers. Future research might also explore other indirect outcomes of ANC, such as mothers' care-seeking practices for febrile infants and children. The quality diagnostic tool is not limited to ANC or malaria service delivery; instead, it can be used to select quality indicators for services with routine data to look at a range of related outcomes – for example, HIV/AIDS services.

This work may also be extended to other types of studies, in the sense that research methods from studies two and three for linking disparate data sources such as routine surveillance data to survey data can provide invaluable information for public health policy and programmatic decision-making. For example, I am employing geographic linking in a U.S. Center for Disease Prevention and Control-funded study on

imported malaria in immigrant communities using U.S. surveillance data and American Community Survey data. The latter is an annual supplement to the U.S. Census which includes demographic data, and the former is available from state health departments. Geographically linked data on physicians and pharmacies are also included, to identify drivers of imported malaria and potential gaps in accessing services in terms of geographic proximity. Health systems research on malaria service delivery continues to be a priority for all countries, not just LMICs. Aspects of the methods demonstrated in this dissertation may importantly contribute to the malaria service delivery evidence base in a variety of contexts.

G. CONCLUDING THOUGHTS

This dissertation has highlighted the need for and challenges related to systematic and comprehensive quality measurement in health services delivery and health systems research. Service quality was examined through the lens of health systems strengthening and as a multi-dimensional, multi-domain concept. This work also demonstrated a range of methods for linking large secondary data to inform assessment of health system performance, in terms of quality as well as integrated service delivery, both within and across countries.

Through the three studies comprising this dissertation, I attempted to improve understanding of the role of quality in delivery of antenatal and malaria services. The next phase of combatting malaria is aimed at elimination, and will require sustained, high quality interventions including preventive and treatment services, which engage all aspects of the health system. Although this work has primarily focused on health facility-delivered care, quality service delivery must transpire in all sectors. Innovations in

integrated care through communities such as integrated community case management or facility-based primary health care are going to continue to be important prongs of service delivery, in tandem with mass distribution and treatment campaigns.

This work has been but a small component of a much broader endeavor to rid humanity of one of its oldest scourges. Great progress in reducing the burden of malaria has been made under the first Millennium Development Goals, yet great efforts are still needed if we are to reach malaria elimination by 2030 under the Sustainable Development Goals. Continued cross-cutting health systems strengthening activities such as quality improvement, service integration, and monitoring and evaluation are integral to realizing the maternal, child health and malaria targets laid out under the SDGs, and will result in millions of deaths averted.

APPENDICES

APPENDIX A1. QUALITY OF CARE DIMENSIONS WITH CORRESPONDING INDICATORS

Table A1.1 below depicts the mapping of indicators built from the SPA against quality of care dimensions, indicator components, whether and how the indicator was adapted to fit available data, and whether the indicator is a results-based financing (RBF) indicator. In several cases, I adapted indicators from the literature to the Kenya SPA based on data available. Of 14 total indicators, I constructed 3 from the ANC observation/exit interview data, 10 from the facility audit, and 1 jointly from the facility audit and health care worker interview. I identified general ANC indicators from the ANC quality of care literature. I also identified ANC indicators from the results-based financing literature; these are primarily categorical due to their use in calculating composite indices and overall facility score with a dollar amount tied to performance in RBF, e.g. assured privacy during ANC consult. Facilities received an overall score of 0 or 1 for these indicators, as well as whether a health facility is equipped with the medications and supplies necessary to provide evidence-based essential maternal health care. Other indicators (e.g. ANC key services score, ANC readiness score, physical examination score) were coded continuously from 0 to 1 based on an overall score calculated as a simple average of the indicator components. I standardized the indicator 'total days of ANC services per month', which was based on a 28-day month, on a 0 to 1 scale. Standardization was necessary in order to ensure indicators could be combined as components of the respective quality of care dimensions.

Table A1.1. Quality of Care Dimensions with Corresponding Indicators									
Dimension	**Indicator**	**Numerator**	**Denominator**	**Key Components/ Notes**	**Adaptations**	**% Missing**	**SPA[1] Tool**	**RBF[2]**	**Source**
Effectiveness						**53%**			
	Mean % score of ANC key services	Sum of all % scores for key services for a facility.	Total number of key services included in indicator (9).	Weight, blood pressure, protein in urine, anemia, family planning counseling, tetanus toxoid counseling, intermittent preventive treatment of malaria in pregnancy counseling; HIV counseling & testing.	HIV counseling and testing combined from two different SPA questions.	14%	FA		3
	Facility physical exam score for first time ANC visits	Sum of physical exam scores for observed first ANC visits. Exam with all elements =1; exam missing any element=0.	Total count of first ANC visits observed at each facility.	Required services: weight, blood pressure, breast examination, check for edema.	Height measurement excluded due to unavailability from SPA. Adapted from original indicator requiring 5 new first-ANC visit registrant observations; SPA observation data were not sampled in this manner.	49%	O	Yes	4, 5
Efficiency						**28%**			
	Pre-ANC consultation services score	Sum of individual service scores. Presence of each service=1, absence=0. Total possible: 5 points.	Total number of services (5).	Pre-ANC consult services: weight, blood pressure, protein in urine, anemia, group education class.		14%	FA		6, 7
	Whether family planning (FP) counseling is routinely conducted during ANC visit	FP counseling routinely offered during ANC services=1, otherwise=0.	N/A			0%	FA		8, 9

	ANC service readiness	Sum of composite scores from tracer items across readiness domains. Possible domain score: 1=all items present; 0= items missing. Total possible: 4 points.	Total number of domains (4).	Domain 1: Staff & guidelines; Tracers: ANC Guidelines; Staff trained in ANC Domain 2: Equipment; Tracers: Blood pressure apparatus Domain 3: Diagnostics; Tracers: Haemoglobin test; Urine dipstick protein test Domain 4: Medicines & commodities; Tracers: iron; folic acid; tetanus vaccine.	Tests and medications coded as present if observed or reported as available on day of survey. Folate, iron, and tetanus vaccine must be available in ANC service area, a nearby room, and/or the pharmacy.	17%	FA, H		10, 11, 12
Accessibility						**33%**			
	Number of days per month ANC services are provided	Sum of days per month ANC services provided.	Total number of days in a month (28).	Uses a 4-week (28 day) month.		0%	FA		13
	Availability of folic acid on day of interview	Folic acid observed as present on day of survey visit=1; not present=0.	N/A	At least 1 valid (unexpired) folic acid tablet available.	Folic acid tablets could be available in the ANC service area or pharmacy. Presence of combined folic acid/iron tablets was also sufficient.	3%	FA		14
	Available and functional ANC equipment and supplies score	All materials available and functional=1; one material lacking or non-functional=0.	N/A	Available and functional equipment and supplies: consultation table, blood pressure cuff, stethoscope, scale, fetoscope, disposable gloves.	Excluded tape measure; substituted scale for scale with a height gauge; substituted disposable latex gloves (clean/sterile) for unused, non-torn surgical gloves.	0%	FA	Yes	4
	Availability of medications/supplies necessary to provide evidence-based essential maternal health care	All items available=1; One item missing=0.	N/A	Tracer items: Iron supplementation, syphilis screening.	Iron supplementation includes iron tablets as well as combined folic acid/iron tablets.	31%	FA		15
Acceptability/ Patient-centeredness						**31%**			

	Availability of visual aids for client education related to pregnancy/ ANC	Visual aid available in the ANC service area=1, otherwise=0.	N/A			<1%	FA		3
	Patient satisfaction	Sum of all satisfaction scores for a facility.	Number of ANC interviews at a facility.			31%	E		16
	Assured privacy during ANC consult	Individual or shared room with assured privacy for ANC services at ANC facility=1, otherwise=0.	N/A		Original indicator calls for doors that close &individual consult room with curtains or painted windows, OR a shared room with divider. These data are not captured in SPA; substituted questions on auditory and visual privacy.	0%	FA	Yes	4
Safety						**46%**			
	Infection prevention score	Sum of composite scores from tracer items across infection prevention domains. Possible domain score: 1=all items present; 0= items missing. Total possible: 4 points.	Total number of domains (4)	Domain 1: Waste management; Tracers: wastebin (acceptable=with lid and plastic liner); sharps box. Domain 2: Cleaning and disinfection; Tracers: general disinfectant. Domain 3: Aseptic technique; Tracers: Syringes; needles; sterile gloves. Domain 4: Hand hygiene; Tracers: running water; soap/hand disinfectant; single use towels/hand dryer.	Adapted to data available from SPA. Items relevant for ANC related infection prevention which are not captured in SPA data include: sinks or basins, cleaning fluids, cleaning equipment.	23%	FA		18

	ANC visit conducted by qualified provider	Sum of provider scores for observed ANC visits. Exam with qualified provider=1; otherwise=0.	Total count of ANC visits observed at each facility	Qualified ANC provider: specialist, medical officer, clinical officer, BSN nurse, registered nurse, registered midwife, enrolled nurse, enrolled midwife.	Original RBF indicator for Nigerian context & required verification on ANC card. Adapted to Kenyan context based on accepted Kenyan standards for qualified ANC providers; not verified on ANC card.	29%	O	Yes	17
Overall ANC quality of care score						**74%**			

1. SPA: Service Provision Assessment; FA: Facility audit; O: ANC observation; E: ANC Client exit interview; H: Healthcare worker interview.
2. RBF: results-based financing.
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APPENDIX A2. MEANS, MEDIANS AND INTER-QUARTILE RANGES FOR FIGURE 6

Table A2.1 replicates the medians shown in Figure 6 (main document) and adds the means and interquartile ranges.

