
Evaluation of the Impact of Malaria Control Interventions on All-Cause Mortality in Children under Five Years of Age in Rwanda, 2000–2010

Rwanda Malaria Impact Evaluation Group

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Executive Summary

BACKGROUND

This report was co-commissioned by the US President's Malaria Initiative (PMI) and Rwanda's Ministry of Health (MoH) in support of the Roll Back Malaria Partnership's (RBM) and MoH of Rwanda's monitoring and evaluation activities. The objective was to evaluate the impact of the scale-up of malaria control interventions during the period 2000-2010. The interventions evaluated are insecticide treated nets (ITNs), prompt and effective malaria case management, intermittent preventive treatment in pregnancy (IPTp), and indoor residual spraying (IRS) in targeted malaria high burden districts.

During the evaluation period, Rwanda has significantly increased malaria control efforts including the adoption of new first-line treatments, scaled up diagnostics with mandatory confirmatory testing via microscopy or rapid diagnostic test (RDTs), and increased access to and utilization of ITNs. Intermittent preventive treatment of pregnant women was implemented in 2004, however, IPTp was discontinued in 2008. Additional interventions, including IRS, were implemented at a sub-national level.

The evaluation indicators are primarily the population-based indicators recommended by RBM, which include the following three primary impact measures: all-cause childhood mortality (ACCM) in children less than five years of age, malaria parasitemia, and severe anemia (Hb <8g/dL) prevalence in children 6-59 months old.

The evaluation is based on a before-and-after assessment, which uses a plausibility evaluation design that measures changes in malaria intervention coverage, malaria-related morbidity, and ACCM, while accounting for other contextual determinants of child survival. All-cause mortality in children under five years of age is used as malaria-specific mortality cannot be reliably measured in most parts of Sub-Saharan Africa with the currently available sources of data.

Data used in the report mainly come from four large population-based household surveys conducted during 2000, 2005, 2007/2008 and 2010. Most malaria-specific data were available from 2005 after malaria control became a major focus of investment. Other data sources include national service provision assessments (SPA) in 2001 and again in 2007. These data are supplemented, where relevant, by programmatic data such as Health Management Information System (HMIS), Community Health Worker Information System (SIS-com), Integrated Disease Surveillance and Response (IDSR) data, sub-national studies such as epidemiologic and entomologic surveys conducted by the Ministry of Health's National Malaria and Other Parasitic Diseases Division (NMCP) in sentinel sites, and cross sectional and longitudinal studies that have been published in peer-reviewed journals. Data sources are cited throughout the report.

INTERVENTION COVERAGE

During the evaluation period, household ITN ownership increased from 15% in 2005 to 82% in 2010. ITNs were used by 70% of children under-five, 73% of pregnant women,

and 58% of the entire population in 2010. In households that own at least one ITN, 75% of children under five years of age and 81% of pregnant women reported ITN use.

IRS has been conducted since 2007 and has targeted high malaria burden districts defined using epidemiologic and entomologic data. In 2010, IRS was conducted targeting five districts where 87% of households were sprayed in the 12 months preceding the 2010 Rwanda Demographic and Health Survey (DHS). These districts account for more than 70% of the malaria burden and 1.5 million people were protected through the IRS campaign (approximately 14% of population).

Rwanda's national malaria strategic plan includes interventions focused on prevention of malaria in pregnancy. ITNs are distributed at initial antenatal care (ANC) visits along with folate supplementation, and focused antenatal care (FANC) prioritizes effective case management of confirmed malaria illness and anemia. IPTp (two doses of sulfadoxine/pyrimethamine (SP) where at least one was received during an ANC visit), was briefly introduced into the malaria strategy from 2004 to 2008. During this period, IPTp coverage increased from 0.3% in 2005 to 54% in 2007/2008. IPTp was discontinued in 2008 due to Ministry of Health concerns of SP resistance and to decreasing malaria prevalence.¹

OUTCOMES

In the past decade, Rwanda has made great progress in the fight against malaria. Rwanda HMIS data show that malaria incidence declined by 66% between 2005 and 2010 from 186 cases per 1,000 annually to 62/1,000. In addition, the absolute number of malaria outpatient visits declined by 60% from 1.7 million to 660,000 and the test positivity rate declined from 50% in 2001 to 20% in 2010 [3]. Malaria impact indicators measured by household surveys, including prevalence of malaria parasitemia, severe anemia (hemoglobin <8g/dL), and ACCM also declined. Malaria parasitemia prevalence declined from 2.6% in 2007/2008 to 1.4% in 2010 in children 6–59 months of age and from 1.4% in 2007/2008 to 0.7% in 2010 in women of childbearing age (15 – 49 years).

Severe anemia prevalence among children 6–59 months declined significantly from 5% in 2005 to 1% in 2010. The change in prevalence of severe anemia between 2005 and 2010 differed by location of residence; severe anemia prevalence decreased from 9% to 2% in the East and 7% to 2% in Kigali City. Data were stratified by level of malaria transmission. Prevalence of severe anemia declined significantly in each area (low, medium, high and highest transmission strata), but declines were greatest in the areas of highest transmission compared to the others (prevalence decline from 7.1% to 1.7%) over this time period.

¹ Recent studies have shown IPTp-SP to be effective even in areas with high levels of SP resistance [1. ter Kuile F, van Eijk A, Filler S (2007) Effect of Sulfadoxine-Pyrimethamine Resistance on the Efficacy of Intermittent Preventive Therapy for Malaria Control During Pregnancy: A Systematic Review. *JAMA* 297: 2603-2616, 2. World Health Organization (WHO) (2012) Intermittent Preventive Treatment of malaria in pregnancy using Sulfadoxine-Pyrimethamine (IPTp-SP): Updated WHO Policy Recommendation. Global Malaria Programme.

ACCM fell by 61% from 196 deaths per 1000 live births in 1996–2000 to 76 deaths per 1000 live births in 2006–2010. Significant reductions in ACCM occurred in all age subgroups between 1996–2000 and 2006–2010, but the reductions were greatest in children aged 24–59 months (73%). The timing of the change in these mortality trends corresponds with the period during which malaria control interventions such as distribution of ITNs and improvements in community-based case management were being scaled-up.

CONTEXTUAL FACTORS

We undertook a comprehensive review of contextual determinants of child survival, which might offer alternate explanations for the observed changes in mortality during the evaluation period. Several non-malaria related child health factors likely contributed to reductions in ACCM, including improved diarrhea treatment at the community with oral rehydration solution (ORS) and improved diagnosis and treatment of suspected acute respiratory infections (ARI) in conjunction with greater care seeking, and decreasing prevalence of malnutrition. Improvements in maternal health interventions such as ANC attendance and health facility births have also occurred. Extraordinary improvements in GDP have occurred over this period, as have improvements in other indicators of development which are known to decrease child mortality such as women’s literacy and access to potable water and electricity. There has been significant decline in malaria incidence across Rwanda during 2000–2010 and weather patterns may have aided this decline during significant drought periods. Anomalously high rainfall and temperature appears to be involved in the occasional disruptions in the downward trend of malaria (e.g., in 2009).

MODELS

Decomposition models of under-five mortality showed that the observed increase in household bed net ownership, from 8% to 94% could have explained as much as 35% of the observed decline in ACCM between 2000 and 2010, equivalent to a reduction of 42 deaths per 1,000 live births. Improvements in coverage of antenatal care could have explained an additional decline of 11 deaths per 1,000 live births (9% of the total observed ACCM decline). These analyses clearly show the important role of malaria control interventions such as bed nets in the reduction of child mortality in Rwanda.

We estimated the combined potential effect of changes in coverage of essential health interventions on mortality risk using the Lives Saved Tool (LiST) model. Over the 2000–2010 period, scale-up of ITN ownership is estimated to have prevented approximately 5,417 (4,318–6,685) deaths in children under five years of age. It should be noted that this model underestimates the impact of malaria control interventions because the gains associated with improved treatment efficacy and the impact of reduced malaria burden on “indirect” malaria mortality are not accounted for in the model.

CONCLUSIONS

In summary, the impressive decline in child mortality in Rwanda from 1996-2000 to 2006-2010 coincides with a period of rapid scale-up of malaria control interventions such as application of IRS, LLIN distribution and improved malaria case management. ACCM fell 61% during this period and prevalence of severe anemia in children 6-23 months experienced a 71% relative decline between 2005 and 2010. Larger declines in under-five mortality and severe anemia were observed in rural areas, where the burden of malaria is higher compared to urban areas. Although the declines in mortality and in severe anemia were comparable in children 6–23 and 24–59 months old, prevalence of both outcomes has become more homogenous across age groups as malaria levels have fallen. These changes occurred concurrently with a substantial increase in ITN use among children under-five, from 4% to 70%. Multivariable models of the change in under-five mortality between the 2000 and 2010 DHS reveal the importance of increasing bed net ownership and use in explaining the observed mortality declines. Taken as a whole, the evidence supports the conclusion that malaria control interventions substantially contributed to the observed decline in under-five mortality in Rwanda from 2000-2010, even in a context of improving socioeconomic, maternal and child health conditions.

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Acronyms

1q ₀	Infant mortality rate (per 1,000 live births)
4q ₁	Child mortality rate between exact age 1 and exact age 5
5q ₀	Under-five mortality rate (per 1,000 live births)
ACCM	All-cause childhood mortality
ACT	Artemisinin-based combination therapy
AL	Artemether-lumefantrine
ANC	Antenatal care
ARV	Anti-retroviral therapy
ASC	<i>Agents de santé communautaire</i>
ASM	<i>Agents de santé maternelles</i>
BCC	Behavior change communication
BMI	Body mass index
CCM	Community Case Management
CDC	Centers for Disease Control and Prevention
CHERG	Child Health Epidemiology Reference Group
CHW	Community health worker
CI	Confidence interval (95%, unless otherwise stated)
CQ	Chloroquine
DDT	Dichlorodiphenyltrichloroethane
DfID	United Kingdom's Department for International Development
DH	District hospital
DHS	Demographic and Health Survey
DOTS	Directly-observed therapy (short-course)
DPT-HBV	Diphtheria, Tetanus, Pertussis, Hepatitis B virus (vaccine)
EANMAT	East African network for monitoring antimalarial treatment
EDPRS	Economic Development and Poverty Reduction Strategy
EIR	Entomological Inoculation Rate
ENACTS	Enhanced National Climate Services
ENSO	El Niño Southern Oscillation
EVI	Enhanced Vegetation Index
GDP	Gross domestic product
Global Fund	Global Fund to Fight AIDS, Tuberculosis and Malaria
GMAP	Global Malaria Action Plan
GNI	Gross national income
GoR	Government of Rwanda
Hb	Hemoglobin
HBMF	Home based management of fever
HDI	Human development index
HDSS	Health demographic sentinel surveillance
HIV	Human Immunodeficiency Virus
HMIS	Health management information systems
HRP2	Histidine-rich protein II
HSA	Health surveillance assistant
HSSP II	Second Health Sector Strategic Plan
IDA	Iron deficiency anemia
IDSR	Integrated disease surveillance and response
IGME	Interagency group for mortality estimation

IOD	Indian Ocean Dipole
IPTi	Intermittent preventive treatment in infants
IPTp	Intermittent preventive treatment in pregnancy
IRS	Indoor residual spraying
ITN	Insecticide-treated net
IUGR	Intrauterine growth retardation
LBW	Low birth weight
LiST	Lives Saved Tool
LLIN	Long-lasting insecticide-treated net
LMIS	Logistics management information system
M&E	Monitoring and evaluation
MCHIP	Maternal and child health integrated program
MDG	Millennium development goals
MERG	Monitoring and Evaluation Reference Group
MICS	Multiple Indicator Cluster Survey
MIM	Multilateral initiative on malaria
MODIS	Moderate Resolution Imaging Spectroradiometer
MoH	Ministry of Health
MoH-RBC	Ministry of Health Rwanda Biomedical Center
MoLG	Ministry of local government
MSD	Medical Stores Department
MTEF	Medium Term Expenditure Framework
NASA	National Aeronautics and Space Administration
NISR	National Institute of Statistics of Rwanda
NMCP	National Malaria Control Program
NN	Neonatal (mortality)
OPD	Outpatient department
ORS	Oral rehydration solution
<i>PfPR</i> ₂₋₁₀	<i>Plasmodium falciparum</i> parasite rate in children 2-10 years
PMI	President's Malaria Initiative
PMTCT	Prevention of mother-to-child (HIV) transmission
PNN	Postneonatal (mortality)
PSI	Population Services International
RBM	Roll Back Malaria
RDT	Rapid diagnostic test
SIS-Com	Community Information System
SP	Sulphadoxine-pyrimethamine
TT	Tetanus toxoid
UNICEF	United Nations Children's Fund
USAID	United States Agency for International Development
VitA	Vitamin A (supplementation)
WASP	Weighted Anomaly Standardised Precipitation
WHA	World Health Assembly
WHO	World Health Organization

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Introduction

Purpose and Scope

Rwanda is a small, land-locked country in the Great Lakes region of eastern Africa, bordered by Uganda, Burundi, the Democratic Republic of the Congo, and Tanzania. It has a population of approximately 10.8 million (2012 census), making it the most densely populated country in continental Africa with 477 people per square kilometer of land. Administratively, the country is made up of 30 districts, which are divided into sectors, cells (“cellules”), and 14,953 “imidugudu” (villages of 50-100 households). The entire population is at risk for malaria, including an estimated 2.2 million children under five years of age and 443,000 pregnant women/ year (projections based on the 2012 census results).

The country is divided into four malaria ecologic zones based on altitude, climate, level of malaria transmission, and disease vector distribution. Malaria is mesoendemic in the lowlands and prone to epidemics in the high plateaus and hills. The Malaria and Other Parasitic Diseases Division (NMCP) in Rwanda has classified 19 of the country’s 30 districts (63%) as epidemic-prone and the remaining 11 as endemic. Malaria transmission occurs year-round with two peaks (May-June, November-December) in the endemic zones following distinct rainy seasons. In addition to climate and altitude, other factors that influence malaria in the country include high human concentration, population movement, irrigation schemes, and cross-border movement of people.

Due to the serious disease burden caused by malaria and the extensive funding from both domestic and donor sources that has been devoted to malaria control, there is a need to measure the extent to which malaria control interventions have made an impact on malaria. The purpose of this report is thus to assess progress in Rwanda’s malaria control efforts over the past decade, in particular the progress towards the goals set forth in the 2008 Global Malaria Action Plan (GMAP)[4] and in PMI’s 2015-2020 Strategy [5].

This report was co-commissioned by the US President’s Malaria Initiative (PMI), Rwanda’s Ministry of Health (MoH) and the Global Fund. The main objective of the evaluation is to assess the impact of malaria control interventions, such as insecticide treated bednets (ITNs), indoor residual spraying of insecticide (IRS), and malaria case management on malaria morbidity and all-cause mortality (ACCM) in children under-five years of age in Rwanda, during 2000-2010. This report provides detailed descriptions of intervention scale-up and sub-national variations in coverage. The evaluation also considers what other factors might have contributed to the mortality decline over the period.

The evaluation measures progress toward achieving national and international goals and targets that result from the combined efforts of the government of Rwanda and partners supporting malaria control in the country. The evaluation does not document the economic impact of malaria control nor the managerial and administrative performance related to the implementation of interventions. Other resources, such as the Malaria Program Review, Malaria Forum report and PMI’s Malaria Operational Plans are better placed to document

management and implementation issues. The evaluation does not seek to quantify the impact of individual malaria control interventions (e.g. ITN, IRS, IPTp, etc.) or specific initiatives (e.g., Global Fund, President's Malaria Initiative, World Bank's Malaria Booster Program, Roll Back Malaria, WHO or UNICEF) that contribute to control of malaria in Rwanda.

The evaluation focuses on the 2000-2010 period during which ITNs and improved malaria case management (diagnostics and ACTs) were introduced and achieved high coverage levels. Prior to 2000, IPTp had yet to be implemented, new drugs had not yet been introduced and ITN scale-up had not yet begun on a national scale. Mortality data and background information on relevant malaria control policies from earlier time periods are included where this helps to put recent changes into perspective.

This time period is also relevant as it has been a decade of rapid scale-up of malaria control interventions enabled by over \$378.5 million in external funding for malaria control activities and a strong, high-level commitment to reducing malaria burden by the Government of Rwanda.

Evaluation Design

The evaluation is based on a before-and-after assessment, which uses a plausibility evaluation design that measures changes in malaria intervention coverage, malaria-related morbidity, and ACCM while accounting for other contextual determinants of child survival during the evaluation period[6,7].

This report, therefore, describes in detail the changes in malaria control interventions, morbidity and mortality and presents evidence of the plausible link between interventions and impact. The plausibility case is bolstered if the magnitude of impact is consistent with intervention efficacy; if the age-pattern of change is consistent with malaria-mediated morbidity and mortality; if the timing of intervention scale-up matches trend change in impact, and if there is an ecological association between malaria risk and the observed impact. Where data permit, each of these analytical approaches is employed in the evaluation.

Plausibility of causal association is also examined through a number of sub-national studies, where richer data sets variously permit:

- closer examination of temporal association between intervention scale-up and reduction of malaria-related morbidity, malaria cases and/or malaria-associated deaths;
- statistical tests of association between interventions, morbidity and mortality; and
- more detailed analysis of contextual factors that could have contributed to morbidity and mortality change.

At the national level, the report examines changes in other factors that have the potential to mediate changes in malaria-related morbidity and/or ACCM. These contextual factors

include climate, socio-economic factors such as GDP, education, access to improved water and sanitation, access to maternal and child health services, and other predictors of maternal and child health such as nutrition, immunization and comorbidities. The Lives Saved Tool (LiST), created by the Child Health Epidemiology Reference Group (CHERG), is then used to quantify the potential contribution of various health interventions (including, but not limited to malaria control) to changes in mortality of children under five years of age between 2000 and 2010. This tool has been used by the malaria community to estimate the number of deaths prevented due to ITN scale-up in 34 countries in Sub-Saharan Africa.[8,9]

Where data permit, regression analysis is performed to assess impact of malaria control interventions on ACCM. Several case studies are examined in which these analyses are done with sub-national data. Results of a decomposition analysis of ACCM using national data from 2000, 2005 and 2010 are also presented.

Evaluation Indicators

The selection and definition of indicators used in this study for national-level analysis was guided by the recommendations of the Roll Back Malaria (RBM) Partnership’s Monitoring & Evaluation Reference Group (MERG), shown in Table 1.

Table 1: Roll Back Malaria core population-based indicators used in this report

Intervention	Indicator Description
<i>Prevention</i>	
Insecticide-treated nets (ITNs)	1. Proportion of households with at least one ITN.
	2. Proportion of households with at least one ITN for every two people.
	3. Proportion of population with access to an ITN within their household (at least one ITN per 2 persons).
	4. Proportion of population who slept under an ITN the previous night.
	5. Proportion of children under 5 years old who slept under an ITN the previous night.
Prevention and control of malaria in pregnant women	6. Proportion of pregnant women who slept under an ITN the previous night.
	7. Proportion of women who received at least two doses of SP for intermittent preventive treatment (IPTp) for malaria during ANC visits during last pregnancy.
<i>Case Management</i>	
Diagnosis	8. Proportion of children under 5 years old with fever in last 2 weeks who had a finger or heel stick.
Treatment	9. Proportion of children under 5 years old with fever in last 2 weeks for whom advice or treatment was sought.
	10. Among children under 5 years old with fever in last 2 weeks who received antimalarial treatment, proportion who received first-line treatment (ACT).
	11. Proportion of children under 5 years old with fever in last 2 weeks who received any antimalarial

	treatment.*
	12. Proportion of children under 5 years old with fever in last 2 weeks who received first-line treatment according to national policy within 24 hours from onset of fever.*
Impact Measure	Indicator Description
Mortality	13. All-cause under five mortality rate (ACCM).
Morbidity	14. Parasitemia Prevalence: proportion of children aged 6-59 months with malaria infection.
	15. Anemia Prevalence: proportion of children aged 6-59 months with a hemoglobin measurement of <8 g/dL.

Source: *Guidelines for Core Population-Based Indicators Working Paper*

*These indicators are no longer recommended by the RBM MERG but are included here as they are still used to track NMCP targets and/or MDG.

ITNs are one of the principal tools in the arsenal of malaria control. The RBM ITN indicators report on both ownership and use of ITNs. ITN ownership is a household-level indicator, whereas use is measured for the individual. Use at the population level is measured, as is use by the target populations historically at greatest risk of malaria morbidity and mortality: children under five years of age and pregnant women.

Intermittent preventive treatment for malaria in pregnancy (IPTp) is another key tool of malaria control programs which is measured by RBM indicators. The World Health Organization (WHO) recommends IPTp in highly endemic countries. Until October of 2012 IPTp was recommended at a frequency of at least two doses of SP after quickening and at least one month apart; however these recommendations have since changed[2].

Proper diagnosis and treatment of malaria cases is also essential to malaria control. RBM population-based indicators also measure some elements of diagnosis and treatment of malaria; however, facility-based data are often better suited to monitoring trends in malaria case management and are included in this report where relevant. Population-based surveys do not typically contain data on outcomes from visits to health facilities; thus, the proportion of children with fever receiving diagnostic tests for malaria is measured via a proxy indicator in which receipt of a finger or heel stick is considered an indicator for having had a diagnostic test. Questions on care seeking behavior for fever in children under five years of age, and of the type and timing of treatment with antimalarial drugs are also included.

The prevalence of severe anemia and parasitemia in children 6-59 months of age are impact indicators examined in this evaluation. Severe anemia, defined as blood hemoglobin less than 8 grams per deciliter, is a potential impact measure for total malaria-related disease burden as it is associated with malaria-related mortality and it is easily measurable at the population level through household surveys [10]. Parasitemia prevalence is perhaps the most direct measure of malaria burden but there are challenges to using national estimates to measure success of programs given the focal nature of malaria transmission. For this reason, these measures of impact are supplemented by facility-based data on malaria cases where possible.

In line with RBM-MERG guidance, the principal measure of impact employed in this evaluation is ACCM. ACCM is used as a measure of impact as malaria-specific mortality cannot be reliably measured in most parts of sub-Saharan Africa with the current sources of data. This measure is preferable to malaria-attributable mortality for a number of reasons, including: the non-availability of national-level malaria-specific mortality data; concerns about the sensitivity and specificity of the verbal autopsy method for detecting malaria deaths[11] and the fact that malaria is thought to make an “indirect” contribution to under-five mortality that is equivalent to 50%-100% of the mortality that can be directly attributed to malaria [12].

HIV-bias in Mortality Measurement

Mortality estimates presented here have not been adjusted for HIV. In high prevalence countries, deaths of mothers due to AIDS will result in an omission of birth histories that include children with elevated mortality risk. The UN Inter-agency Group for Child Mortality Estimation has developed methods of HIV-adjustment of child mortality estimates and recommends this adjustment in countries where >5% of adult women are infected with HIV. However, other analyses of potential HIV bias by Rajaratnam and colleagues* using DHS data from 21 countries shows substantial variation in effect on child mortality estimates in both directions, even in countries where HIV prevalence exceeds 20%.

Data from the Rwanda DHS indicate that HIV prevalence among women age 15-49 is low and has not changed significantly from 2005 to 2010 (3.6% vs. 3.7%), indicating that any bias introduced in child mortality estimates by HIV has likely not changed over the study period. Finally, improvement in coverage of ARV and PMTCT over the evaluation period should reduce any favorable bias (exaggeration of mortality decline) because birth histories of HIV positive mothers are progressively more likely to be included over time due to improved survival of HIV infected women. Therefore, in this evaluation report, the mortality estimation methods do not take into account potential selection bias arising from high HIV prevalence, and this could be considered a limitation of the report.

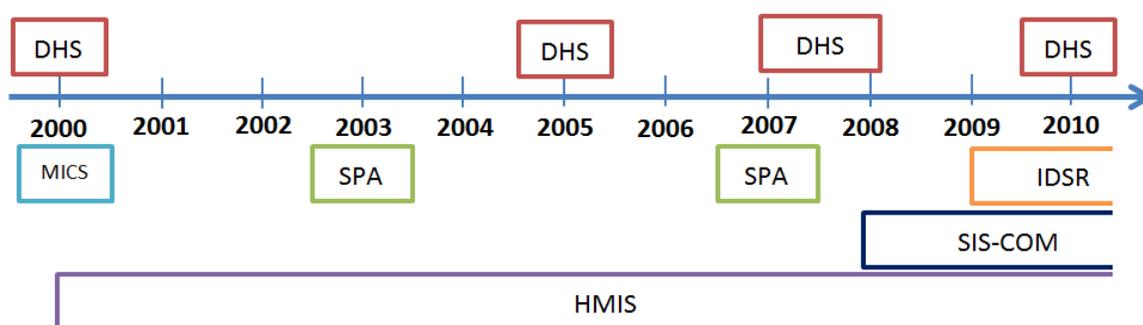
*Rajaratnam et al. *Lancet*. 2010 Jun 5;375(9730):1988-2008.

Data Sources

No new primary data were collected for this evaluation. The data source for mortality in children under-five years of age, malaria control intervention coverage indicators and many contextual factors is Demographic and Health Surveys (DHS) conducted during 2000, 2005, 2007/2008 and 2010. The 2007/2008 HH survey was an interim DHS that used the same sampling frame as the 2005 DHS. Additional data sources are referred to where relevant – particularly where these shed light on variables not measured in the main national surveys. These data are supplemented, where relevant, by programmatic data such as Health Management Information System (HMIS), Community Information System

(SIS-com), Integrated Disease Surveillance and Response (IDSR) data, data on antimalarial stock-outs from Rwanda’s Logistics Management Information System (LMIS), sub-national studies such as NMCP sentinel sites conducting epidemiologic and entomologic surveys, and cross-sectional and longitudinal studies that have been published in peer-reviewed journals. Data sources used for analysis are summarized on a timeline in Figure 1. Finally, this evaluation makes reference to numerous published studies on the relationship between malaria control interventions and their impact. Throughout the report, the source of data is clearly cited and caveats on data quality, comparability and assumptions are indicated. A more detailed description of the data sets, survey methods, sample sizes and other statistical parameters can be found in the annexes.

Figure 1: Data Sources Timeline



Report Structure

The main body of this report is divided into six sections:

- **Background:** A brief description of the country context and malaria situation, including the evolution of the malaria strategy and funding;
- **Interventions:** A description of the scale up of malaria control interventions: ITN, IRS, prevention of malaria in pregnancy (MiP), and case management;
- **Outcomes:** An examination of changes in malaria outcomes including malaria morbidity, specifically malaria parasite prevalence and anemia, and mortality in children under five years of age;
- **Contextual Factors:** A description of changes in contextual factors that may have contributed to reductions in under-five mortality;
- **Further Analyses:** A description of results of published studies in which evidence from case studies where additional data on the intervention-morbidity-mortality relationships are available and a quantitative estimate of the potential contribution to mortality change of malaria control and other health interventions derived using a decomposition model, and;
- **Conclusions:** A presentation of the plausibility analysis, including an assessment of the changes in intervention coverage, the changes in malaria specific outcomes and all-cause childhood mortality, and the changes in contextual factors—other socio-

economic, child and maternal health factors that may have influenced child mortality rates.

Background

Country Context

Rwanda is a land-locked country in Central Africa bordered by the Democratic Republic of Congo in the West, Burundi in the South, Uganda in the North, and Tanzania in the East. It is divided into 5 provinces including the West, North, South, East and the City of Kigali (Figure 2). Rwanda is one of the most densely populated countries in Africa with a population of about 10.54 million people according to the Rwanda census 2012 and a population density of 416 inhabitants per square kilometer [13].

Figure 2: Map of Rwanda



Source: Spatial Data Repository, Demographic and Health Surveys. ICF International. Available from spatialdata.measuredhs.com. [Accessed 18 November 2013].

Some basic development indicators for Rwanda are presented in Table 2. According to the United Nations Development Program (UNDP), Rwanda ranked 166 out of 187 countries in 2011 in the Human Development Index (HDI), a composite measure of health, education and income. Rwanda's HDI score of 0.429 was below the 2011 regional average of 0.463 for Sub-Saharan Africa and far below the global average of 0.682 [14]. GDP per capita in 2010 in current US\$ was 529.4 [15]. As of 2010, the end of the evaluation period, life expectancy at birth was 55 years (world rank = 160). Child and maternal mortality was high (under-five mortality = 76 deaths per 1,000 live births; maternal mortality ratio= 476 deaths per 100,000 births). In 2010, the HIV/AIDS adult prevalence was 3.0% [16]. Stunting amongst children under five years of age was high in 2010 at 44%.

Table 2: Basic development indicators for Rwanda, 2010

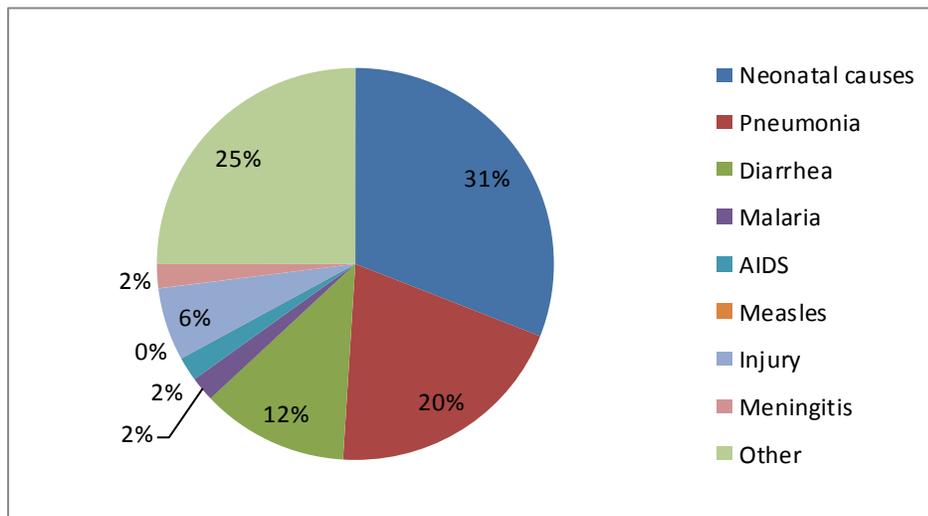
Socioeconomic Indicators	
GDP per capita in current US\$*	540
Rural population*	85.2%
Net primary school attendance rate (attended at least some primary school)**	
Male	95.4%
Female	96.5%
Literacy**	80.4%
Male	76.9%
Female	
Use of improved drinking water sources**	73.6%
Maternal Health Indicators	
Total fertility rate (no. of children per woman)**	4.6
% Births assisted by a skilled provider**	69.0%
% HIV prevalence (women 15-49 years)**	3.7%
Maternal mortality ratio (deaths per 100,000 live births)**	476
Child Health Indicators	
IMR**	38
U5MR**	76
% Children 12–23 months fully vaccinated**	90.1%
% Children under five years who are underweight**	11.4%
% Children under five years who are stunted**	44.0%

*2011 Rwanda Statistical Yearbook [17]

**Data are derived from the Rwanda DHS 2010

The leading causes of death in children in Rwanda in 2010 are neonatal causes, pneumonia, diarrhea, and injury. Malaria is responsible for 2% of child deaths (Figure 3)[18]. The Ministry of Health Annual Statistical Report in 2010 showed malaria as the eighth cause of death [19].

Figure 3: Leading Causes of Death in Children Under Five Years of Age, Rwanda, 2010

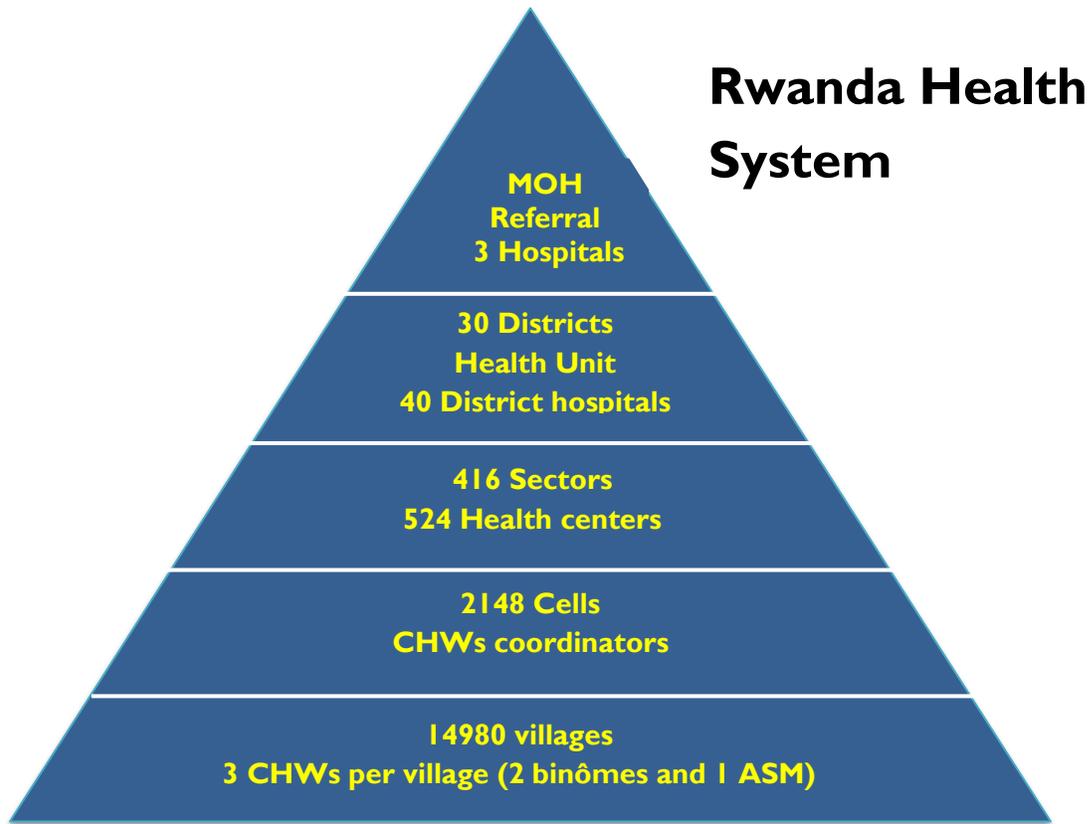


Source: A Promised Renewed Progress Report 2012 [20]

The National Health System

The Rwanda Health System has a five-tiered pyramidal structure led by the MoH (Figure 4). The MoH supports, coordinates and regulates all interventions whose primary objective is to improve the health of the population. The mission statement of the MoH is “to provide leadership of the health sector to ensure universal access to affordable promotive, preventive, curative, and rehabilitative health services of the highest attainable quality.”

Figure 4: Rwanda Health System



Services are provided at different levels of the health care system (community health, health posts, health centres, district hospitals and referral hospitals, see Table 3) and by different types of providers (public, faith-based, private-for-profit and NGO, see Table 4).

Referral System

Rwanda has established a strong foundation in its fight against malaria. A developed network of public sector health facilities exists to meet the health needs of Rwanda’s population. This network is structured as a pyramid with three referral hospitals at the apex followed by 40 district hospitals and 524 health centers. The health centers, in turn, use community health workers and other community based associations for community outreach activities. Referral hospitals also serve also as teaching institutions for doctors and pharmacists.

Table 3: Minimum package of services in different health facilities

Health Facilities	Minimum Package of Services Provided
National Referral Hospital	Advanced inpatient/outpatient services, surgery, laboratory, gynecology, obstetrics, and radiology; specialized services including ophthalmology, dermatology, ear nose and throat, stomatology, and physiotherapy
District Hospitals	Inpatient/outpatient services, surgery, laboratory, gynecology obstetrics, and radiology
Health Centers	Prevention activities, primary health care, inpatient, referral, and maternity
Dispensaries	Primary health care, outpatient, and referral
Health Posts	Outreach activities (i.e., immunization, family planning, growth monitoring, ANC)

Source: Rwanda Ministry of Health Annual Health Statistics Booklet 2011 [21]

Each health facility has at least one functional microscope and reagents needed for the diagnosis of malaria. The referral system is anchored on the provision of an average of four ambulances per district as well the CHWs' access to cell phones.

Human Resources

In 2010, there were 604 doctors and 8,202 nurses/midwives working in Rwanda. In addition to doctors, nurses, midwives and other health care staff Rwanda employs community health workers (CHWs) to provide health services at the village level. CHWs were originally recruited in Rwanda in the post-genocide period to provide mental health counseling among other services. In 1995, there were about 12,000 CHWs. As the country began to recover, Rwanda decided to continue with this strategy and expand the role of CHWs to include additional health services. CHWs, now a team of 60,000, currently provide support in a wide range of health areas including nutrition, environmental health, mental health, integrated community case management (iCCM), tuberculosis, and MCH. CHWs perform their duties by providing health related advice and care, making home visits, and doing algorithmic diagnosis and case management of common diseases including malaria (using malaria rapid diagnostic tests).

Table 4: Human Resources 2004-2010

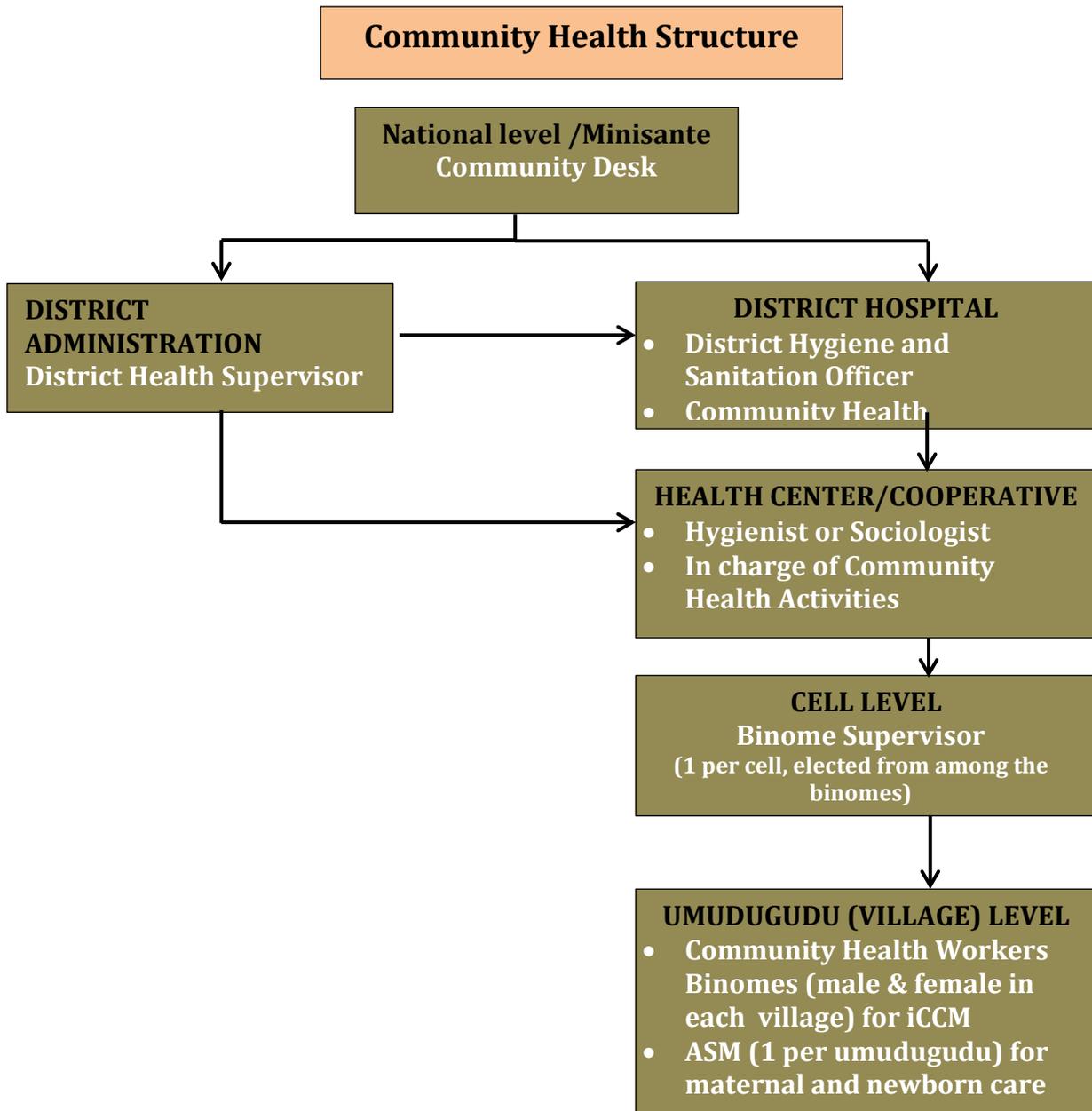
Staff Category	2004	2010
Doctors	432	604
Nurses	3570	8,046
Midwives	--	156
Paramedical	--	613
Laboratory Technician	39	1,144
Administrative and Support Staff	862	2,509
Social Workers	--	1,099
Environmental Officers	101	200
Educators	--	131

Source: Rwanda Ministry of Health Annual Health Statistics Booklet 2011 [21]

The work of CHWs is managed by the Community Health Desk under the MCH Division of the MOH, but it is integrated with other sections. The Community Case Management manager of the NMCP is part of the Community Health technical working group. There are three types of CHWs which equate to four CHWs per village:

- *Agents de santé communautaire – binome* (ASCs): one man and one woman per village who perform iCCM
- *Agents de santé maternelle* (ASMs): one woman per village who is responsible for following up with all pregnant and recently delivered women in the catchment area.
- *Agents chargés des affaires sociales*: one man or woman who is responsible for coordination between the local government and their catchment community.

Figure 5: Community Health Structure



CHWs play a pivotal role in malaria control. CHWs provide diagnosis and treatment to children under five in the community using malaria rapid diagnostic tests and providing prepackaged ACTs. Blister packaging for children, “Primo,” includes information, education and counseling (IEC) materials in the local language (Kinyarwanda) to ensure proper dosing [22]. CHWs also visit homes to check whether families are properly using their bed nets [23]. PMI and the Global Fund have supported the expansion of CHWs through training, provision of materials (CHW kits which include supplies for diagnosis and treatment, registries, job aids, etc.) and supervision and monitoring. All 30 districts have

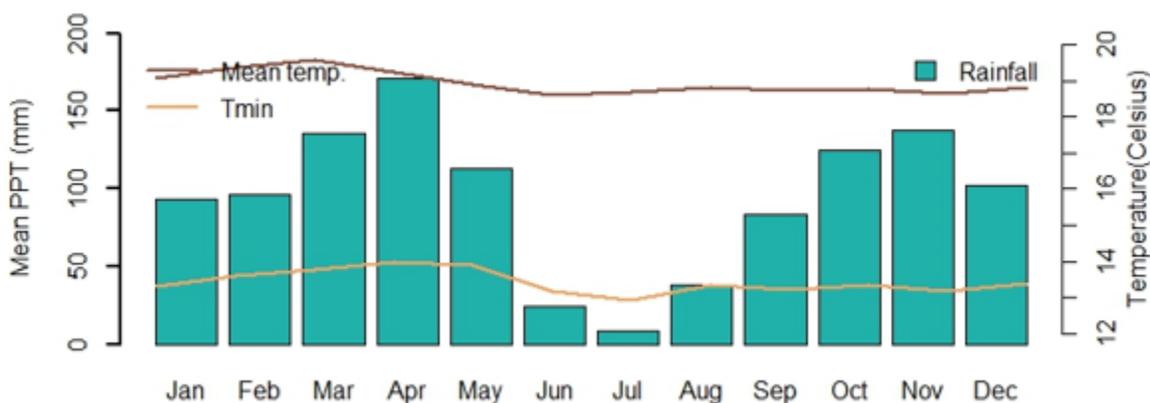
introduced RDTs into the CCM package; districts are in different phases of transition to the full iCCM package. Meanwhile, ASMs ensure that pregnant women receive and use long-lasting insecticide-treated nets (LLINs), attend ANC early and regularly, and receive prompt treatment for malaria cases. As Rwanda moves into pre-elimination, the NMCP sees the role of CHWs expanding to mapping malaria cases, assisting with field investigation, mass distribution of drugs when necessary, as well as continuing with case management as needed and awareness raising efforts.