Table A2.1. Mean, median and interquartile range of quality dimensions by province, facility type and management authority

	Total	Province (n)								Facility type (n)				Management authority (n)		
	(n=144)	Nairobi (7)	Central (20)	Coast (14)	Eastern (19)	North Eastern (9)	Nyanza (16)	Rift valley (26)	Western (33)	National/ Provincial Hospitals (6)	District/ Sub-District/ Other Hospitals (92)	Health center/ Clinic (30)	Dispensary/ Maternity (16)	Public (113)	Private for Profit (9)	Faith-based (22)
Effectiveness																
Median	0.55	0.88	0.97	0.50	0.71	0.50	0.50	0.64	0.56	0.83	0.50	0.68	0.50	0.50	0.88	0.78
Mean	0.67	0.72	0.82	0.57	0.73	0.51	0.63	0.67	0.63	0.79	0.66	0.70	0.65	0.65	0.76	0.73
p25	0.50	0.44	0.58	0.44	0.50	0.38	0.50	0.50	0.50	0.60	0.50	0.50	0.44	0.50	0.50	0.50
p75	0.94	0.94	1.00	0.67	1.00	0.50	0.83	0.94	0.75	1.00	0.94	1.00	0.97	0.90	1.00	1.00
Efficiency																
Median	0.92	0.81	0.93	0.93	0.92	0.92	0.94	0.90	0.88	0.97	0.90	0.92	0.94	0.92	0.89	0.94
Mean	0.84	0.81	0.87	0.87	0.86	0.88	0.93	0.82	0.78	0.97	0.83	0.88	0.81	0.85	0.83	0.83
p25	0.78	0.65	0.84	0.92	0.74	0.79	0.91	0.75	0.64	0.94	0.77	0.82	0.71	0.81	0.74	0.65
p75	0.96	0.96	0.97	0.96	0.96	0.93	0.98	0.96	0.95	1.00	0.95	0.98	0.97	0.96	0.93	0.98
Accessibility																
Median	0.68	0.79	0.93	0.68	0.68	0.93	0.73	0.68	0.68	0.80	0.68	0.77	0.93	0.68	0.86	0.93
Mean	0.71	0.80	0.83	0.66	0.74	0.82	0.65	0.72	0.63	0.80	0.70	0.70	0.75	0.66	0.88	0.89
p25	0.68	0.68	0.68	0.43	0.68	0.68	0.43	0.57	0.43	0.68	0.68	0.43	0.46	0.50	0.79	0.93
p75	0.93	1.00	0.93	0.93	0.93	0.93	0.93	0.93	0.68	0.93	0.93	0.93	0.93	0.93	1.00	0.93
Acceptability / Patient-Centeredness																
Median	1.00	1.00	1.00	1.00	1.00	0.67	1.00	0.75	1.00	0.83	1.00	1.00	1.00	1.00	1.00	1.00
Mean	0.88	1.00	0.86	0.98	0.90	0.63	0.90	0.79	0.92	0.83	0.87	0.89	0.89	0.87	0.91	0.89
p25	0.67	1.00	0.67	1.00	0.83	0.50	0.75	0.67	0.83	0.67	0.67	0.83	0.67	0.67	0.83	0.67
p75	1.00	1.00	1.00	1.00	1.00	0.67	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Safety																

Median	0.75	0.88	0.88	0.75	0.75	0.75	0.75	0.75	0.75	0.81	0.75	0.75	0.75	0.75	0.88	0.81
Mean	0.78	0.82	0.87	0.79	0.74	0.74	0.67	0.78	0.79	0.83	0.78	0.75	0.78	0.77	0.82	0.77
p25	0.75	0.75	0.88	0.75	0.63	0.75	0.63	0.75	0.75	0.75	0.75	0.63	0.75	0.75	0.75	0.75
p75	0.88	0.88	0.88	0.88	0.88	0.75	0.81	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88

APPENDIX A3. RESULTS FROM THE MISSINGNESS ANALYSES.

Results from the missing analyses are presented below in Tables A3.1 and A3.2.

Table A3.1. Predictors of missing data in multivariate regressions for all eligible facilities, by domain.

	(1) Overall	(2) Effectiveness	(3) Efficiency	(4) Accessibility	(5) Acceptability	(6) Safety
Facility type (omitted: national/provincial hospital)						
District/Sub-District/Other Hospitals	-0.19	-0.16	-0.07	-0.11***	-0.02	0.10
	(0.16)	(0.11)	(0.04)	(0.04)	(0.04)	(0.16)
Health Centers/Clinics	-0.32*	-0.33***	-0.13**	-0.28***	-0.09	0.03
	(0.16)	(0.12)	(0.06)	(0.06)	(0.05)	(0.16)
Dispensaries/Maternities	-0.43***	-0.35***	-0.19***	-0.46***	-0.19***	-0.04
	(0.16)	(0.12)	(0.06)	(0.06)	(0.06)	(0.16)
Management authority (omitted: public)						
Private for Profit	-0.21***	-0.29***	-0.14**	0.01	-0.29***	-0.25***
	(0.04)	(0.05)	(0.05)	(0.05)	(0.05)	(0.06)
Mission/Faith-Based	-0.07	-0.10*	0.02	0.14***	-0.15***	-0.16**
	(0.06)	(0.06)	(0.05)	(0.05)	(0.05)	(0.06)
Province (omitted: Nairobi)						
Central	0.00	-0.14*	-0.04	0.06	-0.25***	-0.04
	(0.07)	(0.08)	(0.08)	(0.08)	(0.08)	(0.09)
Coast	0.00	-0.04	-0.10	0.10	-0.16**	0.01
	(0.07)	(0.09)	(0.09)	(0.08)	(0.08)	(0.09)
Eastern	-0.01	-0.03	-0.06	0.00	-0.06	0.06
	(0.08)	(0.09)	(0.08)	(0.08)	(0.08)	(0.09)
Northeastern	-0.06	-0.14	-0.11	-0.14	-0.24***	0.08
	(0.08)	(0.10)	(0.09)	(0.10)	(0.09)	(0.10)
Nyanza	-0.02	-0.02	-0.22***	-0.04	-0.04	0.08
	(0.07)	(0.09)	(0.08)	(0.08)	(0.08)	(0.09)
Rift Valley	0.10	-0.02	0.09	0.05	-0.07	0.11

	(0.07)	(0.08)	(0.07)	(0.08)	(0.08)	(0.09)
Western	0.14**	0.17**	0.00	0.02	0.00	0.22**
	(0.07)	(0.08)	(0.08)	(0.08)	(0.08)	(0.09)
Other covariates						
ANC offered on survey day (0=no; 1=yes)	0.17***	0.25***	0.11	0.04	0.37***	0.39***
	(0.04)	(0.06)	(0.07)	(0.06)	(0.07)	(0.06)
Catchment size estimated (0=no; 1=yes)	0.07*	0.09*	0.15***	-0.05	0.09*	0.07
	(0.04)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)
Generator: yes, functional	0.02	0.06	0.15***	0.11**	0.11***	0.04
	(0.05)	(0.05)	(0.05)	(0.05)	(0.04)	(0.05)
Generator: yes, but some issue	0.04	-0.05	0.11	0.10	0.01	-0.02
	(0.07)	(0.08)	(0.07)	(0.07)	(0.06)	(0.08)
Regular management meetings (0=no; 1=yes)	0.08*	0.12**	0.06	0.21***	0.19***	0.13**
	(0.04)	(0.05)	(0.06)	(0.06)	(0.06)	(0.06)
	0.31*	0.42**	0.61***	0.67***	0.37***	-0.01
	(0.18)	(0.17)	(0.12)	(0.11)	(0.11)	(0.19)
Mean of outcome variable	0.26	0.47	0.72	0.67	0.69	0.54
R2	0.21	0.24	0.18	0.26	0.31	0.21
N	545	545	545	545	545	545

** p<0.10, ** p<0.05, *** p<0.01*

Note: Coefficients (marginal effects) from OLS regression on binary indicator of whether the facility does (=1) or does not (=0) have data. Robust standard errors in parenthesis.

Table A3.2. Comparison of facilities with or without complete data for all domains, by domain.

	Facilities with complete data for all domains			Facilities with some missing data across all domains			Difference in means	p-value
	Mean	**N**	**S.D.**	**Mean**	**N**	**S.D.**		
Effectiveness	0.67	144	0.24	0.67	257	0.25	0.00	0.95
Efficiency	0.84	144	0.17	0.82	394	0.17	0.03	0.10
Accessibility	0.71	144	0.21	0.75	364	0.22	-0.04	0.10
Acceptability / Patient-Centeredness	0.88	144	0.18	0.86	376	0.18	0.02	0.36
Safety	0.78	144	0.14	0.76	294	0.14	0.01	0.31

Note: Results from t-tests comparing the mean values of the subset of facilities with quality measures for all domains versus the larger set of facilities with complete data for the specific dimension tested but missing data for alone or more of the other dimensions.

APPENDIX B1. QUALITY INDICATOR MAPPING METHODS AND RESULTS

To guide comprehensive and systematic selection of quality indicators, I constructed a theory-derived quality tool. The tool aligns quality frameworks of the World Health Organization (WHO)[1] and Donabedian,[2] which characterize quality as a multidimensional and multi-domain concept, respectively. I used the tool in conjunction with previously described methods of Lee et al. 2016[3] to review the literature, map indicators to the tool, and systematically select parsimonious sets of quality indicators for MiP services delivered during ANC and ANC quality generally. The tool includes structure, process, and outcomes domains down the left-hand side, and six quality dimensions of effectiveness, efficiency, accessibility, acceptability/patient-centeredness, safety, and equity across the top. Indicators were either categorical or continuous and fell into both a domain and a dimension of quality. I aimed to qualitatively ensure a minimum of 2-3 indicators per dimension, and at least one indicator per domain, where feasible. I constructed Lee et al. 2016's ANC quality score for each facility as an unweighted average of indicators within each of five dimensions excluding equity, and then overall on a continuous scale of 0 to 100. Of the original ANC quality score indicators, I excluded patient satisfaction with ANC quality which was not available for Tanzania. I followed the same procedure to construct the MiP service quality score. I noted no indicators specifically measuring the dimension of equity.

17 indicators of MiP service quality and 13 indicators of ANC quality were selected using the quality tool (Figure 7 and Appendix B3).[3] Although overall quality scores included a range of structural and process measures to ensure comprehensive assessment, results of the initial tool mapping for MiP quality indicated a relatively more robust emphasis on capture of process measures compared to structural in SPA data. By

contrast, previously published ANC quality indicators were deliberately structural.[3] Structural barriers such as stock-outs and user fees, as well as process barriers such as failure to routinely deliver IPTp as part of antenatal care can have direct effect on receipt of IPTp and dosing,[4] and where possible, I considered inclusion of measures of these barriers. Additionally, process-related barriers and facilitators to provision of care as measured through IPTp uptake include general and specific (e.g. IPTp timing, efficacy and safety) provider training, correct trimester identification, and easy to understand training materials.[5-9] Although many of these factors are not captured in SPA data, I included two indicators of training on IPTp and pregnancy complications.

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APPENDIX B2. MULTILEVEL MODELING METHODS, RATIONALE, AND INTERACTION TESTING

DHS data were multilevel at the individual, cluster and region levels, meaning observations within groups were likely to be correlated. Study outcomes were nonrare and dichotomous. As odds ratios are best for approximating risk ratios when the outcome is rare, I employed a suitable alternative: modified Poisson regression. I calculated crude effects using modified Poisson regression with robust error variance, which estimates risk, avoids overestimation of error by using a sandwich estimator, and is a suitable approach for non-rare outcomes.[1]

Modified Poisson regression can also be extended to multilevel data in Stata 14.0. For the adjusted models, I first built three empty models with random effects only to determine whether for each outcome a two- or three-level model was most suitable, based on the level of variation present at region and cluster levels. I then built three adjusted mixed effects multilevel modified Poisson models with robust variance estimation and random effects at the cluster and region levels for pooled data to test the relationship between ANC and MiP service quality scores with each outcome of interest.