Malaria in Rwanda

Geographical Distribution of Malaria

As elsewhere in Africa patterns of malaria transmission in Rwanda were historically driven by temperature (influenced by topography with altitude varying from 900-4507 meters). The climate of the country is characterized by an alternation of two wet seasons (September to November and March to May) and two dry seasons (December to February and June to August) (see Figure 6). The mean annual temperature ranges between 18°C and 19°C but varies locally according to altitude and orography. Rwanda receives an average of 44 inches (1031mm) of rainfall in a year with more rain falling on the North-West highlands. Malaria cases occur largely between May-June and during November-December, a one to two month lag following the periods of most intense rain.

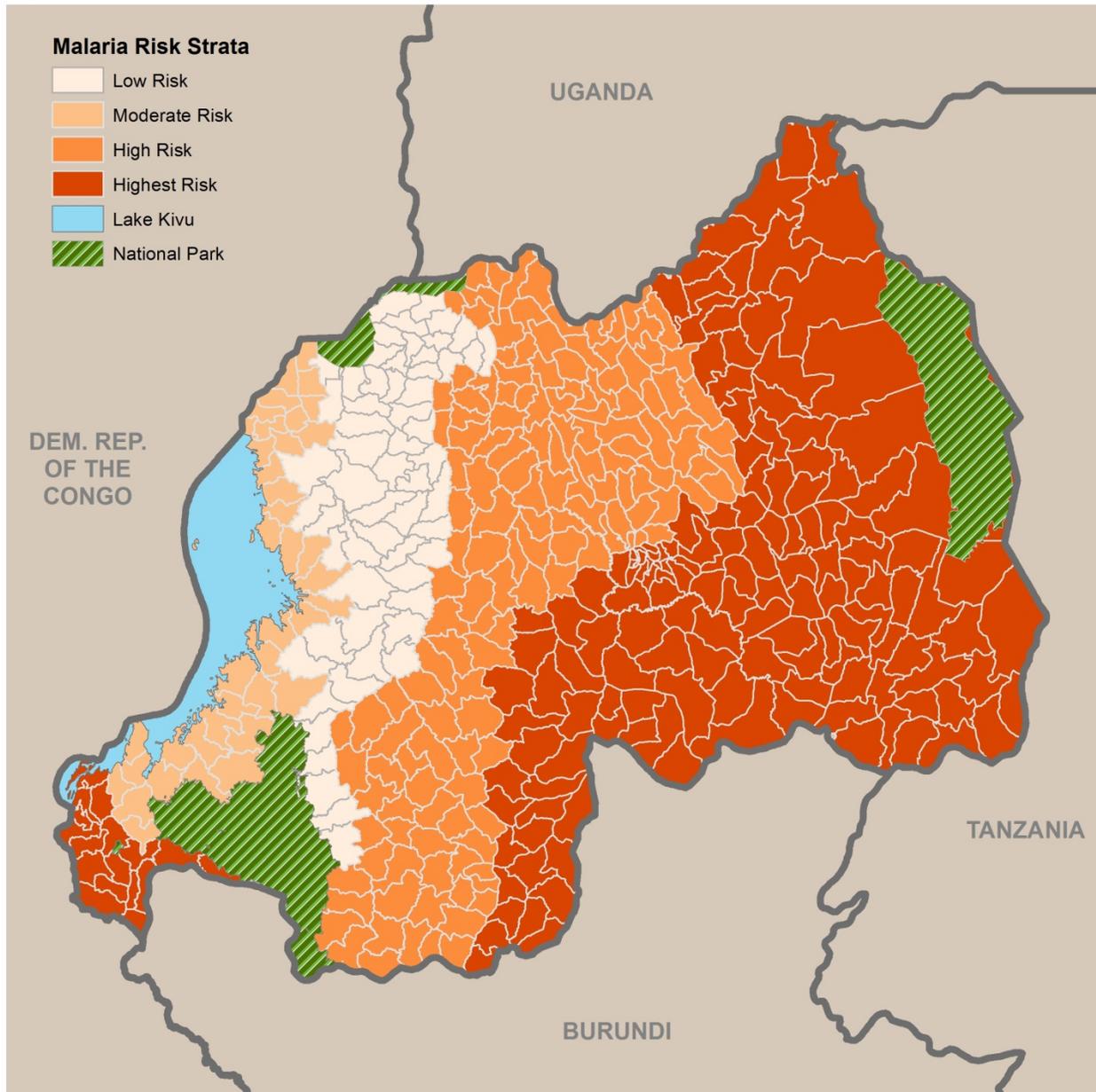
Figure 6: Mean monthly temperature and rainfall for Rwanda from 1981-2013 using ENACTS climate data made available by Meteo Rwanda



In addition to climate and altitude, malaria risk is also determined by demographic, behavioral and infrastructure factors and has thus changed significantly over time. Historic classifications of malaria risk conducted in 1962 divided the country into four “malaria eco-zones” based on altitude, climate, plasmodium index (*Plasmodium* prevalence), and disease vectors. More recently, four eco-epidemiological zones were defined with slightly modified parameters for defining risk. For the purposes of this evaluation new risk strata were defined by the NMCP in consultation with stakeholders in which geography (elevation >1500 – 3000 meters above sea level), climate (rainfall>40 inches or >1000mm), test

positivity rate (TPR), and entomological inoculation rate (EIR) data were used to designate different strata (Figure 7).

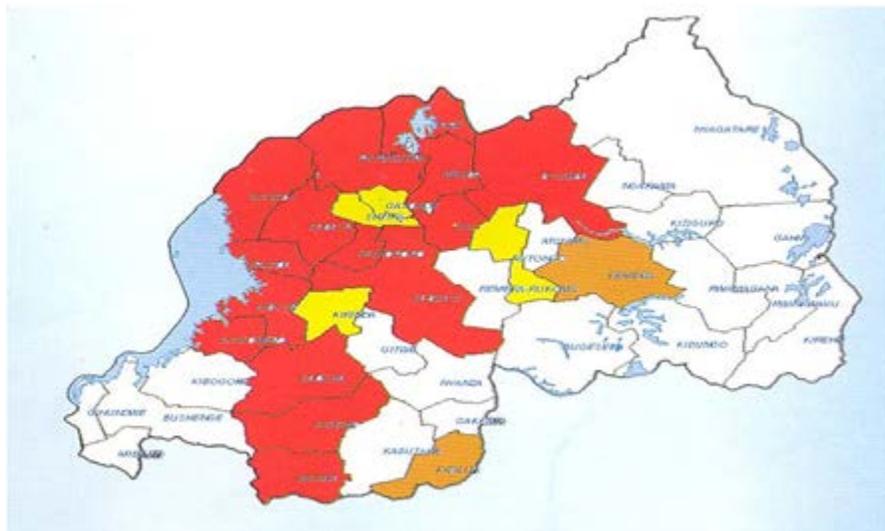
Figure 7: Malaria risk strata in Rwanda



Source: NMCP 2013

Due to the current low prevalence of malaria in Rwanda and the resulting low levels of acquired immunity to malaria, all but the highest risk areas are prone to epidemics. Nineteen districts from eight provinces containing more than 4 million residents are considered as epidemic prone with internal variability: Byumba, Bushenge, Kaduha, Kigeme, Munini, Gisenyi, Kabaya, Muhororo, Kabgayi, Kibuye, Mugonero, Murunda, Remera, Kibilizi, Ruli, Gatonde, Gitare, Nemba and Ruhengeri (Figure 8).

Figure 8: Epidemic-prone districts in Rwanda



	Epidemic-prone districts, likely linked to altitude and climate factors
	Districts where epidemics are known to have occurred.
	District not generally known for epidemics but most likely prone based on altitude and climate conditions.
	Endemic areas

Source: 2007 PMI Malaria Operational Plan [24]

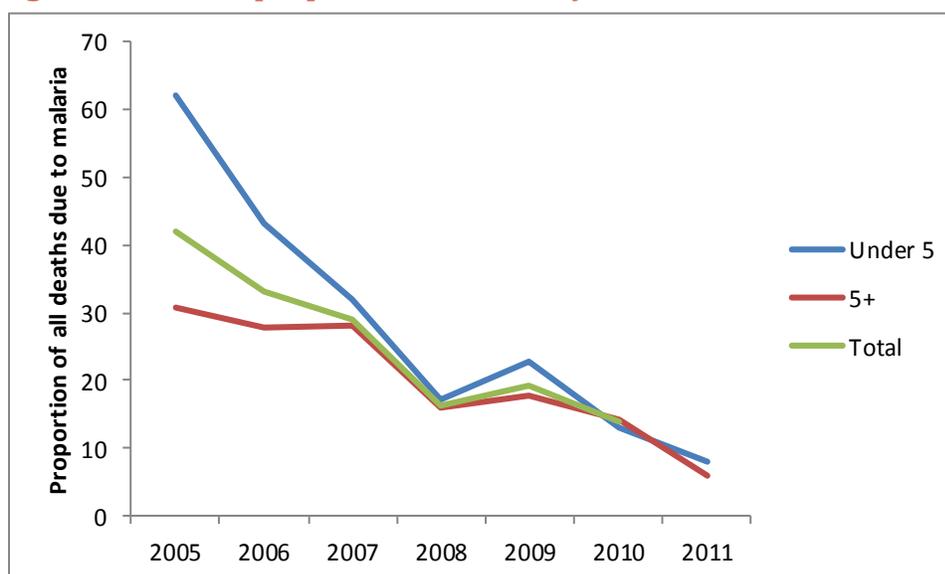
Malaria Parasites and Vectors

The main plasmodium species occurring in Rwanda is *Plasmodium falciparum* (98.5%), with some *P. ovale* and *P. malariae*. There is practically no *P. vivax* detected in Rwanda [25]. Entomology data collected from routine and monthly collections of mosquitoes show that *Anopheles gambiae* s.s, *An. arabiensis*, and *An. funestus* are the main malaria vectors in Rwanda.

Malaria Burden

Malaria was the leading cause of morbidity and mortality in Rwanda since the early 1960s until the end of the evaluation period (2010), with periodic epidemic outbreaks in the high altitude areas. Even as recently as 2005, malaria was estimated to be responsible for 40% of morbidity and 62% of mortality among children less than five years of age as well as for 34% of morbidity and 31% of mortality among persons older than five years of age [26]. By 2010 the proportional mortality had decreased to 13% of all deaths in children less than five years of age and 14% in persons older than five, and by 2011 malaria only accounted for 3% of outpatient visits and 6% of inpatient deaths in district hospitals and health centers [17,27] (Figure 9).

Figure 9: Malaria proportional mortality, 2005-2011



Source: HMIS data

It is important to note that there are provincial and district variations in the reductions in malaria transmission, especially in the Eastern province and districts located on the borders of neighboring countries. The malaria burden in Rwanda has transitioned from a nationwide phenomenon to become focalized in five high malaria burden districts. These five districts, which coincidentally border highly malaria-endemic neighboring countries, account for over 70% of the malaria burden and skew the national TPR (National HMIS database). In fact, 18 out of 30 districts have already achieved TPRs of less than 5%. Many more districts have seen significant declines in their malaria burden and are transitioning from endemic to epidemic-prone status.

Malaria Control Strategy

Development of Rwanda's malaria control program began in 1982 with a discussion of the need for assistance within the Epidemiology Directorate in guiding malaria treatment, reduction of vector density and vector-human contact and in leading malaria operational research. Additional programs and guidelines regarding chemotherapy for children and pregnant women, use of nets, environmental sanitation in rural areas and health education, were implemented in 1986 and in 1987 the MoH developed a strategy on malaria control in the context of primary health care. The Rwanda National Malaria Control Program (NMCP) was formally established as a branch of the Ministry of Health in 1995 with the support of the Belgian Technical Cooperation. Since its formation, NMCP has been housed in various branches of the Rwandan government. In 2010, the NMCP expanded its mandate and became the Malaria and Other Parasitic Diseases Division under the Rwanda Biomedical Center (RBC). In collaboration with the MoH and Development and Research partners, the Center strongly advocates for a participatory approach and strives for community involvement in all aspects to ensure ownership and sustainability of programs.

The NMCP provides technical and financial support to other MOH departments and programs that contribute to malaria control. Partners include the maternal and child health (MCH) Unit; the Rwanda Health Communication Center (HCC) which designs health messages; the Health Information Systems department which compiles malaria-related data being reported by the health districts; the EID/TRACPlus program which contributes to analysis of malaria-related data and detection of malaria epidemics; and the national Reference and Public Health laboratory that ensures the quality of biological analyses in the country. Other key partners are the Medical Procurement and Distribution Division (MPDD), and the Bureau des Formations Médicales Agréées de Rwanda (Office of approved medical training - BUFMAR) a nonprofit mission-sector pharmaceutical wholesaler, and the Central Medical Stores of Rwanda (CAMERWA). BUFMAR and CAMERWA, formerly privately-run non-profit organizations that procure and stock essential drugs and supplies for the country's health facilities, were integrated into the MoH with the formation of the RBC. In addition to government resources, many malaria control interventions are funded through partners whose activities are aligned with the MSP. While some partners contribute directly to the MOH, others work through health districts, NGOs, or other partners such as PMI.

Malaria Control Policies and Guidance

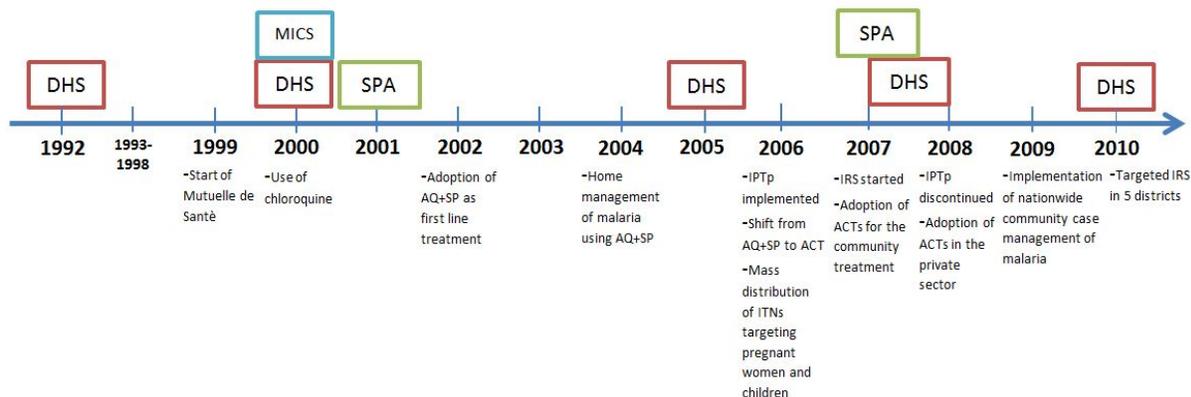
The Malaria Unit has a national monitoring and evaluation (M&E) plan as a complement of the national malaria strategic plan (MSP) 2008-2012 (which has since been updated to the MSP 2013-2018). The M&E strategic plan ensures adequate monitoring and evaluation of strategic approaches to malaria prevention, control and pre-elimination. Program performance is measured through the M&E framework with benchmarks for priority indicators. The Malaria M&E plan also includes guidelines for regular generation and analysis of data and reporting on the progress of interventions. Every year M&E activities are included in the Malaria Unit action plan and are usually updated with findings from the M&E System assessment exercise conducted at the annual review meeting.

National malaria control policies and guidance are scattered in various thematic area guidelines. There is no single consolidated national malaria policy guidance document. However, Rwanda has adopted three interventions for malaria vector control: use of LLINs; IRS targeting high risk areas; and larval source management. WHO training manuals and guidelines for integrated vector management and entomological surveillance are available in-country. In addition, Rwanda follows WHO recommended malaria diagnosis and treatment guidelines including specific guidelines for integrated Community Case Management (iCCM). Additional plans govern epidemic preparedness and response (EPR) and behavior change communication (BCC) policies. Intervention implementation efforts to date are depicted in Figure 10.

At a global level, Rwanda is a signatory to the Abuja Declaration and the Roll Back Malaria (RBM) partnership. The RBM targets therefore form the basis for Rwanda national malaria policy. In addition, the Rwandan national malaria goals align with the Millennium Development Goals to reduce child mortality (Goal 4) and to halt and begin to reverse the

incidence of malaria (Goal 6) [28]. Rwanda is also a member of the African Leaders Malaria Alliance (ALMA), an organization of African Heads of State working in unison to end malaria-related deaths.

Figure 10: National surveys and milestones in strategy in Rwanda



Costs

Malaria also takes a significant financial toll in Rwanda. The direct cost per episode of malaria has been estimated at US\$ 2.09 and the indirect cost at over US\$ 5.00 in 2003. Additionally, owing to the reduced productivity of sick people and the time diverted to caregiving, studies have shown that malaria costs the nation about 2% of the GDP, 34% of household income, and 20% of health expenditure (NHA 2003).

A study on socio-economic impact of malaria conducted in 2005 showed that the total cost of malaria control was estimated to US\$ 32.6 million. This included direct and indirect household expenditures as well as institutional costs engaged by the Government of Rwanda (GoR), parastatal, private and international non-governmental organizations (NGOs). Direct cost of malaria treatment and prevention per household were estimated to be US\$ 7.53 million and indirect cost to be US\$ 7.49 million. Institutional costs were estimated to be around US\$ 17.6 million.

The study also showed also that malaria had a negative impact on GDP. A 1% increase of malaria morbidity has shown to decrease GDP by 0.017%. However these data were collected when the health system utilization was only 33.6%, and prevention was mainly based on conventional insecticide-treated nets (ITN) targeting only children under five and pregnant women, before investments were made in IRS, community health insurance, or home based management (HBM) in malaria endemic districts.

2008 annual institutional needs for malaria control were estimated to be US\$ 246,617,472. Assuming that direct and indirect costs per household has decreased to 25% (given that malaria has decreased, health service utilization has doubled, and subsidized costs for

interventions), the total cost of malaria towards its elimination is estimated to be US\$ 173 per household and US\$ 31.5 per inhabitant (household comprises of 5.5 people and total population is 9.8 million). Table 5 shows a summary of per capita malaria expenditures and out-of-pocket malaria expenditures in Rwanda from 2003-2010.

Table 5: Summary of Malaria Expenditures (Source: Rwanda NHA)

Indicators	2003	2006	2009/10
Total Malaria expenditure per capita	\$2.98	\$4.72	\$4.72
Malaria OOP expenditure per capita	\$1	\$1.91	\$0.24

OOP = Out of pocket

Resources & Inputs

Rwanda depends on donor funding for a large portion of health spending [29]. The major donors are Global Fund and PMI. A breakdown of funds from some major partners is highlighted in Table 6. Where donor and government financing do not fully cover health services, households usually incur the financial burden through out-of-pocket (OOP) payments [30]. An increasing proportion of the population also accesses care through well-established, pre-paid health insurance schemes such as *Mutuelles*.

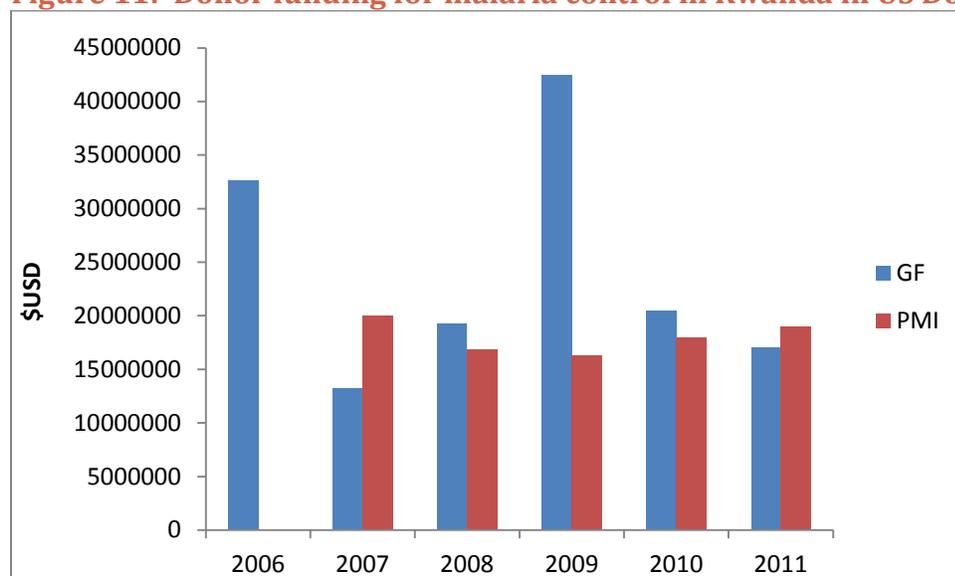
In 2009, the Government of Rwanda has begun to provide more malaria funding. This is within the backdrop of an increasing funding gap for malaria control [31]. Table 6 shows the change in the funding gap from 2007/08 to 2012/13. There has been a sharp increase from about 10% to 70% from 2010/11 to 2013 which is a reversal in the declines observed between 2008 and 2011. It is estimated that the percentage funding gap for 2012 is 55%, which amounts to over 74 million USD and the percentage funding gap for 2013 is 70% which amounts to about 44 million USD [30]. The percent gap in financing is calculated by subtracting the sum of total domestic and external sources of funding from the overall needs costing (Table 6).

In common with other countries in the region, a sharp rise in funding for malaria (Figure 11) has been a driving force behind policy changes and has permitted a dramatic scale-up of key interventions.

Table 6: Trend in funding source for malaria control in Rwanda, 2000–2010

Trends of the financing of malaria control in Rwanda (USD) (as of Oct 2010)			
Financial gap analysis	2008	2009	2010
Overall needs costing (A)	246,617,472	332,731,302	65,719,930
Domestic source: Loans and debt relief (provide donor name)	3,083,332	3,083,332	3,083,332
Domestic source: National funding resources	500,000	1,000,000	1,000,000
Total domestic sources of funding (B)	3,583,332	4,083,332	4,083,332
External source 1:Global Fund Grants	20,104,369	43,270,872	21,890,138
External source 2:WHO	375,000	--	--
External source 3:BTC	1,007,003	839,811	--
External source 3:PMI	17,000,000	17,000,000	17,000,000
External source 5:UNICEF	--	22,500	3,900
Total external sources of funding (C)	38,486,372	61,133,183	38,894,038
Total resources available (B+C)	42,069,704	65,216,515	42,977,370
Unmet need (A) - (B + C)	204,547,768	267,514,787	22,742,560
% gap	83%	80%	35%

Figure 11: Donor funding for malaria control in Rwanda in US Dollars



Source: www.theglobalfund.org; www.pmi.gov; GF = Global Fund

Intervention Coverage

This section describes the scale-up of malaria control and treatment interventions over the evaluation period, from 2000-2010 and before 2000 where relevant to set context. Specifically, ITN distribution since the 1990s is quantified, trends in ownership and use are assessed, and the equity of ITN use across groups is described. The development of Rwanda's indoor residual spraying (IRS) program is outlined and other programs such as community-based environmental management are described. Information about malaria in pregnancy programs and details about malaria case management policies and implementation are presented. Unless otherwise stated, all data cited come from the series of DHS surveys (2000, 2005, 2007/2008 and 2010). ITN/LLIN distribution data come from programmatic data from the NMCP.

Vector Control

In 2009, Rwanda conducted a vector control needs assessment (VCNA) in order to identify the constraints, opportunities, gaps and needs for the implementation of integrated vector management (IVM) in areas of policy, structural arrangements, operational, inter-sectorial collaboration and community mobilization [32]. Rwanda has implemented effective vector control methods such as universal coverage with LLINs and IRS in high risk areas. Other vector control methods such as larval control and environmental management for source reduction have been used on a small scale.

ITN Implementation

In 2006, LLINs were introduced in Rwanda and the ministerial instruction of 2008 prohibited the importation and distribution of untreated mosquito nets. In collaboration with partners, the NMCP developed standard technical specifications for LLINs. Packaging is designed to identify all LLINs as originating in Rwanda to avoid leakage. The Rwanda program uses only World Health Organization Pesticides Evaluation Scheme (WHOPES) approved LLINs.

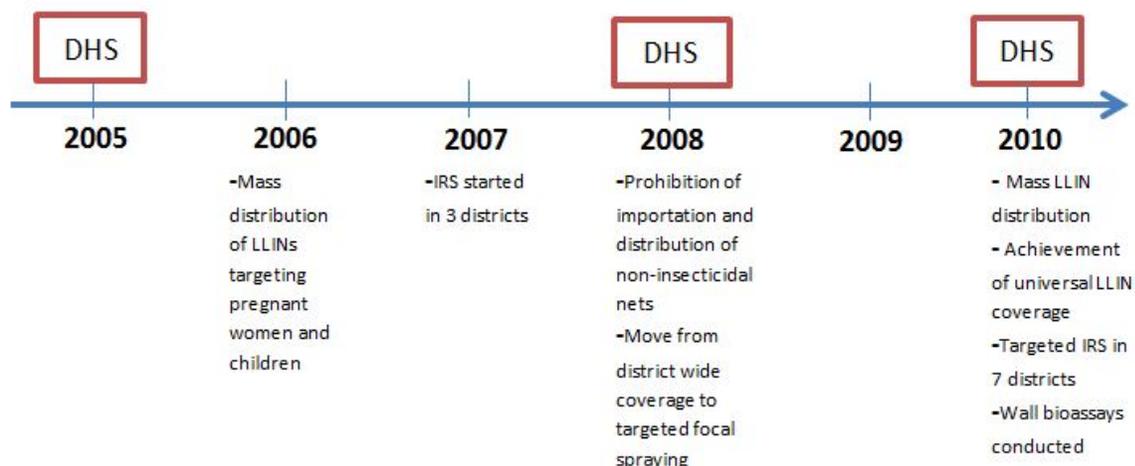
LLIN distribution during the evaluation period in Rwanda was based on two pillars:

- Routine distribution through the EPI and ANC services to children under one year during the measles vaccination and to pregnant women during their first ANC consultation.
- Mass distribution campaigns which are done every three years for children under five years of age and households in order to achieve universal coverage, defined as each household owning at least one LLIN for every two household residents.

During the evaluation period, rectangular LLINs were distributed through routine EPI and integrated vaccination campaigns for children under five years of age, while conical LLINs were distributed routinely through antenatal care for pregnant women and through household campaigns through CHW networks.

A timeline of ITN interventions in Rwanda is presented in Figure 12. Prior to the introduction of LLINs in 2006, the national ITN distribution strategy targeted pregnant women and children under five years of age through ANC and EPI. After the introduction of LLINs in 2006, mass distribution strategies were introduced; a nationwide measles vaccination campaign targeting children under five years of age was used to distribute 1.96 million LLINs [33]. This was followed by the distribution of an additional 1.16 million LLINs in 2007 and 800,000 LLINs in 2009 (Figure 13). In order to meet the universal coverage target for ITNs, and due to estimates of declining ITN coverage, the NMCP and partners implemented a universal coverage campaign in 2010. Almost five million LLINs were distributed in 2010.

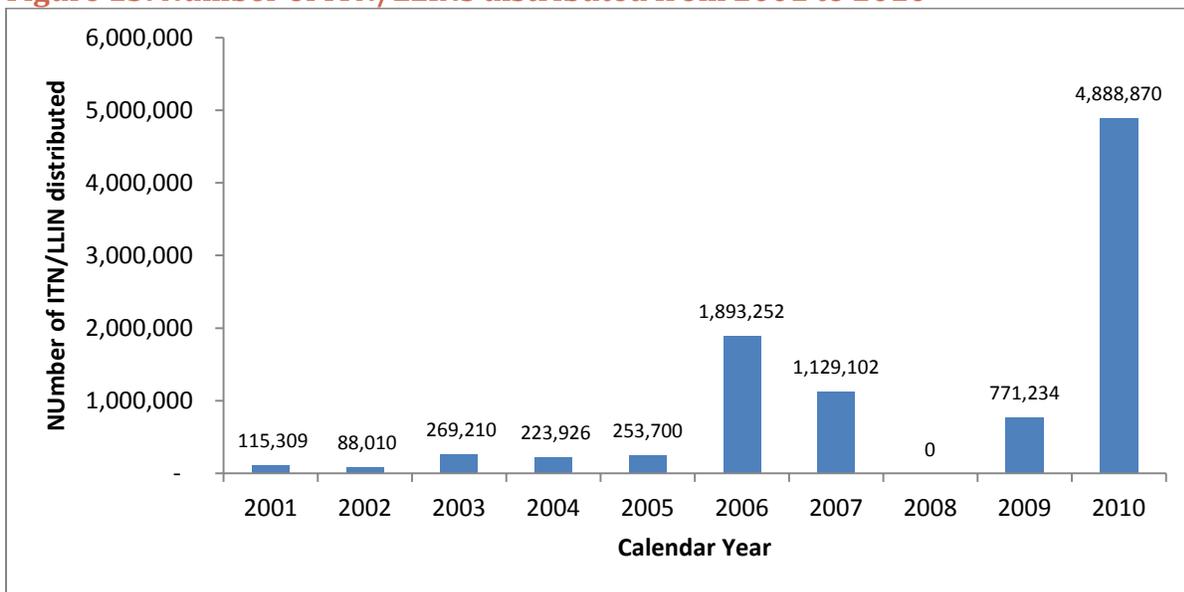
Figure 12: Timeline of data sources and milestones in ITN strategy and interventions in Rwanda



*Continuous distribution of ITNs via antenatal clinics and EPI from 2005.

Figure 13 shows the number of LLINs distributed annually in Rwanda between 2001-2010 [34].

Figure 13: Number of ITN/LLINs distributed from 2001 to 2010



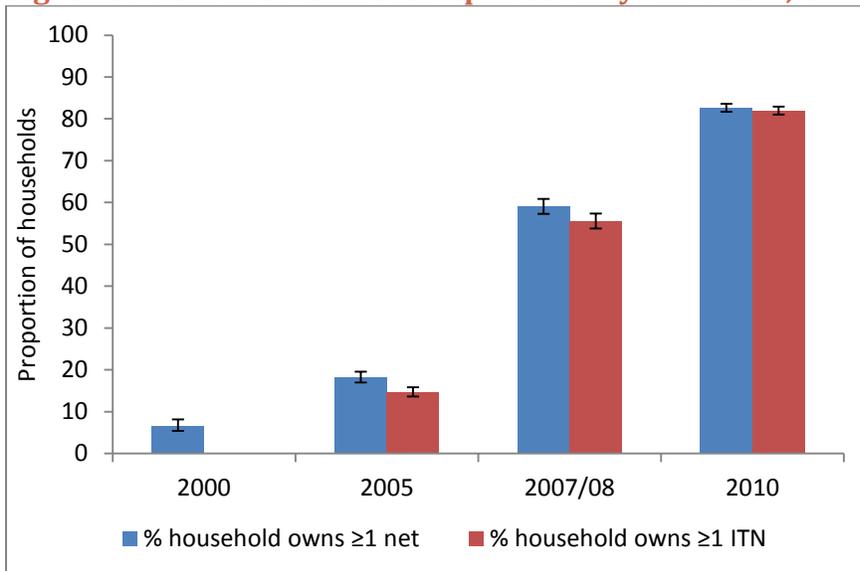
Source: MPR 2013-2018

Note: Distributions intended for 2008 were delayed

Trends in ITN Ownership and Use

The proportion of households that own at least one net (treated or untreated) increased from 7% in 2000 to 83% in 2010 (Figure 14). Ownership of ITNs rose from 15% in 2005 to 82% in 2010 (Figure 14).

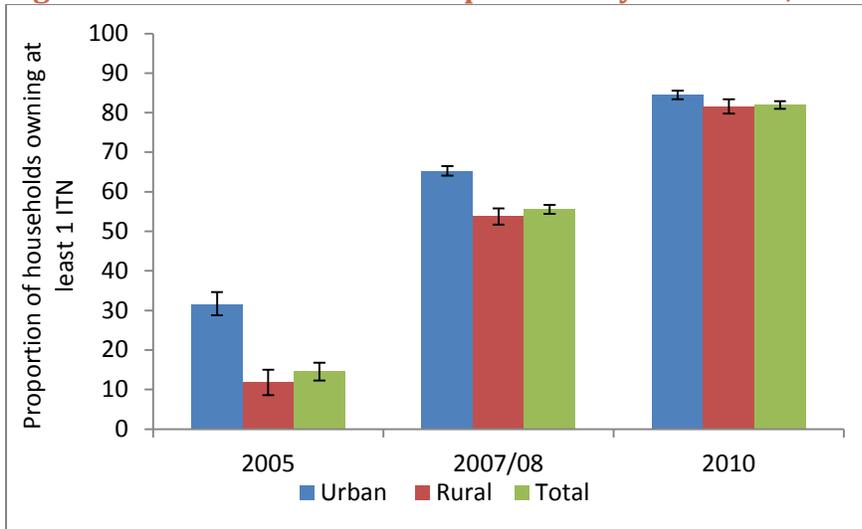
Figure 14: Household ownership of ITNs by residence, 2005-2010



As seen in Figure 15, household ownership of ITNs varied by location of household residence with urban households being more likely to own at least one ITN compared to rural households in 2005 and 2007/08. However, by 2010 the disparity in ITN ownership

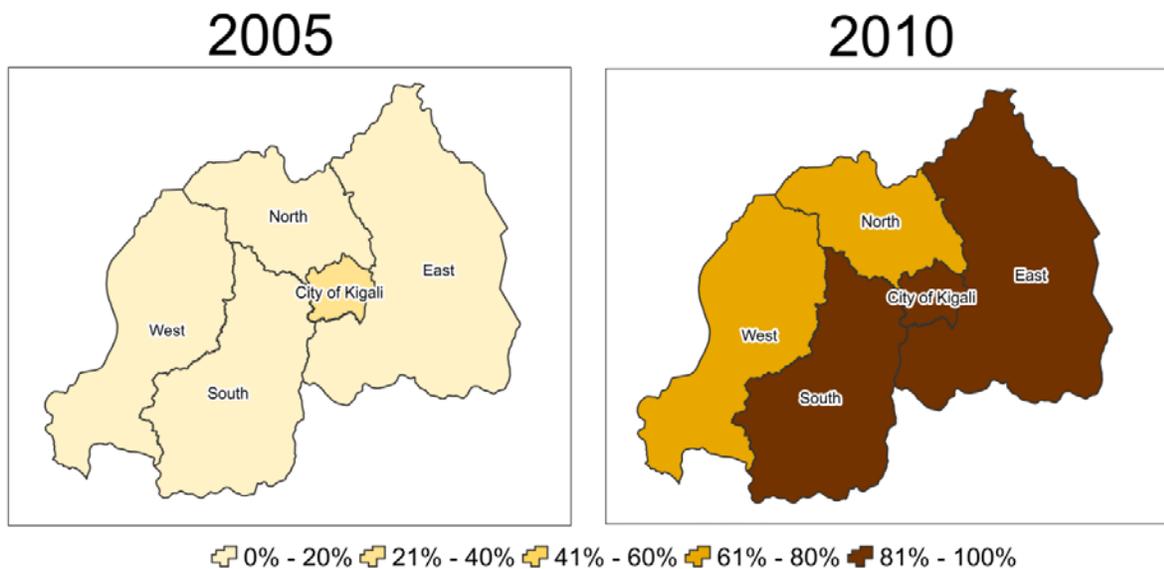
by location of household residence disappeared following the universal coverage campaign that targeted households across the country (Figure 15).

Figure 15: Household ownership of ITNs by residence, 2005-2010



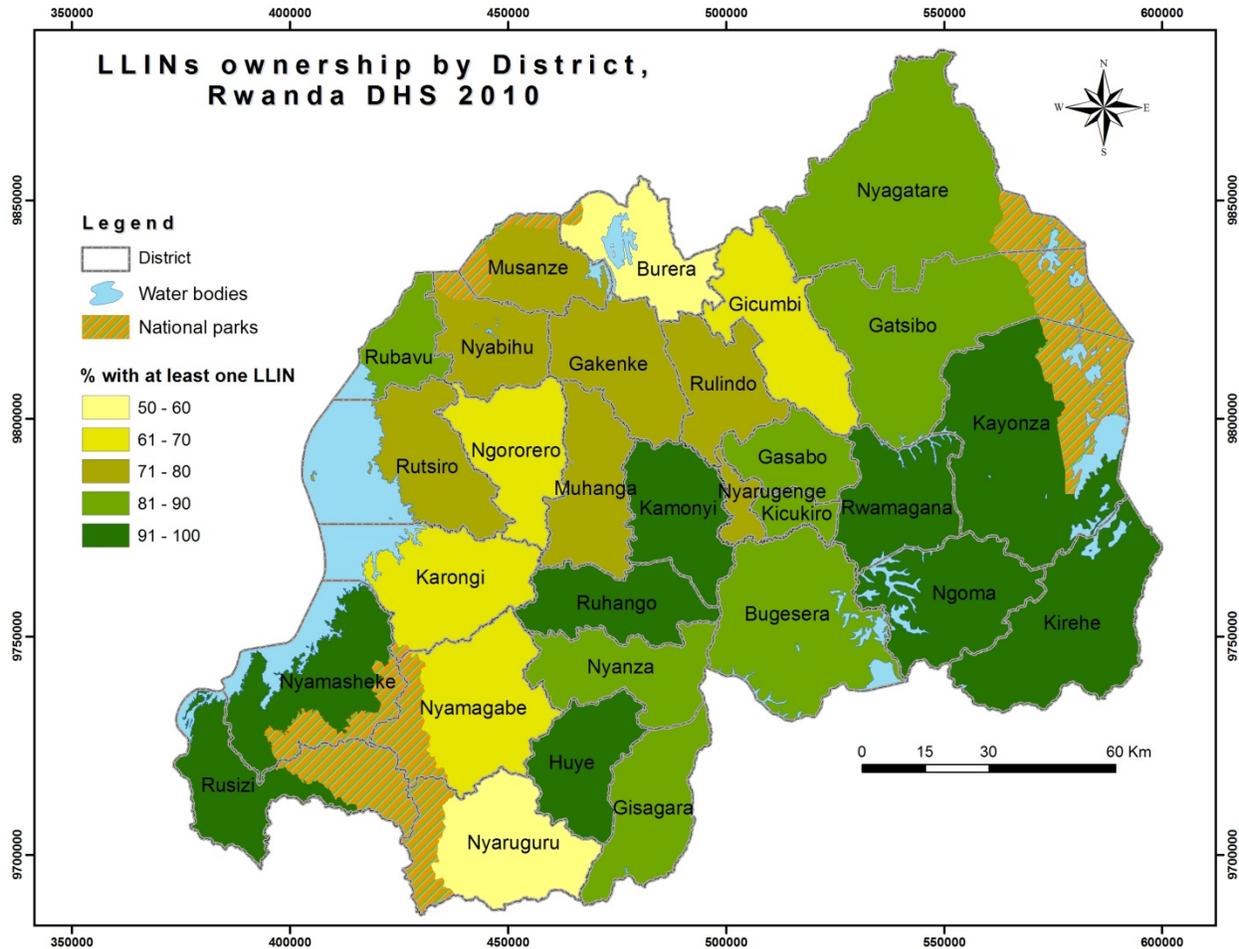
Regional variation in the ownership of ITNs over time is evident in Figure 16. Ownership is highest in the City of Kigali and in the South and East provinces and lowest in the North and West provinces.

Figure 16: Percentage of households owning at least one ITN, by province, 2005 and 2010, DHS



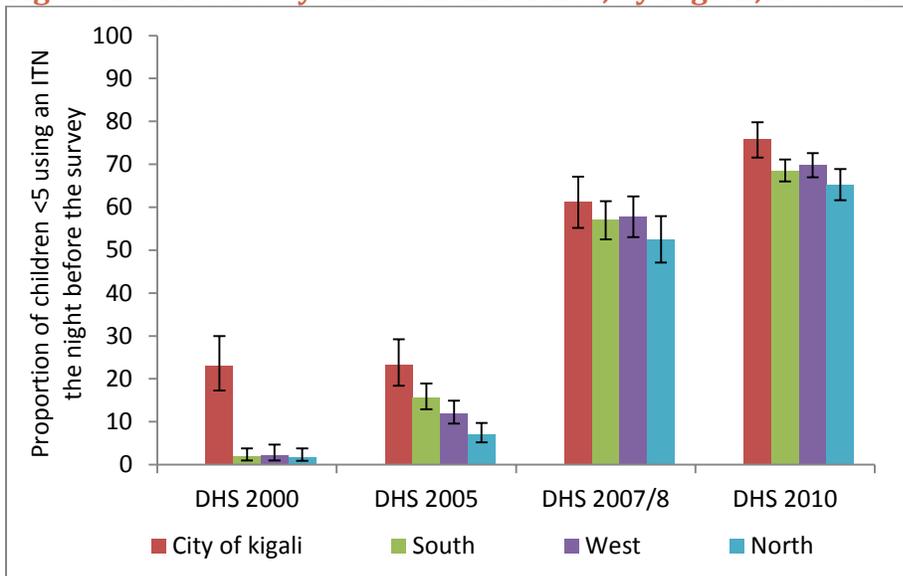
Distribution of ITN ownership varies within province as well. Figure 17 depicts the district-level estimates of ITN ownership in 2010. The West province has particularly diverse net ownership.

Figure 17: LLIN ownership per district, 2010



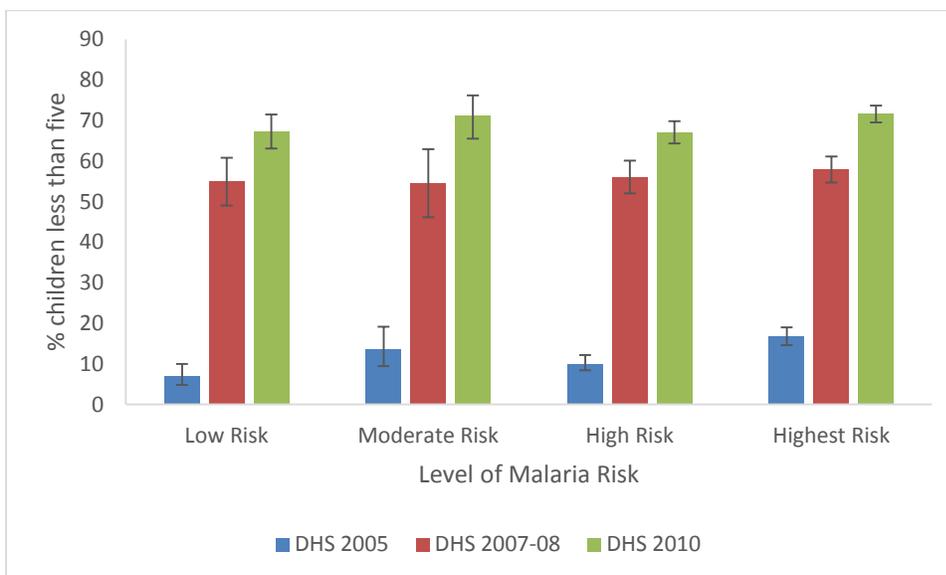
ITN use varies geographically as well. In 2000, there was significant regional variation in ITN use by children under five, with ITN use being significantly higher in the City of Kigali. However, between 2000 and 2010, the increase in ITN use has been spread across regions, so that in 2010 all regions have achieved a high level of coverage (Figure 18). Despite substantial gains across all regions, however, the South and North still have significantly lower ITN use by children under five, compared to the City of Kigali.