I reweighted countries equally in pooled models using probability weights for mother or child as appropriate, to avoid any single country overly-contributing to results. It was not possible to account for survey design using the 'svy' suite of Stata commands as DHS data include probability weights at the individual level only. Multilevel modeling of complex survey data requires weights at the cluster level and re-weighting of lower weight levels in relation to those at higher levels.[2] I instead employed probability weights with standard multilevel modeling with robust variance estimation and adjusted for

residence location in every model irrespective of significance, to account for stratified survey design.[3]

I also considered multiplicative interactions as appropriate for multilevel models by generating the interaction term in advance and examining effect with each component of the interaction term included. To avoid multicollinearity between interaction terms and continuous variables of interest, I mean-centered continuous variables including for MiP and ANC quality, and used the mean-centered form(s) to generate interaction terms. Once a variable was mean-centered, I used this form in every model to ensure comparability and consistency of approach. I used an alpha=0.10 cut-off for interaction inclusion in adjusted models. Both linear and nonlinear associations were explored. Nonlinear main effects and interactions were modeled using fractional polynomials as implemented in the STATA user-written program 'mfpigen' (270). For statistically significant interaction terms, I also graphed the adjusted term to visually assess its effect. This was particularly important for continuous by continuous interaction terms using fractional polynomial terms, as the extent of nonlinear relationships, or lack thereof, may not be apparent from a coefficient and confidence interval alone.[4]

I used pooled findings to evaluate relationships of interest for the entire sub-Saharan African region where malaria is endemic, under the assumption that study countries are randomly drawn from and are representative of the region's population. Multilevel, mixed effects models with dichotomous outcomes require sufficient sample size not only at the individual level but at higher group levels.[5] I met these requirements using a combination of effect size estimation for fixed effects Poisson models using reasonable effect sizes for social science research ranging from 1.5 to 2.0, and rule of

thumb guidance to ensure sufficient sample size at each model level and for linear regression.[6-8]

However, I also conducted and reported a priori stratified country analyses, using individual probability weights divided by 1,000,000 in country models and following DHS guidance. These were meant to be hypothesis-generating and thus exploratory in nature. I felt it was important to do so given likely heterogeneities in country-specific contexts that may affect service quality due to a range of factors (e.g. governance structure, funding, programming). For example, differences in the epidemiological trend for malaria over time could affect country performance in terms of quality of care. Comparing pooled to country findings can also help support stratified country findings based on smaller sample sizes.

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APPENDIX B3. MAPPING OF ANTENATAL CARE QUALITY INDICATORS TO COMBINED QUALITY FRAMEWORK TOOL

I mapped Lee et al. 2016's indicators of antenatal care quality to my adapted quality framework tool. Greyed out indicators were not included in the final quality score due to unavailability in all country data.

		World Health Organization Framework					
		Effectiveness	**Efficiency**	**Accessibility**	**Acceptability/ Patient-centeredness**	**Safety**	**Equity**
Donabedian Framework	**Structure**	- Mean percent score of ANC key services offered.	- ANC service readiness. - Whether family planning counseling is routinely conducted during ANC visit.	- Number of days per month ANC services are provided. - Availability of folic acid on day of interview. - Available and functional ANC equipment and supplies score. - Availability of medications/supplies necessary to provide evidence-based essential maternal health care.	- Availability of visual aids for client education. related to pregnancy/ ANC	- Infection prevention score. - ANC visit conducted by qualified provider.	-
	Process	- Physical exam score for services observed during first time ANC visits.	- Pre-ANC consultation services score (services observed).	-	- Assured privacy during ANC consult.	-	-
	Outcome	-	-	-	- Patient satisfaction	-	-

Abbreviations: ANC – antenatal care.

APPENDIX B4. UNWEIGHTED CHARACTERISTICS OF SURVEYED INDIVIDUALS, CLUSTERS, AND REGIONS BY OUTCOME

Table B4.1. Unweighted characteristics of surveyed individuals, clusters, and regions included in the intermittent preventive treatment in pregnancy analysis.

Variables	Total (n=15175) n (%)/ median (IQR)	Kenya (n=7861) n (%)/ median (IQR)	Namibia (n=1639) n (%)/ median (IQR)	Senegal (n=2682) n (%)/ median (IQR)	Tanzania (n=2993) n (%)/ median (IQR)
Level 1 - Individual					
IPTp uptake during pregnancy (yes)	3516 (23.17)	1409 (17.92)	69 (4.21)	1048 (39.08)	990 (33.08)
Mother's age in years	27 (22, 32)	26 (22, 31)	27 (22, 33)	27 (23, 33)	27 (23, 33)
Mother's education (none)	4422 (29.14)	1681 (21.38)	123 (7.50)	1865 (69.54)	753 (25.16)
Primary	6850 (45.14)	4054 (51.57)	386 (23.55)	555 (20.69)	1855 (61.98)
Secondary or higher	3903 (25.72)	2126 (27.04)	1130 (68.94)	262 (9.77)	385 (12.86)
Parity	3 (2, 5)	3 (2, 5)	2 (1, 4)	3 (2, 5)	3 (2, 5)
Number of ANC visits during last live birth	4 (3, 5)	4 (3, 5)	5 (4, 7)	3 (2, 4)	3 (3, 4)
Household wealth quintile (poorest)	4488 (29.57)	2765 (35.17)	362 (22.09)	761 (28.37)	600 (20.05)
Poorer	3328 (21.93)	1605 (20.42)	343 (20.93)	696 (25.95)	684 (22.85)
Middle	2857 (18.83)	1300 (16.54)	359 (21.90)	578 (21.55)	620 (20.72)
Richer	2489 (16.40)	1153 (14.67)	333 (20.32)	385 (14.35)	618 (20.65)
Richest	2013 (13.27)	1038 (13.20)	242 (14.77)	262 (9.77)	471 (15.74)
Household size	6 (4, 9)	5 (4, 7)	6 (4, 8)	13 (9, 19)	6 (5, 9)
Level 2 - Survey cluster					
Survey administered during malaria season (yes)	10336 (68.11)	5006 (63.68)	1101 (61.68)	1326 (49.44)	2993 (100.00)
Malaria endemicity	6.69 (2.84, 13.03)	9.02 (4.50, 18.91)	5.17 (0.00,7.64)	2.54 (2.05, 3.69)	7.13 (4.34, 13.68)
Residence location (urban)	4615 (30.41)	2539 (32.30)	729 (44.48)	784 (29.23)	563 (18.81)
Level 3 - Region					
Antenatal care quality	74.56 (70.03, 76.90)	76.32 (74.56, 79.18)	73.05 (69.59, 74.35)	73.56 (71.23, 76.64)	57.83 (53.70, 63.26)
Malaria in pregnancy quality	52.94 (41.94, 54.51)	54.47 (53.32, 54.51)	30.18 (16.95, 35.64)	44.51 (42.81, 47.05)	42.26 (38.97, 46.33)
Facility density per 1,000,000 population	14.62 (9.02, 20.96)	12.01 (6.41, 14.64)	131.14 (86.12, 184.40)	24.60 (20.53, 32.14)	9.30 (6.48, 13.91)
Prevalence of HIV in women 15-49 years	6.3 (2.4, 8.5)	6.3 (5.8, 9.2)	15 (12.2, 20.3)	1.2 (0.5, 1.8)	5.7 (2.3, 7.4)

Abbreviations: n- count; IQR- interquartile range; IPTp – intermittent preventive treatment in pregnancy.

Table B4.2. Unweighted characteristics of surveyed individuals, clusters, and regions included in the insecticide treated net use in pregnancy analysis.

Variables	Total (n=2378) n (%)/ median (IQR)	Kenya (n=662) n (%)/ median (IQR)	Namibia (n=207) n (%)/ median (IQR)	Senegal (n=729) n (%)/ median (IQR)	Tanzania (n=780) n (%)/ median (IQR)
Level 1 - Individual					
ITN use the night prior in pregnancy (yes)	1408 (59.21)	470 (71.00)	23 (11.11)	400 (54.87)	515 (66.03)
Mother's age in years	26 (22, 31)	26 (22, 31)	26 (21, 33)	26 (22, 32)	26 (22, 31)
Mother's education (none)	827 (34.78)	103 (15.56)	22 (10.63)	507 (69.55)	195 (25.00)
Primary	1012 (42.56)	339 (51.21)	43 (20.77)	150 (20.58)	480 (61.54)
Secondary or higher	539 (22.67)	220 (33.23)	142 (68.60)	72 (9.88)	105 (13.46)
Parity	2 (1, 4)	2 (1, 3)	1 (0, 3)	2 (1, 4)	2 (1, 4)
Gestational age	5 (3, 7)	5 (3, 7)	6 (4, 7)	6 (4, 7)	5 (3, 7)
Household wealth quintile (poorest)	545 (22.92)	170 (25.68)	40 (19.32)	218 (29.90)	117 (15.00)
Poorer	578 (24.31)	145 (21.90)	51 (24.64)	185 (25.38)	197 (25.26)
Middle	507 (21.32)	122 (18.43)	44 (21.26)	156 (21.40)	185 (23.72)
Richer	460 (19.34)	123 (18.58)	55 (26.57)	108 (14.81)	174 (22.31)
Richest	288 (12.11)	102 (15.41)	17 (8.21)	62 (8.50)	107 (13.72)
Household size	6 (4, 11)	4 (3, 6)	5 (4, 8)	13 (9, 18)	6 (4, 9)
Level 2 - Survey cluster					
Survey administered during malaria season (yes)	1791 (75.32)	477 (72.05)	165 (79.71)	369 (50.62)	780 (100.00)
Malaria endemicity	6.16 (2.65, 12.55)	11.03 (5.90, 21.23)	6.55 (2.37, 7.86)	2.46 (1.96, 3.39)	8.12 (4.39, 14.95)
Residence location (urban)	656 (27.59)	243 (36.71)	83 (40.10)	209 (28.67)	121 (15.51)
Level 3 - Region					
Antenatal care quality	73.37 (63.66, 76.64)	76.32 (74.56, 79.18)	74.24 (70.03, 77.79)	75.09 (71.23, 76.64)	56.64 (53.70, 63.66)
Malaria in pregnancy quality	46.33 (41.38, 53.32)	54.47 (53.32, 54.51)	35.64 (30.18, 38.87)	44.51 (42.81, 47.05)	42.70 (38.97, 46.33)
Facility density per 1,000,000 population	15.54 (9.30, 28.05)	12.01 (6.41, 15.54)	96.38 (86.12, 184.40)	24.60 (20.53, 33.34)	9.16 (6.48, 13.91)
Prevalence of HIV in women 15-49 years	4.10 (0.90, 8.40)	6.30 (5.80, 9.20)	20.30 (14.20, 22.10)	1.10 (0.50, 1.80)	5.70 (2.30, 8.40)

Abbreviations: n- count; IQR- interquartile range; ITN – insecticide-treated bed net.

Table B4.3. Unweighted characteristics of surveyed individuals, clusters, and regions included in the insecticide-treated net use in children under-five analysis.

Variables	Total (n=19145) n (%)/ median (IQR)	Kenya (n=10116) n (%)/ median (IQR)	Namibia (n=1030) n (%)/ median (IQR)	Senegal (n=3729) n (%)/ median (IQR)	Tanzania (n=4270) n (%)/ median (IQR)
Level 1 - Individual					
ITN use the night prior in children under-5 (yes)	12940 (67.59)	7621 (75.34)	183 (17.77)	2121 (56.88)	3015 (70.61)
Child's age in months	19 (9, 33)	20 (10, 35)	20 (9, 35)	18 (9, 30)	19 (9, 32)
Child's gender (female)	9529 (49.77)	4971 (49.14)	500 (48.54)	1885 (50.55)	2173 (50.89)
Mother's age in years	28 (24, 34)	28 (24, 33)	29 (23, 35)	28 (24, 35)	29 (24, 35)
Mother's education (none)	4903 (25.61)	1243 (12.29)	68 (6.60)	2582 (69.24)	1010 (23.65)
Primary	9266 (48.40)	5537 (54.74)	207 (20.10)	809 (21.69)	2713 (63.54)
Secondary or higher	4976 (25.99)	3336 (32.98)	755 (73.30)	338 (9.06)	547 (12.81)
Parity	3 (2, 5)	3 (2, 4)	2 (1, 4)	3 (2, 5)	3 (2, 6)
Number of ANC visits during last live birth	4 (3, 5)	4 (3, 5)	6 (4, 8)	3 (2, 4)	3 (3, 4)
Household wealth quintile (poorest)	4445 (23.22)	2425 (23.97)	254 (24.66)	1011 (27.11)	755 (17.68)
Poorer	4349 (22.72)	2210 (21.85)	238 (23.11)	961 (25.77)	940 (22.01)
Middle	3859 (20.16)	1908 (18.86)	241 (23.40)	833 (22.34)	877 (20.54)
Richer	3515 (18.36)	1806 (17.85)	181 (17.57)	582 (15.61)	946 (22.15)
Richest	2977 (15.55)	1767 (17.47)	116 (11.26)	342 (9.17)	752 (17.61)
Household size	6 (4, 9)	5 (4, 7)	6 (4, 8)	13 (9, 18)	6 (5, 8)
Level 2 - Survey cluster					
Survey administered during malaria season (yes)	14029 (73.28)	7135 (70.53)	707 (68.64)	1917 (51.41)	4270 (100.00)
Malaria endemicity	7.41 (3.14, 15.61)	10.89 (5.99, 21.35)	6.09 (1.83, 7.86)	2.46 (1.99, 3.39)	7.24 (4.34, 14.07)
Residence location (urban)	6100 (31.86)	3726 (36.83)	269 (35.83)	1133 (30.38)	872 (20.42)
Level 3 - Region					
Antenatal care quality	74.56 (69.82, 76.90)	76.90 (74.56, 79.18)	72.42 (69.59, 76.10)	73.56 (71.23, 76.64)	57.83 (53.70, 63.66)
Malaria in pregnancy quality	52.94 (43.13, 54.51)	54.47 (53.32, 54.51)	33.45 (30.18, 37.13)	44.51 (42.81, 50.00)	42.26 (38.07, 46.33)
Facility density per 1,000,000 population	13.57 (9.30, 19.38)	12.01 (6.41, 15.54)	133.84 (92.90, 114.43)	24.60 (20.53, 32.14)	9.43 (6.51, 13.91)
Prevalence of HIV in women 15-49 years	6.2 (2.3, 8.4)	6.3 (5.8, 9.2)	19.8 (14.2, 22.1)	1.2 (0.5, 1.8)	4.9 (2.3, 7.4)

Abbreviations: n- count; IQR- interquartile range; ITN – insecticide-treated bed net.

APPENDIX B5. UNADJUSTED POOLED AND BY COUNTRY RISK ESTIMATES BY OUTCOME

Table B5.1. Unadjusted pooled and by country Poisson-modeled risk estimates for factors associated with receipt of two or more doses of intermittent preventive treatment in pregnancy during last live birth in preceding 24 months.

	Kenya (n=7913)		Namibia (n=2051)		Senegal (n=2710)		Tanzania (n=3156)		Pooled (n=15175)	
Measures of Association	**RR**	**95% CI**	**RR**	**95% CI**	**RR**	**95% CI**	**RR**	**95% CI**	**RR**	**95% CI**
Individual Level										
Mother's age	1.002	(0.992, 1.013)	0.989	(0.953, 1.027)	0.999	(0.991, 1.008)	1.007	(0.997, 1.016)	1.005	(0.999, 1.011)
Mother's education (none)	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Primary	1.000	(0.841, 1.190)	2.347	(0.527, 10.446)	**1.299**	**(1.140, 1.479)**	**1.219**	**(1.023, 1.452)**	**0.822**	**(0.753, 0.896)**
Secondary or higher	0.834	(0.689, 1.010)	2.510	(0.604, 10.431)	1.158	(0.948, 1.414)	**1.799**	**(1.413, 2.290)**	**0.522**	**(0.462, 0.590)**
Parity	**1.033**	**(1.003, 1.063)**	0.895	(0.749, 1.071)	**0.964**	**(0.940, 0.988**	0.979	(0.951, 1.007)	1.008	(0.991, 1.026)
# of ANC visits	**1.115**	**(1.085, 1.146)**	1.037	(0.976, 1.102)	**1.189**	**(1.141, 1.239)**	**1.167**	**(1.122, 1.214)**	0.997	(0.983, 1.012)
Household size	**1.052**	**(1.028, 1.077)**	1.043	(0.978, 1.113)	1.004	(0.997, 1.010)	**0.972**	**(0.953, 0.990)**	**1.031**	**(1.026, 1.035)**
Wealth quintile (Poorest)	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Poorer	**0.835**	**(0.702, 0.992)**	0.591	(0.260, 1.344)	**1.243**	**(1.033, 1.496)**	0.958	(0.775, 1.184)	1.044	(0.927, 1.176)
Middle	1.021	(0.862, 1.210)	1.181	(0.621, 2.248)	**1.594**	**(1.343, 1.893)**	1.078	(0.875, 1.329)	**1.283**	**(1.146, 1.438)**
Richer	**0.691**	**(0.573, 0.833)**	0.919	(0.448, 1.884)	**1.635**	**(1.350, 1.980)**	1.138	(0.915, 1.417)	**1.185**	**(1.043, 1.346)**
Richest	**0.659**	**(0.537, 0.810)**	0.456	(0.185, 1.121)	**1.867**	**(1.528, 2.281)**	**1.282**	**(1.026, 1.602)**	**1.297**	**(1.131, 1.489)**
Cluster Level										
Residence location (urban)	**0.776**	**(0.677, 0.890)**	1.005	(0.614, 1.647)	**1.418**	**(1.261, 1.594)**	**1.199**	**(1.015, 1.417)**	1.085	(0.991, 1.188)
Malaria endemicity	**1.047**	**(1.042, 1.052)**	**1.110**	**(1.032, 1.195)**	**0.965**	**(0.950, 0.981)**	1.003	(0.994, 1.011)	1.003	(0.999, 1.008)
Malaria season (Yes)	2.833	(2.364, 3.395)	2.397	(1.233, 4.659)	1.075	(0.958, 1.205)	--	--	**1.138**	**(1.034, 1.253)**
Location x MIP quality[1,2]	**1.221**	**(1.175, 1.269)**	1.007	(0.948, 1.069)	0.992	(0.971, 1.013)	0.992	(0.976, 1.009)	**1.016**	**(1.009, 1.022)**
Location x ANC quality[1,2]	**0.870**	**(0.842, 0.899)**	1.123	(0.947, 1.333)	1.013	(0.979, 1.048)	1.013	(0.981, 1.045)	**0.989**	**(0.980, 0.999)**
Region Level										

ANC quality[3]	**1.050**	**(1.034, 1.066)**	1.053	(0.978, 1.132)	**0.978**	**(0.961, 0.994)**	1.007	(0.995, 1.020)	**0.994**	**(0.990, 0.998)**
MiP quality[3]	**1.034**	**(1.022, 1.045)**	**1.042**	**(1.010, 1.074)**	**0.988**	**(0.978, 0.999)**	**1.015**	**(1.006, 1.023)**	**1.021**	**(1.018, 1.024)**
Facility density[4]	1.211	(1.184, 1.239)	1.000	(0.997, 1.004)	0.999	(0.997, 1.002)	**1.014**	**(1.011, 1.017)**	**0.994**	**(0.993, 0.995)**
HIV prevalence[5]	**1.032**	**(1.019, 1.045)**	**1.030**	**(1.003, 1.058)**	**0.869**	**(0.808, 0.933)**	**0.960**	**(0.939, 0.981)**	**0.914**	**(0.906, 0.923)**
ANC x MiP quality[1,2]	**1.030**	**(1.026, 1.034)**	0.999	(0.992, 1.008)	0.999	(0.995, 1.003)	**0.998**	**(0.997, 0.999)**	**0.999**	**(0.998, 0.999)**
Country Level										
Country (Kenya)	--	--	--	--	--	--	--	--	Ref	Ref
Namibia	--	--	--	--	--	--	--	--	**0.296**	**(0.230, 0.382)**
Senegal	--	--	--	--	--	--	--	--	**2.464**	**(2.264, 2.681)**
Tanzania	--	--	--	--	--	--	--	--	**1.607**	**(1.465, 1.762)**

Abbreviations: n – count; RR – risk ratio; CI – confidence interval; Ref – reference level; MiP – malaria in pregnancy; ANC- antenatal care; HIV – human immunodeficiency virus.

[1] Calculated using mean-centered quality score(s). [2] Includes individual variables for each interaction term. [3] Mean-centered for each country. [4] per 1,000,000 population. [5] in reproductive-age women 15-49 years.

Table B5.2. Unadjusted pooled and by country Poisson-modeled risk estimates for factors associated with use of insecticide-treated bed net the night prior in current pregnancy.