Figure 18: ITN use by children under five, by region, 2000-2010



Regional differences in ITN use are likely to be at least partly driven by real or perceived regional differences in malaria risk. Although significant differences were seen in ITN use by children under five in 2005, with use being lowest in the low malaria risk areas and highest in areas of highest malaria risk, these differences were no longer significant in 2007/8 and 2010 (Figure 19).

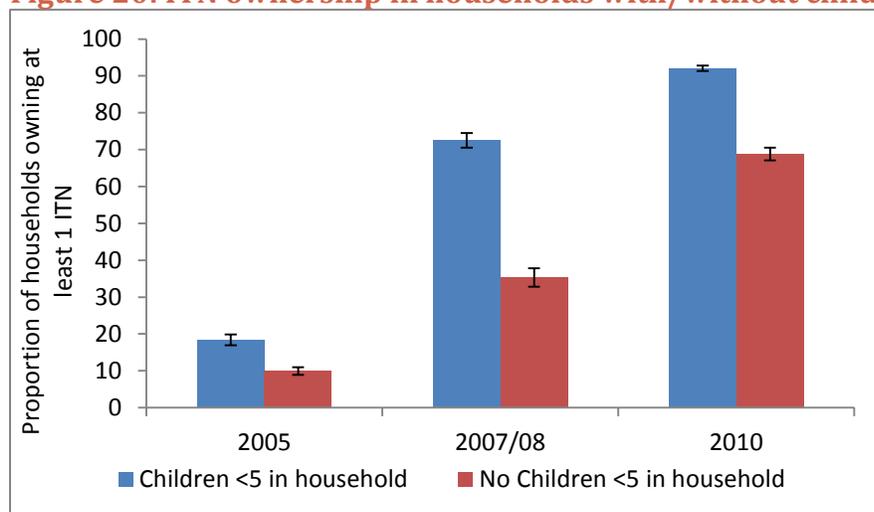
Figure 19: Percentage of children under five years of age who slept under an ITN the night before the survey by malaria risk strata, 2005-2010.



Household ownership of ITNs was significantly higher in households with children under five years of age than in those without (Figure 20). In 2010, 92% of households with

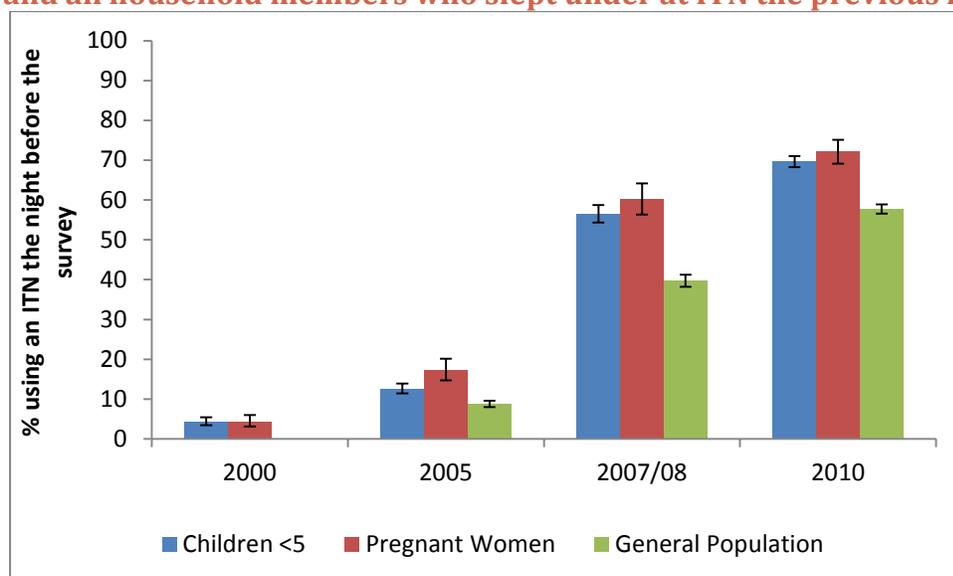
children under five years of age owned at least one ITN whereas 69% of households without children under five years of age owned an ITN. As the mass distribution campaign took place in 2010 the drastic increase in ITN ownership is not fully captured in 2010 DHS data.

Figure 20: ITN ownership in households with/without children under five



Similar to household ownership, use of ITNs increased dramatically during 2000–2010 (Figure 21). ITN use was highest in children under five years of age and pregnant women who have traditionally been targeted by net distribution campaigns; however, increases in ITN use occurred among the entire population.

Figure 21: In all households, the proportion of children under five, pregnant women, and all household members who slept under at ITN the previous night, 2000–2010



In households owning at least one ITN, ITN use has increased from 64% in 2005 to 75% in 2010 in children under five years, and from 52% to 67% in the general population (Figure 22). In pregnant women living in households owning at least one ITN, ITN use did not change significantly between 2005 and 2010, fluctuating around 80%.

Figure 22: In households owning at least one ITN, the proportion of children under five, pregnant women and all household members who slept under at ITN the previous night, 2005-2010

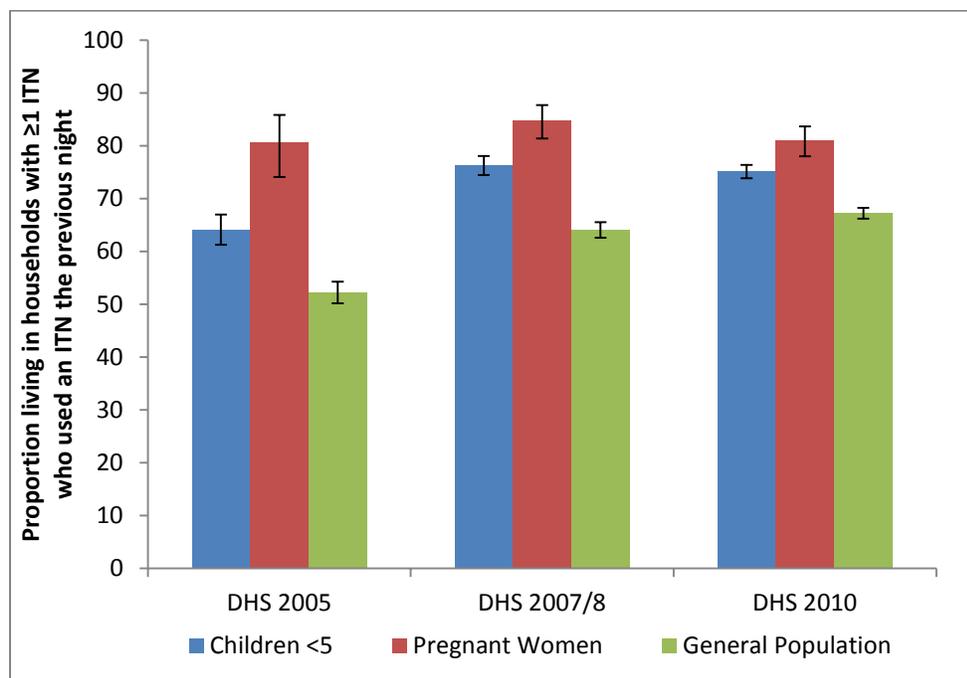


Figure 23 and Figure 24 presents data on ITN use by children under five stratified by household wealth quintile and mother’s education from 2000 to 2010. Since 2000, there has been substantial improvement in ITN use by children across all levels of household wealth and by women’s education. Despite these gains, children in the wealthiest households and those with mothers with more than a secondary education are significantly more likely to use ITNs than those in the poorest households and those whose mothers do not have any formal education.

Figure 23: ITN use by children under five by household wealth quintile, 2000-2010

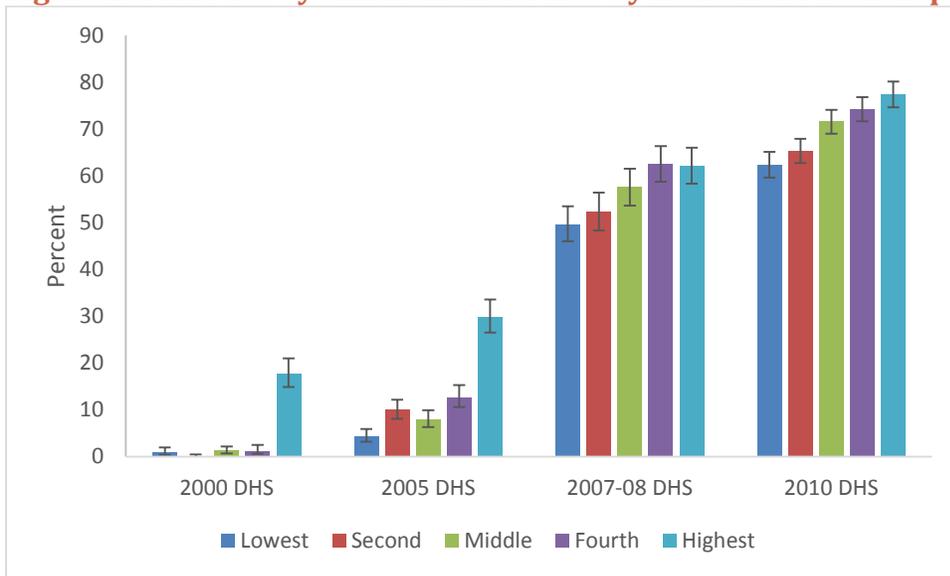
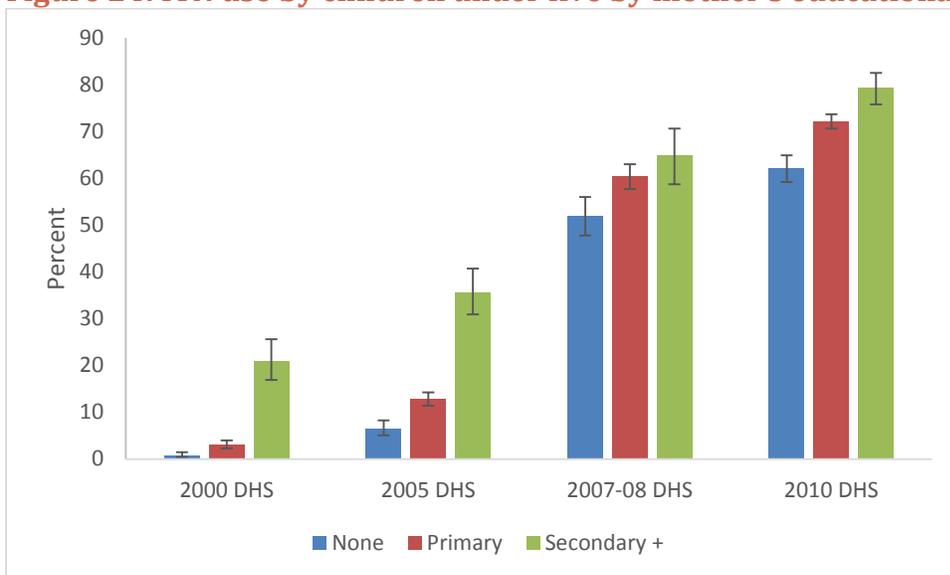


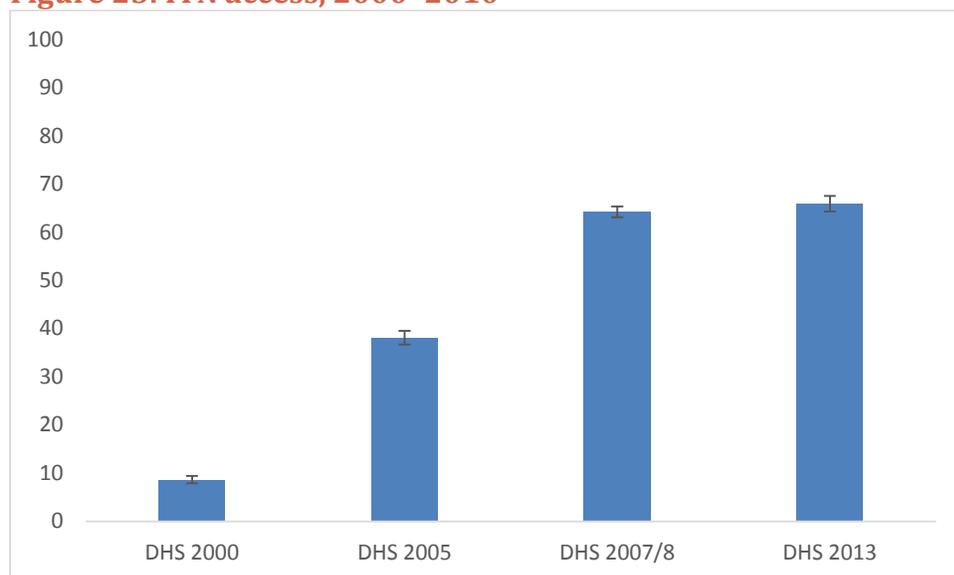
Figure 24: ITN use by children under five by mother's educational level, 2000-2010



ITN Access

ITN access is defined as the proportion of the population that could have slept under an ITN if one ITN can protect two people within a household. The percent of the population with access to ITNs increased from 9% in 2005 to 64% in 2010 (Figure 25).

Figure 25: ITN access, 2000-2010



Indoor Residual Spraying (IRS)

Since 2007, Rwanda has implemented IRS through the NMCP which is responsible for providing technical, management, and operational support. Six spray rounds were completed in three districts of Kigali, and four rounds in Nyarugenge, Kirehe and Nyanza and two rounds in the districts of Bugesera and Nyagatare between 2007 and 2010 with lambda-cyhalothrin, a pyrethroid. An estimate of national IRS coverage from the 2007/8 DHS shows that 4.3% of the population lived in households that were sprayed within 12 months of the survey. From 2008, declining malaria burden led to a decision to move from district wide coverage to targeted focal spraying. The sixth round was implemented from September to October 2010 in the sectors of targeted seven districts. Additional spraying operations were organized in 2010 to control malaria outbreaks in Gisagara district and covered more than 18,886 structures. Spraying is conducted just before the beginning of malaria transmission season (November-July) for about 40 days commencing in August/September each year. Approximately 1.3 million people (approximately 15% of the total population) were protected in the last spray round in 2010 with high coverage >95% of targeted areas. The seven districts which were sprayed in 2010 accounted for over 70% of the malaria burden in the country and one district accounted for over 40%. Therefore, although IRS may only play a limited role in impacting all-cause mortality of children under five at national scale, IRS could play a significant role in reducing malaria specific morbidity and mortality in these high burden districts. IRS districts are depicted in Figure 26 and specifics of each spraying round are summarized in Table 7.

Figure 26: Expansion of the IRS program from 2007 to 2010

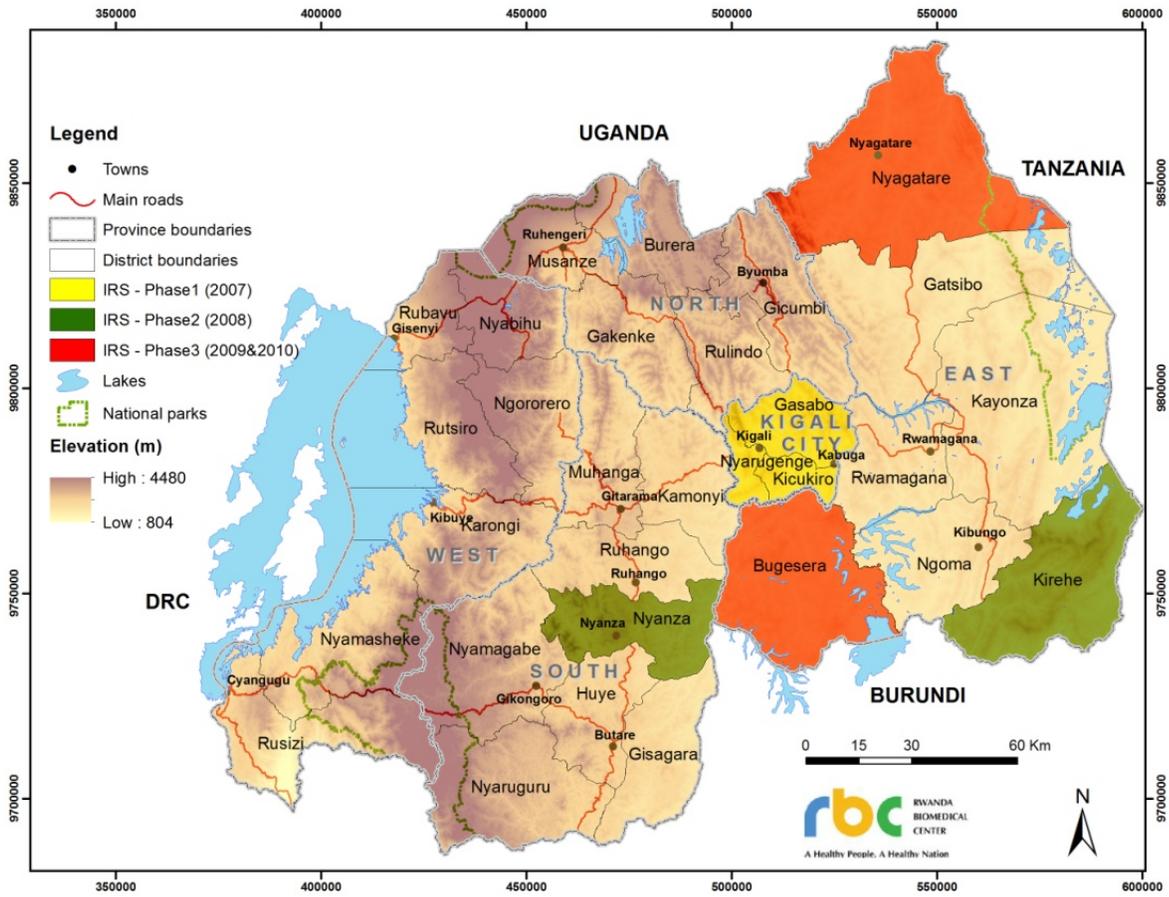


Table 7: Summary of key information on IRS, 2007-2010

Round	Date	Districts	Number of structures sprayed (% coverage)	Population Protected	Insecticide
1	Aug-Sep 2007	Kigali (all three districts)	152,072 (96%)	690,693	Pyrethroid-Lambda-cyhalothrin (ICON@10% Wettable Powder (WP))
2	Aug-Sep 2008	Kigali + Nyanza (South Province) and Kirehe (East Province)	189,756 (94%)	885,957	
3	Jan-Feb 2009	Kigali, Nyanza, and Kirehe	191,051 (97%)	866,002	
4	Aug-Sep 2009	Kigali, Nyanza, and Kirehe + Bugesera (East Province) and Nyagatare (East Province)	295,174 (98%)	1,329,340	
5	Mar 2010	2 Kigali districts (Gasabo and Kicukiro)	63,395 (87%)	280,832	
6	Sep-Oct 2010	Kigali, Nyanza, Kirehe, Bugesera, and Nyagatare	303,659 (99%)	1,365,949	

* Source: RTI's 2011 EOSR (page 2)

Malaria in Pregnancy

Malaria prevention and control during pregnancy typically has a three-pronged approach as recommended by WHO [2], including intermittent preventive treatment (IPTp), ITN use, and case-management of clinical illness.

Risks associated with malaria in pregnancy are greatest in the first and second pregnancies and in all pregnancies for women who are HIV positive [35-39]. Malaria in pregnancy significantly raises the risk of severe illness in the pregnant woman and baby, with serious adverse consequences, including severe anemia, miscarriage, intra-uterine growth retardation, pre-term birth and low birth weight [38,39]. In high transmission settings, malaria is expected to be a significant indirect contributor to maternal death [40]. Malaria in pregnancy is thought to affect neonatal mortality risk via low birth weight and anemia in the newborn [41].

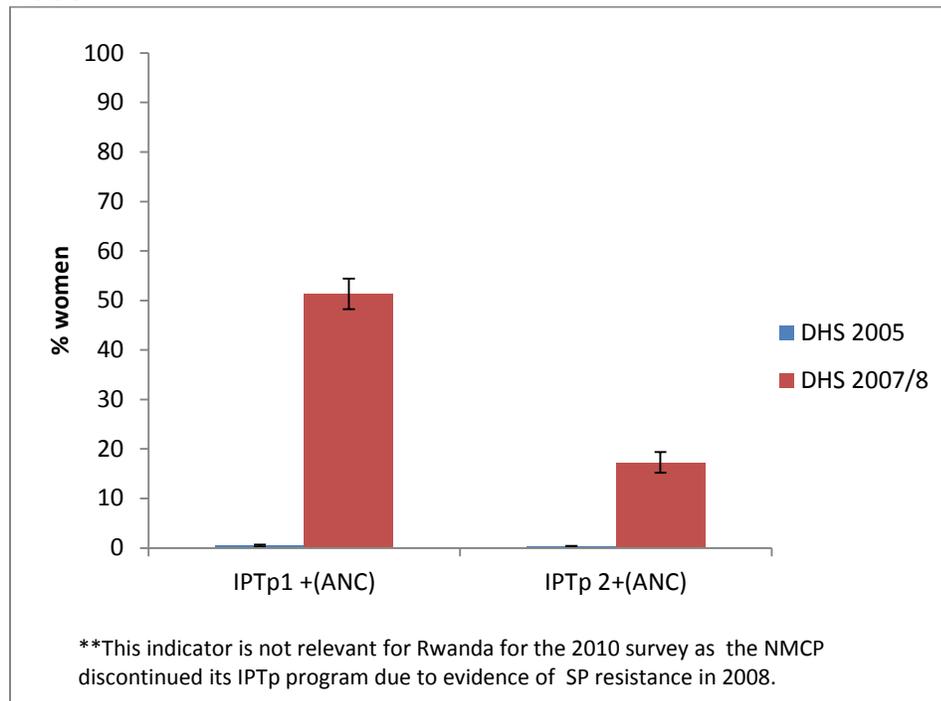
For this impact evaluation we will show how Rwanda applied the three approaches of prevention and control of malaria in pregnancy.

Intermittent Preventive Treatment in Pregnancy (IPTp)

In 2002, WHO recommended intermittent preventive treatment in pregnancy (IPTp) using Sulfadoxine-pyrimethamine (SP) as a prevention policy for countries with endemic malaria [42]. In 2012, WHO updated the recommended regimen to provide SP at each antenatal visit after quickening, with at least four weeks between doses (three tablets each containing 500mg of sulfadoxine and 25mg of pyrimethamine) [2].

In 2004, Rwanda adopted the WHO recommended IPTp regimen with SP in which SP was administered at least two times during pregnancy after the first trimester. The 2005 DHS data showed that only 0.3% of pregnant women received the recommended IPTp regimen. In 2008, based on evidence from therapeutic efficacy testing of SP in children showing 65% therapeutic failure [43,44], a decrease in transmission of malaria (2007/2008 DHS) [45], and high prevalence of gene mutations for resistance to SP [46], the IPTp policy was suspended. Although the intervention was discontinued, the 2007/08 DHS collected data on IPTp coverage and reported that among eligible women, 51.1% had received a dose of SP from an antenatal care visit and 17.2% had received two or more doses of SP (Figure 27).

Figure 27: Proportion of women (15–49 years) with live birth 0–2 years prior to survey receiving at least one and at least two doses of SP at antenatal care, 2005–2008

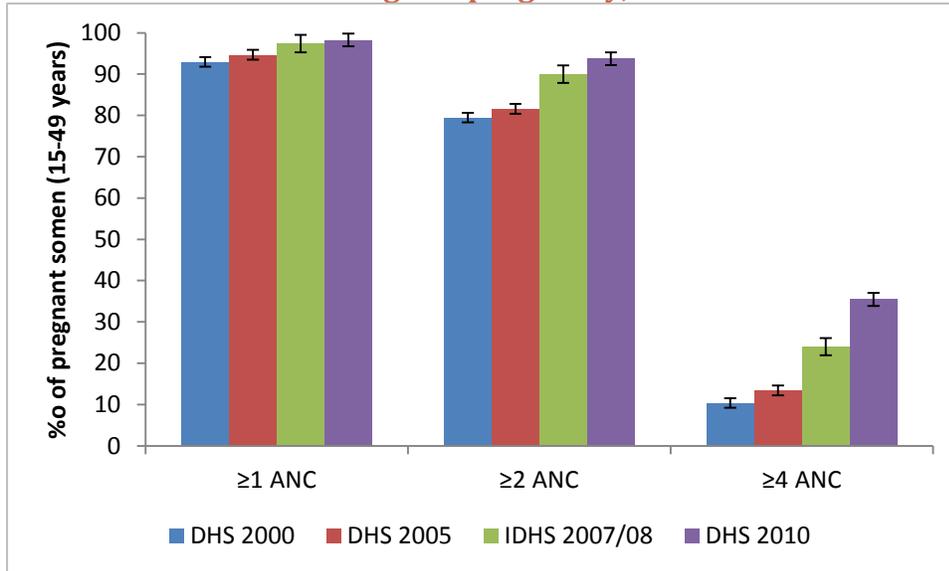


The current policy for addressing malaria in pregnancy focuses on early detection of possible cases followed by early treatment as well as widespread promotion of LLINs.

Early Detection and Treatment

Early detection of malaria in pregnant women in Rwanda is achieved through multiple mechanisms. First, the proportion of pregnant women who receive antenatal care (ANC) is very high (Figure 28). In addition, Rwanda adopted focused antenatal care (FANC) in 2006 and has scaled up with over 1,000 of 8500 total nurses in the country receiving FANC training annually. FANC is comprehensive antenatal care specific to each pregnant woman that includes a birth plan, mitigates risk, and emphasizes malaria, nutrition, birth preparedness, danger signs, and post-partum family planning. In 2010, FANC was implemented nationwide in all ANC clinics.

Figure 28: Proportion of women (15-49 years) with greater than one, two and four antenatal care visits during last pregnancy, 2000-2010

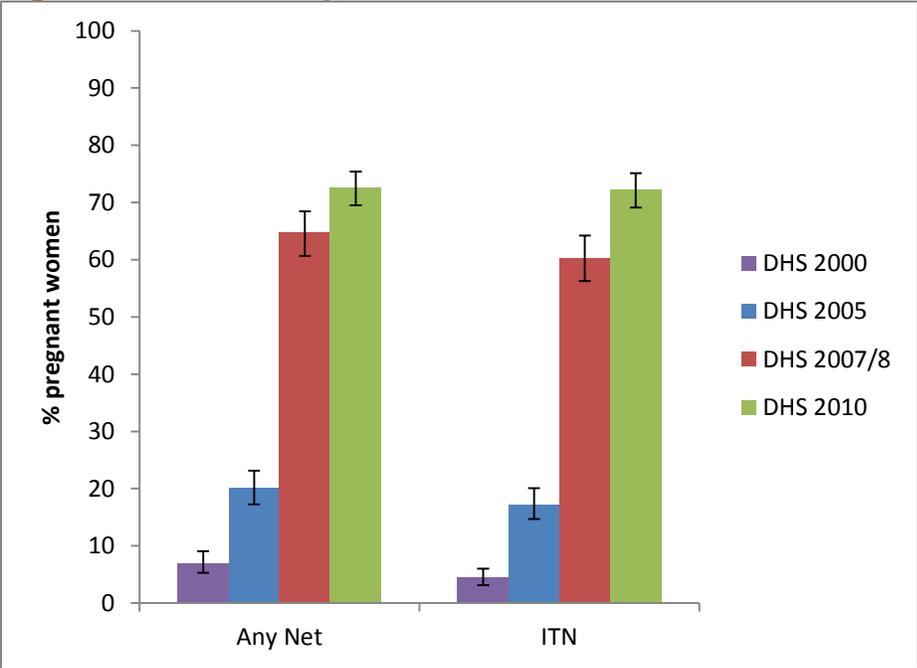


To further increase access to quality antenatal care, Rwanda adopted a new cadre of community health worker in 2008 called *agents de santé maternelle* or maternal health workers (ASMs). ASMs are women chosen by their village to follow pregnant women throughout pregnancy and up to six weeks post-partum. The ASMs provide quarterly home visits (at least three) to pregnant women during which they check for danger signs, provide education on malaria and nutrition, and discuss preparation for delivery. They also encourage pregnant women to make four ANC visits, to use an ITN/ LLIN, to strive for proper nutrition and to deliver at health facilities. If an ASM finds a pregnant woman with danger signs, she will immediately inform the health center by mobile phone and refer the patient. In 2010, there were 15,000 ASMs in Rwanda.

ITN Use by Pregnant Women

A final component of the WHO three pronged approach to MIP is the use of LLINs by women during and after pregnancy. Since 1996, Rwanda has provided free bednets to pregnant women during their first ANC visit. ITN use by pregnant women in Rwanda increased substantially from 17% in 2005 to 72% in 2010 (Figure 29). In 2010, the NMCP distributed approximately 450,000 LLINs to pregnant women nationwide. Currently, Rwandan policy provides free LLINs to primigravid women.

Figure 29: Percentage of pregnant women who used any net and who used an ITN the night before the survey, 2000-2010



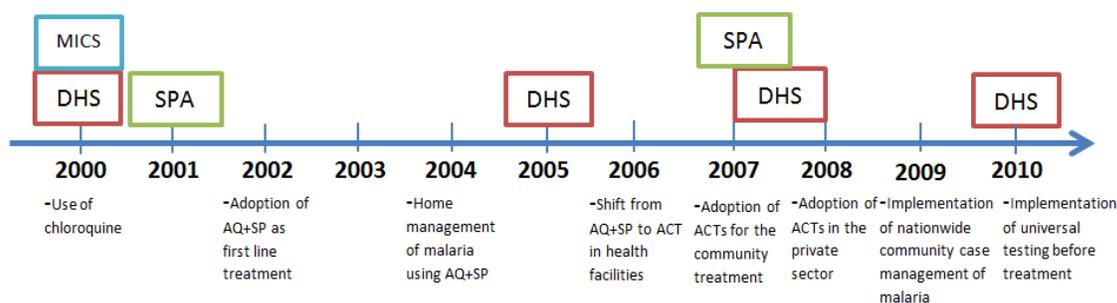
Malaria Case Management

Malaria case management, including the identification, diagnosis, and rapid treatment of all malaria cases with appropriate and effective antimalarial drugs, is one of the key strategic areas for malaria control recommended by the World Health Organization [47]. Most malarial fevers occur at home, and prompt and effective treatment is critical to prevent severe morbidity and mortality related to malaria.

Case Management Policy

Despite high levels of resistance, chloroquine continued to be used for treatment until 2002 when amodiaquine in combination with SP was adopted as first line treatment for uncomplicated malaria. Due to low utilization of health services (17.4% of children under five years of age with fever sought care from health facilities in 2000), Rwanda introduced a home based management of fever (HBMF) program in 2004 in which 19,000 CHWs were trained to assess children with fever, treat uncomplicated cases and provide referrals for complicated malaria cases. The program was initially rolled out in 4 highly endemic districts and reached 18 districts by the end of 2007. This program was expanded to include diagnosis and treatment of other childhood illness beginning in 2006. In 2006, ACTs (specifically, artemether-lumefantrine (AL)) became the recommended first line treatment for uncomplicated malaria and were integrated into the HBMF program as they became available. In 2009, Rwanda implemented a policy of universal parasitological diagnosis by microscopy in health centers and by RDTs at the community level. By 2010, all CHWs were using Rapid Diagnostic Tests (RDTs) before treating with ACTs as per the MoH policy and, according to HMIS reporting, 94% of all suspected malaria cases were tested, either with RDTs or microscopy before treatment[48]. This was well above the average in Africa of 35%. Diagnosis and treatment policy milestones are summarized in Figure 30.

Figure 30: Data sources and milestones in case management of malaria in Rwanda



Malaria Diagnosis

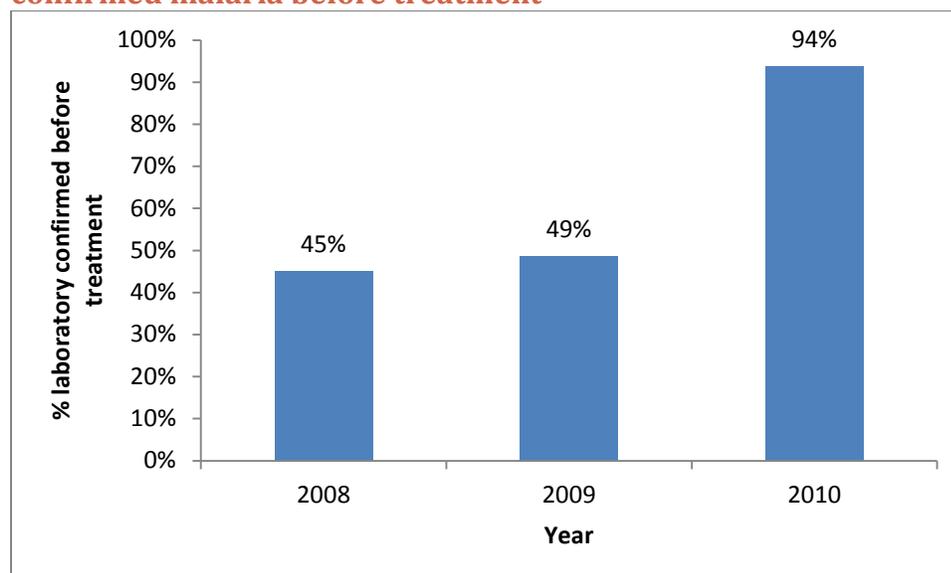
The majority of health centers and hospitals in Rwanda have functional microscopy services to diagnose malaria (98%) [26]. Quality control of microscopy is performed by the National Reference Laboratory (NRL). The results of the 2009-2010 parasitological annual report showed a high concordance between slides read at the health centers, districts, and the NRL indicating high quality results (Table 8). RDTs are used in settings where high quality microscopy is not possible or feasible. RDTs are also used when microscopists are not available at health facilities such as on weekends and during emergencies. RDTs were initially introduced in Rwanda in 2006. Since then, RDT use has expanded across the country and since 2009 RDTs have been used by CHWs for malaria diagnosis and identification of non-malaria fever cases for further examination of other illnesses. Following extensive roll-out of RDTs in 2010, the proportion of suspect cases that received laboratory confirmation of malaria increased from 49% in 2009 to 94% in 2010 (HMIS data, MoH Statistical Handbook, Figure 31).

Table 8: Results of Blood Smear Slides Quality Control, 2009-2010

	Number of slides	Discordance	% of discordance
Positive slides	1585	30	1.8 %
Negative slides	2772	51	1.8 %
Total slides	4357	81	1.8 %

Source: National Reference Laboratory Parasitological Annual Report 2009-2010

Figure 31: Proportion of febrile patients at health facilities with laboratory-confirmed malaria before treatment

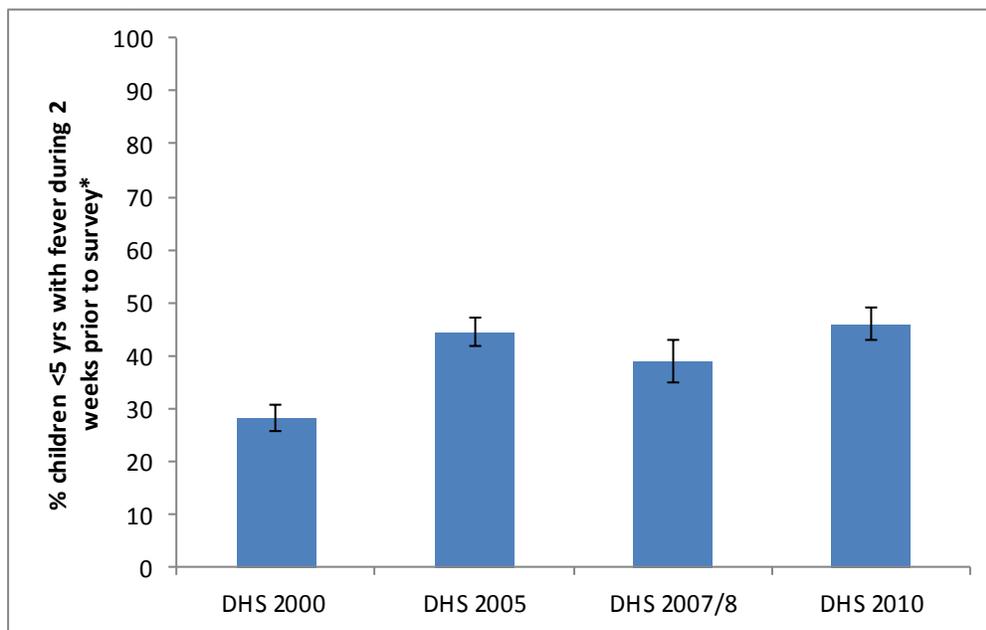


Malaria Case Management in Children

Correct and timely care of children with malaria depends on many factors, including access to health facilities, diagnostic capacity, and availability of appropriate medicines. Measuring trends in malaria case management is further complicated by the many policy changes that have occurred in the past decade, affecting both first-line medications and diagnostic procedures. As a result, the historic RBM indicator measuring the proportion of children with recent fever who receive antimalarial treatment has been supplemented in this report with two new RBM indicators: an estimate of care seeking for fever and an estimate of the proportion of treated children receiving recommended treatments [49].

The DHS surveys ask mothers to report history of fever in children under five years of age during the two weeks prior to the survey. Of children who experienced fever, a series of further questions are asked about care seeking including the source of advice and/or treatment, the timing of care seeking, and type of antimalarial used, if any. Figure 32 presents trends over the period 2000-2010 in care seeking from a health provider, facility or pharmacy. Overall care seeking for young children with fever has increased significantly over the decade from 28% in 2000 to 46% in 2010.

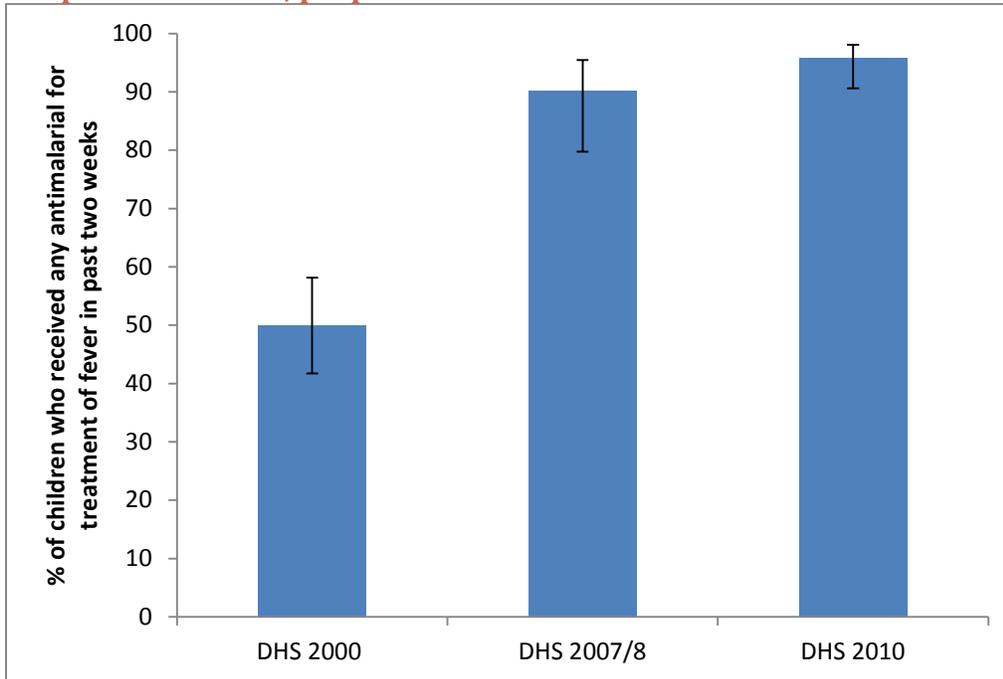
Figure 32: Percentage of children less than five years of age with fever during two weeks prior to interview who ever sought care from a health provider, facility or pharmacy



Note: This includes all “public” and “private” DHS source s of treatment response options (including pharmacy) and excludes all “other” responses (i.e. shop, traditional healer, market)

Although ACTs were not rolled out in Rwanda until 2006, by the 2007/08 DHS, 90% of children who received antimalarials for treatment of fever received ACTs (Figure 33). By 2010, 96% of these children received ACTs. These data indicate that treatment with efficacious and appropriate treatment is very high in Rwanda.

Figure 33: Among children who received any antimalarial for treatment of fever in the past two weeks, proportion who received first-line medications

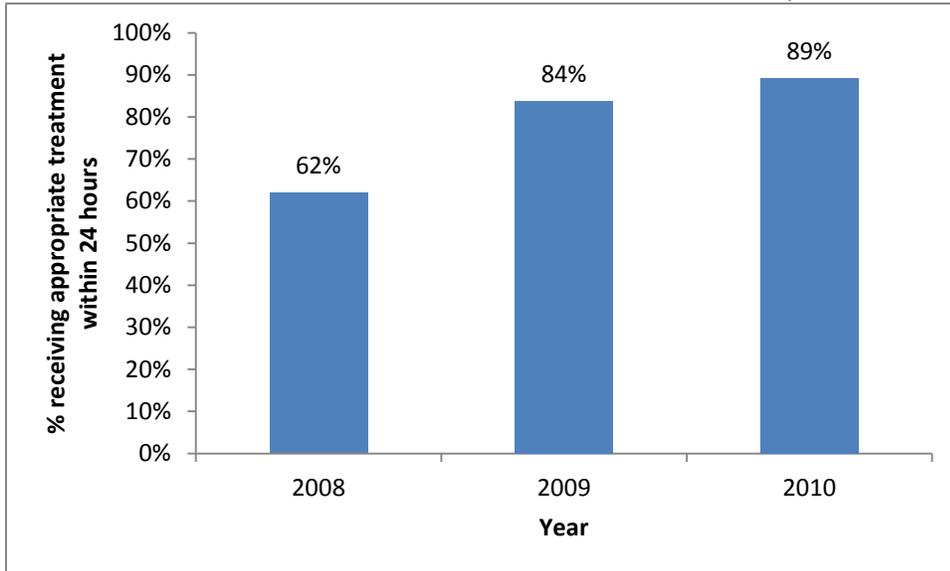


Note: The recommended first-line treatment in 2005 for uncomplicated malaria in children was AQ-SP which was not a response option in the 2005 DHS questionnaire.