	Kenya (n=662)		Namibia (n=207)		Senegal (n=729)		Tanzania (n=780)		Pooled (n=2378)	
	RR	**95% CI**	**RR**	**95% CI**	**RR**	**95% CI**	**RR**	**95% CI**	**RR**	**95% CI**
Measures of Association										
Individual Level										
Mother's age	**1.021**	**(1.011, 1.032)**	1.024	(0.971, 1.079)	1.000	(0.986, 1.014)	1.007	(0.997, 1.016)	1.003	(0.996, 1.011)
Mother's education (none)	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Primary	0.983	(0.831, 1.162)	0.776	(0.158, 3.809)	1.212	(0.981, 1.497)	1.037	(0.899, 1.197)	**1.230**	**(1.108, 1.366)**
Secondary or higher	0.900	(0.744, 1.090)	0.889	(0.218, 3.615)	1.266	(0.947, 1.692)	0.747	(0.533, 1.047)	**0.710**	**(0.601, 0.838)**
Parity	1.028	(0.990, 1.067)	1.130	(0.946, 1.349)	1.015	(0.979, 1.052)	**1.034**	**(1.011, 1.057)**	**1.036**	**(1.016, 1.056)**
Gestational age	1.018	(0.985, 1.052)	0.877	(0.722, 1.065)	0.981	(0.942, 1.021)	1.003	(0.976, 1.030)	0.993	(0.971, 1.015)
Household size	0.978	(0.945, 1.013)	0.946	(0.802, 1.115)	**0.987**	**(0.975, 0.998)**	0.987	(0.972, 1.002)	**0.986**	**(0.978, 0.994)**
Wealth quintile (Poorest)	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Poorer	1.179	(0.983, 1.415)	1.152	(0.428, 3.102)	1.066	(0.826, 1.375)	1.040	(0.885, 1.221)	1.127	(0.981, 1.295)
Middle	1.112	(0.901, 1.373)	0.408	(0.094, 1.774)	**1.469**	**(1.173, 1.840)**	0.941	(0.785, 1.129)	**1.171**	**(1.018, 1.347)**
Richer	1.005	(0.802, 1.260)	0.475	(0.139, 1.621)	1.120	(0.823, 1.524)	0.962	(0.802, 1.153)	0.976	(0.829, 1.149)
Richest	0.967	(0.748, 1.251)	**0.112**	**(0.013, 0.965)**	1.109	(0.753, 1.633)	0.826	(0.649, 1.051)	0.997	(0.822, 1.211)
Cluster Level										
Residence location (urban)	0.987	(0.844, 1.155)	**0.262**	**(0.081, 0.846)**	0.952	(0.763, 1.188)	0.827	(0.680, 1.006)	**0.785**	**(0.689, 0.894)**
Malaria endemicity	**1.017**	**(1.010, 1.024)**	0.995	(0.901, 1.099)	0.984	(0.959, 1.010)	**1.009**	**(1.003, 1.015)**	**1.021**	**(1.017, 1.025)**
Malaria season (yes)	1.149	(0.973, 1.356)	0.600	(0.256, 1.407)	1.209	(1.004, 1.455)	--	--	**1.324**	**(1.159, 1.513)**
Location x MiP quality[1,2]	**1.047**	**(1.001, 1.094)**	**1.151**	**(1.050, 1.261)**	**1.049**	**(1.016, 1.083)**	0.988	(0.967, 1.009)	**1.027**	**(1.014, 1.039)**
Location x ANC quality[1,2]	**0.935**	**(0.897, 0.976)**	1.118	(0.695, 1.796)	0.944	(0.884, 1.009)	1.014	(0.976, 1.053)	1.005	(0.991, 1.020)
Region Level										

ANC quality[3]	0.990	(0.967, 1.013)	**0.815**	**(0.708, 0.937)**	**1.033**	**(1.002, 1.064)**	1.008	(0.997, 1.018)	**0.940**	**(0.980, 0.989)**
MiP quality[3]	1.024	(0.999, 1.048)	**1.040**	**(1.002, 1.080)**	**1.018**	**(1.002, 1.034)**	1.005	(0.997, 1.012)	**1.025**	**(1.020, 1.030)**
Facility density[4]	**1.028**	**(1.010, 1.046)**	**1.013**	**(1.007, 1.019)**	0.999	(0.996, 1.004)	0.995	(0.989, 1.000)	**0.990**	**(0.987, 0.993)**
HIV prevalence[5]	1.008	(0.994, 1.023)	**1.177**	**(1.114, 1.244)**	1.001	(0.894, 1.120)	0.980	(0.960, 1.001)	**0.972**	**(0.964, 0.981)**
ANC quality x MiP quality[1,2]	**1.009**	**(1.003, 1.015)**	1.012	(0.991, 1.034)	1.006	(0.999, 1.013)	0.999	(0.999, 1.001)	1.007	(0.993, 1.021)
Country Level										
Country (Kenya)	--	--	--	--	--	--	--	--	Ref	Ref
Namibia	--	--	--	--	--	--	--	--	**0.141**	**(0.093, 0.215)**
Senegal	--	--	--	--	--	--	--	--	**0.729**	**(0.649, 0.819)**
Tanzania	--	--	--	--	--	--	--	--	0.986	(0.898, 1.083)

Abbreviations: n – count; RR – risk ratio; CI – confidence interval; Ref – reference level; MiP – malaria in pregnancy; ANC- antenatal care; HIV – human immunodeficiency virus.

[1] Calculated using mean-centered quality score(s). [2] Includes individual variables for each interaction term. [3] Mean-centered for each country. [4] per 1,000,000 population. [5] in reproductive-age women 15-49 years.

Table B5.3. Unadjusted pooled and by country Poisson-modeled risk estimates for factors associated with use of insecticide-treated bed net the night prior in children under-five.

	Kenya (n=10116)		Namibia (n=1030)		Senegal (n=3729)		Tanzania (n=6175)		Pooled (n=19145)	
Measures of Association	**RR**	**95% CI**	**RR**	**95% CI**	**RR**	**95% CI**	**RR**	**95% CI**	**RR**	**95% CI**
Individual Level										
Child's age in months	**0.999**	**(0.998, 0.999)**	**0.999**	**(0.998, 0.999)**	**0.999**	**(0.998, 0.999)**	**0.999**	**(0.998, 0.999)**	**0.999**	**(0.998, 0.999)**
Child's sex (Female)	0.976	(0.952, 1.001)	0.976	(0.952, 1.001)	0.976	(0.952, 1.001)	0.976	(0.952, 1.001)	0.980	(0.950, 1.011)
Mother's age in years	0.999	(0.997, 1.001)	0.994	(0.974, 1.014)	1.000	(0.995, 1.005)	1.000	(0.998, 1.004)	0.998	(0.996, 1.001)
Mother's education (none)	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Primary	**1.099**	**(1.035, 1.168)**	1.391	(0.594, 3.257)	1.001	(0.911, 1.101)	1.028	(0.973, 1.086)	**1.167**	**(1.124, 1.211)**
Secondary or higher	**1.167**	**(1.097, 1.242)**	1.548	(0.691, 3.464)	**1.155**	**(1.020, 1.308)**	0.963	(0.872, 1.063)	**0.947**	**(0.902, 0.993)**
Parity	**0.990**	**(0.983, 0.997)**	0.976	(0.908, 1.048)	0.994	(0.980, 1.009)	1.003	(0.994, 1.012)	1.003	(0.996, 1.009)
# of mother's ANC visits for last live birth	1.009	(0.999, 1.018)	**0.951**	**(0.915, 0.989)**	**1.053**	**(1.028, 1.078)**	1.003	(0.988, 1.018)	**0.960**	**(0.951, 0.968)**
Household size	**0.975**	**(0.969, 0.982)**	0.953	(0.903, 1.006)	**0.985**	**(0.980, 0.990)**	**0.988**	**(0.981, 0.995)**	**0.982**	**(0.978, 0.985)**
Wealth quintile (poorest)	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Poorer	**1.115**	**(1.068, 1.164)**	0.935	(0.648, 1.351)	**1.275**	**(1.144, 1.420)**	0.974	(0.913, 1.038)	**1.128**	**(1.076, 1.183)**
Middle	**1.105**	**(1.056, 1.157)**	**0.521**	**(0.342, 0.794)**	**1.449**	**(1.308, 1.605)**	0.938	(0.897, 1.005)	**1.125**	**(1.072, 1.180)**
Richer	**1.116**	**(1.063, 1.172)**	0.804	(0.532, 1.216)	**1.319**	**(1.167, 1.490)**	0.995	(0.932, 1.062)	**1.168**	**(1.111, 1.228)**
Richest	**1.082**	**(1.028, 1.140)**	0.552	(0.311, 0.982)	**1.186**	**(1.009, 1.295)**	0.929	(0.862, 1.001)	**1.135**	**(1.074, 1.200)**
Child's sex x MiP quality[1,2]	**1.010**	**(1.000, 1.020)**	1.008	(0.964, 1.054)	0.996	(0.985, 1.008)	1.002	(0.997, 1.007)	1.000	(0.996, 1.004)
Child's sex x ANC quality[1,2]	0.994	(0.984, 1.005)	1.001	(0.926, 1.081)	0.999	(0.976, 1.022)	1.002	(0.994, 1.010)	0.998	(0.995, 1.001)
Child's age x MiP quality[1,2]	0.999	(0.999, 1.000)	1.000	(0.999, 1.002)	1.000	(0.999, 1.000)	0.999	(0.999, 1.000)	1.000	(0.999, 1.000)
Child's age x ANC quality[1,2]	0.999	(0.999, 1.000)	**0.997**	**(0.994, 0.999)**	**0.999**	**(0.998, 0.999)**	0.999	(0.999, 1.000)	0.999	(0.999, 1.000)
Cluster Level										
Residence location (urban)	1.018	(0.985, 1.053)	1.074	(0.796, 1.450)	1.072	(0.985, 1.166)	0.956	(0.902, 1.013)	0.993	(0.958, 1.029)
Malaria endemicity	**1.007**	**(1.005, 1.008)**	1.009	(0.970, 1.050)	**0.969**	**(0.957, 0.981)**	**1.007**	**(1.004, 1.009)**	**1.016**	**(1.015, 1.017)**
Malaria season (yes)	**1.099**	**(1.062, 1.136)**	0.829	(0.616, 1.1163)	**1.190**	**(1.105, 1.282)**	--	--	**1.248**	**(1.198, 1.299)**
Location x MiP quality[1,2]	**1.020**	**(1.011, 1.030)**	**1.061**	**(1.013, 1.111)**	1.012	(0.999, 1.024)	1.002	(0.996, 1.008)	**1.008**	**(1.004, 1.012)**
Location x ANC quality[1,2]	**0.973**	**(0.964, 0.982)**	1.020	(0.936, 1.111)	**0.923**	**(0.901, 0.945**	0.999	(0.989, 1.011)	**1.007**	**(1.004, 1.010)**
Region Level										
ANC quality[3]	0.998	(0.992, 1.003)	**0.913**	**(0.879, 0.949)**	**1.022**	**(1.010, 1.033)**	0.999	(0.995, 1.003)	**0.994**	**(0.993, 0.996)**
MiP quality[3]	**1.008**	**(1.003, 1.013)**	**1.034**	**(1.010, 1.057)**	**1.018**	**(1.012, 1.024)**	1.001	(0.999, 1.004)	**1.022**	**(1.020, 1.024)**
Facility density[4]	**1.014**	**(1.010, 1.017)**	**1.007**	**(1.004, 1.009)**	0.999	(0.998, 1.001)	**0.996**	**(0.994, 0.998)**	**0.993**	**(0.992, 0.994)**
HIV prevalence[5]	**1.007**	**(1.004, 1.010)**	**1.077**	**(1.057, 1.098)**	0.975	(0.931, 1.021)	0.997	(0.990, 1.003)	**0.984**	**(0.981, 0.987)**
ANC quality x MiP quality[1,2]	**1.004**	**(1.002, 1.005)**	1.002	(0.996, 1.008)	**1.006**	**(1.003, 1.008)**	**1.001**	**(1.000, 1.001)**	**1.002**	**(1.001, 1.002)**
Country Level										
Country (Kenya)	--	--	--	--	--	--	--	--	Ref	Ref
Namibia	--	--	--	--	--	--	--	--	**0.241**	**(0.209, 0.278)**
Senegal	--	--	--	--	--	--	--	--	**0.731**	**(0.702, 0.760)**
Tanzania	--	--	--	--	--	--	--	--	**0.968**	**(0.943, 0.995)**

Abbreviations: n – count; RR – risk ratio; CI – confidence interval; Ref – reference level; MiP – malaria in pregnancy; ANC- antenatal care; HIV – human immunodeficiency virus.