Community Case Management of Malaria

Data collected at the community level showed that in 2008, 62% of children under five years of age with fever received antimalarial treatment within 24 hours of the onset of fever. Timely treatment of fever increased to 84% in 2009 and 89% in 2010 (Figure 34).

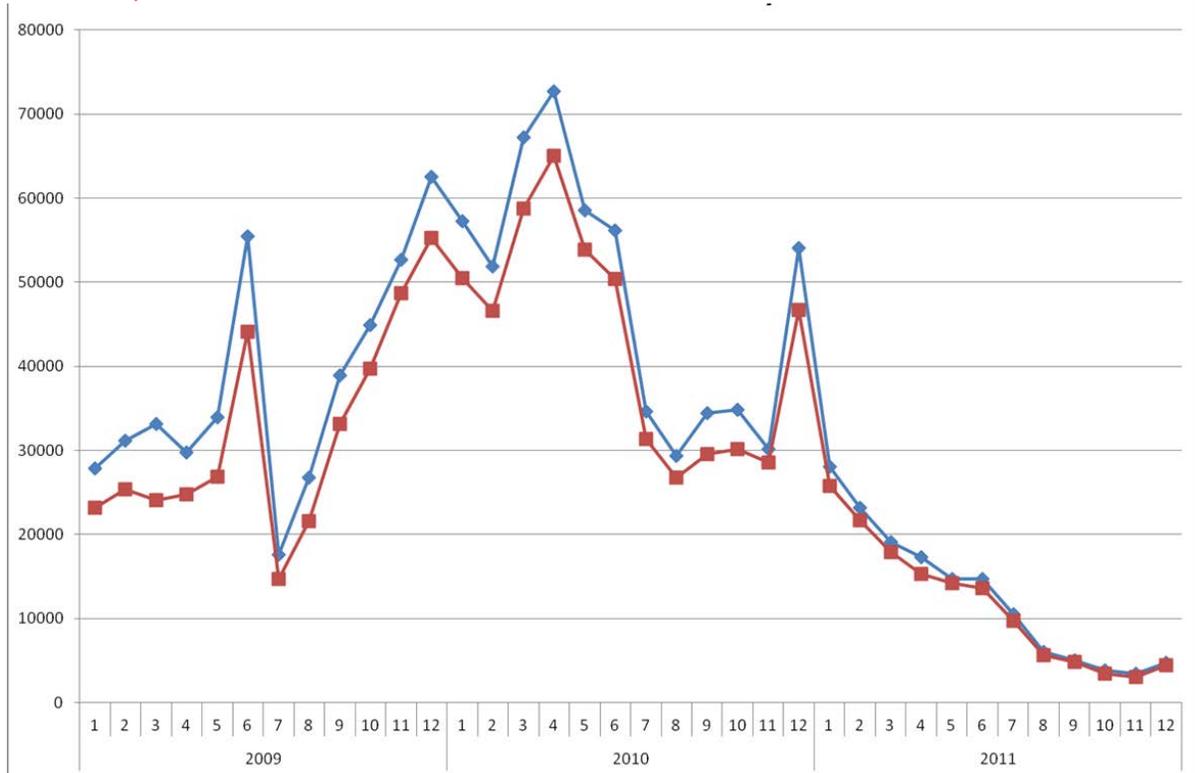
Figure 34: Proportion of children under five years of age seen by CHW receiving antimalarial treatment within 24 hours of fever onset, 2008-2010



Source: SIS-com

The increase in timely treatment of fevers occurred concurrently with a decrease in the total number of fever cases treated with antimalarials by CHWs (Figure 35). This trend is likely due to the roll-out of RDTs at the community level that occurred during this period; In 2009, CHWs relied on presumptive treatment for diagnosis of malaria, thus all fever cases should have received antimalarials. In 2010, RDT roll-out began and 5.5% of febrile cases were confirmed by RDT. By 2011, 63% of fever cases seen by CHW received RDT tests [26]. Thus, part of the decline in total numbers of fever cases treated is likely due to the shift in case definition as diagnosis changed from presumptive treatment to parasitological confirmation.

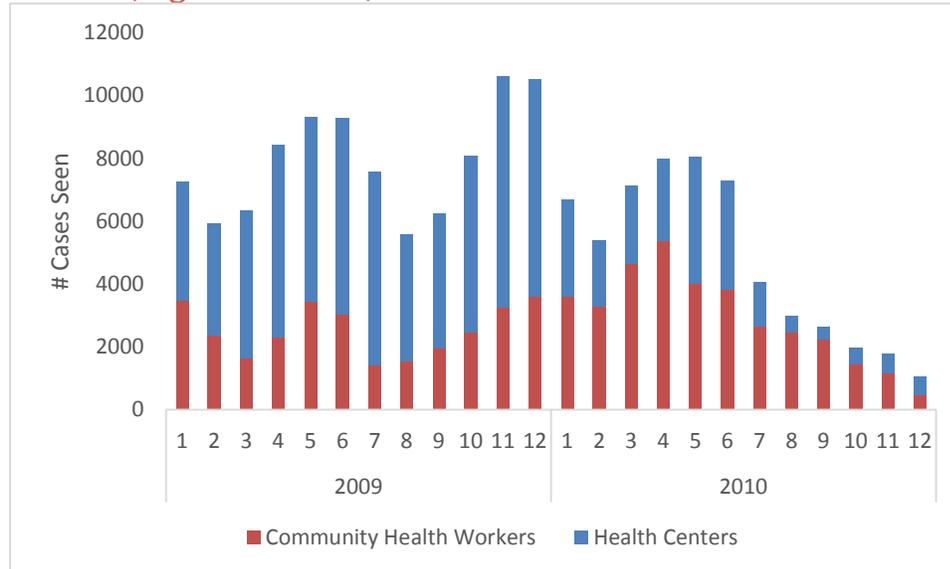
Figure 35: Number of fever cases treated with antimalarials by Community Health Workers, Rwanda 2009-2011



*Blue lines represent the number of children 6-59 months treated for fever, red lines represent the number of children 6-59 months treated for fever within 24 hours.

The proportion of all malaria cases treated by CHW instead of in facilities increased between 2009 and 2010, as total numbers of cases declined. This is illustrated in Figure 36 which depicts trends in malaria treatment in Ngoma District.

Figure 36: Malaria cases treated at the health center versus by community health workers, Ngoma District, 2009-2010



During the evaluation period in Rwanda, recommended case management of fever in young children changed significantly. From presumptive treatment of fevers using chloroquine, to parasitological testing followed by treatment of positive cases with ACTs, the policies and available tools have evolved during this time. Care options have also shifted from facility-based case management to increasingly community-based case management. According to national survey data, the percentage of children under five years of age with recent fever for whom advice or care was sought increased from 26% in 2000 to 48% in 2010. Despite this increase, less than half of children with fever are appropriately screened for malaria.

Among young children with fever who sought care and who received antimalarials, the percentage who received the recommended first-line treatment for uncomplicated malaria increased significantly from 50% in 2000 to 96% in 2010. At the community level, the proportion of children under five with confirmed or presumed malaria seeking care from CHWs who received antimalarials within 24 hours of fever onset has increased between 2008 and 2010 (from 62% to 89%). According to HMIS data, the proportion of children receiving parasitological tests for malaria before administration of antimalarials has increased from 45% in 2008 to 94% in 2010 as RDTs have been rolled out. These results indicate that Rwandan children who receive health services for fever are very likely to receive appropriate testing and treatment, however improvements in care seeking for fever are still needed.

Outcomes

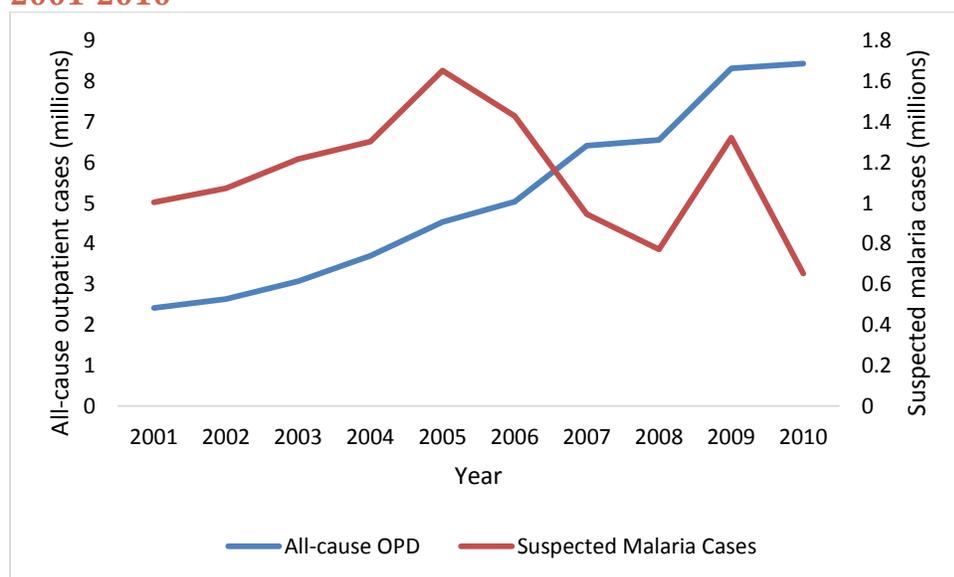
Malaria Morbidity

Routinely-collected Malaria Data

In Rwanda, during the Evaluation period there were two major sources of routine malaria morbidity data. The health management information system (HMIS) provides passive surveillance of suspected outpatient malaria cases from health facilities, and the community information system (SIS-COM) collects data reported by community health workers. The percent of facilities or communities reporting on malaria cases is presented whenever possible as incomplete reporting is an important factor that could bias trends in malaria cases. Rwanda ensures accuracy of the HMIS by quarterly data quality audits (DQAs) (MoH/NISR). WHO has conducted two rapid HMIS assessments in 2008 and 2010. The Global Fund also conducts on-site data verification (OSDV), providing annual system scoring and recommendations for improvement.

Trends in reporting and use of outpatient services at health centers (measured by total outpatient department visits) from HMIS data are shown in Figure 37. Between 2001 and 2008 total outpatient visits increased substantially from 2.4 million to 6.6 million. Suspected malaria cases also increased from 2001 to 2005 but then declined between 2005 and 2010 with a spike in 2009. Overall, outpatient reported malaria cases declined 60% between 2001 and 2010 [34]. It should be noted that changes in reporting rates over the time period likely affected the observed trend in cases. As reporting improved over the period and more cases were being detected by the HMIS, the decline in malaria cases is likely underestimated. By 2010, 94% of expected monthly reports were entered for district hospitals and health centers [21].

Figure 37: Trend in all-cause outpatient cases and in suspected malaria cases, HMIS 2001-2010

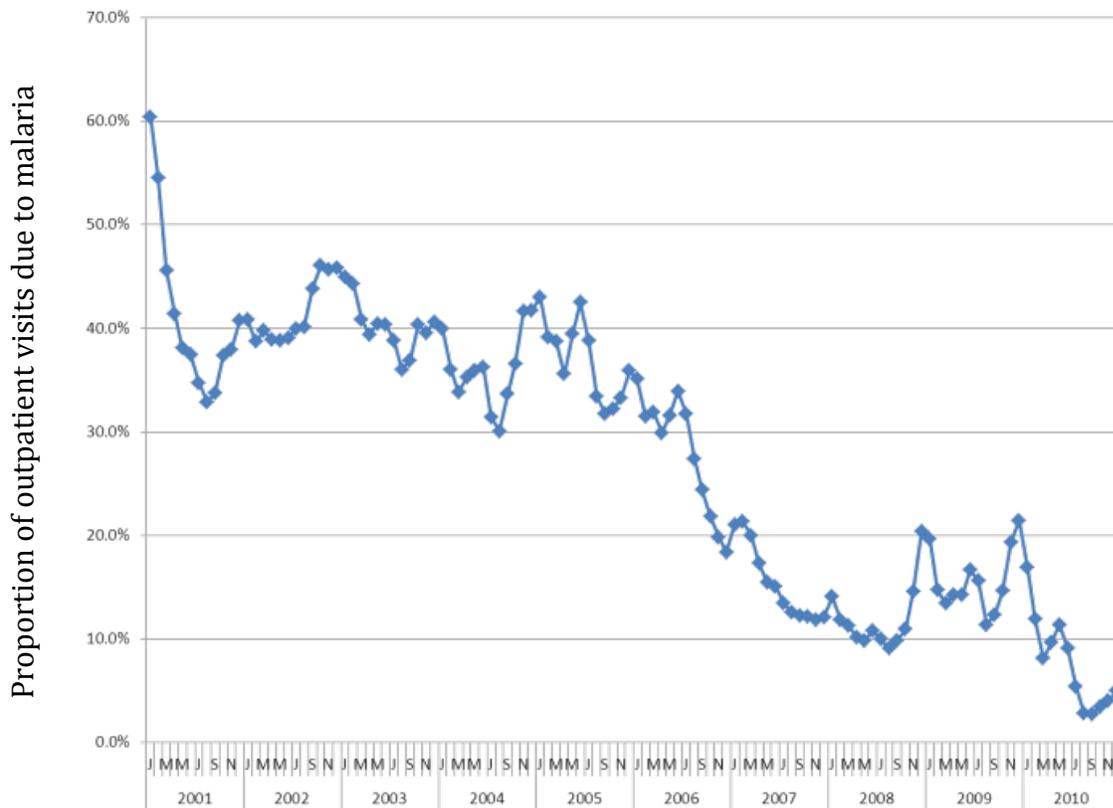


The decline in reported OPD malaria cases may be partially due to the scale up of community-based health care programs which tracked cases detected by CHWs through a separate reporting system (SIS-com) during the later years of the evaluation period notably 2009 and 2010. However, the reporting system for malaria cases in the community only includes children less than five and 52% of reported cases were detected by CHWs in 2010. The effect on the overall trend could therefore be substantial yet occurred late in the evaluation period.

Monthly proportional malaria morbidity is the number of malaria cases each month over total number of admissions to health centers in the same month. Proportional malaria morbidity has been steadily decreasing over the evaluation period (Figure 38). Seasonal peaks are evident throughout the evaluation period but mean annual peak percentage has declined from 60% in January of 2001 to less than 20% in January of 2010. According to HMIS data malaria cases represented 74% of all outpatient consultations in 2001 compared to only 8% in 2010.

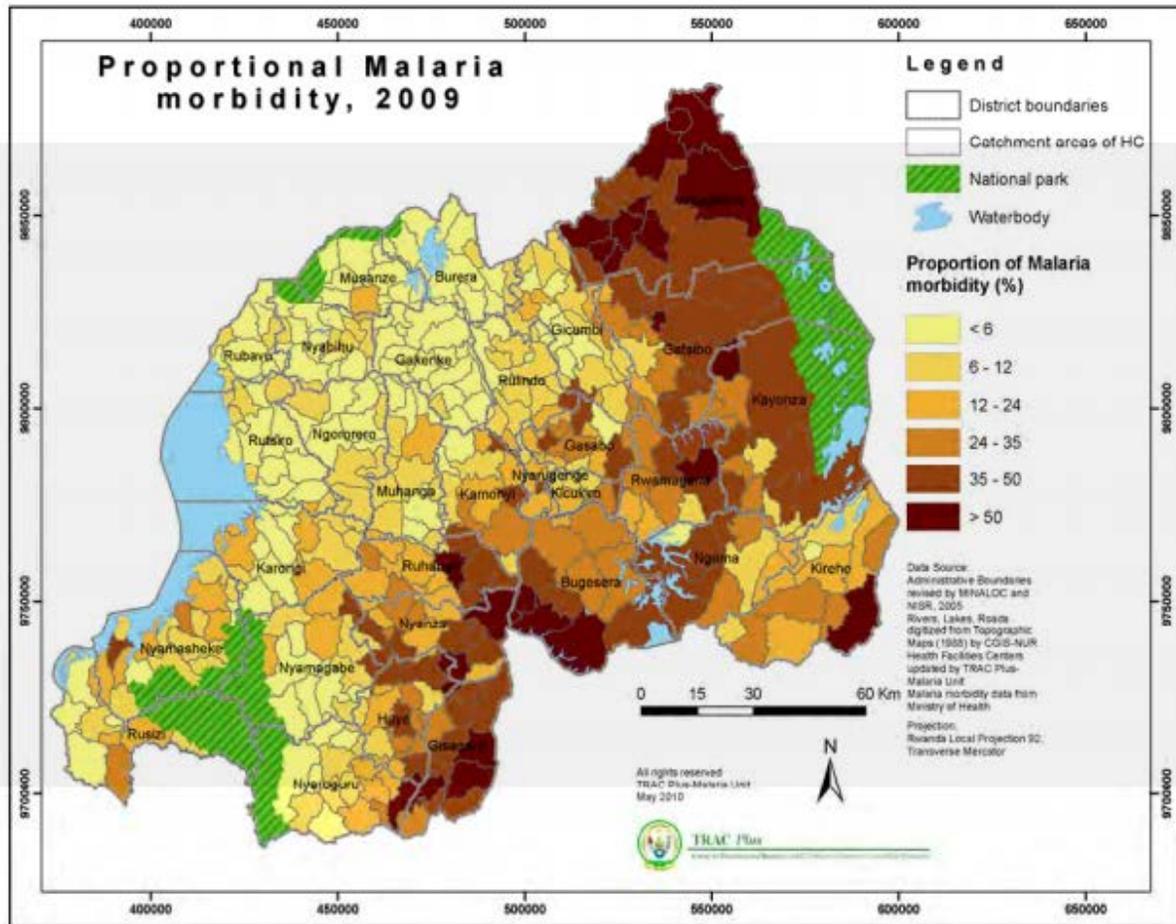
Figure 43 shows the spatial variation of proportional malaria morbidity in Rwanda in 2009, with higher proportions of outpatient visits due to malaria in the northeastern districts and the southern districts.

Figure 38: Monthly proportional malaria morbidity in children under five, 2001-2010



Source: HMIS

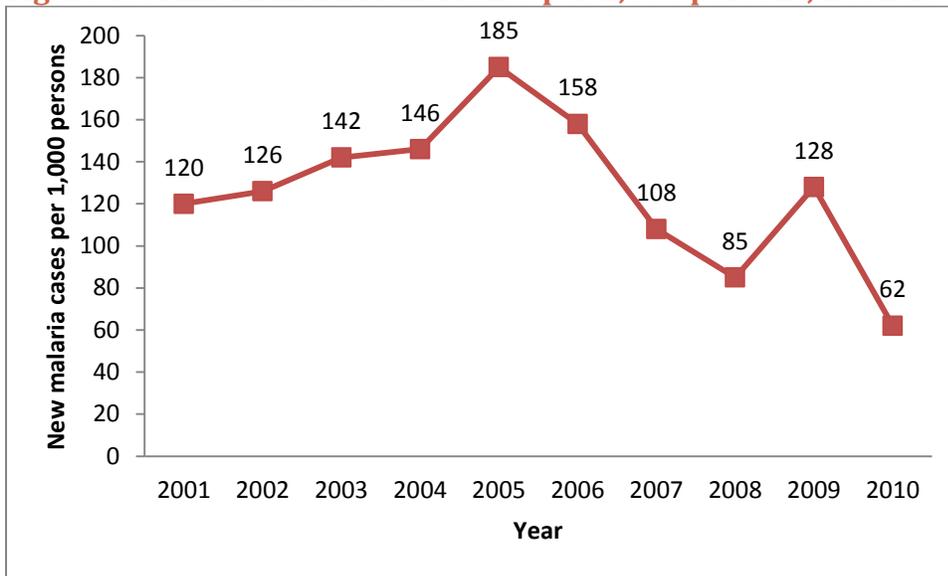
Figure 39: Annual proportional malaria morbidity by health center, 2011



Source: President’s Malaria Initiative Malaria Operational Plan 2010 [50]

Malaria incidence is derived from data on new cases and population at risk. Overall, yearly malaria incidence, defined as suspected and confirmed malaria cases by district per 1,000 inhabitants, increased from the baseline 2001 incidence to a peak in 2005 but then declined from 186 cases per 1000 in 2005 to 62 per 1000 in 2010 (67% decline) for a total decrease of 50% during the evaluation period (Figure 40). The reduction could partly be the result of increased use of diagnostic testing for case confirmation; use of microscopy or RDTs for parasitological confirmation of infection in health facilities increased from 48.5% in 2009 to 93.7% in 2010. The decrease in incidence is thus the result of refining case definition from presumed malaria to parasitologically-confirmed malaria which is a much more restrictive definition as well as due to scale-up of effective malaria control.

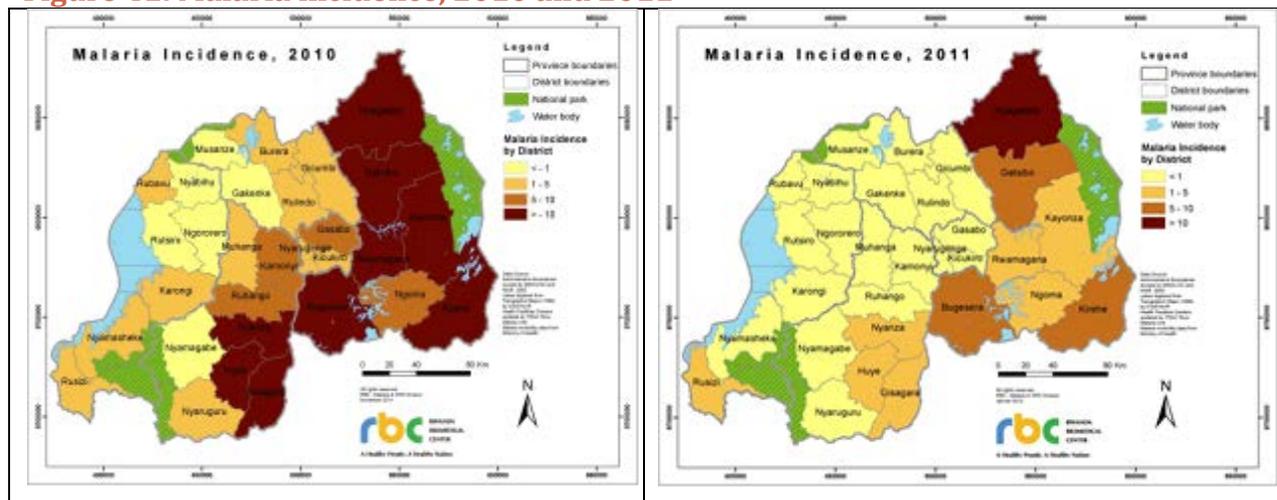
Figure 40: Annual malaria incidence per 1,000 persons, 2001-2010



Source: HMIS

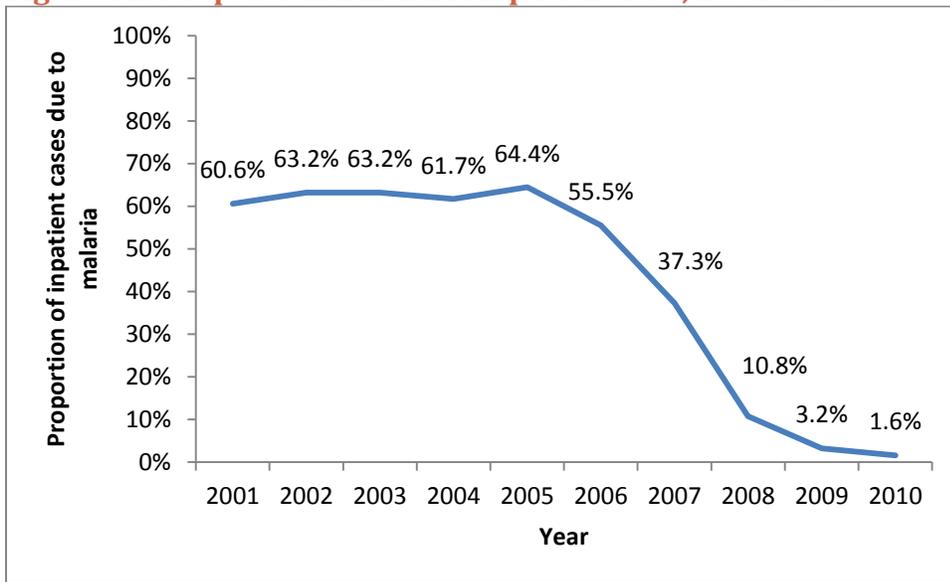
Malaria incidence was not homogenous throughout the country in 2010-2011 (Figure 41). The malaria annual incidence maps show higher incidence in the East compared to the West, with reductions over time in both regions. The maps also show regional variability in malaria incidence with differences among districts in the same regions. In 2011, the highest incident rates were found in Nyagatare District in the north and in other eastern districts.

Figure 41: Malaria incidence, 2010 and 2011



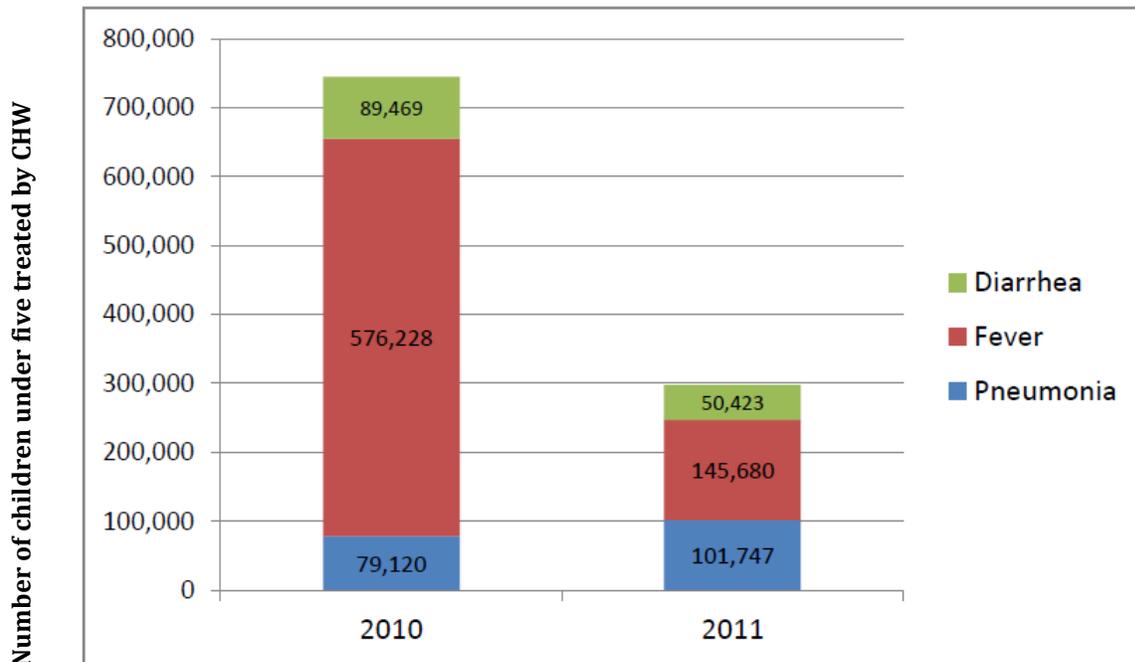
Proportional malaria inpatient rate is the number of malaria inpatient cases over total number of inpatient admissions to health facilities. Proportional malaria inpatient rates were fairly constant from 2001 to 2005 and then decreased substantially from 64% in 2005 to 1.6% in 2010 (Figure 42).

Figure 42: Proportional malaria inpatient rate, 2001-2010



Source: HMIS

Figure 43: Children treated by Community Health Workers as part of C-IMCI, 2010-2011



Source: SIScom, 2011

Test positivity rate (TPR) is a measure limited to those who use health services (facility or CHW) and who receive a diagnostic test. Thus, trends in TPR should reflect actual changes in malaria transmission provided utilization of health services and the quality of testing did not change over the evaluation period. The stability of the estimates for each year are dependent on sample sizes (numbers of individuals who sought care and were tested)

which are likely to have changed over time as access to health services and to diagnostic tests improved. Over the evaluation period in Rwanda, the test positivity rate has decreased substantially from over 50% in 2001 to approximately 20% in 2010 (Figure 44). As access to health services and numbers of suspected malaria cases receiving parasitological tests have increased over the evaluation period (Figure 32 and Figure 37), actual declines in total malaria infections are likely underestimated, provided the source of health care sought has not shifted to traditional or private sectors. The spatial distribution of TPR in 2010 is shown in Figure 46.

Figure 44: Test positivity rate, 2000-2010, HMIS

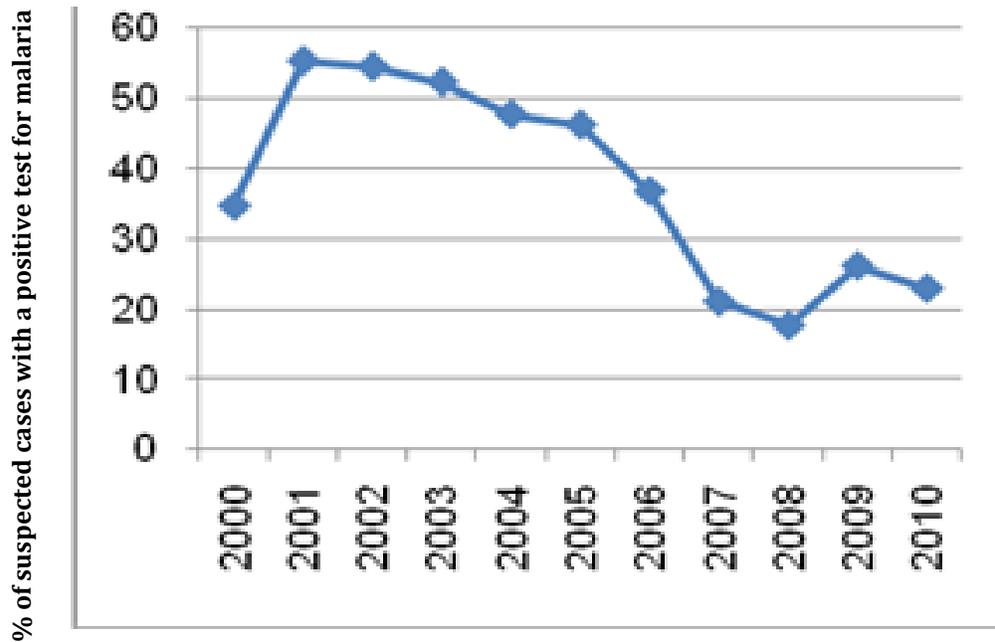
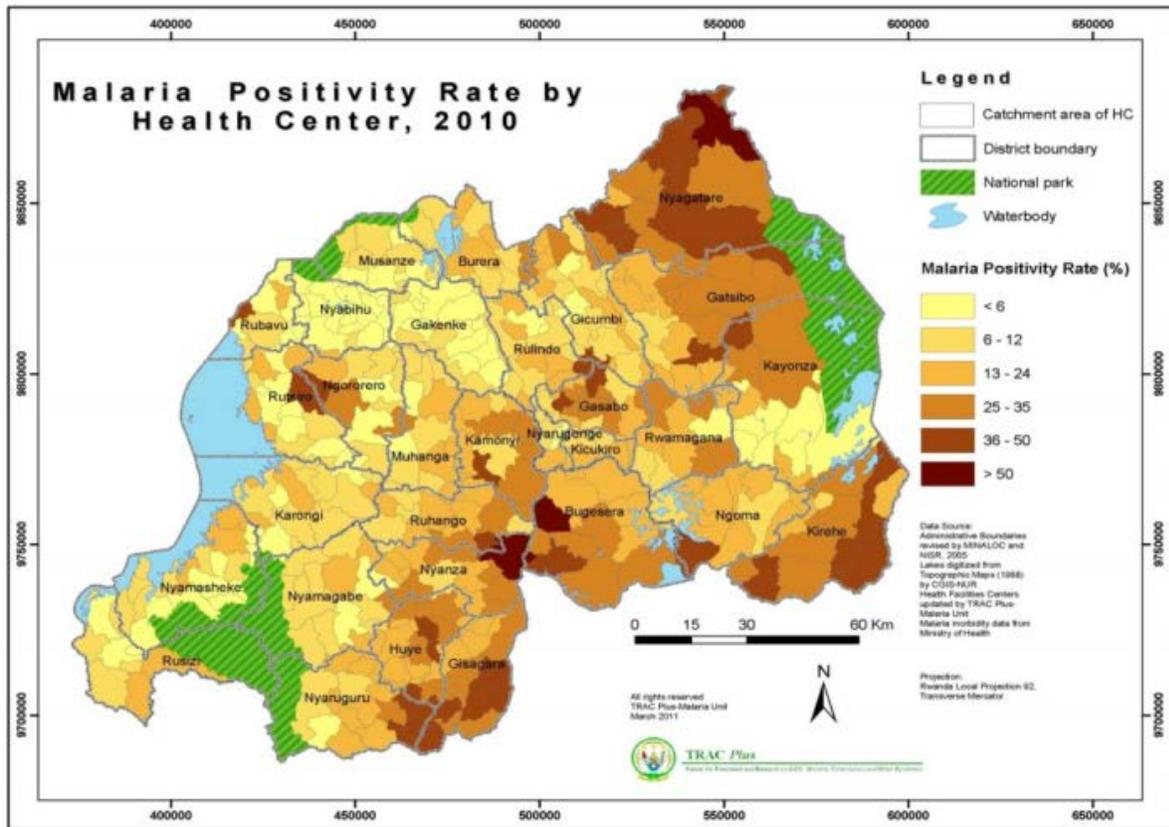


Figure 45: Malaria test positivity rate by health center catchment area, 2010



In summary, according to HMIS data, the burden of malaria in Rwanda declined considerably between 2000 and 2010 with a 60% decrease in suspected or confirmed malaria cases (morbidity), a 50% decrease in malaria incidence and a 30% decline in TPR.

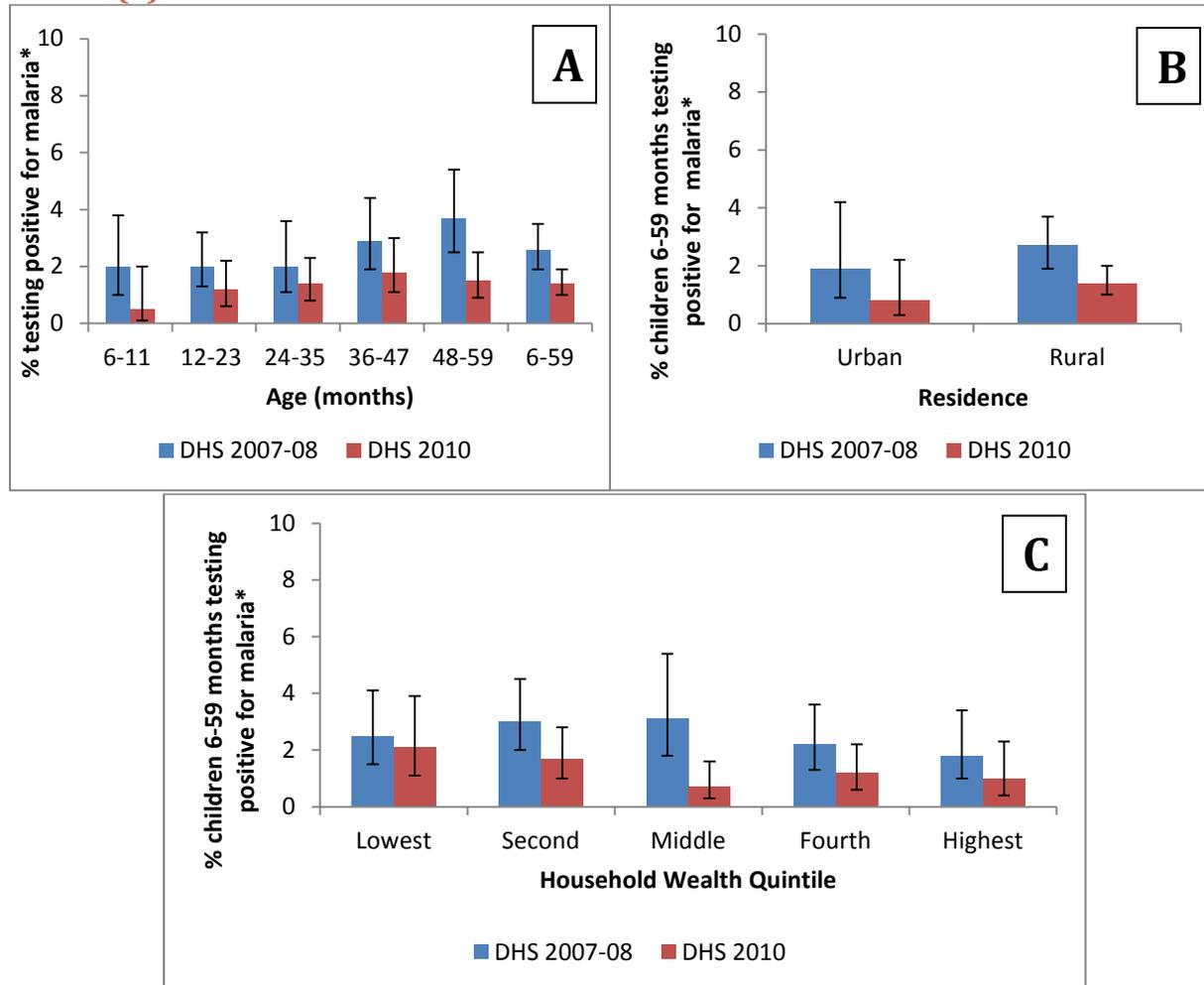
Malaria Parasitemia Prevalence from National Surveys

Interpreting trends in malaria parasitemia prevalence is a challenging task; malaria transmission dynamics are quite sensitive to local ecological settings and are heterogeneous over small areas [51,52]. In addition, year to year variations in environmental conditions may complicate interpretation of national trends [53]. For example, parasitemia prevalence can fluctuate drastically between seasons within the period of one year (inter-annual variation). In addition to seasonal trends, fluctuations in weather patterns over several years may contribute to similar fluctuations in parasitemia levels (intra-annual variation) which could mask successes or lapses in malaria control efforts, as was seen recently in Zambia [54-56]. Thus, parasitemia is a challenging impact measure to interpret in many settings, although it is arguably one of the most direct measures of success in malaria control efforts in high prevalence settings; to make best use of parasitemia prevalence data, many data points are needed for analysis of robust trends.

The Rwanda 2007/2008 Interim DHS and 2010 DHS tested children aged 6–59 months for the presence of the *P. falciparum* HRP2 antigen using First Response© RDT and for parasites using microscopic examination of thick and thin blood smears. These surveys were conducted from December 2007 to March 2008 and from September 2010 to April 2011. These dates encompassed one of the two annual peak transmission seasons each year. There are no national malaria parasitemia prevalence data prior to 2007 as prior surveys did not include malaria testing.

Likely due to the low prevalence of malaria parasitemia in Rwanda, distribution appears to be very homogeneous across age, urban/rural residence, sex, and wealth strata (Figure 52 A-C). Parasitemia decreased significantly between the two surveys in children 6-59 months of age from 2.6% in 2007/08 to 1.4% in 2010; however, no significant differences in parasitemia by age, by household residence, or by household wealth were evident for either survey.

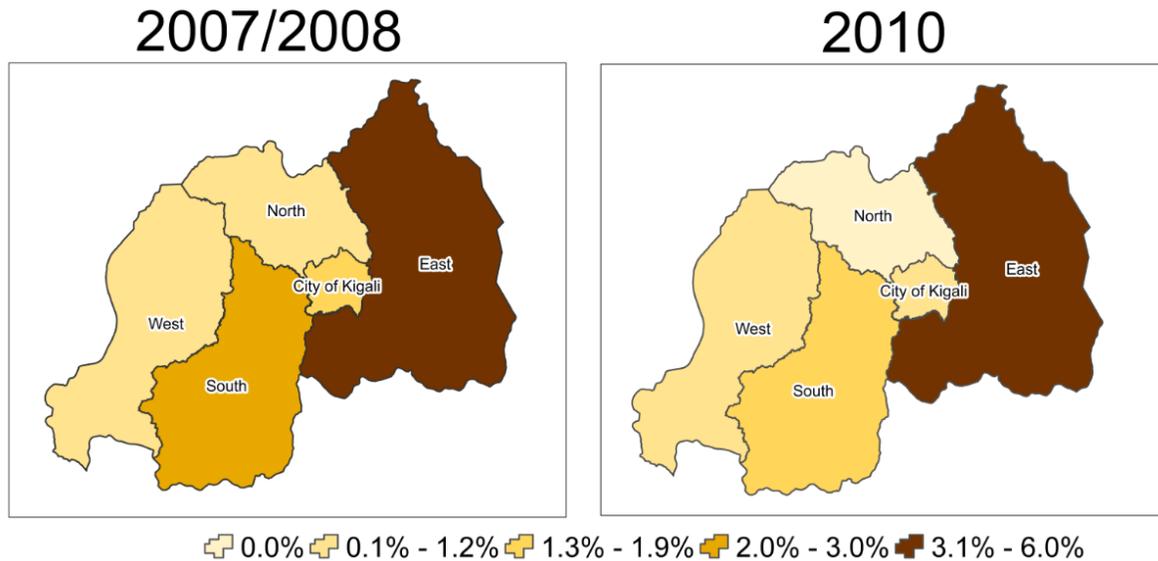
Figure 46: Malaria parasitemia prevalence in children 6–59 months, Rwanda, 2007/2008, 2010, stratified by age (A), by household residence (B) and by household wealth (C)



* Measured via microscopy

Regional patterns in parasitemia prevalence as measured by microscopy between the two surveys are portrayed in Figure 47. In both surveys, parasitemia prevalence was significantly higher in the East than in the North or West provinces. Regional declines in prevalence over time were not statistically significant. As previously shown malaria incidence is quite focal and varies significantly within provinces (Figure 46).