[1] Calculated using mean-centered quality score(s). [2] Includes individual variables for each interaction term. [3] Mean-centered for each country. [4] per 1,000,000 population. [5] in reproductive-age women 15-49 years.

APPENDIX C1. DESCRIPTION OF DATA PREPARATION METHODS

I prepared endemicity, population density, and urban/rural location data in ArcGIS 10.3.1 for further use in Stata for my analyses. Using endemicity data, I assigned respective values to a facility's latitude and longitude coordinates using the "Extract Values to Points" tool in the Spatial Analyst toolbox. Facilities with no endemicity value (i.e. located next to a body of water) were manually re-classified by using the nearest adjacent pixel value (42 were assigned values greater than zero; 215 were assigned a value of zero); facilities missing coordinates were excluded (n=26). Raster values for population density were assigned to geographic regions by using the "Zonal Statistics as Table" tool in the Spatial Analyst toolbox. Lastly, to assign facilities a status of rural or urban, I determined the maximum raster value for each facility using "Zonal Statistics" in the Spatial Analyst toolbox, and then the "Extract Values to Points" tool. Point extraction has previously been shown to be suitable for autocorrelated data such as the endemicity and urban/rural data used in this study, resulting in limited misclassification (see Perez-Heyrich C, Warren J, Burgert C, Emch M. Guidelines on the use of DHS GPS data. Calverton, Maryland: ICF International; 2013). I manually re-classified facilities with no urban/rural value according to the nearest pixel value (n=10), so long as they were not missing latitude and longitude coordinates.

USAID's Demographic and Health Surveys Program normalizes SPA survey weights for individual countries to account for oversampling of certain survey strata. Following Demographic and Health Survey Program guidance, I de-normalized survey weights prior to appending country datasets for a pooled analysis by dividing facility weights by 1,000,000, and then dividing these facility-level values by the ratio of total facilities in the sample to total facilities in the country (see: Ren R. Note on DHS

standard weight de-normalization Rockville, MD: ICF International; 2013. Available from: http://userforum.measuredhs.com/index.php?t=msg&th=54&S=2a94262452e7cc1bf322b1e384d650d7) De-normalized weights, with facility type and region grouped as survey strata, were used to account for the complex survey design using the 'svy' suite of commands for weighted bivariate and multivariable analyses.

APPENDIX C2. UNWEIGHTED CHARACTERISTICS OF FACILITIES PROVIDING MALARIA SERVICES AND ANTENATAL CARE IN THE ANALYTIC SAMPLE AND EXCLUDED FACILITIES.

Variables	Categories	Included Facilities/Analytic Sample (n= 826)	Excluded ANC and Malaria Facilities (n=55)	Total Eligible ANC and Malaria Facilities (n=883)
		n (%)/ Median (IQR)	n (%)/ Median (IQR)	n (%)/ Median (IQR)
Malaria service readiness	--	0.83 (0.75, 0.92)	0.71 (0.42, 0.75)	0.83 (0.75, 0.92)
	Missing data	*0 (0%)*	*47 (82%)*	*47 (5%)*
Endemicity	--	0.03 (0.01, 0.06)	0.03 (0.00, 0.06)	0.03 (0.01, 0.06)
	Missing data	*0 (0%)*	*0 (0%)*	*0 (0%)*
Health facility type[1]	Tertiary Care	271 (33%)	17 (30%)	288 (33%)
	Secondary Care	181 (22%)	14 (25%)	195 (22%)
	Primary Care	374 (45%)	24 (42%)	398 (45%)
	Missing data	*0 (0%)*	*2 (4%)*	*2 (<1%)*
Health facility managing authority	Public	575 (70%)	36 (63%)	611 (69%)
	NGO/FBO	116 (14%)	12 (21%)	128 (14%)
	Private-for-profit	135 (16%)	9 (16%)	144 (16%)
	Missing data	*0 (0%)*	*0 (0%)*	*0 (0%)*
Facility location	Urban	561 (68%)	26 (46%)	587 (66%)
	Missing data	*0 (0%)*	*9 (16%)*	*9 (1%)*
Country Regions				
Kenya	Nairobi	43 (5%)	1 (2%)	44 (5%)
	Central	66 (8%)	2 (4%)	68 (8%)
	Coast	58 (7%)	3 (5%)	61 (7%)
	Eastern	60 (7%)	--	60 (7%)
	Northeastern	31 (4%)	--	31 (4%)
	Nyanza	52 (6%)	9 (16%)	61 (7%)
	Rift Valley	62 (8%)	1 (2%)	63 (7%)
	Western	61 (7%)	1 (2%)	62 (7%)
Namibia	Caprivi	19 (2%)	--	19 (2%)
	Erongo	5 (1%)	1 (2%)	6 (1%)
	Hardap	5 (1%)	5 (9%)	10 (1%)
	Karas	7 (1%)	--	7 (1%)
	Kavango	41 (5%)	3 (5%)	44 (5%)
	Khomas	4 (1%)	--	4 (<1%)

	Kunene	14 (2%)	1 (2%)	15 (2%)
	Ohangwena	31 (4%)	--	31 (4%)
	Omaheke	14 (2%)	--	14 (2%)
	Omusati	37 (4%)	1 (2%)	38 (4%)
	Oshana	11 (1%)	--	11 (1%)
	Oshikoto	21 (3%)	--	21 (2%)
	Otjozondjupa	19 (2%)	4 (7%)	23 (3%)
Senegal	Dakar	15 (2%)	9 (16%)	24 (3%)
	Diourbel	19 (2%)	--	19 (2%)
	Fatick	4 (1%)	--	4 (<1%)
	Kaffrine	19 (2%)	2 (4%)	21 (2%)
	Kaolack	15 (2%)	1 (2%)	16 (2%)
	Kédougou	3 (1%)	1 (2%)	4 (<1%)
	Kolda	5 (1%)	1 (2%)	6 (1%)
	Louga	17 (2%)	2 (4%	19 (2%)
	Matam	2 (1%)	1 (2%)	3 (<1%)
	Saint Louis	17 (2%)	2 (4%)	19 (2%)
	Sédhiou	10 (1%)	--	10 (1%)
	Tambacounda	10 (1%)	1 (2%)	11 (1%)
	Thiès	10 (1%)	3 (5%)	13 (1%)
	Ziguinchor	19 (2%)	2 (4%)	21 (2%)
	Missing data	*0 (0%)*	*0 (0%)*	*0 (0%)*
Number of health worker interviews	1-5	497 (60%)	29 (51%)	526 (60%)
	6-11	246 (30%)	15 (26%)	261 (30%)
	12-21	83 (10%)	13 (23%)	96 (11%)
	Missing data	*0 (0%)*	*0 (0%)*	*0 (0%)*
Drug register updated daily	Yes	680 (82%)	42 (74%)	722 (82%)
	Missing data	*0 (0%)*	*0 (0%)*	*0 (0%)*
Facility density per 100,000 population	--	1.72 (1.29, 11.29)	2.65 (1.72, 13.63)	1.72 (1.29, 11.29)
	Missing data	*433 (52%)*	*17 (30%)*	*450 (51%)*
Number of funding sources	0	35 (4%)	4 (7%)	38 (4%)
	1	338 (41%)	26 (46%)	364 (41%)
	2	263 (32%)	19 (33%)	282 (32%)
	3	133 (16%)	6 (11%)	139 (16%)
	4 or more	58 (7%)	2 (4%)	60 (7%)
	Missing data	*0 (0%)*	*0 (0%)*	*0 (0%)*
Month surveyed	January	56 (7%)	6 (11%)	62 (7%)
	February	127 (15%)	7 (12%)	134 (15%)
	March	188 (23%)	7 (12%)	195 (22%)

	April	159 (19%)	9 (16%)	168 (19%)
	May	44 (5%)	5 (9%)	49 (6%)
	June	--	1 (2%)	1 (<1%)
	July	15 (2%)	--	15 (2%)
	August	68 (8%)	8 (14%)	76 (9%)
	September	111 (13%)	6 (11%)	117 (13%)
	October	36 (4%)	3 (5%)	39 (4%)
	November	14 (2%)	3 (5%)	17 (2%)
	December	8 (1%)	2 (4%)	10 (1%)
	Missing data	*0 (0%)*	*0 (0%)*	*0 (0%)*
Administrative meetings	Not held /irregular	139 (17%)	17 (30%)	156 (18%)
	Every 2-6 months	121 (15%)	5 (9%)	126 (14%)
	Monthly	566 (69%)	35 (61%)	601 (68%)
	Missing data	*0 (0%)*	*0 (0%)*	*0 (0%)*
Score: state of drug storage area	--	1.0 (1.0, 1.0)	1.0 (1.0, 1.0)	1.0 (1.0, 1.0)
	Missing data	*4 (<1%)*	*1 (2%)*	*5 (1%)*
Score: state of physical infrastructure	--	0.75 (0.5, 1.0)	0.75 (0.5, 1.0)	0.75, (0.5, 1.0)
	Missing data	*1 (<1%)*	*0 (0%)*	*1 (<1%)*

Abbreviations: N, count; IQR, inter-quartile range; NGO, non-governmental organization; FBO, faith-based organization.
[1]Tertiary care: hospitals; Secondary care: health centers, maternities; Primary care: health posts, clinics, dispensaries, sickbays.

APPENDIX C3. CONVERGENT AND DISCRIMINANT VALIDITY TESTING OF THE MALARIA SERVICE READINESS INDEX

Results of convergent and discriminant validity testing to establish construct validity of the malaria service readiness index are presented below. I calculated Greiner's rho, which is a transformation of Kendall's tau-a, a suitable correlation statistic for skewed complex survey data.[1] Kendall's tau-a can be computed using the 'somersd' package in Stata, and is a rank correlation statistic on a scale of -1 to 1 calculated as the covariance between sign(X1 − X2) and sign(Y1 − Y2), and which ignores ties.[1] As discussed in Newson 2002, transformation of Kendall's tau-a into Greiner's rho allows interpretation of coefficient values as a rho on a -1 to 1 scale, much like interpretation of Pearson's correlation coefficient for parametric data, yet it is much more robust to extreme observations and to nonlinearity. Study findings suggest that for my data, overall malaria service readiness has a statistically significant positive, albeit weak, correlation with child curative service readiness (Greiner's rho: 0.102). Corresponding domain relationships similarly showed weakly positive correlations. However, malaria service readiness was weakly negatively correlated overall with antenatal service readiness, contrary to my hypothesis (Greiner's rho: -0.100). In spite of this overall negative correlation, domain 1 – trained staff and guidelines (Greiner's rho: 0.116) and domain 3 – medicines and commodities (Greiner's rho: 0.118) showed weak, but significant, correlations. One possible explanation is that basic services like antenatal care reflect prevention-oriented care which may differ substantially from malaria diagnosis and treatment; consequently, I might not expect the two to be well-correlated, as seen with child curative services. Further, I expected antenatal and malaria service readiness to be positively correlated as these services should be well-integrated, but this may not be the case. I also tested for discriminant validity of the malaria service readiness index with two additional indicators:

presence of a client feedback system (-0.049) and use of user-fees for sick adult services (-0.003). As anticipated, the index was not significantly correlated with either of these indicators.

[1]Newson R. Parameters behind "nonparametric" statistics: Kendall's tau, Somers' D and median differences. The Stata Journal. 2002;2(1):45-64

		Malaria Service Readiness							
		Overall		Staff, Guidelines		Diagnostics		Medicines, Commodities	
	Indices and components	β	95% CI	β	95% CI	β	95% CI	β	95% CI
Convergent Validity	**Antenatal care (n=724)**	-0.100*	(-0.193, -0.007)	-0.191*	(-0.288, -0.094)	0.001	(-0.046, 0.048)	0.036	(-0.058, 0.130)
	Trained Staff, Guidelines	0.116*	(0. 005, 0. 228)	0.156*	(0.047, 0.264)	0.0004	(-0.067, 0.068)	0.062	(-0.033, 0.156)
	Equipment	0.010	(-0.023, 0.043)	0.024	(-0.012, 0.061)	-0.007*	(-0.012, -0.001)	-0.002	(-0.027, 0.023)
	Diagnostics	-0.208*	(-0.301, -0.114)	-0.318*	(-0.410, -0.226)	-0.026	(-0.088, 0.035)	-0.017	(-0.111, 0.178)
	Medicines, Commodities	-0.118*	(-0.224, -0.013)	-0.245*	(-0.347, -0.142)	0.041	(-0.010, 0.091)	0.021	(-0.077, 0.119)
	Child Curative (n=763)	0.102	(-0.032, 0.236)	-0.016	(-0.127, 0.096)	0.127*	(0.031, 0.221)	0.041	(-0.064, 0.146)
	Trained Staff, Guidelines	0.090	(-0.021, 0.202)	0.170*	(0.048, 0.292)	0.012	(-0.035, 0.060)	-0.046	(-0.160, 0.067)
	Equipment	0.125*	(0.027, 0.223)	0.156*	(0.064, 0.248)	0.032	(-0.038, 0.102)	-0.012	(-0.087, 0.062)
	Diagnostics	-0.110*	(-0.215, -0.055)	-0.242*	(-0.334, -0.150)	0.080*	(0.028, 0.131)	-0.037	(-0.131, 0.058)
	Medicines, Commodities	0.285*	(0.139, 0.431)	0.098	(-0.028, 0.225)	0.116*	(0.010, 0.222)	0.259*	(0.140, 0.379)

Discriminant Validity	**Client feedback system (n=840)**	-0.049	(-0.157, 0.060)	-0.171*	(-0.266, -0.075)	0.064*	(0.004, 0.125)	0.027	(-0.071, 0.125)
	User-fees for sick adult services (n=838)	-0.003	(-0.021, 0.014)	0.003	(-0.018, 0.024)	-0.004*	(-0.008, -0.0002)	-0.001	(-0.013, 0.012)

Abbreviations: N – count; CI – confidence interval; β – beta.
Underlined numbers denote hypothesized relationships. * Denotes significance at the $p<0.05$ level.

APPENDIX C4. RELIABILITY TESTING OF THE MALARIA SERVICE READINESS INDEX

I calculated a Cronbach's alpha value of 0.59 for the malaria service readiness index, using the total pool of SPA facilities while allowing facilities to vary by availability of data for an indicator. A one-sided confidence interval is provided for the overall Cronbach's alpha, indicating that I am 95% confident the calculated alpha of 0.59 is greater than 0.57. Cronbach's alpha can be used to demonstrate reliability of an index, or how well the individual indicators comprising the index correlate with another hypothetical set of the same number of indicators from a total population of indicators representing an underlying construct – in this case, malaria service readiness. A qualitative threshold of 0.70 is frequently employed for defining the adequate lower bound of performance of an index, suggesting that the calculated Cronbach's alpha value is lower than ideal.[1] However, removal of availability of valid paracetamol, and then paracetamol as well as the diagnostics indicator results in somewhat higher alpha values of 0.62 and 0.65, respectively. This suggests that quantitatively these indicators may be less necessary for measuring malaria service readiness than others included. It may also be that the lack of heterogeneity for these indicators (their availability was nearly ubiquitous across facilities) falsely suggests they are less important for reliability of the index than in actuality. Simultaneously, results suggest that trained staff are important for measuring malaria service readiness.

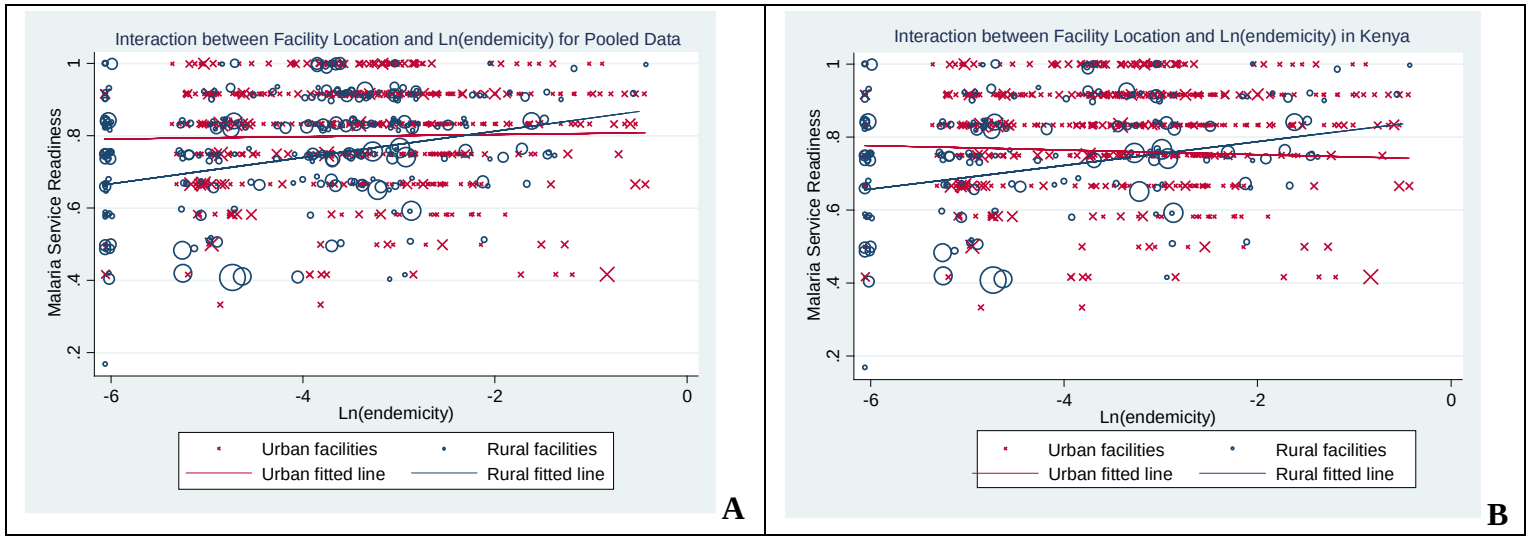
[1] DeVellis, R. F. (2012). *Scale Development: Theory and Applications*. Los Angeles, United States, Sage.

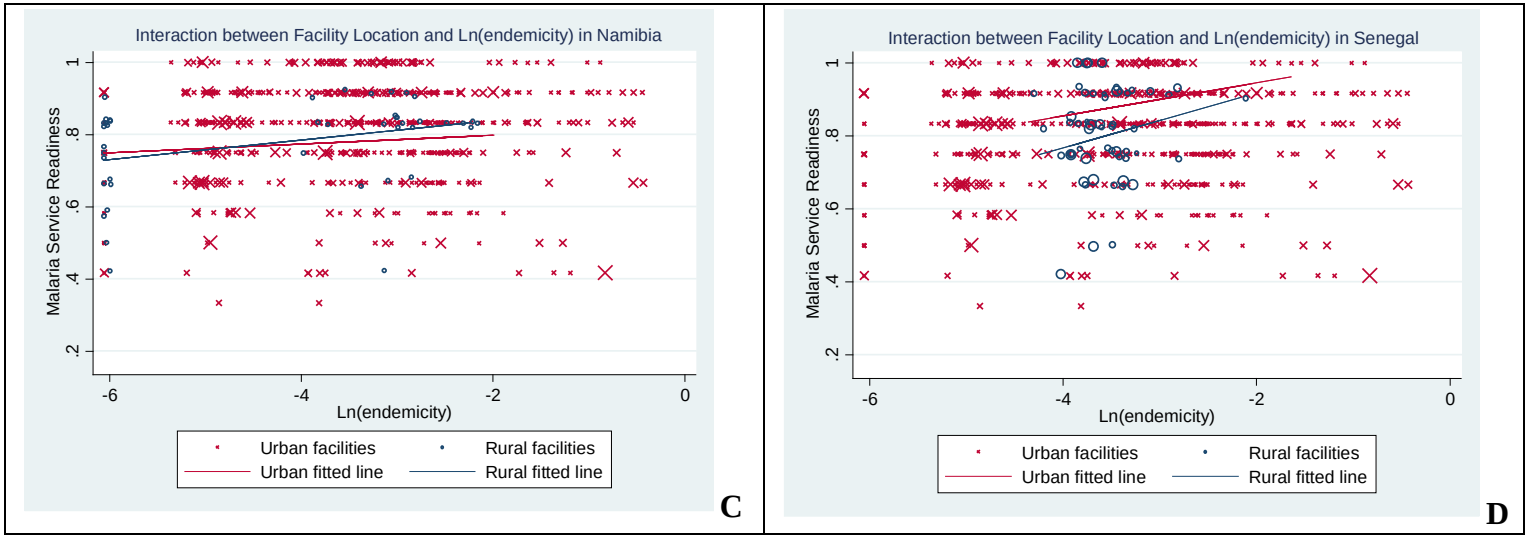
Variable	n	Cronbach's alpha	95% CI
Guidelines for diagnosis and treatment of malaria	1527	0.57	
Guidelines for IPTp	1428	0.56	
Facility has on-duty staff trained in malaria diagnosis and treatment	1538	0.50	
Facility has on-duty staff trained in IPTp	1538	0.48	
Rapid diagnostic test available, valid or microscopy supplies present	917	0.61	
Paracetamol cap/tab available, valid	1363	0.62	
First-line antimalarial in stock, valid	1364	0.58	
IPTp drug available and valid (SP)	1364	0.57	
ITNs or vouchers available	1432	0.55	
Overall Cronbach's alpha and 95% CI		**0.59**	**0.57**

Abbreviations: N - count; CI - confidence interval; IPTp - intermittent preventive treatment in pregnancy; ITN - insecticide-treated bed net; SP - sulfadoxine-pyrimethamine.