Figure 47: Malaria parasitemia prevalence by microscopy in children 6–59 months by province, Rwanda, 2007/08, 2010



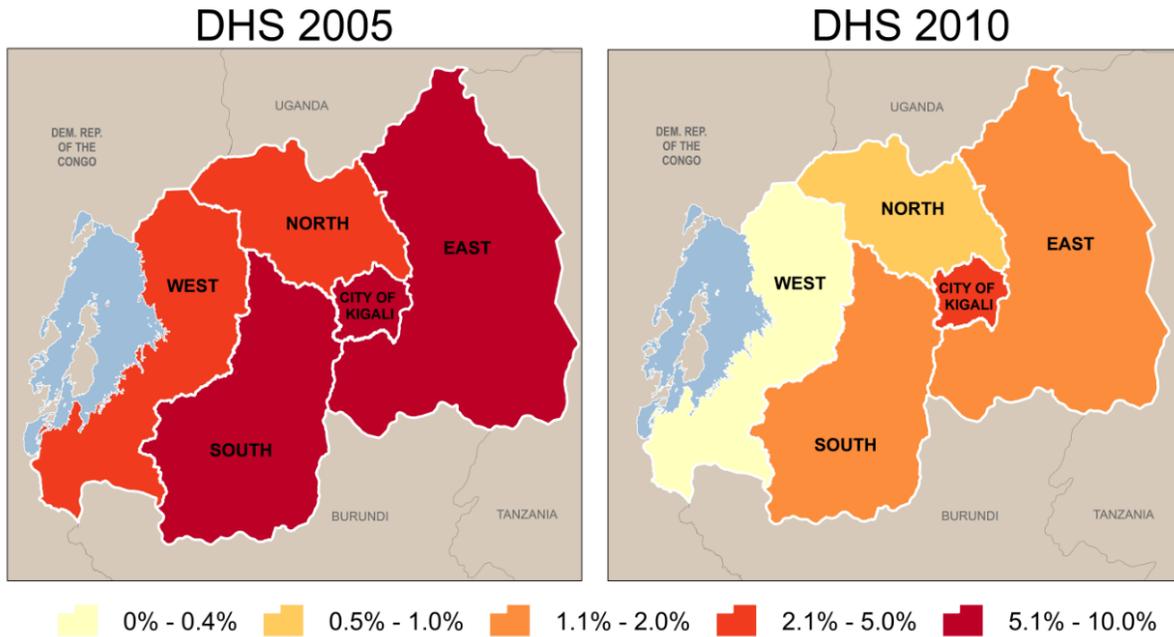
Severe Anemia

Severe anemia, defined as blood hemoglobin levels less than 8 grams per deciliter, is a potential impact measure for total malaria-related disease burden as it is associated with malaria-related mortality. Declines in severe anemia have been found to be associated with malaria control interventions [57]. Severe anemia prevalence has also been collected in many more population-level surveys than parasitemia, and therefore, it is possible to establish longer trends using retrospective survey data. In Sub-Saharan Africa, between 17% and 54% of malaria-attributable deaths are estimated to be due to severe anemia [57-60].

National estimates of the prevalence of severe anemia (hemoglobin <8 g/dL) in children aged 6–59 months are available from the 2005, 2007/2008, and 2010 DHS. Hemoglobin values from DHS surveys were adjusted for altitude using the CDC formulae [61].

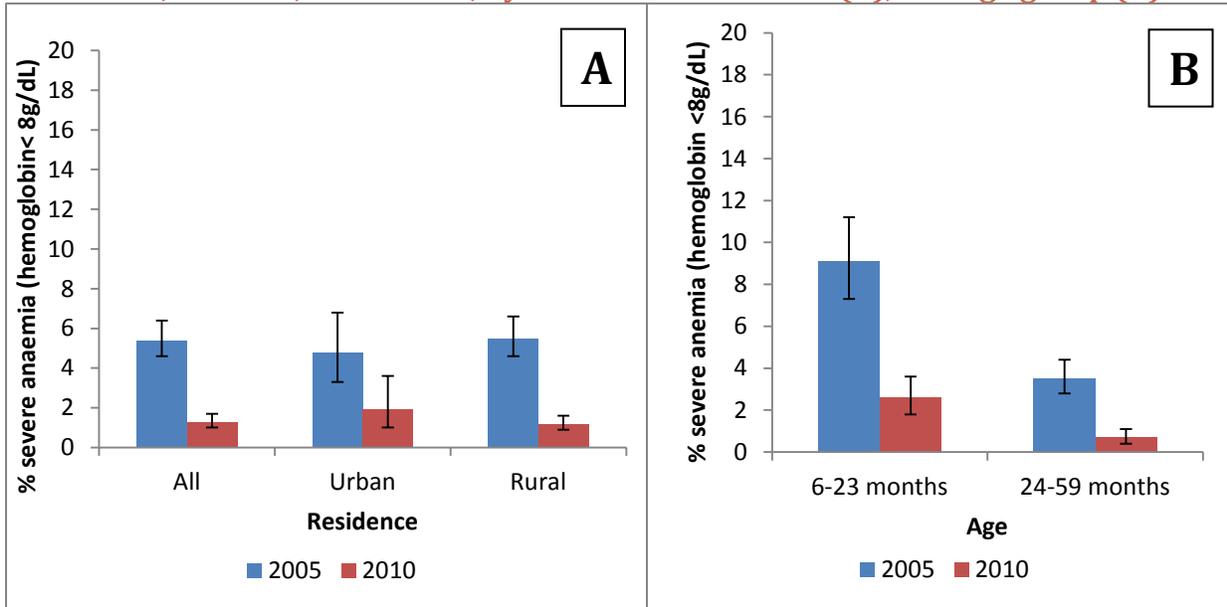
Spatial differences in severe anemia in children 6–59 months are depicted in Figure 48. Severe anemia prevalence decreased in all regions between 2005 and 2010.

Figure 48: Prevalence of severe anemia in children 6–59 months, by region, 2005 and 2010, DHS



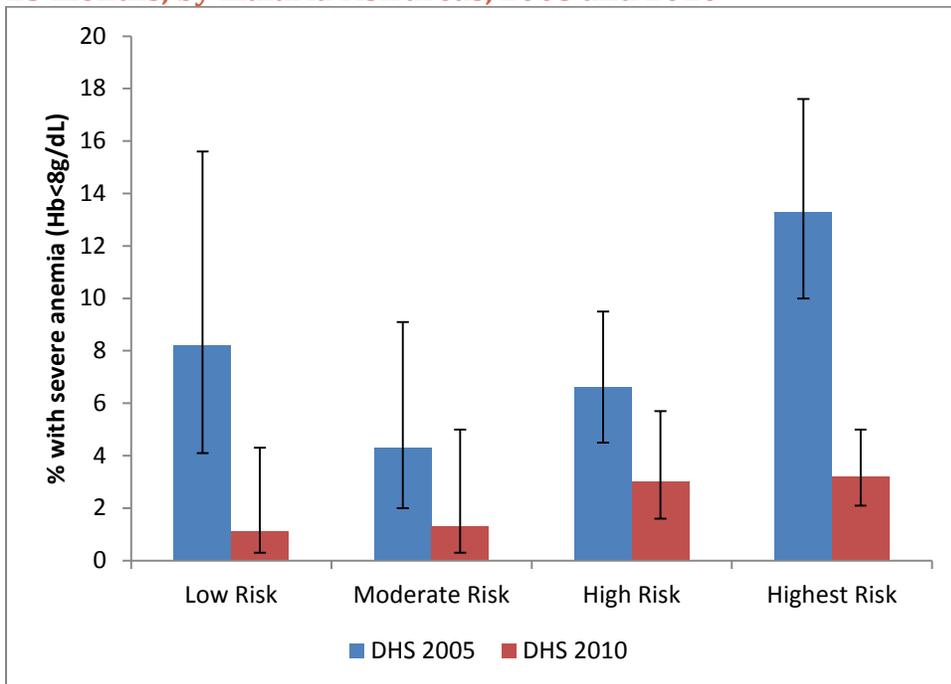
Severe anemia decreased dramatically between 2005 and 2010. These declines were significant in rural regions (Figure 49A), in children 6-23 months of age (Figure 49B) and in the East region of the country (Figure 48), all groups that are most likely to have experienced the greatest declines in malaria over that time period.

Figure 49: Trends in severe anemia (Hemoglobin < 8g/dL) prevalence in children 6-59 months, Rwanda, 2005-2010, by household residence (A), and age group (B)



Malaria transmission is not homogenous across Rwanda. If the reduction in anemia was associated with malaria decline, we would expect to see a higher baseline and greater reduction in severe anemia prevalence in areas with relatively higher risk of malaria at baseline. Trends over time for severe anemia prevalence in these four categories are shown in Figure 50.

Figure 50: Trends in severe anemia (Hemoglobin < 8g/dL) prevalence in children 6-23 months, by malaria risk areas, 2005 and 2010



As expected, the greatest decline in severe anemia occurred in the higher risk areas in children aged 6–23 months. Anemia in young children is multifactorial. The relative contribution of malaria to the overall anemia burden in young children would be expected to be greater in areas of medium-high transmission, thus control of parasite transmission would be expected to reduce anemia in these populations. In populations with low malaria transmission, successful malaria control may not lead to reductions in anemia as most cases of anemia are likely to be due to other causes.

Summary of Malaria Morbidity

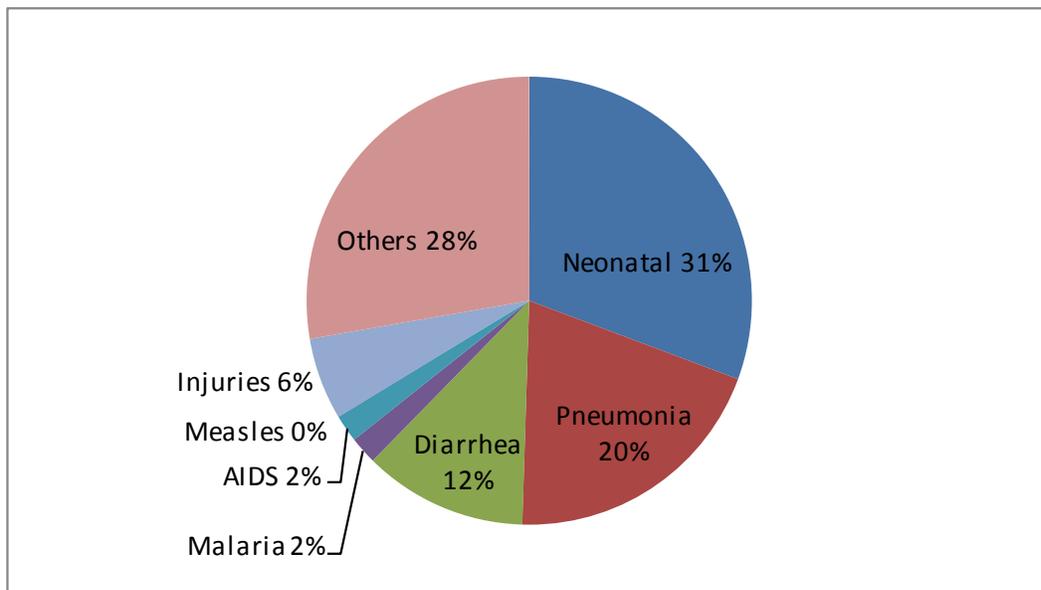
Health facility data show evidence of significant declines in outpatient malaria cases as well as declines in malaria incidence, proportional malaria morbidity, and test positivity rates from 2000-2010. Most of the decreases in these morbidity measures occurred in the second half of the decade, from 2005-2010. Distinct seasonal patterns are also evident. Nationally-representative household survey data from 2005-2010 support these findings; significant decreases occurred in severe anemia between 2005 and 2010 and in parasitemia prevalence between 2007-08 and 2010. Declines in severe anemia were not evenly distributed throughout the country; children in rural areas, younger children and those from areas with the highest risk of malaria transmission experienced relatively larger declines.

Mortality

This section reviews trends in ACCM over the evaluation period, with a view to assessing the magnitude, timing, and age-pattern of change between the 2000 and 2010 DHS surveys. In addition, it includes an ecological analysis that examines changes in mortality with respect to malaria risk. Mortality estimates for 1988 to 1992, from the 1992 DHS, are described in order to provide a longer-term context. All mortality figures represent direct estimates, and unless otherwise stated, represent the period 0-4 years before each survey.

In Rwanda, in 2010, malaria was estimated to account for 2% of deaths in children under five years of age (Figure 51).

Figure 51: Causes of death among children under five years, 2010

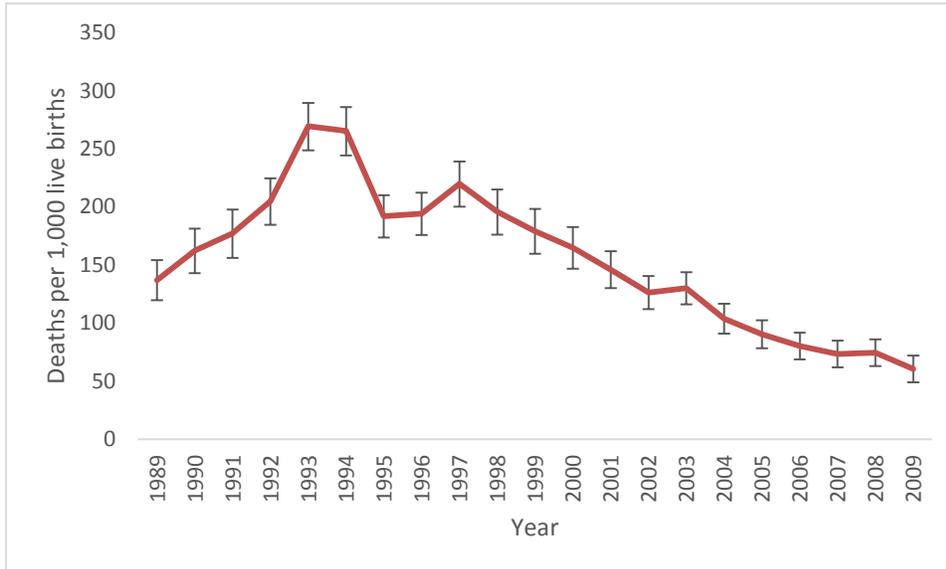


Note: Includes all neonatal causes except neonatal pneumonia and diarrhea.
Source: UNICEF progress report, 2012 [20]

ACCM from National Survey Data

Although DHS typically report five-year estimates of mortality it is possible to generate annual mortality estimates using DHS data. These estimates typically have greater levels of uncertainty due to smaller samples sizes, but allow examination of more fine-scale trends and improved assessment of changes in acceleration of mortality rates. Estimates of annual ACCM from successive DHS surveys conducted between 1992 and 2010 are presented in Figure 52.

Figure 52: Annual all-cause under-five mortality (ACCM) rates from DHS data, 1989-2010

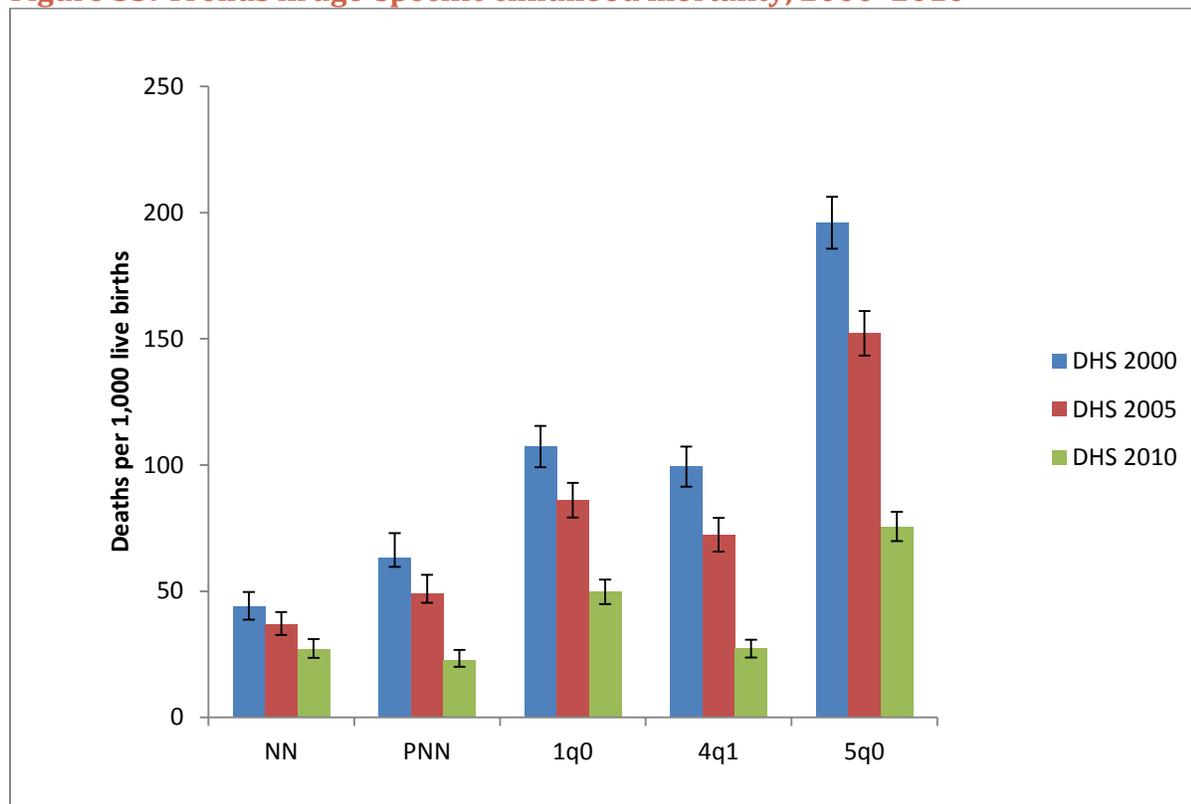


Note: Data points are mid-year mortality estimates

From 1998 to the end of the evaluation period in 2010, significant reductions in ACCM are evident between all five-year periods. Between the five-year period ending in 2000 and the five-year period ending in 2005, ACCM declined by 22%. Between the five-year period ending in 2005 and the five-year period ending in 2010, ACCM declined by 50%. Between the five-year period ending in 2000 and the five-year period ending in 2010, ACCM declined by 61%.

Trends in age-specific childhood mortality across the last four DHS surveys are presented in Figure 53. Childhood mortality has been steadily decreasing over the past decade in all age groups except for neonates (0-1 months of age) in which declines have been less substantial.

Figure 53: Trends in age-specific childhood mortality, 2000–2010

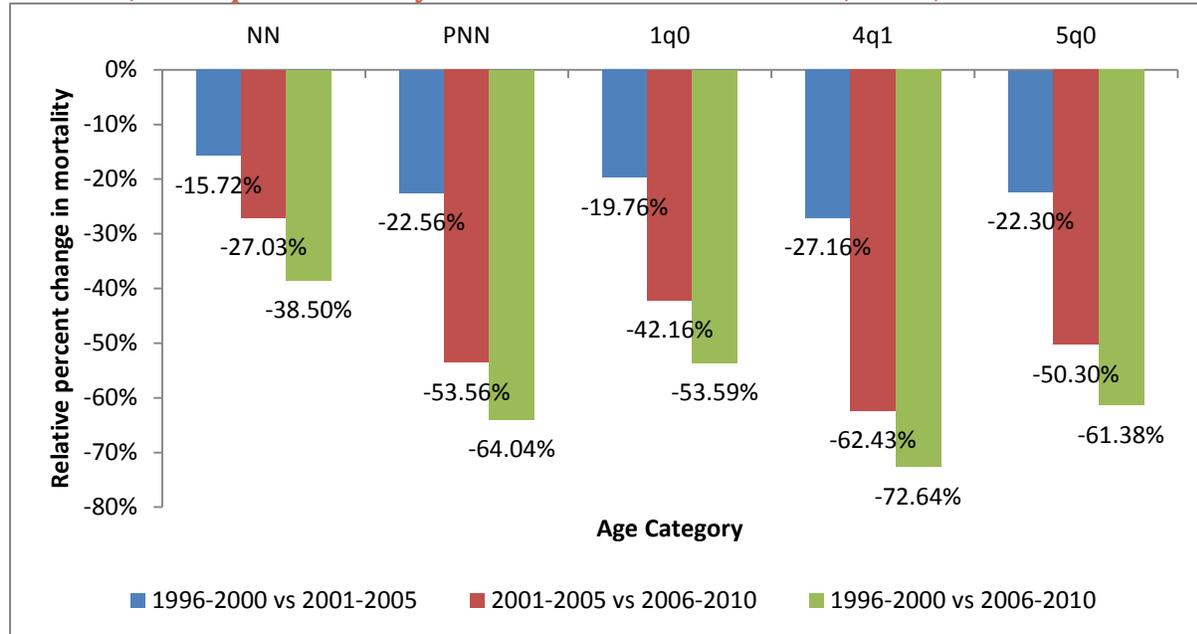


Key: NN = neonatal mortality (first month), per 1,000 live births; PNN = post-neonatal mortality (age 1-11 months), per 1,000 live births; $1q_0$ = infant mortality (first year), per 1,000 live births; $4q_1$ = child mortality between exact age 1 and exact age 5, per 1,000 children surviving to 12 months of age; $5q_0$ = under-five mortality, per 1,000 live births. Error bars represent upper and lower 95% confidence limits for the estimates.

The mortality estimates and relative change in these estimates by age categories are shown in Figure 54. Observed mortality declines between the five-year period ending in 2000 and the five-year period ending in 2010 are lowest in the neonatal and infant age groups (39% and 54% relative reductions, respectively) and are over 60% for all other age groups.

Relative change in mortality increased over time for most age categories; the relative decline in mortality between the five-year period ending in 2000 and the five-year period ending in 2005 was less than that for the second half of the decade, the five-year period ending in 2005 to the five-year period ending in 2010 (blue bars vs. red bars in Figure 54).

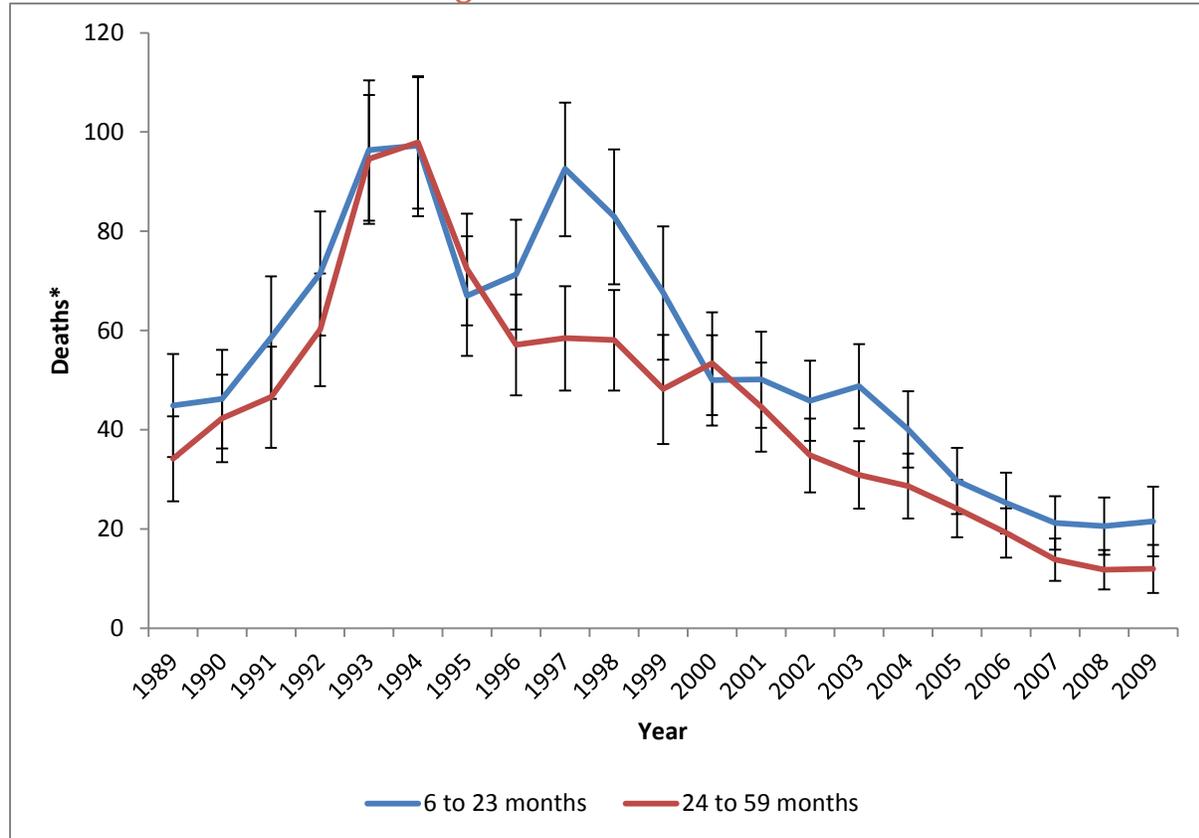
Figure 54: Relative percent change in age-specific childhood mortality in children in Rwanda; a comparison of 5-year estimates from the 1996, 2000, 2005 and 2010 DHS



Key: NN = neonatal mortality (first month), per 1,000 live births; PNN = post-neonatal mortality (age 1-11 months), per 1,000 live births; $1q_0$ = infant mortality (first year), per 1,000 live births; $4q_1$ = child mortality between exact age 1 and exact age 5, per 1,000 children surviving to 12 months of age; $5q_0$ = under-five mortality, per 1,000 live births.

If a major proportion of ACCM was due to malaria, declines in all-cause deaths over the period of scale-up in malaria control interventions should be greatest in the children most susceptible to severe malaria outcomes. Figure 55 shows the annual estimates of mortality in 6–23 month old children compared to those of 24–59 month old children. Both age groups experienced decreases in mortality over the two decades. With the low malaria prevalence in Rwanda, the age range at highest risk for malaria morbidity and mortality may be older children and adults, as has been seen elsewhere [62]. As DHS surveys do not collect mortality data for children older than five years, the relevant comparisons cannot be made with these data.

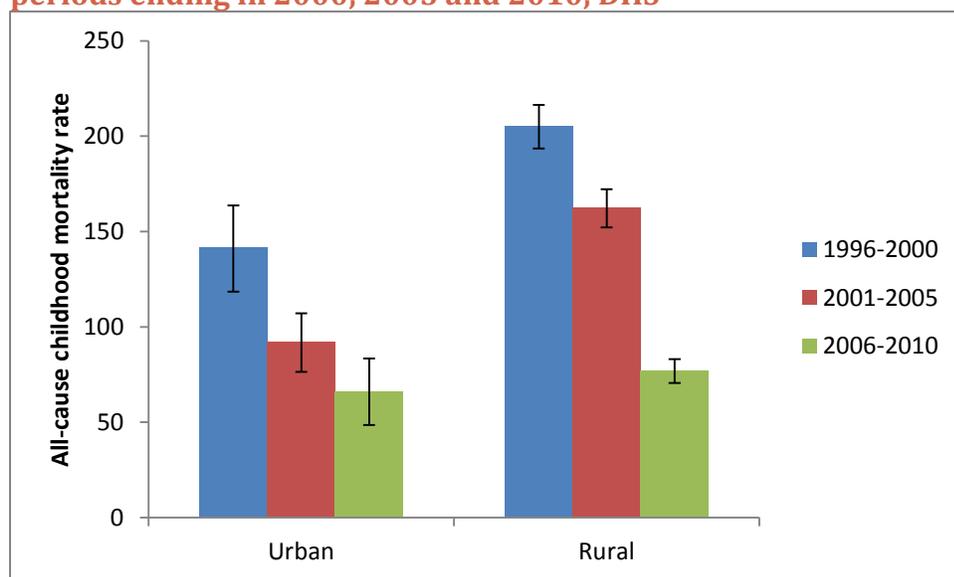
Figure 55: Annual estimates of death in 6–23 month old and 24–59 month old children from 1990–2009 using DHS 2010 and DHS 2000 data



*6–23 month mortality is measuring annual deaths per 1,000 children surviving to 6 months; 24–59 month mortality is measuring annual deaths per 1,000 children surviving to 24 months.

Figure 56 shows mortality rates for the five-year periods ending in 2000, 2005 and 2010 stratified by rural and urban residence. ACCM in rural areas declined from 205 to 77 deaths per live births in the five-year period ending in 2000 to the five-year period ending in 2010; a relative decline of 62%. In urban areas, the absolute and relative difference in mortality was smaller (141 deaths per 1,000 live births in the five-year period ending in 2000 to 66 in the five-year period ending in 2010; a 53% relative reduction).

Figure 56: ACCM by location of residence, five-year estimates for the five-year periods ending in 2000, 2005 and 2010, DHS



If a major part of the decline in ACCM was malaria-related, we would expect to see a greater decline in mortality, from a higher baseline, among children living in areas of greater malaria risk – as compared to areas of lower malaria risk [63,64].

To test this hypothesis, we examined trends in childhood mortality rates stratified by malaria risk zones as defined previously. For children between birth and one year of age, the mortality rates during the five-year period ending in 2005 were 103, 79, 83, and 62 deaths per 1,000 live births in the highest, higher, moderate and lower risk categories, respectively (Figure 57). During the five-year estimation period ending in 2010, the mortality rates had dropped to 47, 51, 45 and 59 deaths per 1,000 live births, respectively, in the highest, higher, moderate and lower risk categories. These changes are statistically significant in all but the lowest risk category and the greatest declines were seen in the highest risk area. No significant differences in infant mortality were evident in the five-year period ending in 2010 across malaria risk groups. For children under five years of age, mortality rates in the four risk categories in the five-year period ending in 2000 were 124, 143, 136 and 180 deaths per 1,000 live births, respectively (Figure 58). These had declined to 82, 63, 68 and 81 deaths per 1,000 live births by the five-year period ending in 2010, statistically significant changes in all risk areas. By the five-year period ending in 2010, ACCM did not vary significantly by malaria risk. Taken together, these results are consistent with the hypothesis that malaria control interventions have contributed to declines in ACCM. Results also suggest that for both infants and children under five years of age, mortality rates have become homogeneous between areas of varied malaria risk by the five-year period ending in 2010.

Figure 57: Trends in infant mortality in four malaria risk areas for the five-year periods ending in 2005 and 2010, DHS

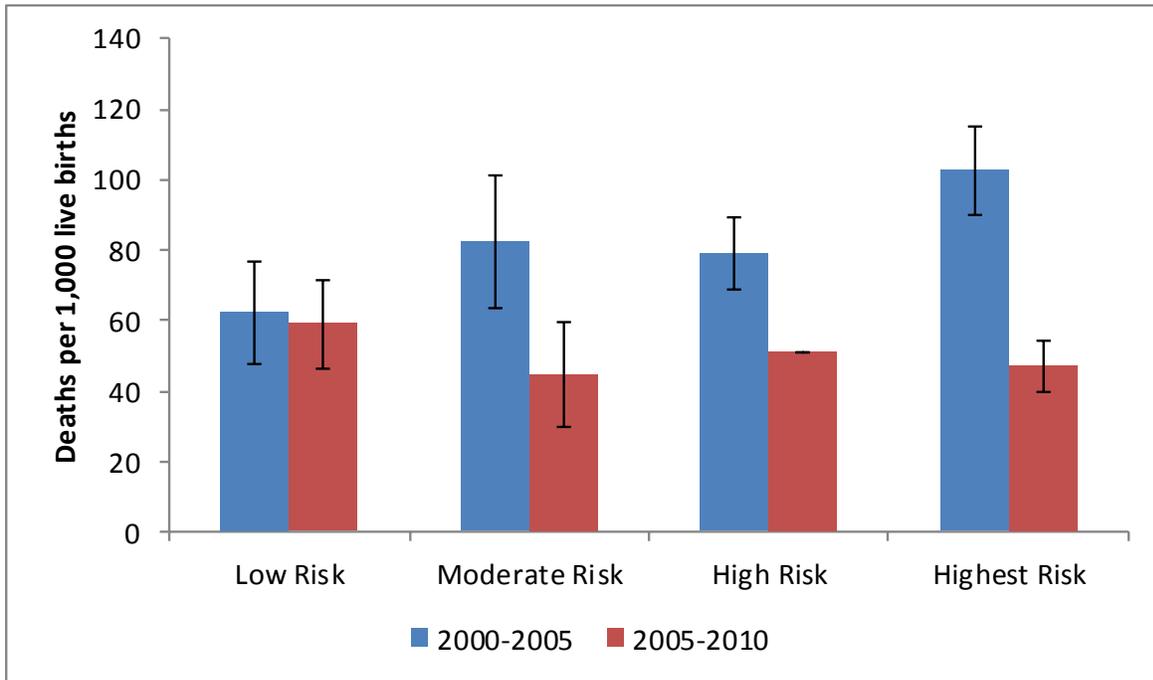
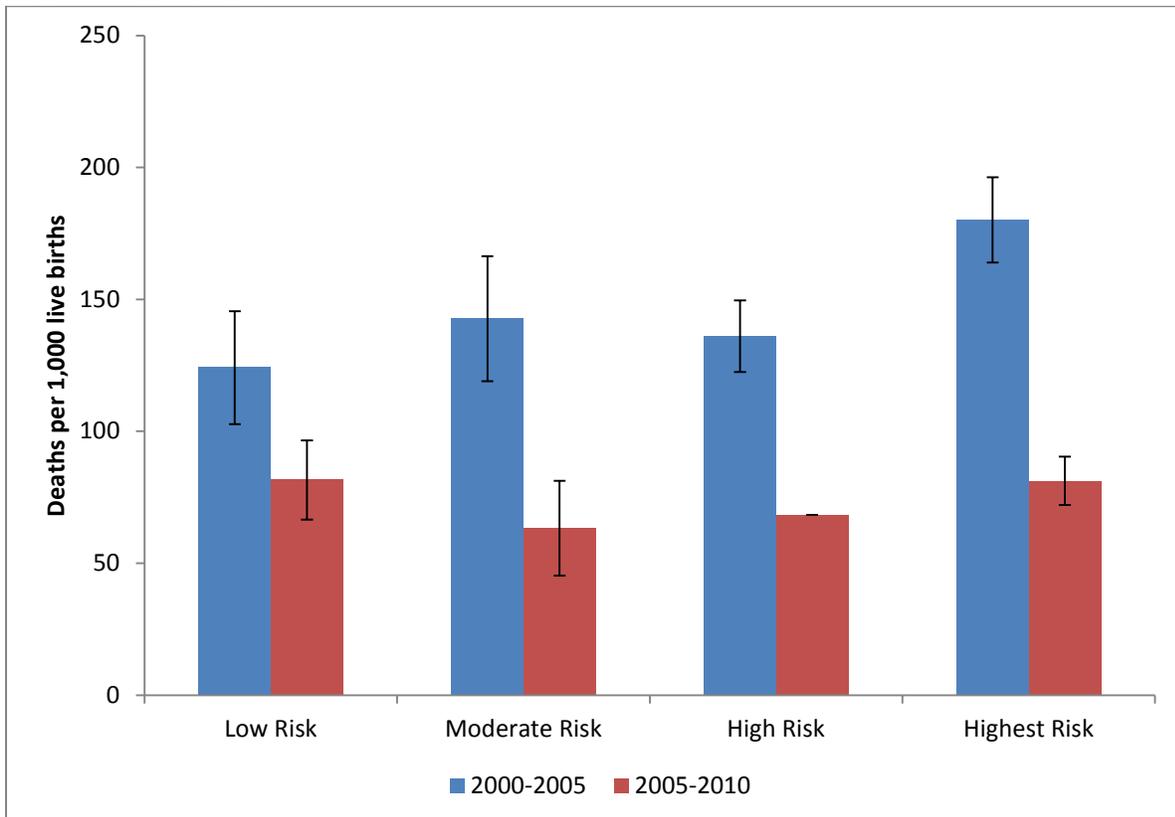


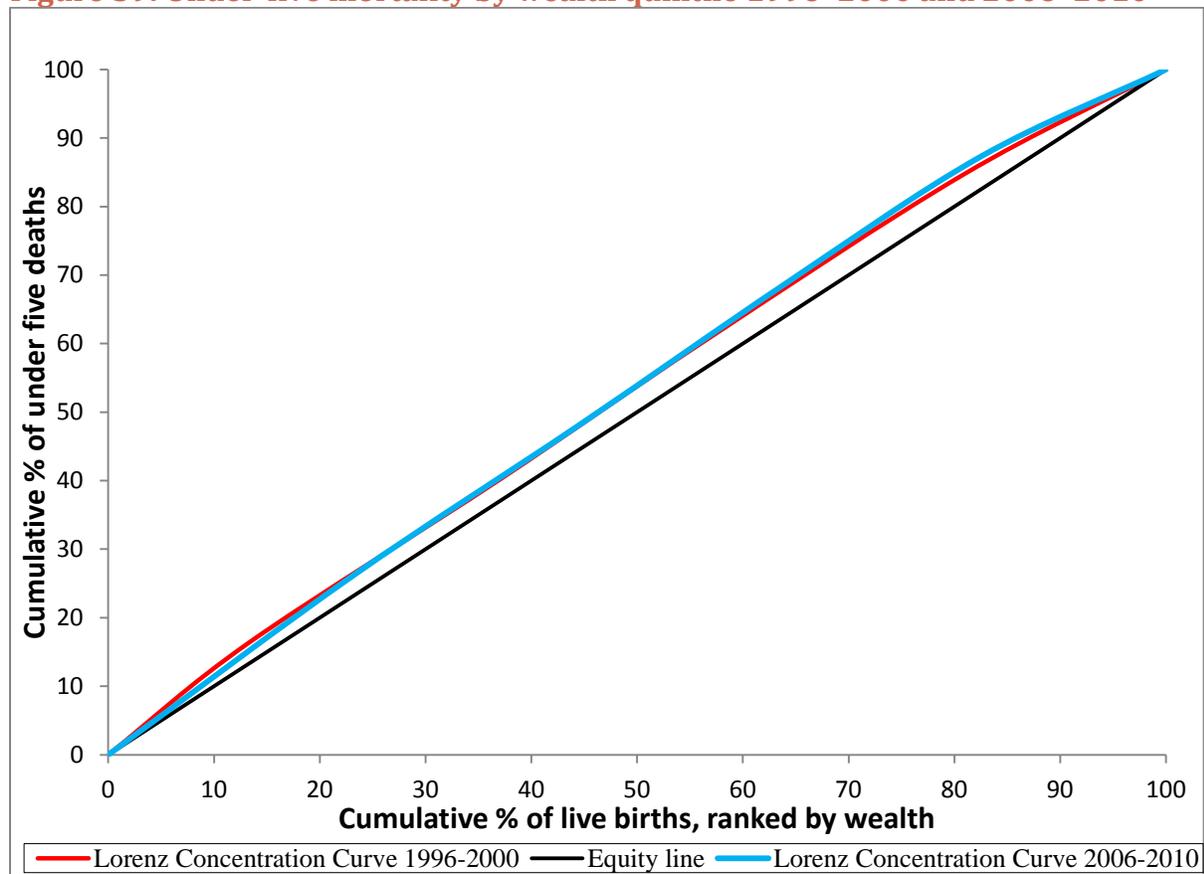
Figure 58: Trends in ACCM in four malaria risk areas for the five-year periods ending in 2005 and 2010



It is conceivable that mortality changes described in this section could have occurred through disproportionately large gains in groups with higher socio-economic status. If this were the case, the differential in mortality by wealth quintile would have widened over time. Inequities in mortality by wealth quintile are presented here using concentration curves where the straight line represents perfect equity (with a concentration index of zero), and “upward” departure from the diagonal indicates excessive mortality in poorer population quintiles (with a negative sign on the concentration index).

Figure 59 shows the results of this analysis for ACCM estimates during the five-year time periods ending in 2000 and in 2010. The concentration index in the five-year period ending in 2010 was -0.059 (95% CI = -0.117, -0.001) indicating that ACCM was disproportionately concentrated in children from the households in the lower wealth quintiles. During the five-year period ending in 2000 the concentration index was -0.063 (95% CI= -0.132, 0.005) suggesting that ACCM did not vary significantly between households of different wealth quintiles (the value of zero was included in the 95% CI). In addition, the overlapping confidence intervals between the two time periods suggests that equity in ACCM did not change significantly between these two survey periods.

Figure 59: Under-five mortality by wealth quintile 1996-2000 and 2006-2010

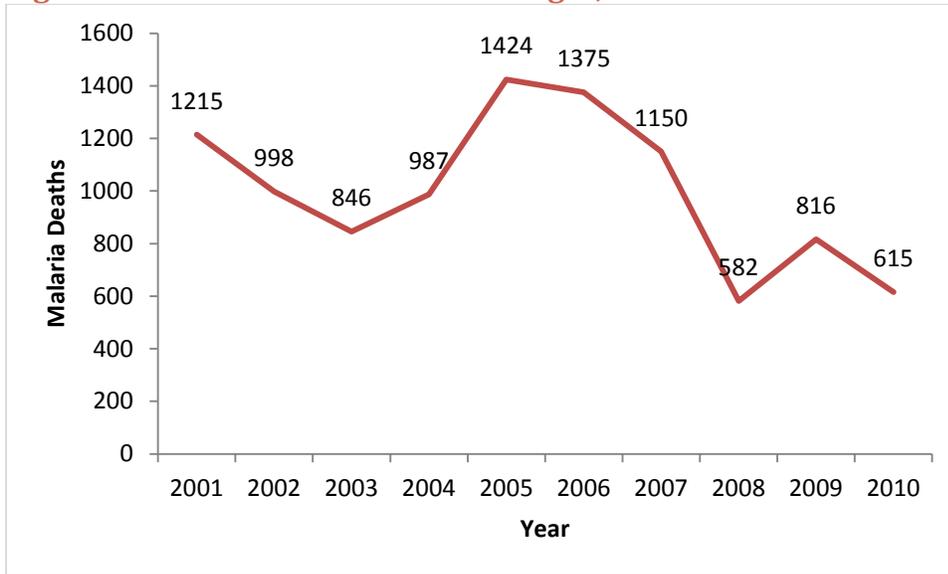


Concentration Index	
1996-2000:	-0.059 (95% CI: -0.117, -0.001)
2006-2010:	-0.063 (95% CI: -0.132, 0.005)

Facility-based Malaria Mortality Data

Reporting on mortality from facility-based data should be interpreted with the understanding that deaths occurring outside of facilities are seldom reported, the proportion of deaths occurring in facilities may have changed overtime, and determination of cause of death may be limited. Malaria deaths in all ages reported by the HMIS peaked mid-way through the evaluation period, in 2005, and then declined significantly to a low in 2008 (Figure 60).

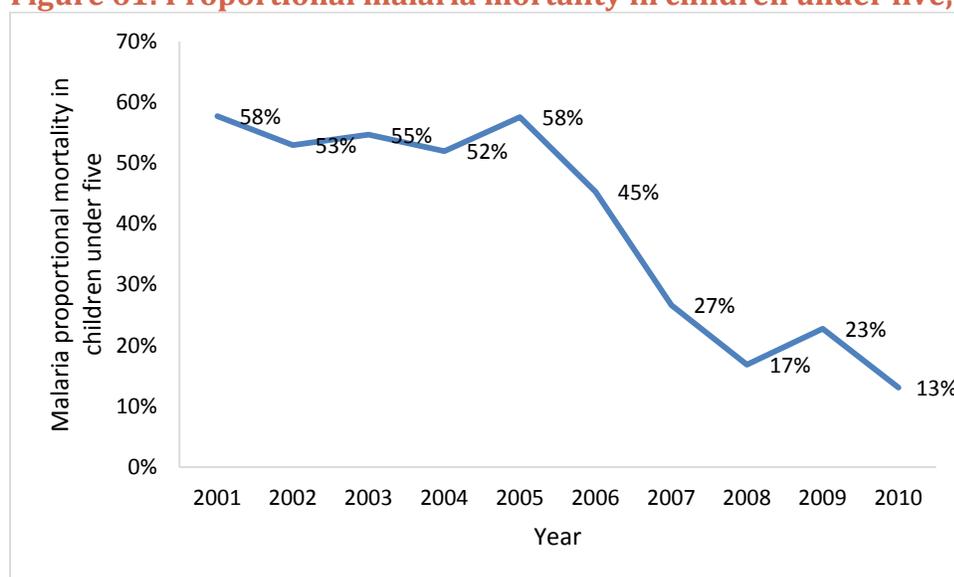
Figure 60: Malaria deaths across all ages, 2001-2010



Source: HMIS

The proportion of all reported inpatient deaths attributed to malaria (proportional malaria mortality) in the HMIS for 2001-2010 is shown in Figure 61. As was seen for malaria morbidity indicators, proportional malaria mortality clearly declined between 2005 and 2010, despite the evidence of an upsurge in 2009.

Figure 61: Proportional malaria mortality in children under five, 2001 - 2010



Source : HMIS

Summary of Mortality

In summary, the data show that a significant decline in ACCM has occurred in Rwanda between 2000 and 2010, a period of intense investment in malaria control interventions. It should be noted that the majority of the decline in ACCM over the period 2000-2010 occurred in the latter part of the decade after scale-up of malaria control interventions had begun. Available health facility data indicate declines in malaria-specific mortality, and in proportional malaria mortality.

The mortality decline over the last decade was largest among children 1 to 5 years of age (73% reduction) compared to infants (54% reduction) and in rural areas (62% reduction) compared to urban areas (53% reduction). Stratification of child mortality by malaria risk showed the greatest reduction in ACCM in children living in areas of moderate to highest malaria risk compared to those in low malaria risk areas (50-55% reductions compared to 34%) with significant reductions in all risk categories. Infant mortality also decreased significantly in all but the low risk area over the evaluation period.

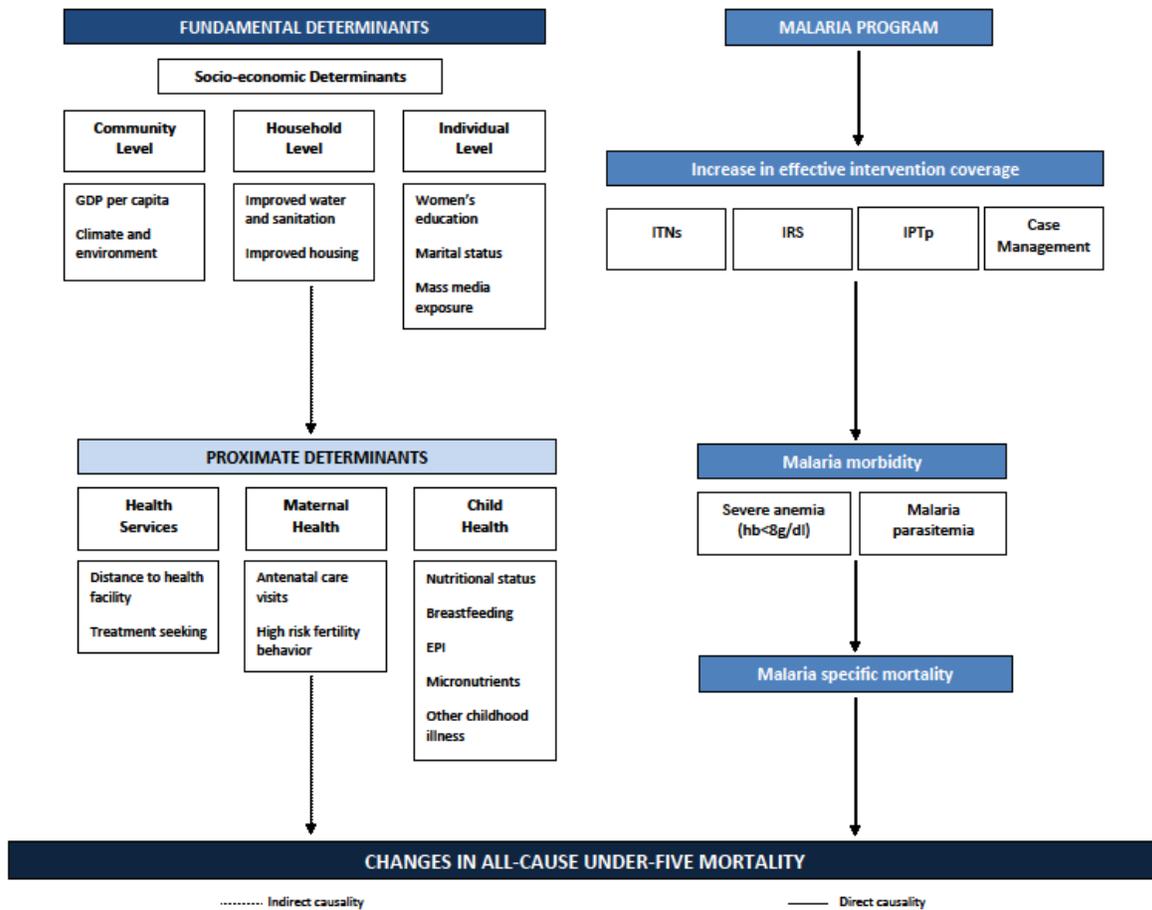
Many aspects of the mortality analyses presented in this section (timing, age-pattern, residence differentials, and relationship to malaria risk) are consistent with the results that would be expected if malaria were a major factor underlying the mortality change in Rwanda. Numerous other factors could have contributed to the observed decline in ACCM, however. The next section of this report presents results of analyses in which associations between malaria control interventions and mortality are assessed with consideration of other variables known to affect child mortality.

Contextual Factors

Appropriate consideration of contextual factors is essential for ensuring the internal and external validity of evaluations of large-scale health programs [65], particularly for evaluations that are conducted when rapid changes are under way in many other aspects of health services [66]. It is also important to consider contextual factors when the associations of interest are based on ecological data which is the case in this evaluation.

Contextual factors associated with childhood mortality and illness, including malaria, can be broadly categorized into the fundamental and proximate determinants of disease [67-74]. Fundamental determinants are the social and economic conditions under which people live, while proximate determinants are biological risks. The conceptual framework [7,66,75,76] for the evaluation design in Rwanda incorporates numerous contextual factors within various subcategories of the fundamental and proximate determinants of disease (Figure 62). In the following sections, relevant information and levels and trends of various contextual determinants – fundamental and proximate – of childhood mortality and illness are reviewed. Data on contextual factors were obtained from large population-based household surveys such as the DHS, as well as other sources such as WHO/UNICEF and UNAIDS.

Figure 62: Conceptual framework for the impact evaluation of the malaria control program, 2000-2010



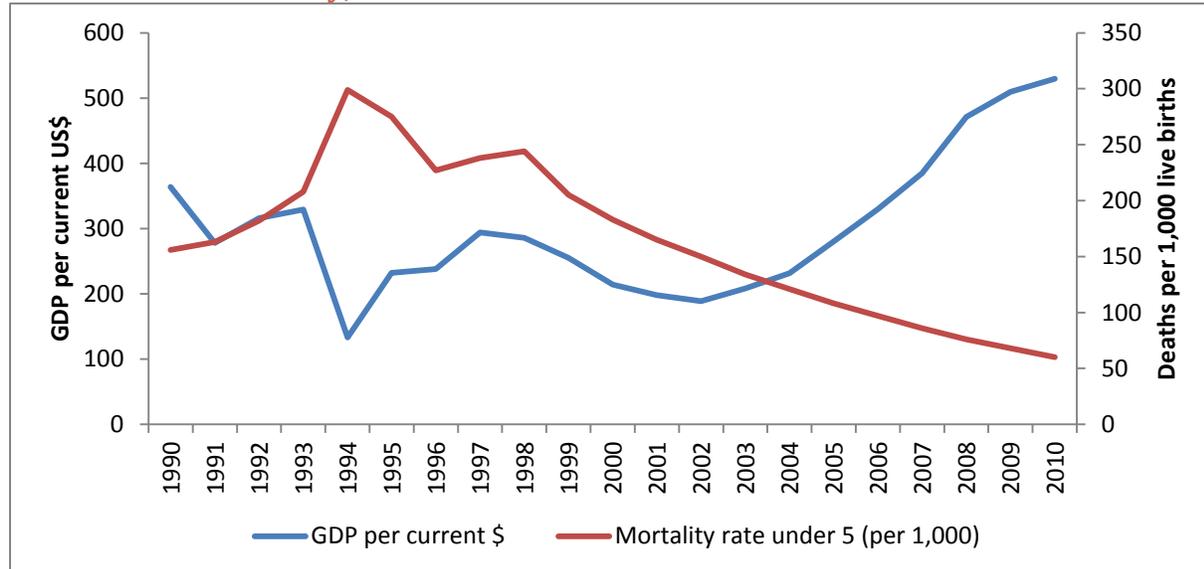
Fundamental Determinants

Socioeconomic Factors

A range of socioeconomic determinants at the community, household, and individual level are associated with child survival [70,77,78], as shown in the impact model in Figure 62.

Economic poverty, either at the country or individual level, strongly correlates with poorer health outcomes [79]. Gross Domestic Product (GDP) per capita income, a measure of population wealth in a country, is considered to be a typical macroeconomic determinant of health [78]. Modeling of the relationship between GDP per capita and under-five mortality indicates that a 1 percent annual increase in GDP per capita is associated with a 0.4-0.6 percent reduction in under-five mortality [80]. In Rwanda, the GDP per capita was US\$ 214 in 2000, as compared to US\$ 529 in 2010, a two-fold increase [81]. Trends in GDP per capita and all-cause childhood mortality in Rwanda are shown in Figure 63.

Figure 63: Trends in Gross Domestic Product (GDP) per capita and annual estimates of under-five mortality, 1990 - 2010



Source: World Bank Group Website [82]

Household and microeconomic factors are also important determinants of child health and malaria risk [77,83]. Socio-economic differentials² at household level are associated with access to malaria interventions [84]. Levels and trends in household attributes and other proxy of socio-economic status are summarized in Table 9.

Safe water and sanitation facilities contribute to improved child health and survival [85]. In 2010, 74% of households surveyed reported having access to an improved water source (i.e., protected, borehole, piped), as compared to 40% in 2000. The proportion of households with a water source within 15 minutes of the household did not change significantly over the decade. During 2000-2010, access to improved water and sanitation generally improved although the changes were not as dramatic as those seen in malaria control interventions.

Housing construction, such as flooring and roofing material, has been used to assess household socioeconomic status, but house construction also can directly affect malaria risk [86,87]. From 2000 to 2010, households with modern floor materials (i.e., not earth, sand, or dung) rose from 14 to 18%. No data are available on the proportion of houses that have sealed or screened eaves or ceiling boards – two important factors associated with malaria risk [88-91].

² Socioeconomic status of households can be measured using asset index. The index is constructed using simple weighted average of proportion of households that own individual durable goods, such as such as, radio, TV, and cell phones, as well as access to electricity, piped water and improved toilet facilities. These are considered validated microeconomic proxy of household income²²⁻²⁴.

Table 9: Household attributes and asset ownership, 2000–2010

Survey year	2000			2010			Relative change (%)	Sig.*
	%	95% CI	n	%	95% CI	n		
Improved water source (protected, borehole, piped), (% households)	40.4	37.1–43.7	9,696	73.8	71.4–76.0	12,540	82.7	S
Time to water source <15 min, (% households)	25.6	23.3–28	9,696	26.4	24.7–28.2	12,540	3.1	NS
Improved /not shared pit latrine with slab?	6.0	5.0-7.2	9,696	57.6	56.3–59.0	12,540	860.0	S
Modern floor material (not earth/sand/dung), (% households)	13.6	11.4–16.1	9,696	18.2	16.7–19.8	12,540	33.8	S
Electricity, (% households)	6.2	4.7–8.1	9,696	9.7	8.4–11.2	12,540	56.5	S
Telephone (landline or mobile), (% households)	1.1	0.8–1.7	9,696	40.6	38.8–41.8	12,540	3590.9	S

Sig.= Statistical significance. Statistics with non-overlapping 95% confidence intervals are considered significantly different change. NS denotes no statistically significant change; S denotes statistically significant change.

Climate and weather

Rwanda is situated in Eastern Africa which is one of the most complex regions in Africa in terms of its climatology. The position of the Inter-tropical convergence zone (ITCZ), sea-surface temperatures in the Indian Ocean and the strength of the Indian monsoon are important controllers of climate in this region [92]. Rwanda has four seasons: a short rainy season from September to November and a longer season between March and May. Between these seasons are two dry periods, a short one between December and February and a long one from June to August. The mean national annual temperature during 1981-2012 ranged between 18°C and 19°C, but varied according to local topography. The national annual rainfall dated 1981-2013 was approximately 44 inches although there is considerable variation across the country.

It is well established that temperature, rainfall and humidity are important factors for mosquito and parasite development and activity [93]. In Rwanda, malaria transmission is characterized by distinct patterns that seem to follow seasonal rainfall (Figure 64A) and the spatial distribution of temperature (Figure 64B). Newly available high resolution rainfall and temperature products created using the satellite and reanalysis products blended with the quality controlled data from the national meteorological archive for the last 30 years make it possible to analyze Rwanda's climate in detail despite severe data limitations [53].

Figure 64: Average monthly rainfall, January 2000-December 2013 (A); and average monthly temperature January 2000-December 2012 (B)

As shown in Figure 65, the annual peak in monthly mean temperature occurs around March. The annual peak in monthly minimum temperature occurs around May at the start of the main dry season. Annual mean monthly rainfall peaks in April.

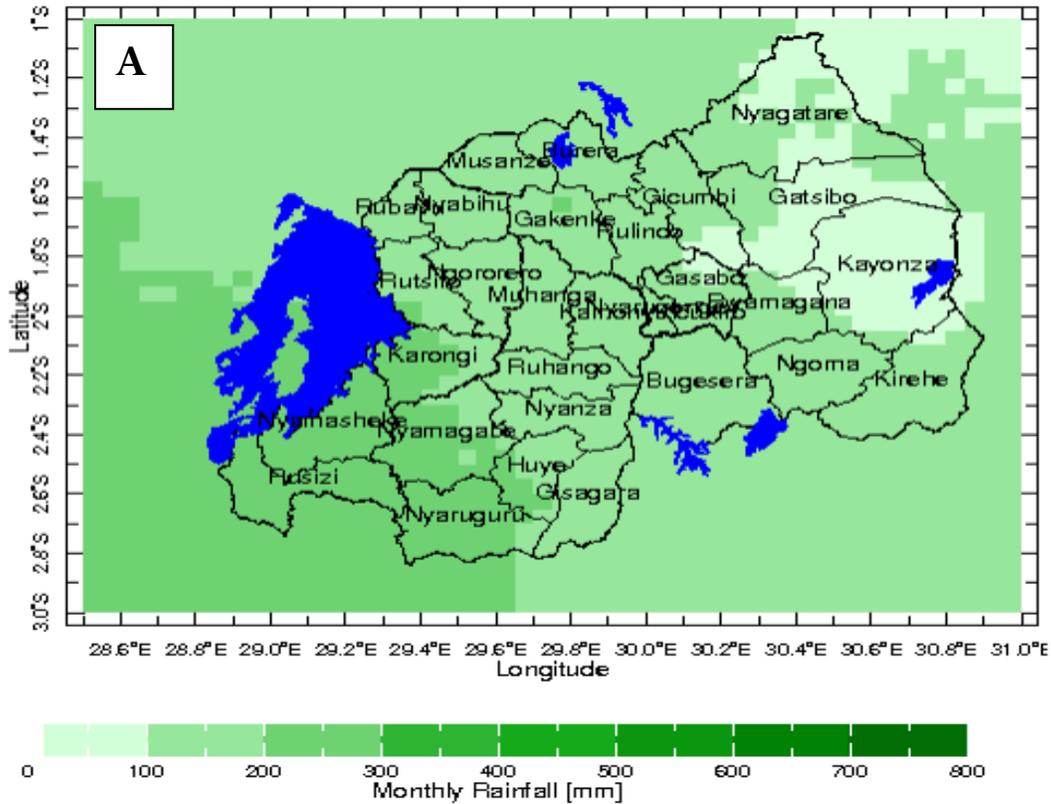
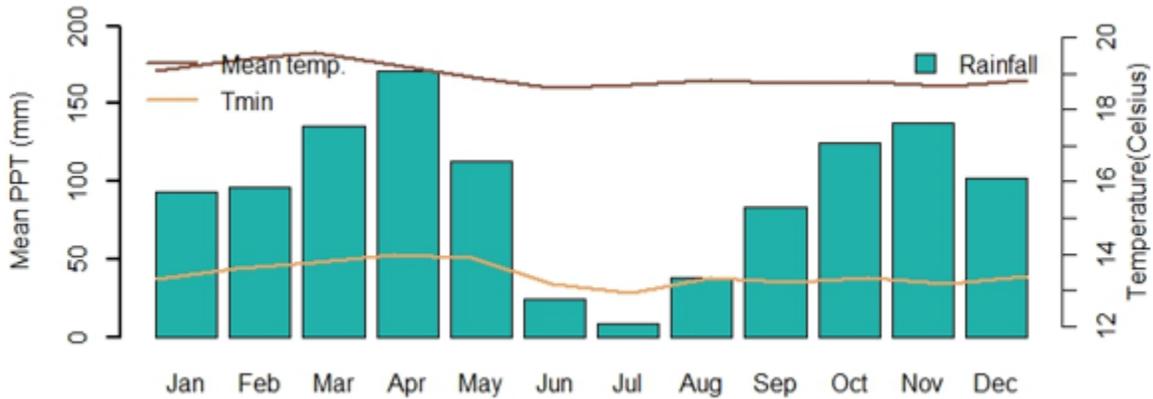


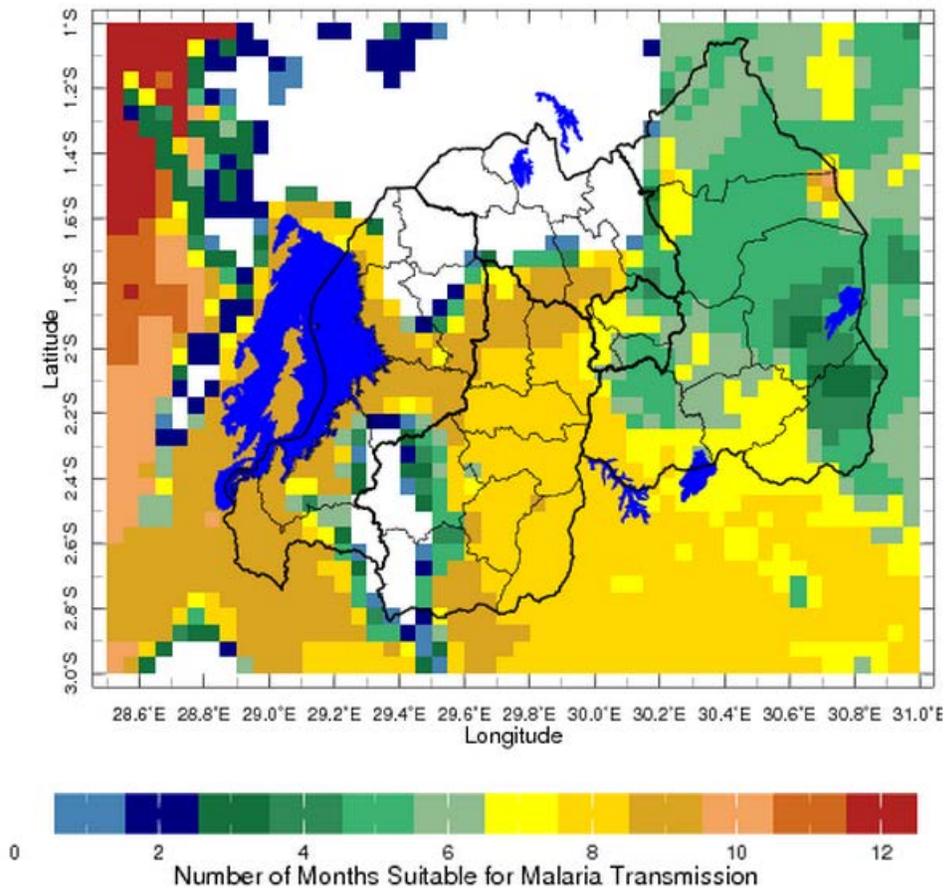
Figure 65: Monthly meteorological data of Rwanda, depicting the seasonality of rainfall, minimum temperature and mean temperature



Source: ENACTS, Rwanda 1981-2013

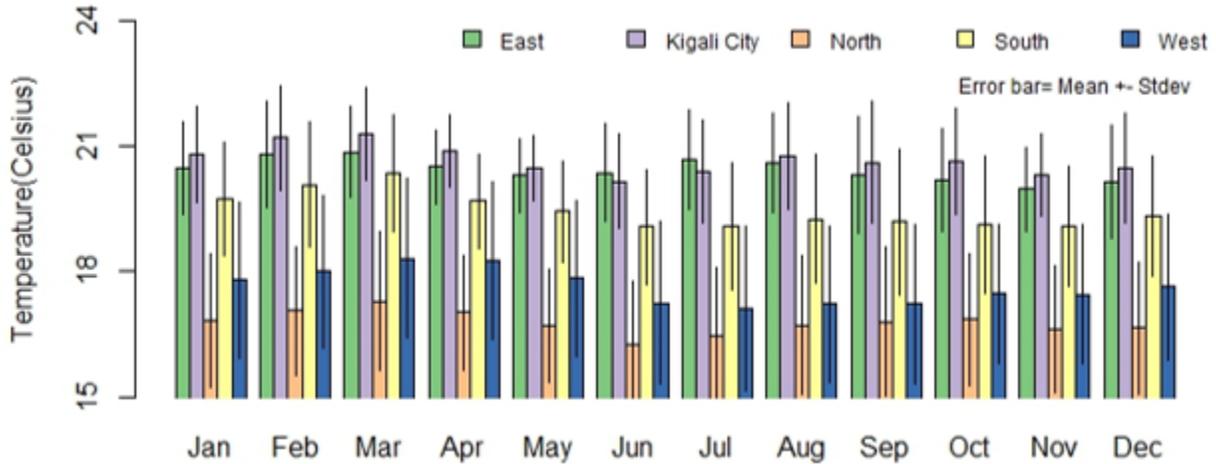
The Climate Suitability for Malaria Transmission (CSMT) (Figure 66)[94], is a tool designed to identify the number of months deemed suitable for malaria transmission wherever the disease is poorly controlled. The tool is based on a simple series of climate thresholds and uses the historic 30 year climate ENACTS database. If there is coincidence of rainfall accumulation greater than 80 mm, average temperature between 18°C and 32°C, and relative humidity greater than 60% the region is deemed suitable for transmission for the particular month and year which can be represented as a probability distribution (not shown) given that in some places transmission suitability might vary from year to year depending on climate variability. The map in Figure 66 indicates the average total months over the two malaria seasons when the conditions for malaria transmission suitability are met but does not indicate how intense transmission might be for any given positive month.

Figure 66: Climate Suitability for Malaria Transmission (CSMT)



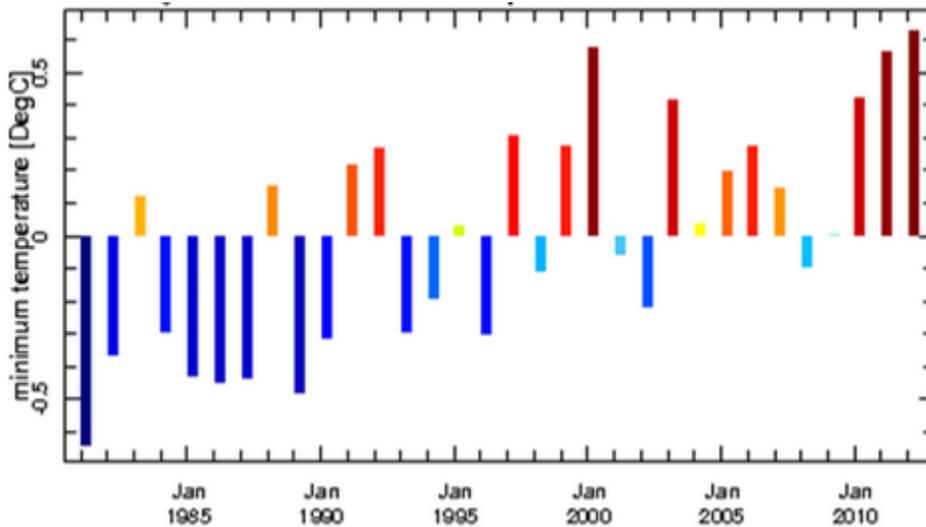
While rainfall is necessary for creating mosquito breeding sites, temperature is critical to the rate of development of mosquito and parasite, including the intrinsic incubation period. During the malaria season, many highland areas in the North and West seldom approach the temperatures that are optimal for malaria parasite-mosquito life cycle and development [95], even though they receive enough rain to support mosquito breeding during the season (Figure 67). However, warm temperature anomalies in high altitudes may be involved in the sporadic malaria incidence in these regions, indicated in Figure 10 (Epidemic-prone districts in Rwanda). The lowlands in the East (Figure 66) may have less rainfall but are warmer and therefore have a longer bimodal malaria transmission season despite a shorter less intense rainy season. The mean monthly temperature over the annual cycle by province indicates the variation over the country (Figure 67).

Figure 67: Mean monthly temperatures by provinces, 1981-2012



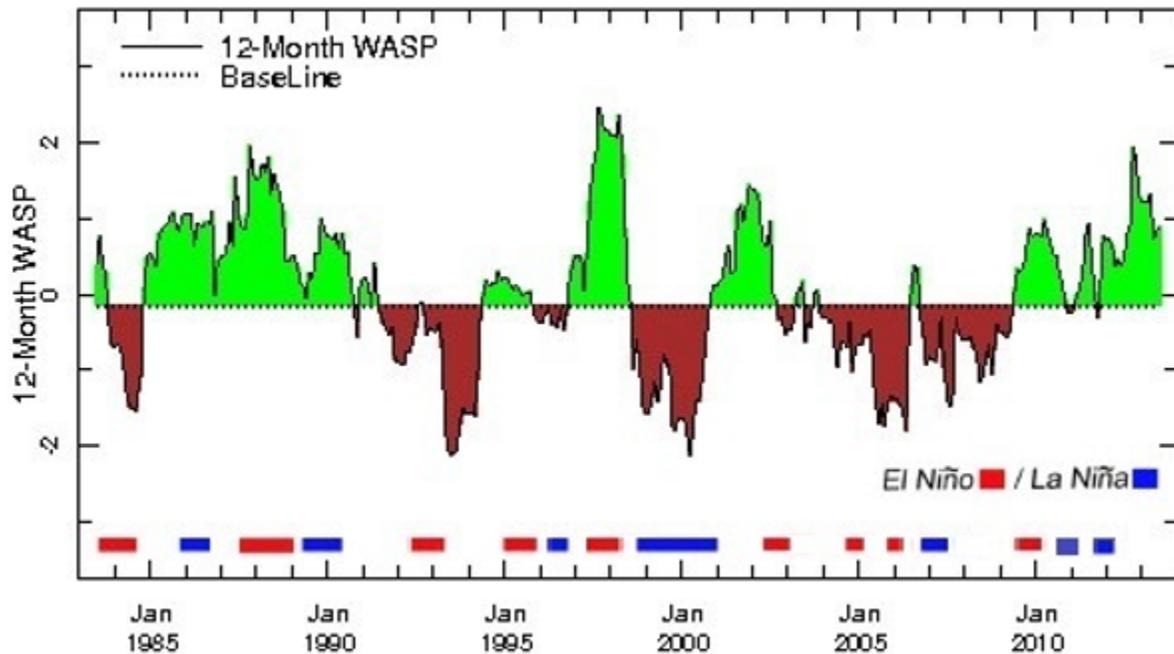
A notable feature of the climate of Rwanda is that temperatures have been rising over the last 30 years. However, this rise, which can be observed in all regions, is only apparent for the January-June time period (Figure 68).

Figure 68: Yearly, seasonal (January-June) minimum temperature anomalies from 1981-2012, in the Northern Province



A tool designed to assess if the climate is more or less suitable for malaria pre- and post-intervention is the Weighted Anomaly of Standardized Precipitation (WASP) (Figure 69) [96].

Figure 69: WASP Analysis for Rwanda using ENACTS rainfall data and a 1996-2000 baseline



Note: Green shows wetter than expected time periods (positive WASP values) and dark red shows drier than expected periods (negative WASP values). Dotted line indicates baseline, or neutral rainfall values.

Figure 69 shows a time series of the country-averaged value of the 12-Month Weighted Anomaly Standardized Precipitation (WASP) index calculated using the latest version of the ENACTS monthly rainfall dataset for a user-selected baseline period. The WASP clearly indicates periods of excessive rainfall (e.g. the El Niño of 1997/98) which was immediately followed by a major drought period.

The El Niño Southern Oscillation (ENSO) results in significant temperature and rainfall anomalies in specific seasons and regions around the world [97]. The warm phase of ENSO (El Niño) is associated with increased rainfall in the October-December short rainy season in parts of Eastern Africa [98] and has been shown to impact on malaria transmission in Eastern Africa [99]. The droughts in 2005-2009 (Figure 69) may have favored the decline in malaria cases. Note the corresponding major reductions in malaria in 2006-2008 and up-tic in 2009 (Figure 40).

In summary, climate is an important driver of malaria transmission in Rwanda where the rainy season is bi-modal and the varied topography impacts local temperatures. Although there has been significant decline in malaria incidence across Rwanda since 2000, climate is likely involved in the occasional disruptions in the downward trend of malaria, most likely due to abnormal rainfall and temperature.

Both rainfall and temperature respond to ENSO forcing, and the associated Indian Ocean Dipole (IOD) influences the 'Short' rainy season. The pre-intervention period (1996-2000)

included the 1997/98 El Niño whereas the intervention decade (2001-2010) included two major drought periods which are likely to have aided the control efforts.

Mother's Education and Marital Status

At an individual level, maternal education is an important determinant of maternal and child health [78,100-106]. In Rwanda, 28% of women aged 15-49 had completed primary education in 2000, as compared to 30% in 2010, an insignificant change. However, women's literacy increased significantly from 66% in 2000 to 77% in 2010 (Table 10).

Survivorship and health outcomes of children under five years of age are better among married women [107-109]. In 2000, 49 % of women were married or living with a partner, as compared to 51% in 2010.

Table 10: Women's education, and marital status in Rwanda, 2000-2010

Indicator	2000			2010			Relative change (%)	Sig.
		95% CI	n		95% CI	n		
Median years of education (years)	3.7	3.5-3.9	10410	4.4	4.3-4.5	13671	18.9	S
Completed primary education (%)	27.9	26.0-29.9	10421	30.1	28.7-31.5	13671	7.9	NS
Literacy (%)	66.1	64.4-67.7	10421	76.9	75.8-78.0	13671	16.3	S
Married (%)	48.5	47.2-49.8	10421	50.5	49.4-51.5	13671	4.1	NS

Note: Women aged 15-49 years

Sig.= Statistical significance. Statistics with non-overlapping 95% confidence intervals are considered significantly different change. NS denotes no statistically significant change and S denotes statistically significant change

Proximate Determinants

Maternal Health

Antenatal care visits are considered a key entry point for a continuum of care during and after pregnancy. They offer timely opportunities for receiving health promotions, as well as preventive and therapeutic interventions aimed at improving maternal, fetal, and newborn survival and wellbeing [110]. Through antenatal visits, Rwandan women benefit from various interventions, including counseling about healthy lifestyles, the provision of iron/folic acid supplements, and tetanus toxoid vaccinations to protect newborns against neonatal death in addition to malaria prevention interventions such as IPTp and distribution of ITNs. In Rwanda, 10% of women attended four or more antenatal care visits (ANC4+) as recommended by WHO in 2000, compared to 35% in 2010, a significant increase over the decade (Table 11).

Neonatal tetanus is often the result of infection from unhygienic cutting/cleaning of the umbilical cord at the time of delivery. To help prevent infection, WHO recommends that women receive a total of five doses of the tetanus toxoid vaccine: 2 doses given one month

apart in the first pregnancy, then 1 dose in each subsequent pregnancy (or intervals of at least 1 year), to a total of five doses [111]. Maternal vaccination against tetanus creates antibodies that are passed to the child *in utero* thus providing protection in the first weeks of life [112]. Studies have shown a conclusive reduction in neonatal tetanus mortality through the scale-up in tetanus vaccination of women of childbearing age [113]. In Rwanda, the proportion of women whose most recent births (within the last two years) were protected against neonatal tetanus (two or more doses of tetanus toxoid administered during pregnancy) increased marginally from 30% in 2000 to 34% in 2010 (Table 11).

Child birth at health facilities, usually by skilled attendants, can reduce the chances of maternal and newborn complications. In 2000, only 27% of live births occurred in health facilities, compared with 69% in 2010. Births in women with high-risk fertility behavior³ can increase the risk of early childhood mortality. From 2000 to 2010, births in any high-risk fertility category decreased from 60% to 53% whereas birth in women with unavoidable fertility risk⁴ increased from 18% in 2000 to 24% in 2010.

Table 11: Maternal health indicators in Rwanda, 2000-2010

Indicators	2000			2010			Relative change (%)	Sig
	%	95% CI	N	%	95% CI	N		
ANC visits 4+ (% women, most recent live birth, 0-2yrs)	10.3	9.2-11.5	5141	35.4	33.9-37.0	6405	194.8%	S
Tetanus toxoid 2+ (% women, most recent live births, 0-2yrs)	30.2	28.6-31.8	5141	34.1	32.8-35.5	6405	3.1%	S
Delivery at a health facility (% women, live births 0-4yrs)	26.5	24.3-28.9	8188	68.9	67.3-70.5	9137	132.9%	S
Births in any high-risk fertility category (%)	59.6	58.1-61.0	8188	53.3	52.1-54.5	9137	-14.6%	S
Births with unavoidable fertility risk (%)*	18.3	17.4-19.2	8188	23.5	22.6-24.5	9137	17.7%	S
Births with avoidable fertility risk (%)**	58.8	57.4-60.2	8188	52.1	50.9-53.3	9137	-15.4%	S

Sig.= Statistical significance. Statistics with non-overlapping 95% confidence intervals are considered significantly different change. NS denotes no statistically significant change and S denotes statistically significant change
*First order births to women between the ages of 18 and 34
** Births to women <18 and >34 and births <2 years apart

³ Births, in women who are less than 18 years of age or greater than 34 years of age, births less than 24 months apart, and birth order greater than 3.

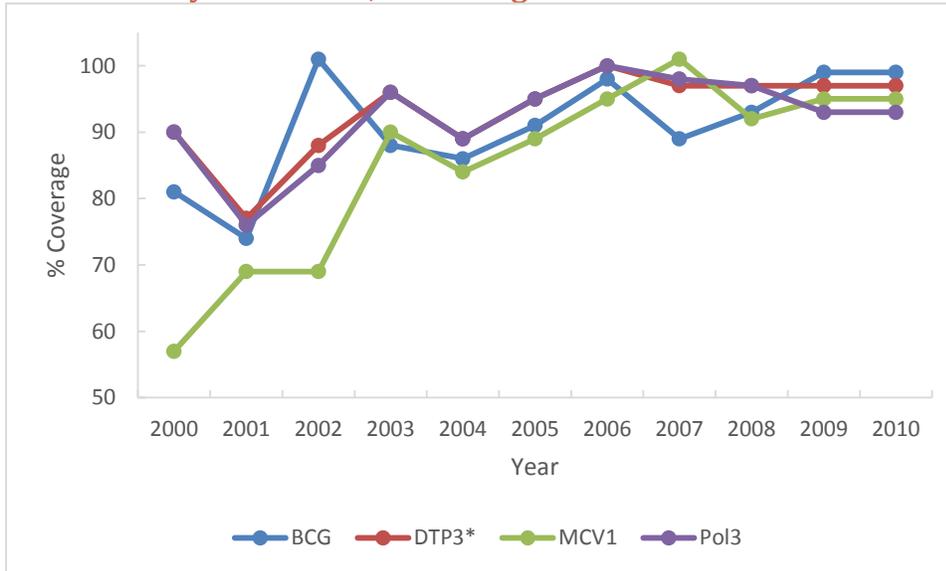
⁴ First order births to women between the ages of 18 and 34. The risks associated with these births are unavoidable as they are first order births for women between the ages of 18 and 34 who would otherwise be at low risk for adverse birth outcomes (any first birth is higher risk than subsequent births; teen births and births to women of advanced age are also associated with higher risk).

Child Health

The WHO Expanded Program on Immunization (EPI) offers vaccinations against common childhood communicable diseases and is one of the most cost-effective child survival interventions [114,115]. Effective coverage of these vaccinations contributes substantially to reductions in under-five mortality. Rwanda's recommended EPI schedule for children includes immunizations to protect against tuberculosis (BCG), polio (OPV), diphtheria, pertussis, and tetanus (DPT), hepatitis B (HepB), *Haemophilus influenzae (b)* (Hib), pneumococcal disease (PCV7) and measles. The immunization schedule calls for BCG and the first dose of OPV within 14 days after birth, DPT-HepB-Hib, OPV, and PCV7 at 6, 10 and 14 weeks after birth, and measles at or soon after 9 months of age [116]. Rwanda was among the first countries in Africa to introduce the pentavalent vaccine which combines DPT/HepB/Hib 3 in 2002. Rwanda was also the first developing country to introduce the pneumococcal vaccine (PCV7) in its routine immunization program countrywide in 2009. Recommendations call for complete immunizations before one year of age and specify that they should be recorded on an immunization card. The program of vaccination in Rwanda is one of the best programs in Africa and has had good coverage since 2000. Coverage of each of these childhood vaccinations during 2000-2010, according to vaccination cards or mother's report during household surveys, is shown in Table 12. In 2010, 90.1% of children aged 12-23 months received all of the vaccinations recommend in the EPI schedule, as compared to 76.0% in 2000.

Measles vaccination, in children aged 12-23 months, increased from 87% in 2000 to 95% in 2010. BCG coverage in the same age group increased from 97% to 99% over the decade. Coverage with three doses of DPT increased from 86% to 97% and coverage with three doses of OPV from 88% to 93%, all significant increases. Immunization coverage as reported by WHO is shown in Figure 70. According to the WHO estimates, the largest increase in EPI coverage occurred between 2000 and 2006 at which point coverage leveled off.

Figure 70: Immunization coverage in Rwandan children 12-23 months of age, vaccinated by 12 months, according to WHO-UNICEF estimates



Source: WHO, 2012 [117]; Note: HepB3 and Hib3 were added to DTP3 in 2002 and PCV3 in 2010.

Acute Respiratory Infections (ARI) and diarrheal diseases, caused by a variety of viral and bacterial pathogens, are among the leading causes of illness and death in children under five years of age, both globally and in Rwanda. Interventions to control these two diseases mainly include immunizations against specific pathogens, early diagnosis and treatment, improvements in nutrition and feeding practices and safer environments, defined as access to clean water and sanitation and minimized exposure to indoor air pollution. Data on the prevalence and treatment seeking practices of these two conditions were collected during household surveys in Rwanda by asking mothers whether their children under five years of age had been ill with a cough accompanied by short, rapid breathing and whether they suffered from diarrhea in the two weeks preceding the survey (Table 12). In the two weeks before the surveys in 2000, 21% of children under five years of age were ill with symptoms of ARI (cough, and rapid breathing) as compared to 10% in 2010. Fifty-four percent of children under five years of age with symptoms of ARI sought treatment at a health facility in 2000, as compared to 62% in 2010. During the two weeks preceding the 2000 survey, 17% of children under-five had diarrhea, as compared to 13% in 2010. Thirty percent of children with diarrhea were taken to a health provider and 29% were treated with ORS in 2000, whereas 48% were taken to providers and 14% were treated with ORS in 2010.

Table 12: Child health indicators in Rwanda, 2000-2010

Indicators	2000			2010			Relative change (%)	Sig
	%	95% CI	N	%	95% CI	N		
BCG	97	95.8-97.9	1,330	99.1	98.6-99.5	1,616	0.7	S
DPT3 / DPT3-HBV-Hib	86.2	83.7-88.3	1,328	96.8	95.6-97.7	1,616	8.3	S
Polio3	88	85.8-90.0	1,323	93.3	91.7-94.6	1,616	1.9	S
Measles	86.9	84.6-88.9	1,330	95	93.7-96.1	1,616	5.4	S
EPI Vaccination coverage	76.0	73.0-78.8	1330	90.1	88.3-91.7	1616	12.1	S
Children 0-4yrs had ARI symptoms in previous 2 weeks*	21.2	19.8-22.7	7,033	10	9.3-10.8	8,605	-59.0	S
Children 0-4yrs with ARI sought treatment	54.2	51-57.5	1493	62.1	55.4-68.4	322	-3.7	NS
Children 0-4yrs with diarrhea in previous 2 weeks	16.9	15.8-18.0	7,033	13.2	12.3-14.1	8,605	-31.7	S
Children 0-4yrs with diarrhea sought treatment	30.2	27.5-33.1	1186	48.1	44.7-51.5	1132	35.0	S
Children 0-4 yrs with diarrhea used ORS	13.6	11.6-16.0	1186	29.1	26.3-32.1	1132	64.4	S

Sig.= Statistical significance. Statistics with non-overlapping 95% confidence intervals are considered significantly different change. NS denotes no statistically significant change and S denotes statistically significant change
 *Definition of ARI is based on data available in the 2000 survey: child had illness with cough in past two weeks and he/she breathed faster than usual with short, fast breaths.

Breastfeeding Practices and Undernutrition in Children and Women

In addition to serving as a source of nutrition, breastfeeding during infancy provides protection against infectious diseases, including diarrhea and ARI, the leading causes of under-five mortality [74,118]. Early and exclusive breastfeeding is an important child survival intervention which reduces neonatal, infant, and child mortality [119]. Currently the WHO recommends early and exclusive breastfeeding for the first six months following birth [120]. In Rwanda, 83% of children less than six months of age were exclusively breastfed in 2000, as compared to 85% in 2010, an insignificant change (Table 13). Similarly, the proportion of children born in the five years prior to interview who initiated breastfeeding early did not change significantly between 2000 and 2010 (48% and 50%, respectively).

Undernutrition due to chronic dietary deficiency of protein, energy, essential vitamins, and minerals (collectively referred to as micronutrients) is an important determinant of maternal and child health [121]. The continuum of maternal, fetal, and child undernutrition results in 3.5 million preventable child and maternal deaths globally, per year [122].

In children under five years of age, the standardized anthropometric measures of under-nutrition [123] are a) low birthweight due to intrauterine growth restriction (IUGR); b) underweight, a reflection of low weight-for-age; c) stunting, a chronic restriction of growth in height indicated by a low height-for-age; and d) wasting, an acute weight loss indicated by a low weight-for-height. In Rwanda, the percent of babies born live with low-birth weight (< 2500 grams) increased significantly over the study period (2 % in 2000 and 6% in 2010) (Table 13). Underweight, stunting, and wasting prevalence in children under five, was 20%, 48%, and 8%, respectively in 2000, as compared to 11%, 44% and 3%, respectively, in 2010, all statistically significant but small absolute reductions.

Vitamin A deficiency has been implicated in increased morbidity and mortality from infectious diseases prevalent in children under five years of age and results in up to 600,000 under-five deaths annually [122]. Periodic vitamin A supplementation (i.e., every six months) in areas with pre-existing vitamin A deficiency has been shown to replenish vitamin A stores needed for essential physiological functions and to decrease ACCM by up to 23% [124,125]. In 1996, Rwanda began organizing National Immunization Days (NIDs). In addition to provision of essential childhood vaccinations, NIDs provide an opportunity to administer vitamin A to children to complement routine supplementation of Vitamin A after birth at health care facilities. Progress on reducing vitamin A deficiency is measured using coverage of micronutrient supplementation campaigns. In Rwanda, 69% of children age 6–59 months received a vitamin A supplement in the six months prior to the survey in 2000 as compared to 93 % in 2010 (Table 13).