APPENDIX C5. COMPARISON OF THE INTERACTION OF FACILITY LOCATION AND LN(ENDEMICITY) FOR THE ANALYTIC SAMPLE AND BY COUNTRY

The figure below presents weighted scatterplots of the interaction between facility location with natural log of endemicity for adjusted analyses as follows: A) pooled facility data in Kenya, Namibia and Senegal (n=826); B) Kenya (n=433); C) Namibia (n=228); D) Senegal (n=165). The relative weight of each facility is depicted by increasing symbol size.




Interaction between Facility Location and Ln(endemicity) in Namibia
Malaria Service Readiness
.2
.4
.6
.8
1
-6
-4
-2
0
Ln(endemicity)
Urban facilities
Rural facilities
Urban fitted line
Rural fitted line
C
Interaction between Facility Location and Ln(endemicity) in Senegal
Malaria Service Readiness
.2
.4
.6
.8
1
-6
-4
-2
0
Ln(endemicity)
Urban facilities
Rural facilities
Urban fitted line
Rural fitted line
D

APPENDIX C6. RESULTS OF LOGISTIC REGRESSION ANALYSIS FOR MISSING DATA

		Adjusted Logistic Regression Results (n=865)	
Predictor	**Category**	**OR**	**95% CI**
Ln(endemicity)	Continuous	2.02	(1.17, 3.49)
Managing authority	NGO/FBO	4.63	(1.03, 20.82)
	Private-for-profit	6.09	(1.14, 32.39)
Month of survey	February	0.60	(0.09, 4.18)
	March	0.19	(0.03, 1.26)
	April	0.38	(0.07, 2.05)
	May	0.17	(0.02, 1.27)
	June	1.00	--
	July	1.00	--
	August	9.78	(0.33, 287.06)
	September	1.24	(0.03, 43.96)
	October	2.61	(0.22, 30.78)
	November	0.31	(0.04, 2.74)
	December	0.13	(0.01, 1.92)
Number of health worker interviews	6-19	0.53	(0.22, 1.30)
	11-21	0.93	(0.24, 3.57)
Country	Namibia	0.50	(0.02, 11.62)
	Senegal	25.99	(5.71, 118.23)
Facility Type	Secondary Care[1]	0.47	(0.17, 1.32)
	Primary Care[2]	0.23	(0.05, 1.20)

Abbreviations: N – count; OR – odds ratio; CI – confidence interval.
Outcome variable for missing data coded as 0=not missing, 1=missing.
[1]Secondary Care: health centers, maternities; [2]Primary Care: health posts, clinics, dispensaries, sickbays.

APPENDIX C7. POOLED ESTIMATES OF MEAN MALARIA SERVICE READINESS FOR KENYA, NAMIBIA AND SENEGAL: COMPARISON OF COMPLETE CASE AND MULTIPLE IMPUTATION ANALYSES IN THE ANALYTIC SAMPLE

The table below provides a comparison of the complete case analysis for the analytic sample versus the results using imputed facility data. I imputed missing data (n=55 or 6.2% of eligible facilities) to examine whether inclusion of these facilities had any impact on study findings. To deal with singleton primary sampling units (PSU), I used two methods for the complete case analysis: I binned singleton PSUs with the next highest stratum with any PSUs, and I also set values for singleton PSUs at the grand mean. I made this comparison as binning singleton PSUs was used for the primary complete case analysis, and it was not possible to do so for the imputed analyses. Multiple imputation was conducted using the 'mi impute' and 'mi estimate' commands in Stata 12.0 with 20 iterations to predict missing values for malaria service readiness using the following non-missing covariates: ln(endemicity), managing authority, facility type, survey month, number of health worker interviews, country and region. This method is appropriate for missing at random data, as is suggested are present given results presented in S6 Table. S7 Table provides a comparison of the means with 95% confidence intervals for each of the three methods. Results of this analysis suggest no difference between the complete case analysis and my analysis using imputed data for the outcome variable.

Analysis Type	N	$\bar{y}$	se($\bar{y}$)	95% CI	*df*
Complete case, singleton PSUs binned together	826	0.782	0.010	(0.762, 0.801)	1307
Complete case, singleton PSUs grand mean-centered	826	0.782	0.010	(0.762, 0.801)	1317
Multiple imputation[1], singleton PSUs grand mean-centered	881	0.783	0.010	(0.764, 0.802)	1233.13

Abbreviations: N – number; $\bar{y}$ – mean; se($\bar{y}$) – standard error of the mean; CI – confidence interval; *df* – degrees of freedom.

APPENDIX C8. POOLED ESTIMATED LINEAR REGRESSION MODELS FOR MALARIA SERVICE READINESS IN KENYA, NAMIBIA AND SENEGAL: COMPARISON OF COMPLETE CASE AND MULTIPLE IMPUTATION ANALYSES

The table below compares results of the adjusted linear regression models for the complete case analysis using two approaches for dealing with singleton primary sampling units (previously described in Appendix C7) to the model for multiply imputed data. Results are slightly more precise for the imputed data, although there is qualitatively no difference for these data compared to results of the complete case analyses.

		Complete Case Analysis, singleton PSUs binned together (n=826)			**Complete Case Analysis, singleton PSUs grand mean-centered (n=826)**			**Multiple Imputation, singleton PSUs grand mean-centered (n=872)**		
Predictor	**Category**	$\hat{B}$	**se($\hat{B}$)**	**95% CI**	$\hat{B}$	**se($\hat{B}$)**	**95% CI**	$\hat{B}$	**se($\hat{B}$)**	**95% CI**
Intercept	Constant	0.854	0.042	(0.772, 0.936)	0.854	0.042	(0.772, 0.936)	0.852	0.042	(0.769, 0.934)
Ln(endemicity)	Continuous	0.028	0.010	(0.008, 0.047)	0.028	0.010	(0.008, 0.047)	0.028	0.010	(0.008, 0.047)
Facility location	Urban	-0.075	0.063	(-0.198, 0.049)	-0.075	0.063	(-0.198, 0.049)	-0.071	0.061	(-0.191, 0.049)
ln(endemicity) x facility location	Continuous	-0.032	0.017	(-0.064, -0.001)	-0.032	0.017	(-0.064, -0.001)	-0.031	0.016	(-0.062, 0.001)
Managing authority	NGO/FBO Private-for-profit	-0.012 -0.102	0.032 0.026	(-0.075, 0.050) (-0.154, -0.050)	-0.012 -0.102	0.032 0.026	(-0.075, 0.050) (-0.154, -0.050)	-0.012 -0.100	0.0314 0.026	(-0.073, 0.048) (-0.150, -0.049)
Month of survey	February March April May June July August September October November December	-0.011 -0.002 0.061 0.092 Omitted 0.021 0.030 -0.024 0.003 0.006 -0.013	0.035 0.034 0.033 0.036 Omitted 0.037 0.032 0.032 0.043 0.038 0.046	(-0.078, 0.057) (-0.068, 0.064) (-0.003, 0.125) (0.022, 0.162) Omitted (-0.051, 0.092) (-0.033, 0.092) (-0.086, 0.039) (-0.082, 0.089) (-0.068, 0.080) (-0.103, 0.077)	-0.011 -0.002 0.061 0.092 Omitted 0.021 0.030 -0.024 0.003 0.006 -0.013	0.035 0.034 0.033 0.036 Omitted 0.037 0.032 0.032 0.043 0.038 0.046	(-0.078, 0.057) (-0.068, 0.064) (-0.003, 0.125) (0.022, 0.162) Omitted (-0.051, 0.092) (-0.033, 0.092) (-0.086, 0.039) (-0.082, 0.089) (-0.068, 0.080) (-0.103, 0.077)	-0.009 - 0.0002 0.064 0.093 0.176 0.022 0.028 -0.022 0.006 0.003 0.003	0.034 0.033 0.032 0.036 0.161 0.036 0.031 0.031 0.047 0.042 0.053	(-0.075, 0.057) (-0.066, 0.065) (0.001, 0.126) (0.023, 0.163) (-0.165, 0.517) (-0.049, 0.094) (-0.034, 0.089) (-0.083, 0.039) (-0.086, 0.098) (-0.080, 0.086) (-0.102, 0.108)

Number of health worker interviews	6-10	0.029	0.020	(-0.011, 0.069)	0.029	0.020	(-0.011, 0.069)	0.030	0.020	(-0.009, 0.068)
	11-21	0.070	0.020	(0.031, 0.110)	0.070	0.020	(0.031, 0.110)	0.069	0.021	(0.027, 0.110)

Abbreviations: n- count; $\hat{B}$ – coefficient or adjusted mean value; se($\hat{B}$) – standard error of the mean; CI – confidence interval; ln() – natural log.

APPENDIX C9. COMPARISON OF FACILITY DISTRIBUTION IN THE NATIONALLY-REPRESENTATIVE, WEIGHTED SPA SAMPLE TO THE WEIGHTED ANALYTIC SAMPLE FOR KENYA 2010 AND SENEGAL 2012-2013

		Kenya		Senegal	
Variable	**Category**	**SPA Sample (n=695)**	**Analytic Sample (n=433)**	**SPA Sample (n=458)**	**Analytic Sample (n=165)**
Managing Authority	Government	50%	42%	83%	93%
	NGO/FBO	16%	26%	5%	5%
	Private	34%	32%	12%	2%
Facility Type	Tertiary Care[1]	7%	15%	5%	4%
	Secondary Care[2]	13%	23%	8%	11%
	Primary Care[3]	79%	62%	87%	85%
	Other: VCT	1%	N/A	N/A	N/A

Abbreviations: n – count; SPA – Service Provision Assessment; NGO – non-governmental organization; FBO – faith-based organization; VCT – voluntary counseling and testing facility.

[1]Tertiary care: hospitals; [2]Secondary care: health centers, maternities; [3]Primary care: health posts, clinics, dispensaries, sickbays.

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