Table 13: Breastfeeding and undernutrition in children and women in Rwanda, 2000–2010

Indicator	2000			2010			Relative change (%)	Sig.
	%	95% CI	n	%	95% CI	n		
Early initiation of breastfeeding	48.1	45.9-50.3	7,950	49.9	48.8-50.9	8,990	3.7	NS
Exclusive breastfeeding in children <6 months of age	83.3	80.3-86.0	776	84.9	82.0-87.5	718	1.9	NS
Small/very small size at birth (mother's estimate)	11.1	10.2-12.1	8,188	15.3	14.5-16.2	9,137	37.8	S
Low birth weight <2500g	2.2	1.9-2.6	8,188	6.2	5.6–6.9	6,196	181.8	S
Under-fives stunted **	48.3	46.7–50.0	6,514	44.2	42.5–46.0	4,356	-8.5	S
Under-fives underweight **	19.5	18.3–20.7	6,514	11.4	10.4–12.5	4,356	-41.5	S
Under-fives wasted**	8.3	7.5–9.1	6,514	2.8	2.3–3.4	4,356	-66.3	S
Vitamin A supplementation within past 6 mo.(% children 6-59 mo)	68.9	66.9–70.9	6,245	92.9	92.1–93.6	7,873	34.8	S

** Definitions and methods per WHO reference population.

Sig.= Statistical significance. Statistics with non-overlapping 95% confidence intervals are considered significantly different change. NS denotes no statistically significant change and S denotes statistically significant change

HIV/AIDS among Children and Women

The advent of HIV/AIDS epidemic in the 1980s threatened child survival gains made globally since the 1960s [126]. Child survival stagnated and even reversed in many countries in sub-Saharan Africa [127] and HIV/AIDS became an increasingly important cause of under-five mortality in Sub-Saharan Africa [128].

In Rwanda, the first cases of HIV infection were reported in 1983 and the epidemic rapidly spread. Population trends in prevalence of HIV infection in Rwanda were monitored through the 2005 and 2010 DHS. Among women aged 15–49, HIV prevalence did not change between 2005 and 2010 with an estimated 3.6% infected in 2005 and 3.7% infected in 2010.

Data from the 2010 DHS show large regional disparities in HIV prevalence with 6.7% of men and women aged 15-49 in Kigali city infected compared to 2.0% in the North province, 2.5% in the East, 2.7% in the South and 3.2% in the West. Despite these regional disparities in prevalence there has not been a differential change in HIV prevalence by region since 2005. In addition, regional ACCM patterns do not correlate with regional HIV prevalence patterns. This suggests that HIV prevalence over the study period is unlikely to have affected trends in ACCM.

Population-based estimates of HIV infection in children under five are not available. However, analyses based on national models of HIV and AIDS show that the HIV-attributable under-five mortality per 1000 live births (corrected for other competing causes of mortality) was around 4% in 2000 as compared to 2% in 2010 [129,130].

Summary of Contextual Factors

Rwanda has experienced many positive developments during the evaluation period, many of which would be expected to lead to improved child survival. A summary of these changes and the expected relationship with under-five mortality in Rwanda is presented in Table 14.

Table 14: Summary of evidence of changes in factors that could be associated with under-five mortality in Rwanda, 2000–2010

	Evidence supporting lower mortality	No evidence suggesting change in mortality	Evidence supporting higher mortality
Malaria control interventions	<ul style="list-style-type: none"> • Household ownership of ITNs • ITN use by children under-five • ITN use by pregnant women • IRS (in selected areas) • Care seeking for fever • Use of ACTs • Improvements in case management 		
Other contextual determinants	<p>Fundamental determinants</p> <ul style="list-style-type: none"> • GDP per capita growth • Maternal literacy • Housing conditions <p>Proximate determinants</p> <ul style="list-style-type: none"> • Antenatal Care attendance 4+ • Neonates protected from Tetanus • Births at a health facility • Proportion of births that are high risk • Nutritional status • Vitamin A supplementation • Hib vaccination • HepB vaccination • BCG, Polio, DPT, measles vaccinations • ARI prevalence • Diarrhea prevalence • PMTCT, ART • Diarrhea treatment (oral rehydration solution/extra fluids) • ARI and diarrhea care seeking 	<p>Fundamental determinants</p> <ul style="list-style-type: none"> • Rainfall • Women married • Maternal education <p>Proximate determinants</p> <ul style="list-style-type: none"> • HIV prevalence (female 15-49 years) • Exclusive breastfeeding • Early initiation of breastfeeding 	<p>Proximate determinants</p> <ul style="list-style-type: none"> • Low birth weight/size

In addition to the rapid improvements in malaria control that are hypothesized to have contributed to reduced child mortality, other favorable changes have occurred in fundamental and proximal determinants. GDP has increased, the proportion of literate women has risen, and the percent of households with improved floors and electricity has

increased. Stunting, wasting and underweight prevalence has declined over the evaluation period, as has the proportion of children with symptoms of ARI and diarrhea. Care seeking for childhood illness increased over the time period as did treatment of diarrhea with ORS. Although immunization coverage increased, fairly high coverage of most immunizations already existed at baseline. Over the evaluation period, maternal health indicators such as tetanus immunizations, and facility births improved as well. All of these improvements are likely to positively influence child survival, although the relative importance of each factor is difficult to predict. Only one contextual factor presented here changed in a direction that would be expected to favor higher mortality, or congruously, slower declines in mortality: the prevalence of low birth weight increased between 2000 and 2010. The next section estimates the effect of malaria control interventions on child survival while accounting for these important contextual factors.

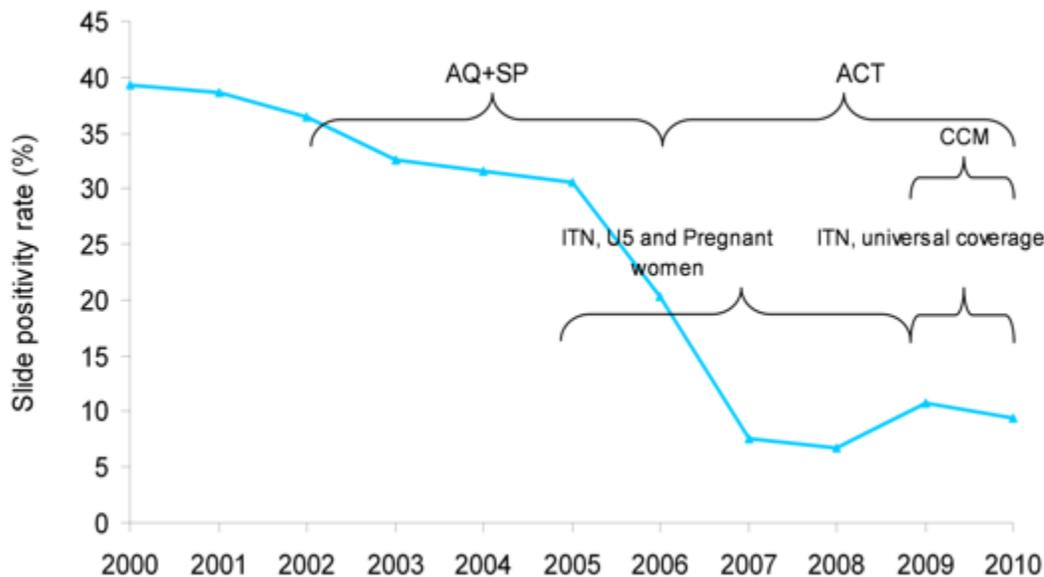
Further Analyses

Summary of published studies

Trends in Malaria Control Efforts and in Malaria Outcomes, 2000-2010

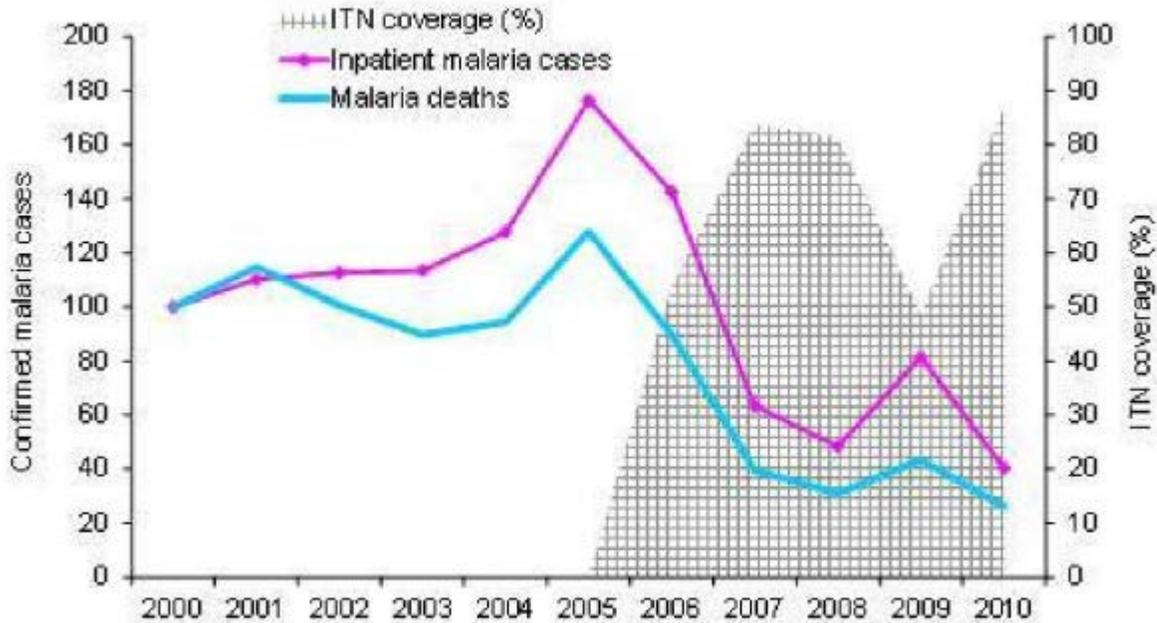
A recent publication by Karema and colleagues [131] summarized trends in malaria control interventions in Rwanda during the 2000-2010 period and how they relate to trends in malaria outcomes. Figure 72 displays the temporal patterns in ITN coverage with distribution beginning in 2005, a decline in coverage from 2008 to a low in 2009, and finally a sharp resurgence in coverage following a distribution campaign in 2010. In addition to ITNs, other malaria control interventions that occurred during this time period include new antimalarial treatments and roll out of community case management (Figure 71). The changes in malaria outcomes such as inpatient malaria cases and malaria deaths for children under five (Figure 72) decreased as ITN coverage increased.

Figure 71: Slide positivity rate in district hospitals for all ages and timing of interventions, 2000-2010



Source: Karema et al, 2012 [131]. Slide positivity rate in hospitals (n=30). CCM = community case management

Figure 72: Trends of malaria cases and deaths in children less than five years, 2000-2010



Source: Karema et al, 2012 [131]

Retrospective Study of Hospital Records in Rural District Hospitals

A study done by Sievers *et al.* [132] attempted to measure the impact of mass distribution of long-lasting insecticide-treated nets and distribution of anti-malarial medications by community health workers on pediatric hospitalizations for malaria and on laboratory markers of disease severity in Rwanda. The retrospective study utilized hospital records to study the impact of pre- and post-community-based malaria control interventions (mass insecticide treated net distribution and community health workers' administration of malaria treatment) at the district hospital level in rural Rwanda. The study outcomes were change in the proportion of laboratory-confirmed clinical malaria admissions among children who were admitted for malaria and change in clinical markers of malaria disease, especially hemoglobin and peripheral parasitemia. The results of this study showed that, after the interventions, there was a significant reduction in the proportion of children admitted for suspected malaria who were diagnostically confirmed from 80.4% pre-intervention period to 48.1% post-intervention (PR=1.67; 95% CI:1.39-2.02, p<0.001). There was also a decrease in parasite burden among children hospitalized with malaria.

Pre- and Post-Intervention Analysis of LLIN distribution, 2001-2007

Another study was carried out by Otten et al. [33] before and after the targeted mass distribution of 1.96 million LLIN to children under five years, integrated with measles vaccination in September 2006 by the MOH, followed by the introduction of ACT in October 2006 through public-sector health facilities throughout the country (Figure 73). As a result

of the specific malaria control interventions, in-patient malaria cases and deaths in children under five years old in Rwanda fell by 55% and 67%, respectively (Figure 74). Over this same time period, non-malaria inpatient cases and deaths generally remained stable or increased (Figure 74). The results suggested that the combination of these malaria control interventions was associated with substantial declines of in-patient malaria cases and deaths in Rwanda.

Figure 73: Hospital and Health Center Locations, 2010

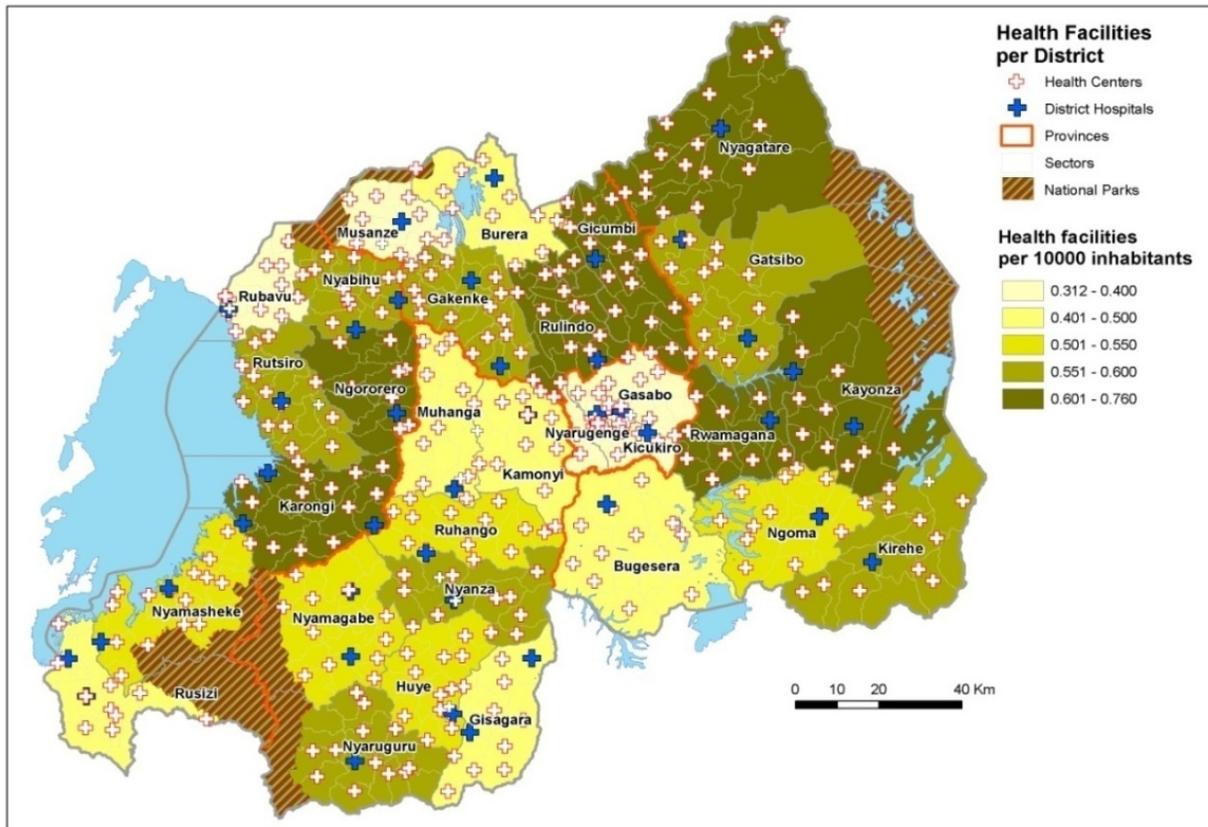
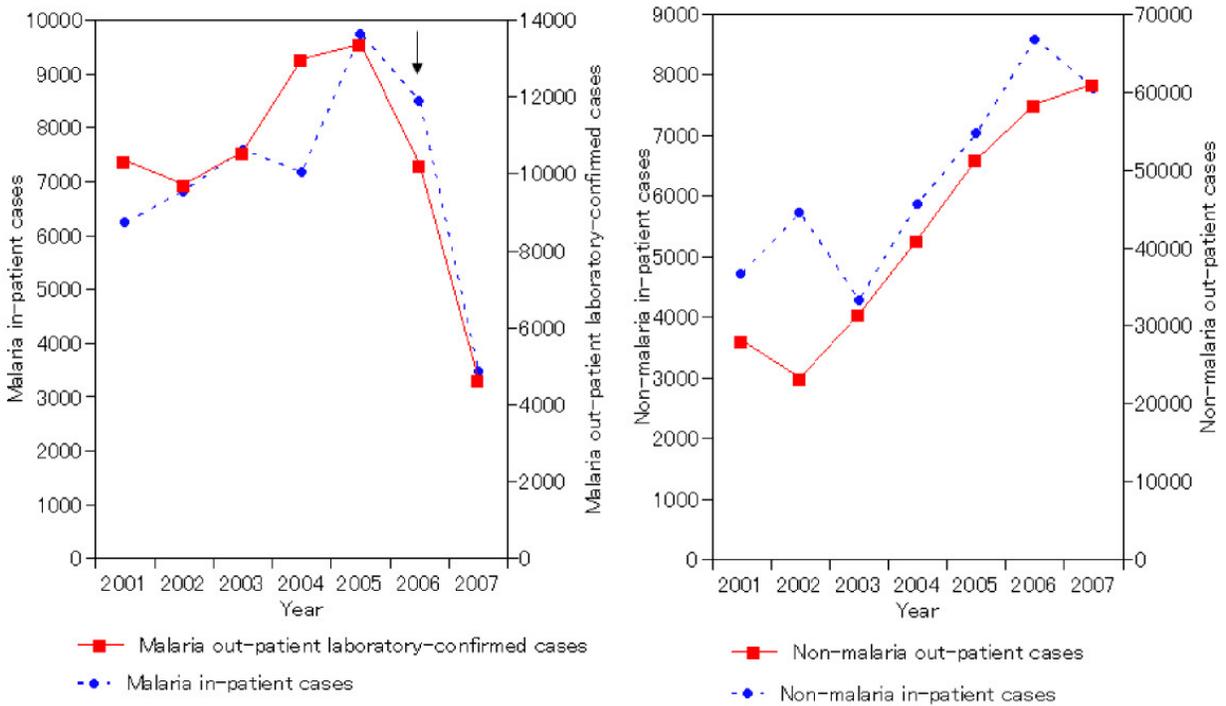
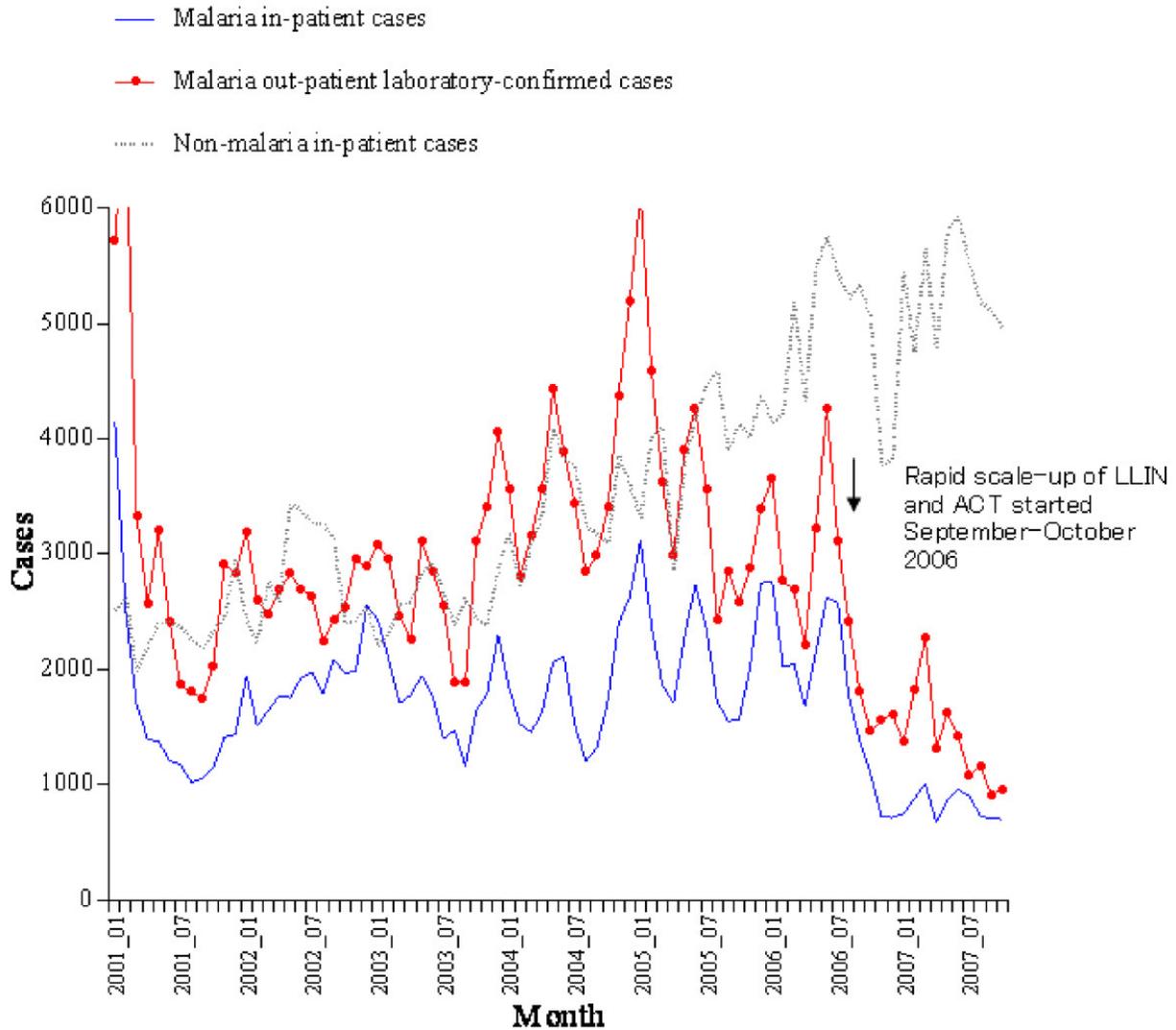


Figure 74: Malaria and non-malaria in- and out-patient cases, children <5 years old, January to October 2001-2007



Source: Otten et al, 2009 [33]

Figure 75: In-patient malaria cases, out-patient laboratory-confirmed cases, and in-patient non-malaria cases, by month, all ages, January 2001 to October 2007



Source: Otten et al. 2009 [33]. _01 refers to January and _07 refers to July.

Decomposition Analysis of ACCM, 2000-2010

This analysis examines various socioeconomic factors as well as child and maternal health interventions that are likely to have played a role in determining the level of all-cause under-five mortality (ACCM) in Rwanda. Data from the 2000 and 2010 Demographic and Health Surveys (DHS) are used for the analysis.

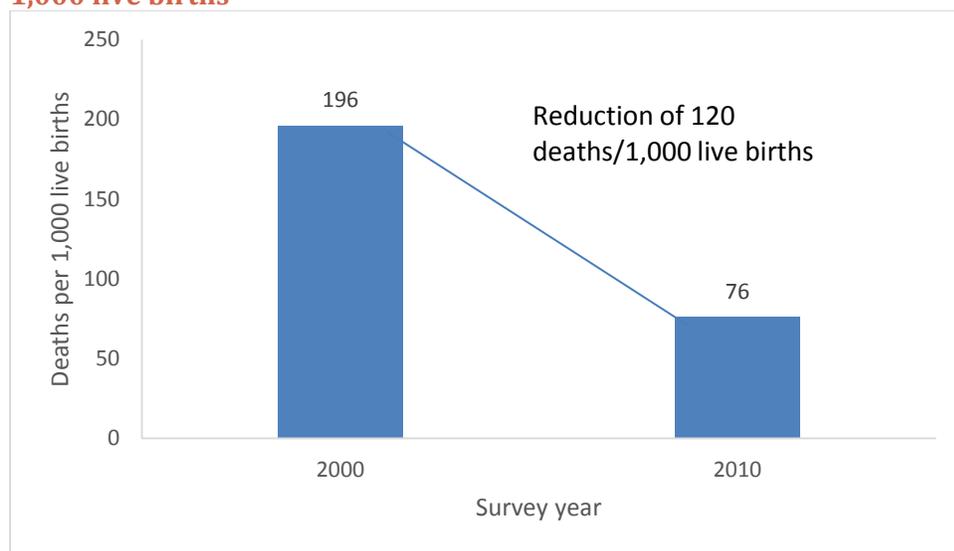
Multivariate decomposition models were used to identify which factors contributed to a significant reduction in ACCM between surveys, either due to changes in the distribution of the variables over time (endowments) or due to changes in the strength of the effect of

these variables on mortality (coefficients). Multivariate log probability models were used following the `mvcmp` procedure in Stata 13 with a logit distribution.

Outcome

All-cause under-five mortality declined significantly in the past 10-15 years in Rwanda (Figure 76). According to the 2000 DHS, ACCM was 196 deaths per 1,000 live births between 1996 and 2000. By the 2010 DHS, ACCM for 2006-2010 had declined to 76 deaths per 1,000 live births, a reduction of 120 deaths per 1,000 live births.

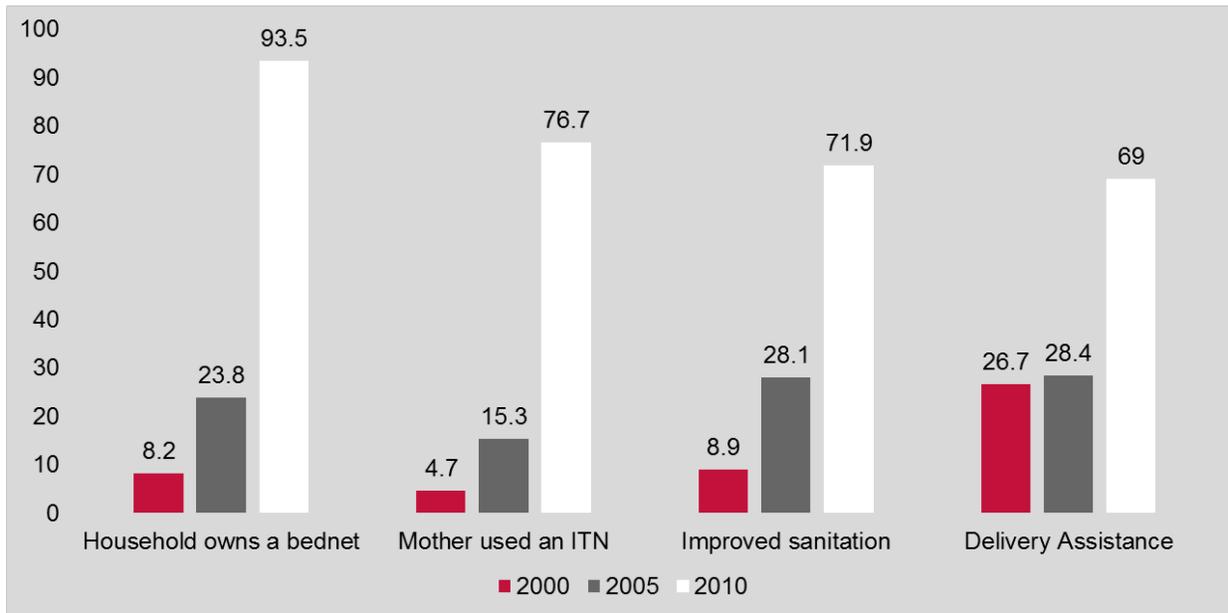
Figure 76: All-cause under-five mortality in Rwanda 1996-2000 and 2006-2010, deaths per 1,000 live births



Endowments

Between 2000 and 2010 Rwanda has experienced rapid development and improvements in many health indicators. A few examples are presented in Figure 77. The most drastic changes in health and socioeconomic indicators between 2000 and 2010 occurred in the percentage of households with improved sanitation (9% to 72%), the percentage of households with mosquito nets (8% to 94%) and the percent of mothers using ITNs (5% to 77%). Also, the percentage of children living in regions in which over 80% of children 12-23 months were fully immunized increased from 36% to 89% and the percentage of births that were assisted by a health professional increased from 27% to 69%. The full details are shown in Annex B (Table A.2.2a).

Figure 77: Trends in selected health and socioeconomic indicators that could have influenced child mortality, 2000-2010

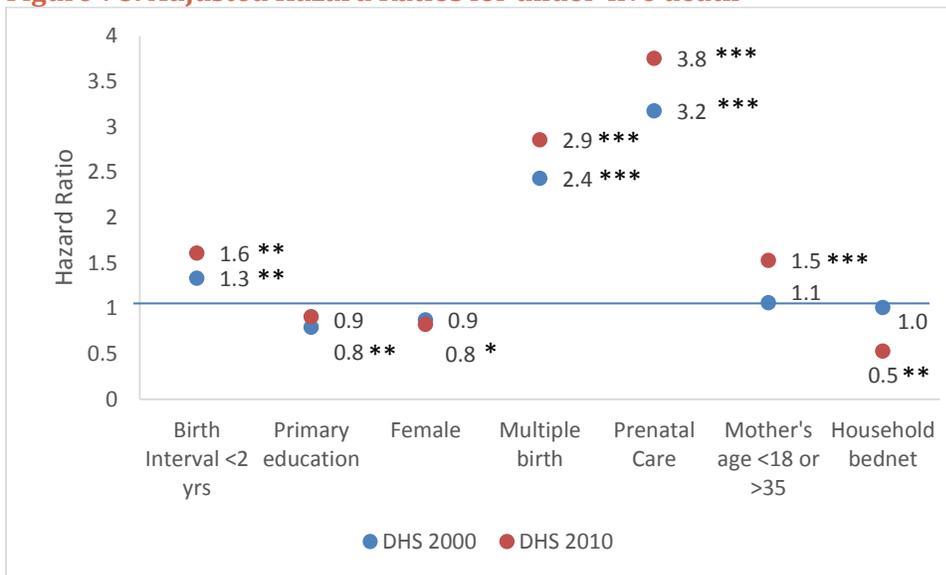


Coefficients

Figure 2 shows the adjusted multivariate associations between several socioeconomic and health covariates and under-five mortality from each survey. Of the highlighted variables, only three remain significantly associated with ACCM across both surveys in adjusted multivariate models. Multiple births are consistently associated with higher ACCM (hazard ratio > 2.0). A child who was born within 2 years of a previous birth has a greater risk of dying before five years of age than a first born child (HR = 1.3 and 1.6). Children of mothers who do not receive antenatal care from a health professional have significantly higher mortality (HR >3.0). Maternal age at birth also influences a child’s risk of dying before age five in the 2010 survey; children whose mothers were less than 18 or older than 35 had significantly higher mortality than those whose mothers were 18-35 years of age (HR = 1.5).

The strength of effect of some variables on ACCM has changed between surveys. Children whose mothers had a primary education or greater were less likely to die before the age of five than those whose mothers had no formal education in 2000 (HR= 0.8), however, this variable was not significant in the 2010 models. Female children were less likely to die before age five in the 2010 survey model (HR= 0.8). Household ownership of mosquito nets did not affect a child’s risk of dying in 2000 or 2005 but was protective in the 2010 model. Detailed tables from these hazard models are included in Annex B (Table A.2.2b).

Figure 78: Adjusted Hazard Ratios for under-five death



Decomposition Results

Results of the decomposition analysis are shown in Table 15. These models deconstruct the relative importance of changes in distribution of variables (endowments) between surveys and changes in the strength of effects of variables (coefficients) across two groups from the multivariate log probability models. The groups, in this case, are surveys; the 2000 DHS and the 2010 DHS.

According to the decomposition model, mortality declined by 83 deaths per 1,000 live births between the 2000 and 2010 surveys. As the actual reduction in mortality (Figure 78) was 120 deaths per 1,000 live births, the decomposition model explains 70% of the actual reduction in mortality between the pair of surveys. Most of the reduction in mortality occurred due to changes in the distribution of variables (endowments) between surveys as compared to changes in the strengths of effect (coefficients) of variables on mortality (89% vs. 11%). Figure 79 presents a graphical representation of the decomposition model results including the proportion of total observed reduction in ACCM captured by the model, the proportion of modeled reduction in ACCM due to changes in endowments compared to changes in coefficients and the proportion of the modeled reduction in ACCM that could be explained by changes in endowments of specific variables.

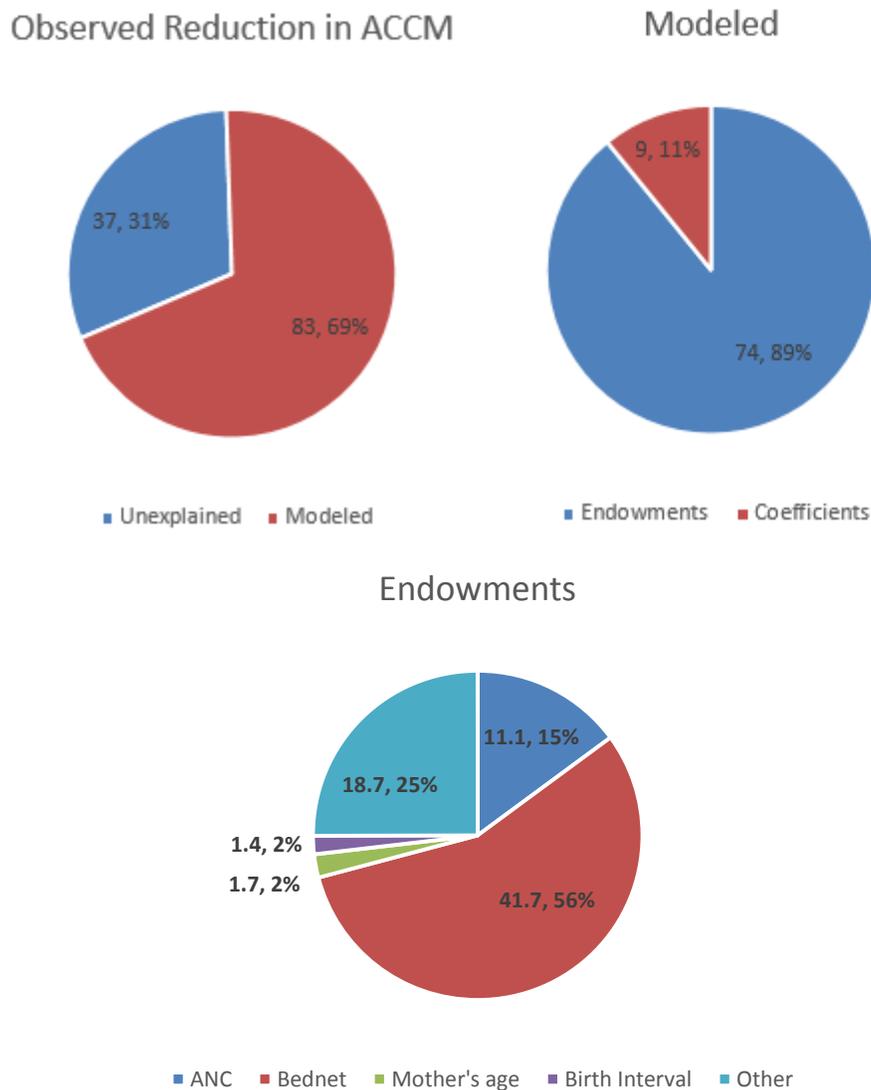
Table 15: Decomposition model results comparing 2000 and 2010 DHS

Characteristics	Endowments	Coefficients	Model Total	Observed Total
Child's sex	0.10 *	-5.09		
Multiple birth	0.25 ***	0.22		
Antenatal care	-11.12 ***	13.90		
Mother's age at birth	-1.72 ***	26.87		
Birth Interval	-1.35 **	5.53		
Household bednet ownership	-41.71 **	-3.07		
Mother used an ITN	-7.80	-0.06		
Mother's tetanus immunization	-1.03	-6.78		
Household wealth	0.35	1.60		
Mother's education	-1.09	5.25		
Vaccination coverage	3.33	3.47		
Assisted delivery	-5.62	10.72		
Protected water source	-2.90	20.73		
Improved sanitation	-4.07	-9.15		
Rural residence	-0.31	-47.02		
Constant		-26.23		
Change in ACCM	-74.48 ***	-9.12	-83.47	-120
% of modeled change	89%	11%	100%	
% of observed change	62%	8%	70%	100%

Note: Values represent change in numbers of deaths per 1,000 live births between 2000 and 2010 estimated due to changes in variable distributions (endowments) or changes in associations between variables and ACCM (coefficients).

*= p<0.05, ** = p<0.01, ***= p<0.0005

Figure 79: Graphical representation of decomposition model results



Results show that the distribution of several variables (endowments) between surveys explained a significant proportion of the change in ACCM between 2000 and 2010 (Table 15 and Figure 79). Important variables included the child’s sex, multiple birth status, antenatal care, mother’s age at birth, interval between births, and household bed net ownership. The proportion of male children increased slightly between surveys and this change would have been responsible for a small but significant increase in ACCM (0.1 death per 1,000 live births) if it occurred independently of other changes. Similarly, the proportion of births that were multiple (twins, triplets, etc.) increased between surveys. This change would have significantly increased ACCM if it occurred independently of other changes (by 0.25 deaths per 1,000 live births). In contrast, increases in the proportion of women receiving antenatal care, the proportion of women between 18 and 34 years of age at birth, and the proportion of households owning bed nets, would have led to significant decreases in

mortality if occurring independently of other changes (-11, -1.7, and -41.7 deaths per 1,000 live births, respectively). Declines in the proportion of children born within 24 months of a previous birth would also have led to a significant decline in ACCM (-1.4 deaths per 1,000 live births) if occurring independently of other changes. Of all of the compositional changes, the increase in household bed net ownership explained the greatest proportion of the observed reduction in ACCM (-41.7/-74.5 = 56%). When looking at the proportion of the total decline in ACCM measured by the model, the increase in household bed net ownership explained 50% (-41.7/-83.5 = 50%). Of the total observed decline in ACCM between 2000 and 2010 measured in DHS surveys, the increase in household bed net ownership explained 35% (-41.7/120 = 34.8%). See Table 16 for a summary.

None of the changes in strength of associations between variables and ACCM (coefficients) accounted for a significant proportion of the reduction in ACCM between 2000 and 2010.

Table 16: Proportion of total modeled and observed reduction in ACCM explained by changes in the distributions of select variables between 2000 and 2010.

Characteristics	% of Modeled ACCM Change	% of Observed ACCM change
Antenatal care	13.3%	9.3%
Mother's age at birth	2.0%	1.4%
Birth interval	1.6%	1.1%
Household bednet ownership	50%	34.8%
Change in ACCM	-83.47	-120

In summary, between 2000 and 2010 significant improvements have been made in many development and health indicators and child mortality rates have drastically declined. Decomposition models show that the observed increase in household bed net ownership, from 8% to 94% could have explained as much as 50% of the modeled decline in ACCM between 2000 and 2010 and as much as 35% of the observed decline in ACCM, equivalent to a reduction of 42 deaths per 1,000 live births. Improvements in coverage of antenatal care could have explained an additional decline of 11 deaths per 1,000 live births (13.3% of total modeled ACCM decline and 9.3% of observed ACCM decline). In addition, changes in the distribution of child's sex, multiple births, mother's age at birth (18-34 vs. <18 or >34) and birth intervals (<24 months) between 2000 and 2010 were all found to contribute significantly to the modeled change in ACCM, however the modeled changes in ACCM attributable to these variables were small (an increase of 0.1 and 0.25 deaths per 1,000 live births for sex and multiple births, and a decrease of 1.7 and 1.4 deaths per 1,000 live births for mother's age and birth intervals). This analysis clearly shows the important role of bed nets in the reduction of child mortality in Rwanda.

Conclusions

Plausibility Argument

In this section, the success of malaria control intervention scale-up and changes in malaria related outcomes in Rwanda are summarized, and the plausibility that the malaria intervention scale-up led to changes in malaria-related outcomes and impact during the evaluation period is assessed.

To determine if the scale-up of malaria control interventions could have contributed to the observed 61% reduction in all-cause under-five mortality we examined the fundamental and proximate determinants of child mortality that were in the causal pathways of the impact model (Figure 62, Table 14).

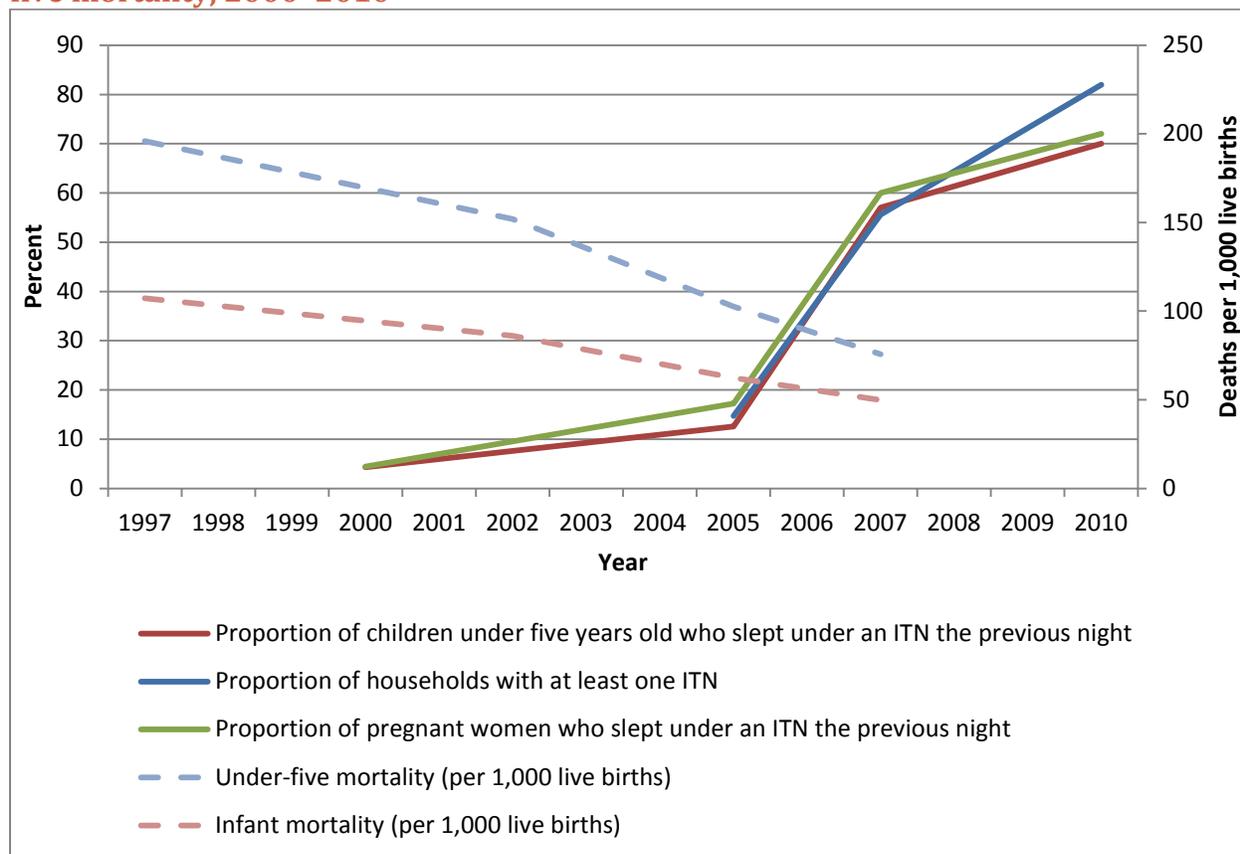
Malaria control interventions have been scaled up

Ownership of ITNs by households increased from 15% in 2005 to 82% in 2010 and ITN use among children under five years of age increased from 4% to 70% during the evaluation period (2000–2010). Similarly, the percent of the general population who had access to an ITN (assuming one ITN covers up to two people) increased from 9% in 2005 to 38% in 2007/08 to 64% in 2010. Estimates of net coverage using distribution suggest that universal coverage has been achieved. This coverage represents significant improvement over the evaluation period. Inequities in ITN use by children under five years of age and pregnant women present earlier in the decade decreased by 2010. IRS programs, implemented in three districts of Kigali City in 2007 and expanded to seven high risk districts in 2009, protected anywhere from 7% to 15.6% of the national population in any one year.

During the evaluation period in Rwanda, case management of fever in young children changed significantly. From presumptive treatment of fevers using chlorquine, to parasitological testing followed by treatment of positive cases with ACTs, the policies and available tools have evolved during this time. Care options have also shifted from facility-based to increasingly community-based. According to national survey data, the percentage of children under five years of age with recent fever for whom advice or care was sought increased from 26% in 2000 to 48% in 2010. Despite this increase, results indicate that less than half of children with fever are being appropriately screened for malaria. Among young children with fever who sought care and who received antimalarials, the percentage who received the recommended first-line treatment for uncomplicated malaria increased significantly from 50% in 2000 to 96% in 2010. At the community level, the proportion of children under five with fever/malaria receiving antimalarials within 24 hours of fever onset has increased between 2008 and 2010 (from 62% to 89%). The proportion of children receiving parasitological tests for malaria before administration of antimalarials has increased from 45% in 2008 to 94% in 2010 as RDTs have been rolled out. These results indicate that Rwandan children who receive health services for fever are very likely to receive appropriate testing and treatment.

Although it is an effective malaria control intervention in other countries, IPTp was only used for a short time in Rwanda. Rwanda continues to implement early detection and treatment of malaria and targeted ITN distribution for pregnant women effectively. Use of ITNs by pregnant women increased from 4% in 2000 to 72% in 2010. ANC attendance increased as well, with the percentage of pregnant women attending at least one ANC visit rising from 93% to 98% and the percentage attending at least two visits rising from 79% to 94% over the evaluation period. A summary of trends in interventions is depicted in Figure 80.

Figure 80: Summary of trends in malaria control interventions and infant and under-five mortality, 2000-2010



Note: Mortality estimates are centered at the middle of the five year estimation period preceding each survey.

Malaria-related morbidity has declined

Health facility data show evidence of significant declines in outpatient malaria cases as well as declines in malaria incidence, proportional malaria morbidity, and slide positivity rates from 2000-2010. Most of the decreases in these morbidity measures occurred in the second half of the decade, from 2005-2010. Distinct seasonal patterns are evident. Nationally-representative household survey data from 2005-2010 support these findings; significant decreases occurred in severe anemia and parasitemia prevalence between 2005 and 2010. Declines in severe anemia were not evenly distributed throughout the country;

children in rural areas, younger children and those from areas with the highest risk of malaria transmission experienced relatively larger declines.

Mortality in children under five years of age has declined

A significant decline in ACCM occurred in Rwanda between 2000 and 2010, a period of intense investment in malaria control interventions. Mortality in children under five years of age decreased by 61% between 2000 and 2010, from 196 to 76 deaths per 1000 live births. This decline may be attributable to a number of child survival interventions, including scale-up of malaria control interventions. To further examine this decline, mortality in children under-five was stratified by residence (i.e., urban or rural), age (e.g., 6–23 months, 24–59 months) and underlying malaria risk. The mortality declines were larger in children residing in rural areas (62%) as compared to children living in urban areas (53%). During the same period, the relative decline in mortality in children 6–23 months (69%) who are at higher risk of severe malaria and mortality was similar to the relative decline in children 24–59 months (73%). Mortality declines from 2000 to 2010 were also larger in regions with moderate to highest malaria risk (50-56% reductions) than in those with lower malaria risk (34%). It should be noted that significant decline in ACCM over the period 2000-2010 occurred in the latter part of the decade (2006-2010) after malaria control interventions had begun to be significantly scaled-up.

Contextual factors and the plausibility argument

To examine whether the marked reduction in ACCM could be attributed to scale-up of malaria control interventions, we reviewed other determinants of child survival that could offer alternate explanations for the observed changes in mortality during 2000–2010 (summarized in Table 14).

Among the social and economic determinants of child survival, increases were seen in GDP per-capita and women's education, which could have contributed significantly to declines in ACCM between 2000 and 2010. However, the dynamics of socio-economic determinants on population health are often complex [133,134] and these determinants, arguably [135], must operate through the proximate determinants to affect child survival [70].

Due to the high degree of temporal and spatial heterogeneity in climate, vector abundance, malaria intervention coverage, and health seeking behavior, the association between climate and malaria is also often complex. Climate was found to be an important determinant of malaria in Rwanda and observed warming in highland areas may increase risk of transmission.

During the evaluation period, several proximate determinants changed favoring lower mortality: care seeking and use of ORS for diarrhea, prevalence of diarrhea and ARI, and proportion of deliveries that took place in a health facility (Table 14). Care seeking for diarrhea increased 35% over the evaluation period. Trends in treatment of diarrhea with ORS (relative 64% increase) and declining prevalence of diarrhea and suspected ARI

(relative 35% and 59% reductions, respectively) suggest improvements in care and prevention of childhood illness, in SES or in environmental conditions such as access to clean water and sanitation, that are likely to have contributed to reductions in ACCM.

Coverage of other child survival interventions, such as immunization services, increased less dramatically between 2000 and 2010. Sustained high coverage of BCG, measles, DPT3 and polio3 were observed during the evaluation period with coverage at levels exceeding 80% throughout. The small increases in coverage of these vaccines are unlikely to have had a great impact on mortality in children under five years as sufficient levels for protection by herd immunity already existed in 2000. One exception may be the increase in measles immunization coverage (87% in 2000 to 95% in 2010); measles is highly contagious, so immunization coverage levels of at least 90% need to be maintained to confer population-level protection [136]. Also, *Haemophilus influenza (b)* and Hepatitis B immunizations were added to the EPI package, as a component of the pentavalent vaccine DPT3-HBV-Hib, during the evaluation period (2002); thus coverage of this vaccination rose from near-zero in 2000 to 97% in 2010. Although the increase in Hepatitis B vaccine coverage, as part of the DPT3-HBV-Hib vaccine, over the study period could have lowered the burden of transmission and infections, it is unlikely to have contributed substantially to reduction in ACCM as the Hepatitis B mortality burden, typically falls on the older age groups [137]. While the improvements in these interventions may have reached statistical significance, the magnitude of changes sustained during the evaluation period was small. It is therefore possible that there was little or no relative increase in the contributions of these interventions on the observed reductions in ACCM.

Stunting, underweight, and wasting in children under-five declined significantly relative to their 2000 baseline by 9%, 42% and 66%, respectively; however, absolute declines were small (from 48% to 44% for stunting, from 20% to 11% for underweight, and from 8% to 3% for wasting). It should be noted that nutritional improvement cannot be considered as a factor completely independent of malaria control. Recurrent illness is a major contributor to malnutrition and there is some evidence that malaria control interventions are associated with improved anthropometric indices [138]. It is also worth noting that the age-pattern of mortality decline observed in the post-neonatal period in this evaluation was comparable to the mortality decline among children aged 1 to 5, counter to what would be expected if nutrition improvement were the dominant driver of mortality change. It is therefore unlikely that improved nutrition could have independently and substantially contributed to lower mortality.

Other changes in proximate determinants that may have favored lower ACCM include a 133% relative increase in the proportion of women giving birth in health facilities (27% to 69%), and an increase in the percentage of women attending at least 4 ANC visits during pregnancy (10% to 35%). Most of these improvements are likely to affect mortality in neonates or infants but less likely to have an effect on ACCM.

Multivariable regression analyses

Between 2000 and 2010, significant improvements have been made in many development and health indicators and child mortality rates have drastically declined. Decomposition

models show that the observed increase in household bed net ownership from 8% to 94% could explain as much as 35% of the observed decline in ACCM between 2000 and 2010, equivalent to a reduction of 42 deaths per 1,000 live births. Improvements in coverage of skilled antenatal care could have explained an additional decline of 11 deaths per 1,000 live births (9% of the total observed ACCM decline). These analyses clearly show the important role of bed nets in the reduction of child mortality in Rwanda.

Lives Saved Tool

LiST Model: Quantifying the lives saved by scale-up of malaria control interventions

Given the evidence shown in this report of a decline in all-cause mortality in children under five years of age and a decline in anemia and a decline in parasitemia from 2000 to 2010, we used modeling to determine the potential impact the malaria control interventions could have had on malaria mortality. The Lives Saved Tool (LiST) was used to estimate the deaths prevented due to the scale-up of malaria control interventions in the context of a complex set of health interventions. For information on the LiST model, intervention coverage estimates, the cause-specific breakdown of child mortality and the protective efficacy of malaria control interventions used in this model see Annex B. The LiST model is not used here to provide evidence of a malaria-specific mortality decline; instead it is a modeling exercise to examine what the potential impact of malaria control intervention scale-up could look like.

One of the primary malaria prevention measures in Rwanda has been ITNs. Figure 81 shows the lives saved due to the scale-up of ITNs in Rwanda from 2000–2010. The midline estimate is shown with uncertainty bounds (see Annex B for a description of uncertainty calculations). It is estimated that over the 10 years of ITN scale-up, approximately 5,417 (4,318–6,685) deaths were prevented in children 0–59 months, compared to what would have happened if no vector control scale-up had occurred since 2000 coverage levels (Table 17). The number of deaths prevented per year steadily increased throughout this period, with an increase after 2005. These estimates fall within the range of those obtained by Eisele *et al.* of 4,296 (range 3,135–6,131) child deaths prevented by vector control scale-up between 2001–2010 [8,9].

Figure 81: Deaths prevented by scale-up of household ITN ownership, children 0–59 months, 2000–2010

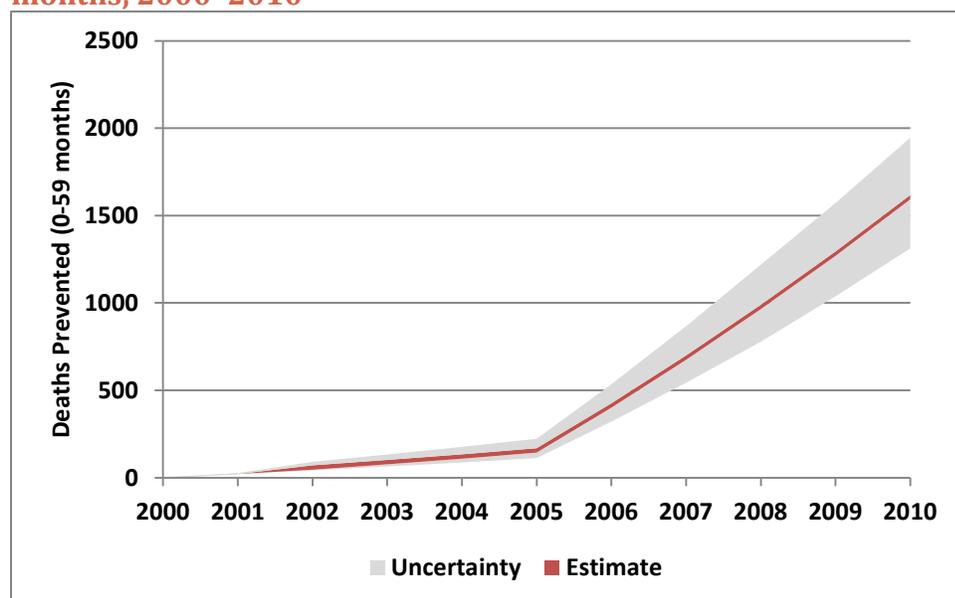


Table 17: Annual deaths prevented by scale-up of household ITN ownership, children 0-59 months, 2000–2010

Deaths Prevented	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Total
Lower	0	21	42	64	87	112	321	543	778	1,038	1,312	4,318
Midline	0	29	58	89	121	156	413	687	977	1,282	1,605	5,417
Upper	0	39	78	120	164	210	522	854	1,206	1,559	1,933	6,685

Under-five child mortality (specifically neonatal and post-neonatal mortality) is also affected by interventions to control malaria in pregnancy, including ITN use by pregnant women or IPTp during pregnancy. Prevention of malaria in pregnancy is thought to affect under-five mortality by decreasing intrauterine growth retardation (IUGR) [118,139]. The coverage values for pregnant women sleeping under an ITN the night before the survey in rural areas was used in the LiST model. The LiST model estimated 671 (386-945) deaths were averted due to the scale-up of ITN use by pregnant women in Rwanda from 2000 to 2010 (Figure 82 and Table 18).

Figure 82: Deaths prevented in children 0-59 months due to ITN use by pregnant women, 2000-2010

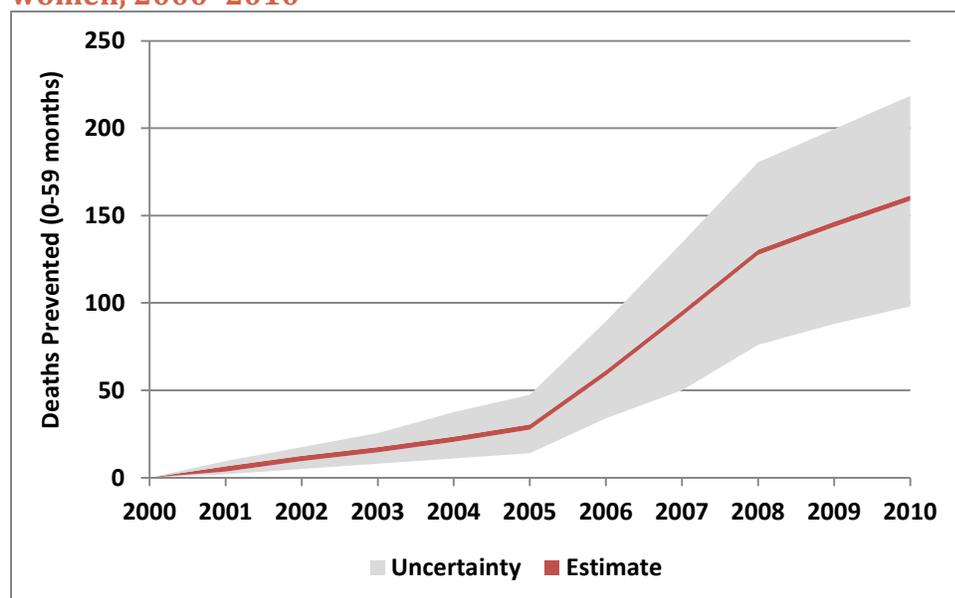


Table 18: Annual deaths prevented in children 0-59 months due to ITN use by pregnant women, 2000-2010

Deaths Prevented	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Total
Lower	0	2	5	8	11	14	34	50	76	88	98	386
Midline	0	5	11	16	22	29	60	94	129	145	160	671
Upper	0	8	16	24	36	46	88	133	179	198	217	945

The LiST analysis presented here models the potential direct effect of malaria interventions on reducing malaria-specific mortality. This estimate is likely an underestimate of the effect of malaria interventions given the conservative nature of the LiST model (see Annex B for more details). Calculations using the LiST model conservatively estimate that the scale-up of malaria control interventions during 2000-2010 prevented at least 6,088 (4,704-7,630) deaths combined among children under five years of age in Rwanda and were responsible for a 44% reduction in malaria-specific mortality in 2010 compared to what it would have been without intervention scale-up.

Summary

The impressive decline in all-cause child mortality in Rwanda from 2000 to 2010 coincides with declines in malaria-specific morbidities and with a period of rapid scale-up of malaria control interventions. ACCM fell 61% during this period accompanied by a 71% relative decline in severe anemia prevalence in children 6–23 months. These changes occurred concurrently with major improvements in malaria control. During this period Rwanda has made dramatic progress in scaling up vector control and malaria case management. Household ownership of ITNs has increased from near zero to 82% and the proportion of children less than five years of age who use ITNs has risen from 4% to 70% over the evaluation period. Although limited in surface area coverage, IRS has been used strategically to target the areas of highest transmission and in 2010 protected 15% of the population. Among young children with fever who sought care and who received antimalarials, the percentage who received the recommended first-line treatment for uncomplicated malaria increased significantly from 50% in 2000 to 96% in 2010. According to HMIS data, the proportion of children receiving parasitological tests for malaria before administration of antimalarials has increased from 45% in 2008 to 94% in 2010 as RDTs have been rolled out. Larger declines in under-five mortality and severe anemia were observed in rural areas, where the burden of malaria is higher compared to urban areas and where children had a greater potential to benefit from increased malaria intervention coverage. Although the relative declines in mortality and in severe anemia were comparable in children 6–23 and 24–59 months old, prevalence of both outcomes has become more homogenous across age groups as malaria levels have fallen. Multivariable models of the change in under-five mortality between the 2000 and 2010 DHS reveal the importance of increasing bed net ownership and use in explaining the observed mortality declines; the observed increase in bed net ownership could have explained as much as 45% of the observed decline in ACCM over this period, in the absence of change in other variables. The models suggested that improvements in coverage of antenatal care and in use of contraception could have explained an additional 13% and 12%, respectively of the total decline in ACCM. These models suggest the importance of maternal health factors in explaining ACCM declines. Survey data show that significant improvements occurred in deliveries at health facilities (27% to 69%) and 4+ANC visits (10% to 35%) over the evaluation period. Other important contributors to declines in ACCM likely include socioeconomic factors such as improved GDP per capita over the evaluation period, improved literacy among women (66% to 77%), child health factors such as improvements in vitamin A supplementation in young children (69% - 93%), increased EPI vaccination coverage (76% to 90%), declines in ARI symptoms (21% to 10%) and increase in use of ORS for diarrhea (14% to 29%). Climate is also an important determinant of malaria in Rwanda. Droughts during the evaluation period likely created conditions favoring reductions in malaria transmission thus the observed decline in ACCM may be partially explained by meteorological conditions. Taken as a whole, the evidence supports the conclusion that malaria control interventions, particularly ownership and use of ITNs, contributed significantly to the observed decline in under-five mortality in Rwanda from 2000-2010, in a context of improving socioeconomic, maternal and child health factors.

References

1. ter Kuile F, van Eijk A, Filler S (2007) Effect of Sulfadoxine-Pyrimethamine Resistance on the Efficacy of Intermittent Preventive Therapy for Malaria Control During Pregnancy: A Systematic Review. *JAMA* 297: 2603-2616.
2. World Health Organization (WHO) (2012) Intermittent Preventive Treatment of malaria in pregnancy using Sulfadoxine-Pyrimethamine (IPTp-SP): Updated WHO Policy Recommendation. Global Malaria Programme.
3. Rwanda Ministry of Health (2011) Rwanda Malaria Programme Performance Review.
4. Roll Back Malaria Partnership (2008) The Global Malaria Action Plan for a malaria-free world. Roll Back Malaria Partnership.
5. President's Malaria Initiative (PMI) (2015) President's Malaria Initiative Strategy 2015-2020. Washington, D.C.: U.S. Agency for International Development.
6. Rowe AK, Steketee RW, Arnold F, Wardlaw T, Basu S, et al. (2007) Viewpoint: evaluating the impact of malaria control efforts on mortality in sub-Saharan Africa. *Trop Med Int Health* 12: 1524-1539.
7. Victora CG, Black RE, Boerma JT, Bryce J (2011) Measuring impact in the Millennium Development Goal era and beyond: a new approach to large-scale effectiveness evaluations. *Lancet* 377: 85-95.
8. RBM (2010) Saving Lives with Malaria Control: Counting Down to the Millennium Development Goals
9. Eisele TP, Larsen DA, Walker N, Cibulskis RE, Yukich JO, et al. (2012) Estimates of child deaths prevented from malaria prevention scale-up in Africa 2001-2010. *Malar J* 11: 93.
10. Korenromp EL, Armstrong-Schellenberg JR, Williams BG, Nahlen BL, Snow RW (2004) Impact of malaria control on childhood anaemia in Africa -- a quantitative review. *Trop Med Int Health* 9: 1050-1065.
11. Snow RW, Armstrong JR, Forster D, Winstanley MT, Marsh VM, et al. (1992) Childhood deaths in Africa: uses and limitations of verbal autopsies. *Lancet* 340: 351-355.
12. Murphy SC, Breman JG (2001) Gaps in the childhood malaria burden in Africa: cerebral malaria, neurological sequelae, anemia, respiratory distress, hypoglycemia, and complications of pregnancy. *Am J Trop Med Hyg* 64: 57-67.
13. National Institute of Statistics of Rwanda (2012) Population and Housing Census-Provisional Results.
14. UNDP (2011) Human Development Index (HDI) Methodology.
15. World Bank Group Website (2010) Rwanda Data Profile.
16. National Institute of Statistics of Rwanda (NISR) Ministry of Health (MOH) and ICF International (2011) Rwanda Demographic and Health Survey 2010. Calverton, Maryland, USA: NISR.
17. National Institute of Statistics of Rwanda (2011) Statistical Yearbook 2011. Kigali, Rwanda: National Institute of Statistics of Rwanda.
18. UNICEF (2012) Committing to Child Survival: A Promise Renewed-Progress Report.
19. World Health Rankings (2010) Rwanda Health Profile.

20. UNICEF progress report (2012) Committing to Child Survival: a promise renewed. New York.
21. Rwanda Ministry of Health (2012) Rwanda Health Statistics Booklet 2011.
22. President's Malaria Initiative (PMI) (2012) Malaria Operational Plan (MOP) Rwanda
23. Sundaram A UNICEF News Bulletin: In Rwanda, successfully fighting a resurgence of malaria
24. Presidents Malaria Initiative (PMI) (2007) Malaria Operational Plan (MOP) Rwanda FY 2007.
25. Culleton R, Mita T, Ndounga M, Unger H, Cravo P, et al. (2008) Failure to detect *Plasmodium vivax* in West and Central Africa by PCR species typing. *Malar J* 7: 174.
26. National Institute of Statistics of Rwanda (2011) Statistical Yearbook 2010. Kigali, Rwanda: National Institute of Statistics of Rwanda.
27. Rwanda NIOSo (2013) Statistical Yearbook 2012. Kigali, Rwanda: National Institute of Statistics of Rwanda.
28. UN (2010) Millennium Development Goals. United Nations.
29. Republic of Rwanda MOH (2008) National Health Accounts Rwanda 2006 with HIV/AIDS, Malaria, and Reproductive Health Subaccounts. Kigali, Rwanda.
30. Wright J SC, Kizza D, De S, Carlson K (October 27, 2008) Trends in malaria financing in Rwanda. Health Systems 20/20. Presentation made at the American Public Health Association conference. San Diego, CA.
31. Ndoli F (2011) News Report: ExxonMobil Malaria Decreases By 70 Percent The New Times.
32. Rwanda Ministry of Health (2010) Republic of Rwanda Vector Control Needs Assessment (VCNA). Rwanda Ministry of Health and USAID.
33. Otten M, Aregawi M, Were W, Karema C, Medin A, et al. (2009) Initial evidence of reduction of malaria cases and deaths in Rwanda and Ethiopia due to rapid scale-up of malaria prevention and treatment. *Malaria Journal* 8: 14.
34. Rwanda Malaria Program Review (MPR) (2011) Presentation by Malaria Unit/TRACPlus-MOH, External Review Team (2 PNILPs, 4 WHO, 1 UNIVAF, and 1 ALMA).
35. ter Kuile FO, Parise ME, Verhoeff FH, Udhayakumar V, Newman RD, et al. (2004) The burden of co-infection with human immunodeficiency virus type 1 and malaria in pregnant women in sub-saharan Africa. *Am J Trop Med Hyg* 71: 41-54.
36. Ayisi JG, van Eijk AM, ter Kuile FO, Kolczak MS, Otieno JA, et al. (2003) The effect of dual infection with HIV and malaria on pregnancy outcome in western Kenya. *AIDS* 17: 585-594.
37. Nkhoma ET, Kalilani-Phiri L, Mwapasa V, Rogerson SJ, Meshnick SR (2012) Effect of HIV Infection and *Plasmodium falciparum* Parasitemia on Pregnancy Outcomes in Malawi. *The American Journal of Tropical Medicine and Hygiene* 87: 29-34.
38. Garner P, Gulmezoglu AM (2006) Drugs for preventing malaria in pregnant women. *Cochrane Database Syst Rev*: CD000169.
39. Steketee RW, Nahlen BL, Parise ME, Menendez C (2001) The burden of malaria in pregnancy in malaria-endemic areas. *Am J Trop Med Hyg* 64: 28 - 35.
40. Granja AC, Machungo F, Gomes A, Bergström S, Brabin B (1998) Malaria-related maternal mortality in urban Mozambique. *Annals of Tropical Medicine and Parasitology* 92: 257-263.

41. Guyatt HL, Snow RW (2001) Malaria in pregnancy as an indirect cause of infant mortality in sub-Saharan Africa. *Transactions of the Royal Society of Tropical Medicine and Hygiene* 95: 569-576.
42. World Health Organization (WHO) (2000) A Strategic Framework for Malaria Control During Pregnancy in the WHO Africa Region.
43. Rulisa S, Gatarayiha JP, Kabarisa T, Ndayisaba G (2007) Comparison of different artemisinin-based combinations for the treatment of *Plasmodium falciparum* malaria in children in Kigali, Rwanda, an area of resistance to sulfadoxine-pyrimethamine: artesunate plus sulfadoxine/pyrimethamine versus artesunate plus sulfamethoxypyrazine/pyrimethamine. *Am J Trop Med Hyg* 77: 612-616.
44. Karema C, Imwong M, Fanello CI, Stepniewska K, Uwimana A, et al. (2010) Molecular correlates of high-level antifolate resistance in Rwandan children with *Plasmodium falciparum* malaria. *Antimicrob Agents Chemother* 54: 477-483.
45. Rulisa S, Mens PF, Karema C, Schallig HD, Kaligirwa N, et al. (2009) Malaria has no effect on birth weight in Rwanda. *Malar J* 8: 194.
46. Zeile I, Gahutu JB, Shyirambere C, Steininger C, Musemakweri A, et al. (2012) Molecular markers of *Plasmodium falciparum* drug resistance in southern highland Rwanda. *Acta Trop* 121: 50-54.
47. World Health Organization (WHO) (2010) Guidelines for the Treatment of Malaria. Second edition.
48. Presidents Malaria Initiative (PMI) (2015) Malaria Operational Plan (MOP) Rwanda FY 2015.
49. MEASURE Evaluation, MEASURE DHS, President's Malaria Initiative, Roll Back Malaria Partnership, UNICEF, et al. (2013) Household Survey Indicators for Malaria Control.
50. President's Malaria Initiative (PMI) (2010) Malaria Operational Plan (MOP) Rwanda FY 2011.
51. Bejon P, Williams TN, Liljander A, Noor AM, Wambua J, et al. (2010) Stable and Unstable Malaria Hotspots in Longitudinal Cohort Studies in Kenya. *PLoS Med* 7: e1000304.
52. Ye Y, Kyobutungi C, Louis V, Sauerborn R (2007) Micro-epidemiology of *Plasmodium falciparum* malaria: Is there any difference in transmission risk between neighbouring villages? *Malaria Journal* 6: 46.
53. Dinku T (2014) Reconstructing Rwanda's Historical Climate Data. New York: IRI.
54. Presidents Malaria Initiative (PMI) (2010) Zambia Malaria Operational Plan (MOP).
55. Zambian Ministry of Health National Malaria Control Centre (2010) Zambia Malaria Indicator Survey (MIS).
56. Githeko A, Ndegwa W (2001) Predicting malaria epidemics in the Kenyan highlands using climate data: a tool for decision makers. *Global Change & Human Health* 2.
57. Korenromp EL, Armstrong-Schellenberg JRM, Williams BG, Nahlen BL, Snow RW (2004) Impact of malaria control on childhood anaemia in Africa -- a quantitative review. *Tropical Medicine & International Health: TM & IH* 9: 1050-1065
58. Slutsker L, Chitsulo L, Macheso A, Steketee R (1994) Treatment of malaria fever episodes among children in Malawi: results of a KAP survey. *Trop Med Parasitology* 45: 61-64.
59. Biemba G, Dolmans D, Thuma PE, Weiss G, Gordeuk VR (2000) Severe anaemia in Zambian children with *Plasmodium falciparum* malaria. *Tropical Medicine & International Health* 5: 9-16.

60. Marsh K, Forster D, Waruiru C, Mwangi I, Winstanley M, et al. (1995) Indicators of life-threatening malaria in African children. *The New England Journal of Medicine* 332: 1399-1404
61. CDC (1998) Recommendations to prevent and control iron deficiency in the United States. *MMWR Recommendation Reports* 47: 1-29.
62. Carneiro I, Roca-Feltre A, Griffin JT, Smith L, Tanner M, et al. (2010) Age-Patterns of Malaria Vary with Severity, Transmission Intensity and Seasonality in Sub-Saharan Africa: A Systematic Review and Pooled Analysis. *PLoS ONE* 5: e8988.
63. Snow RW, Marsh K (2002) The consequences of reducing transmission of *Plasmodium falciparum* in Africa. *Advances in Parasitology* 52: 235-264
64. Trape JF, Rogier C (1996) Combating malaria morbidity and mortality by reducing transmission. *Parasitology Today (Personal Ed)* 12: 236-240
65. Victora CG, Schellenberg JA, Huicho L, Amaral J, El Arifeen S, et al. (2005) Context matters: interpreting impact findings in child survival evaluations. *Health Policy Plan* 20 Suppl 1: i18-i31.
66. Bryce J, Victora CG, Habicht JP, Vaughan JP, Black RE (2004) The multi-country evaluation of the integrated management of childhood illness strategy: lessons for the evaluation of public health interventions. *Am J Public Health* 94: 406-415.
67. Stratton L, O'Neill MS, Kruk ME, Bell ML (2008) The persistent problem of malaria: addressing the fundamental causes of a global killer. *Soc Sci Med* 67: 854-862.
68. Link BG, Phelan JC (1996) Understanding sociodemographic differences in health--the role of fundamental social causes. *Am J Public Health* 86: 471-473.
69. Link BG, Phelan J (1995) Social conditions as fundamental causes of disease. *J Health Soc Behav Spec No*: 80-94.
70. Mosley WH, Chen LC (2003) An analytical framework for the study of child survival in developing countries. 1984. *Bull World Health Organ* 81: 140-145.
71. Inhorn M, Brown P (1990) Anthropology of Infectious Diseases. *Annual Reviews of Anthropology* 19: 89-117.
72. Casman E, H D (2002) Contextual determinants of Malaria. Washington, DC: Resources for the Future.
73. Taylor C, Newman J, Kelly N (1978) The child survival hypothesis. *Population Studies* 30: 263-278.
74. Jones G, Steketee RW, Black RE, Bhutta ZA, Morris SS (2003) How many child deaths can we prevent this year? *Lancet* 362: 65-71.
75. Bryce J, Victora CG, Habicht JP, Black RE, Scherpbier RW (2005) Programmatic pathways to child survival: results of a multi-country evaluation of Integrated Management of Childhood Illness. *Health Policy Plan* 20 Suppl 1: i5-i17.
76. Rowe AK, Onikpo F, Lama M, Osterholt DM, Deming MS (2011) Impact of a Malaria-Control Project in Benin That Included the Integrated Management of Childhood Illness Strategy. *Am J Public Health*.
77. Wang L (2003) Determinants of child mortality in LDCs: empirical findings from demographic and health surveys. *Health Policy* 65: 277-299.
78. Boyle MH, Racine Y, Georgiades K, Snelling D, Hong S, et al. (2006) The influence of economic development level, household wealth and maternal education on child health in the developing world. *Social Science & Medicine* 63: 2242-2254.

79. Subramanian SV, Belli P, Kawachi I (2002) The macroeconomic determinants of health. *Annu Rev Public Health* 23: 287-302.
80. Filmer D, Pritchett L (1999) The impact of public spending on health: does money matter? *Soc Sci Med* 49: 1309-1323.
81. (2011) *World Development Indicators* Washington, DC: World Bank.
82. World Bank Group Website (2012) World Bank GDP per capita (current US\$). World Bank.
83. Coleman M, Mabaso ML, Mabuza AM, Kok G, Coetzee M, et al. (2010) Household and microeconomic factors associated with malaria in Mpumalanga, South Africa. *Trans R Soc Trop Med Hyg* 104: 143-147.
84. Worrall E, Basu S, Hanson K (2005) Is malaria a disease of poverty? A review of the literature. *Trop Med Int Health* 10: 1047-1059.
85. Günther I, Fink G (2011) *Water and Sanitation to Reduce Child Mortality: The Impact and Cost of Water and Sanitation Infrastructure*. Washington DC: The World Bank.
86. Gamage-Mendis AC, Carter R, Mendis C, De Zoysa AP, Herath PR, et al. (1991) Clustering of malaria infections within an endemic population: risk of malaria associated with the type of housing construction. *Am J Trop Med Hyg* 45: 77-85.
87. Ye Y, Hoshen M, Louis V, Seraphin S, Traore I, et al. (2006) Housing conditions and *Plasmodium falciparum* infection: protective effect of iron-sheet roofed houses. *Malar J* 5: 8.
88. Kirby M, West P, Green C, Jasseh M, Lindsay S (2008) Risk factors for house-entry by culicine mosquitoes in a rural town and satellite villages in The Gambia. *Parasites & Vectors* 1: 41.
89. Lindsay SW, Emerson PM, Charlwood JD (2002) Reducing malaria by mosquito-proofing houses. *Trends in Parasitology* 18: 510-514.
90. Lindsay S, Snow R (1988) The trouble with eaves; house entry by vectors of malaria. *Trans R Soc Trop Med Hyg* 82: 645-646.
91. Ogoma S, Kannady K, Sikulu M, Chaki P, Govella N, et al. (2009) Window screening, ceilings and closed eaves as sustainable ways to control malaria in Dar es Salaam, Tanzania. *Malar J* 8: 221.
92. Nicholson SE (2014) A detailed look at the recent drought situation in the Greater Horn of Africa. *Journal of Arid Environments* 103: 71-79.
93. Thomson MC, Connor SJ, Milligan PJM, Flasse SP (1996) The ecology of malaria - As seen from Earth-observation satellites. *Annals of Tropical Medicine and Parasitology* 90: 243-264.
94. Grover-Kopec E, Blumenthal B, Ceccato P, Dinku T, Omumbo J, et al. (2006) Web-Based Climate Information Resources for Malaria Control in Africa. *Malaria Journal* 5: 38.
95. Bayoh MN, Lindsay SW (2003) Effect of temperature on the development of the aquatic stages of *Anopheles gambiae sensu stricto* (Diptera: Culicidae). *Bulletin of Entomological Research* 93: 375-381.
96. Lyon B, Barnston AG (2005) ENSO and the spatial extent of interannual precipitation extremes in tropical land areas. *Journal of Climate* 18: 5095-5109.
97. Zebiak SE, Orlove B, Muñoz AG, Vaughan C, Hansen J, et al. (2014) Investigating El Niño-Southern Oscillation and society relationships. *WIREs Climate Change*.
98. Lyon B (2014) Seasonal Drought in the Greater Horn of Africa and its Recent Increase During the March-May Long Rains. *Journal of Climate*.

99. Lindsay SW, Bodker R, Malima R, Msangeni HA, Kisinza W (2000) Effect of 1997-98 El Nino on highland malaria in Tanzania. *Lancet* 355: 989-990.
100. Gakidou E, Cowling K, Lozano R, Murray CJ (2010) Increased educational attainment and its effect on child mortality in 175 countries between 1970 and 2009: a systematic analysis. *Lancet* 376: 959-974.
101. Hobcraft J (1993) Women's education, child welfare and child survival: a review of the evidence. *Health Transit Rev* 3: 159-175.
102. Sandiford P, Cassel J, Montenegro M, Sanchez G (1995) The Impact of Women's Literacy on Child Health and its Interaction with Access to Health Services. *Population Studies* 49: 5-17.
103. Cleland JG, van Ginneken JK (1988) Maternal education and child survival in developing countries: The search for pathways of influence. *Social Science & Medicine* 27: 1357-1368.
104. Jejeebhoy S (1995) Women's education, autonomy and reproductive behaviour: experience from developing countries: Oxford: Clarendon Press.
105. Hobcraft J (1993) Women's education, child welfare and child survival: a review of the evidence. *Health Transit Rev* 3: 159-190.
106. Becker G (1960) Demographic and Economic Change in Developed Countries. Princeton: Princeton University Press. pp. 209-240.
107. Clark S, Hamplova D (2011) The impact of mother's marital status on child mortality in sub-Saharan Africa: an analysis of birth and marital histories. Sixth African Population Conference. Ouagadougou, Burkina Faso.
108. Bennett T, Braveman P, Egerter S, Kiely JL (1994) Maternal Marital Status as a Risk Factor for Infant Mortality. *Family Planning Perspectives* 26: 252-256.
109. MMWR (August 03, 1990) Infant Mortality by Marital Status of Mother -- United States, 1983 CDC. 521-523 p.
110. The Partnership for Maternal N, and Child Health,, (2006) Opportunities for Africa's newborns: Practical data, policy and programmatic support for newborn care in Africa.
111. World Health Organization (WHO) (2012) Maternal and Neonatal Tetanus (MNT) elimination.
112. Roper M, Vandelaer J, Gasse F (2007) Maternal and neonatal tetanus. *Lancet*.
113. Michael K, Roy N, McElrath T, Shahidullah M, Wojityniak B (1998) Duration of Protective Immunity Conferred by Maternal Tetanus Toxoid Immunization: Further Evidence from Matlab, Bangladesh. *Am J Public Health* 88: 903-907.
114. World Bank (1993) Investing in Health. World Development Report. New York: World Bank; 1993 1993/06/30. Report No.: 12183.
115. World Health Organization (WHO) (2002) State of the World's Vaccines and Immunizations. Geneva: United Nations; 2002.
116. World Health Organization (2013) WHO vaccine-preventable diseases: monitoring system. 2013 global summary. In: Rwanda, editor.
117. World Health Organization (WHO) (2012) Immunization Profile-Rwanda.
118. Bhutta ZA, Ahmed T, Black RE, Cousens S, Dewey K, et al. (2008) What works? Interventions for maternal and child undernutrition and survival. *Lancet* 371: 417-440.
119. Bhutta ZA, Labbok M (2011) Scaling up breastfeeding in developing countries. *Lancet*.

120. Kramer M, Kakuma R (2002) The optimal duration of exclusive breastfeeding. A systematic review. Geneva, Switzerland: World Health Organization.
121. West J, KP, Caballero B, Black R (2001) Nutrition. In: Merson M, Black R, Mills A, editors. International Public Health: Diseases, Programs, Systems, and Policies 1st ed: Aspen Publishers, Inc.
122. Black RE, Allen LH, Bhutta ZA, Caulfield LE, de Onis M, et al. (2008) Maternal and child undernutrition: global and regional exposures and health consequences. *Lancet* 371: 243-260.
123. World Health Organization (WHO) (2006) WHO Child Growth Standards: Length/height-for-age, weight-for-age, weight-for-length, weight-for-height and body mass index-for-age: Methods and development. Geneva: World Health Organization.
124. Sommer A, Tarwotjo I, Djunaedi E, West KP, Jr., Loeden AA, et al. (1986) Impact of vitamin A supplementation on childhood mortality. A randomised controlled community trial. *Lancet* 1: 1169-1173.
125. Beaton GH MR, L'Abbé, et al. (1993) Effectiveness of vitamin A supplementation in the control of young child morbidity and mortality in developing countries.
126. Jamison D, Feachem R, Makgoba M, Bos E, Baingana F, et al. (2006) Disease and Mortality in Sub-Saharan Africa, 2nd edition Washington (DC): World Bank.
127. Ahmad O, Lopez A, Inoue M (2000) The decline in child mortality: a reappraisal. *Bulletin of the World Health Organization* 78: 1175-1191.
128. Walker N, Hill K, Zhao F (2012) Child Mortality Estimation: Methods Used to Adjust for Bias due to AIDS in Estimating Trends in Under-Five Mortality. *PLoS Med* 9: e1001298.
129. Walker N, Schwartzlander B, Bryce J (2002) Meeting international goals in child survival and HIV/AIDS. *Lancet* 360: 284-289.
130. Stanecki K, Daher J, Stover J, Akwara P, Mahy M (2010) Under-5 mortality due to HIV: regional levels and 1990–2009 trends. *Sexually Transmitted Infections* 86: ii56-ii61.
131. Karema C, Aregawi MW, Rukundo A, Kabayiza A, Mulindahabi M, et al. (2012) Trends in malaria cases, hospital admissions and deaths following scale-up of anti-malarial interventions, 2000-2010, Rwanda. *Malar J* 11: 236.
132. Sievers A, Lewey J, Musafiri P, Franke M, Bucyibaruta B, et al. (2008) Reduced paediatric hospitalizations for malaria and febrile illness patterns following implementation of community-based malaria control programme in rural Rwanda. *Malar J* 7: 167.
133. Sen A (1998) Mortality as an Indicator of Economic Success and Failure. *The Economic Journal* 108: 1-25.
134. Sen A (1999) Health in development. *Bull World Health Organ* 77: 619-623.
135. Macassa G, Hallqvist J, Lynch J (2011) Inequalities in child mortality in sub-Saharan Africa: A social epidemiologic framework. *Afr J Health Sci* 18: 14-26.
136. UNICEF (2001) We the Children: Meeting the promises of the World Summit for Children--Measles.
137. Amin J, Law MG, Bartlett M, Kaldor JM, Dore GJ (2006) Causes of death after diagnosis of hepatitis B or hepatitis C infection: a large community-based linkage study. *Lancet* 368: 938-945.

138. Ter Kuile FO, Terlouw DJ, Kariuki SK, Phillips-Howard PA, Mirel LB, et al. (2003) Impact of Permethrin-Treated Bed Nets on Malaria, Anemia, and Growth In Infants in an Area of Intense Perennial Malaria Transmission in Western Kenya. *The American Journal of Tropical Medicine and Hygiene* 68: 68-77.
139. Eisele TP, Larsen D, Steketee RW (2010) Protective efficacy of interventions for preventing malaria mortality in children in Plasmodium falciparum endemic areas. *International Journal of Epidemiology* 39 Suppl 1: i88-101 %U <http://www.ncbi.nlm.nih.gov/pubmed/20348132>.